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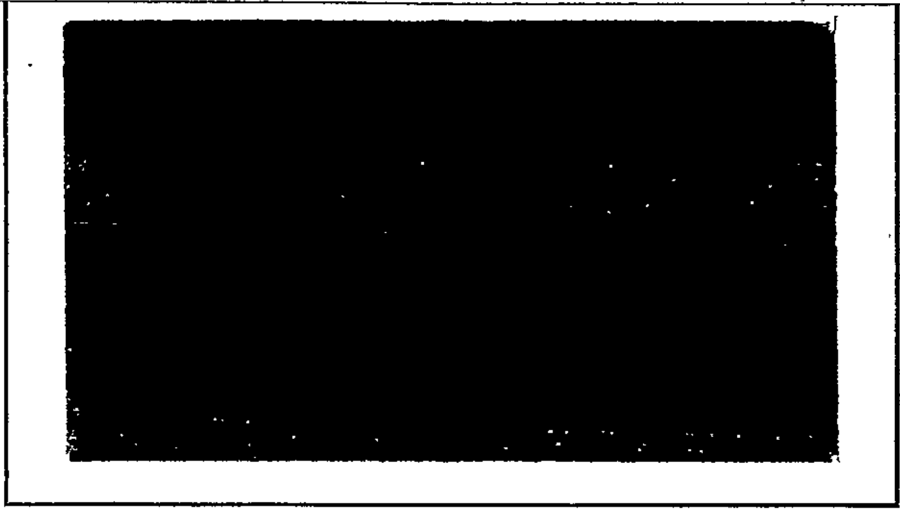

Contract JPL-954796
Quarterly Report April to July 1978
(DRD Line Item 6)

November 1978

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The JPL Low-Cost Silicon Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DoE.

DoE/JPL-954796-78/4
Distribution List 647 of 5-15-1978

ANALYSIS AND EVALUATION OF PROCESSES AND EQUIPMENT IN TASKS II and IV of the LOW-COST SOLAR ARRAY PROJECT

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ABSTRACT

The significant economic data for the current production multiblade wafering and inner diameter slicing processes were tabulated and compared to data on the experimental and projected Varian multiblade slurry, STC ID diamond coated blade, Yasunaga multiwire slurry and Crystal Systems fixed abrasive multiwire slicing methods. Cost calculations were performed for current production processes and for 1982 and 1986 projected wafering techniques.

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1. INTRODUCTION

The manufacturing methods for photovoltaic solar energy utilization systems consist, in complete generality, of a sequence of individual processes. This process sequence has been, for convenience, logically segmented into five major "work areas": Reduction and purification of the semiconductor material, sheet or film generation, device generation, module assembly and encapsulation, and system completion, including installation of the array and the other subsystems. For silicon solar arrays, each work area has been divided into 10 generalized "processes" in which certain required modifications of the work-in-process are performed. In general, more than one method is known by which such modifications can be carried out. The various methods for each individual process are identified as process "options". This system of processes and options forms a two-dimensional array, which is here called the "process matrix".

In the search to achieve improved process sequences for producing silicon solar cell modules, numerous options have been proposed and/or developed, and will still be proposed and developed in the future. It is a near necessity to be able to evaluate such proposals for the technical merits relative to other known approaches, for their economic benefits, and for other techno-economic attributes such as energy consumption, generation and disposal of waste by-products, etc. Such evaluations have to be as objective as possible in light of the available information, or the lack thereof, and have to be periodically updated as development progresses and new information becomes available. Since each individual process option has to fit into a process sequence, technical interfaces between consecutive processes must be compatible. This places emphasis on the specifications for the work-in-process entering into and emanating from a particular process option.

The objective of this project is to accumulate the necessary information as input for such evaluations, to develop appropriate methodologies for the performance of such techno-economic analyses, and to perform such evaluations at various levels. The first application of this developing methodology was made to the Czochralski's crystal pulling process.

Previously, we had examined the reduction of quartzite to metallurgical grade silicon and did a comparative evaluation of competing Czochralski techniques for growing single crystal, cylindrical ingots. The next major process step in the sequence for producing single crystal silicon wafers, today and in the near future (up to 1982), is the slicing technique. The evaluations were started with the current methods of multiblade slurry slicing, and inner diameter slicing using a diamond coated blade for which a large amount of the needed information is available. Nevertheless, substantial gaps or uncertainties were found in important information required for both technical and economical evaluation of the currently practiced processes. In proceeding to the evaluation of processes which are still in the developmental or even conceptual stage, the gaps in needed information become very large. In these cases, it is necessary to fill the gaps more extensively with estimates based on extrapolations or analogies. Such estimates always leave some doubt on the accuracy of the evaluations, and it will be necessary to also make "probable error" estimates to reduce decision mistakes based on early evaluations. Nevertheless, collecting the information and carrying our evaluations at the earliest possible time provides not only a planning tool, but also aids in uncovering the deciding attributes about which information ought to be obtained at an early stage of the development process.

We have tabulated production experience data obtained from Spectrolab[1] for slicing 2-cm rectangular, 5.4-cm and 7.5-cm diameter wafers using the Varian multi-blade slicing system, and similar data obtained from HAMCO[2], for ID slicing of 10.16-cm diameter ingots using their equipment. Experimental data from OCLI[3], Varian[4] and TI[5] for multiblade wafering, from OCLI[6] and STC[7] for ID slicing, and from JPL[8] for the Yasunaga multi-wire slurry slicing system, were also tabulated. To complete the analysis, projections made by Varian[9] for multiblade slicing, by STC for ID slicing[7] by Crystal Systems[10] for their fixed abrasive multi-wire system, and by Solarex[11] for the Yasunaga multi-wire slurry system were examined.

2. TECHNICAL DISCUSSION

A. BRIEF DESCRIPTIONS OF THE SLICING TECHNIQUES

1. Multiblade Slicing

The multiblade slurry sawing method is one of the two techniques used in current production slicing. In its present configuration 230-250 blades of 38-cm length of hardened 1095 steel are mounted and evenly spaced on a blade head that is, for slicing, reciprocated, at frequencies below 2 Hz (normally about 1.6 Hz), across the workpiece using approximately a 20-cm stroke. The abrasive slurry is pulsed sprayed or, at times, dripped onto the top surface of the workpiece and recirculated by a pump. The slurry is a SiC abrasive suspended in PC oil. It is normally used for one load before it is discarded. There are no practical ways, at present, to re-use the abrasive slurry for more than one load.

The current multiblade slicing machines can accept blade heads up to 18.5-cm wide. However, the number of blades in a blade head, and consequently, the number of slices that could be produced per load, is not limited by the blade head width per se, but rather by the maximum tension force the blade head can exert on the blades. This is about 401,800 N for current production blade heads[4]. An adequate saw force commonly called "blade load", is necessary to achieve economically acceptable cutting rates in the slicing process. A blade load of about 1-2 N/blade[5], is usually applied. Excessive blade loading, and even normal loading after some blade wear, can cause deflection of the blades, often called "buckling", which results in inaccurately sliced wafers or even broken wafers. To minimize buckling, the blades need to be stressed as much as possible, which, in current practice, is 80% of the yield strength of 1095 steel, or 1.37 GPa[5]. Therefore, the maximum number of blades permitted per blade head is 401.8/1.37*A, where A is the cross-sectional blade area in mm^2. For a 6.35 mm high blade, 0.20 mm thick, a size that is normally used in production[4], the maximum number of blades thus is 230. Reducing the blade thickness to 0.15 mm will increase the maximum number of 6.35 mm high blades to 307. At present, the thicker 0.20 mm blades are used in production because of their better wafer yield, as they are less susceptible to buckling which can be caused by vertical misalignment at the beginning of the slicing process and by increased blade tension, resulting from reduced crossection because of blade wear near the end of slicing[5].

There are two types of blade packages available: the drill-pin package and the epoxy package. In the former, the alternately arranged blades and spacers which determine the thicknesses of the kerf and wafers are held together by four threaded rods. It is the cheaper of the two types of package ($50 compared to $175),but often requires additional alignment before mounting on the slicing machine[3]. In the epoxy package, an adhesive is applied between the spacers and the blade ends to hold the package together[4].

The production procedure for multi-blade slicing involves first mounting the workpiece, or silicon crystal, with wax, epoxy, or other suitable cement on a graphite or ceramic base plate. The workpiece is then clamped by the baseplate to the slicing machine. To help increase the yield, ceramic bars are often similarly cemented longitudinally onto the cylindrical crystal near its top and bottom horizontal tangents. The bars "smooth-out" the slicing by decreasing the variation in kerf length and blade load as the blades travel downward through the cylindrical crystal. In addition, ceramic bars near the top tangent minimize the effect of vertical misalignment by reducing blade buckling by the time they enter the silicon crystal. Those bars near the bottom, help to smooth the transition of the blades cutting into the base material by equalizing the slicing properties above and below the crystal to base transition. Some of these benefits are also obtained, in some places, without the use of ceramic bars by varying the blade load according to the changing kerf length during the slicing process. After the slicing is finished, the wafers, still attached to the base, are removed from the slicing machine and the wafers are then detached from the base.

The effective linear cutting rate of the multiblade process is presently about 550 times smaller than the ID diamond saw. The linear cutting rate cannot be increased significantly because of the limit on the blade load and because of the blade head mass which limits the reciprocating frequency. The blade load cannot be increased much beyond its present value without significantly increasing blade buckling since the tensile strength of the blades is fixed. Varian found that a blade load of 2.77 N/blade caused severe enough buckling to separate the crystal from its mount[4]. In another experiment, a reciprocating frequency increase to 2 Hz resulted in sufficient vibration to break all wafers[4]. Therefore, in order to increase the throughput rate, or the wafer area produced in the multi-blade slicing process per unit time, either the number of slices in the load, or the area yield per load, has to be increased without significantly increasing the time of the run. The area output per load can be increased in a combination of several ways: by increasing the number of blades per unit blade head width, as can be achieved by decreasing the blade and/or spacer thickness; by increasing the width of the blade head without changing blade and spacer thicknesses; or by increasing the width of the workpiece.

The blade thickness has a lower bound set by its strength. If the blade is too thin, it will buckle under the blade load, or break from the blade tension, resulting in broken wafers and low yields. Reduction of the spacer thickness is limited by the wafer strength. Slicing wafers too thin increases their chance of breakage due to pressure from the lateral blade movement, blade vibration, blade buckling, etc. As the blade and spacer thicknesses are decreased, the increased fragility of the blades and the wafers ultimately leads to significantly lowered yields. Experimentally, Varian[9] has found that using 0.15 mm thick blades with 0.30 mm spacers still results in good yields. Under these conditions 0.25 mm thick wafers with 0.20 mm kerf are produced. This gives, assuming a wafer yield of 95%, which has been demonstrated by Varian, an area conversion ratio of 0.9 m^2/kg-Si which is a 50% improvement over Spectrolab's recently experienced area conversion ratio in slicing 5.4-cm and 7.5-cm diameter wafers.

Varian is also currently experimenting with a larger blade head width that can accept 900 to 1000 blades. This blade head weighs approximately one ton. Therefore, the workpiece will be reciprocated against the stationary blades. The workpiece size is projected to be 12-cm in diameter and 40.5-cm long yielding a wafer area of 9.67 m^2/load using the 900-blade machine with the aforementioned blade and spacer thicknesses. This area yield is over four times higher than obtained in present commercial practice. Details on the Varian 900-blade head slicing machine, as well as other slicing processes discussed in the report, are listed in Tables I-III, and in the "University of Pennsylvania Process Characterization" formats which are attached as an Appendix.

A third method to potentially increase the area yield per load without increasing the slicing time would be to increase the width of the workpiece, or the kerf length, by slicing two or more ingots, placed side-by-side, simultaneously. TI[(5)] has found that the machine slicing time, and, correspondingly, the linear cutting rate, is essentially independent of the kerf length. TI has therefore proposed slicing two 12-cm diameter ingots at one time to increase the multi-blade slicing productivity. The area yield per load, with details of this projection given in Tables I to III, can thus be doubled without significantly changing the slicing time.

2. Inner Diameter Slicing

In the process of inner diameter, or ID, slicing, one wafer is sliced at a time with a rotating, diamond impregnated blade. The rotation speed depends upon the blade size, and is 2,100 rpm for a blade with a

15.25-cm diameter hole, and 1650 rpm for a 20.32-cm diameter, inner diameter blade. The blade consists of a stainless steel core which is 0.10 and 0.15 mm thick for 15.24 and 20.32-cm blades, respectively, with diamond plated edges. The total thickness of the 15.24-cm blade is approximately 0.30 mm, and the 20.32-cm blade is about 10% thicker. The blade is mounted around its rim in a vise-like holder where hydraulic pressure is applied to tension it radially.

The linear cutting rate, or the rate that the inner diameter blade traverses the silicon can be up to 305 cm/h, or almost three orders of magnitude higher than for the slurry, multi-blade process. There are several reasons for this. First, the inner diameter blade speed is approximately 1,600 cm/sec as opposed to less than 80 cm/sec for multiblade slicing. Therefore, the contact length per unit time between the blade and the silicon for ID slicing is twenty times higher than for multiblade slicing. Also, fixed abrasive slicing removes more kerf in a unit contact length because there are two surfaces moving relative to each other instead of three as in slurry slicing. In slurry slicing, the abrasive is pushed into the workpiece and is "rolled out". Whereas for fixed abrasive slicing, the abrasive cuts into the workpiece to remove the kerf. Finally, the diamond plated layer on the ID blade increases the blade's rigidity and thickness and allows the application of more force, by the blade, on the workpiece than in multiblade slicing. The total thickness of the ID blade is 300-330 μm thick while the multiblade is 150-200 μm thick. It should be noted that the effective ID cutting rate is about 10-20% lower than indicated by the blade's linear cutting rate because of the 18 to 24 seconds between two consecutive slices, when the blade is returning to its original vertical position and the silicon crystal is being indexed.

In mounting the ingot, one end is attached to a graphite base with epoxy and the ingot is then placed in a box with rubber supports along it's length to keep it rigid. The stiffness of the mount will affect the vibration level between the blade and workpiece, influencing the wafer thickness and yield[3]. At present, ID machines can accommodate ingots up to 50-cm long[2,3]. The current practice of slicing 10.16-cm diameter wafers, 0.50 mm thick with a 0.33 mm kerf, yields a area of 4.8 m^2/load or 0.50 m^2/kg, at a practical wafer yield of 98%. During slicing, either water or water mixed with a small percent of Rust-Lick is sprayed on the cutting edge, at a rate of about 2 mℓ/sec, to cool the blade. The blade must be dressed, every 50 slices for the 15.24-cm blade and every 25 slices for the 20.32-cm blades for proper slicing, in order to remove dirt and expose a fresh cutting surface. The dressing is done with 5 cuts of an alumina stick. The lifetime of the blade is dependent on the rate of diamond "pull-out" and the degree of metal fatigue and varies quite extensively from blade-to-blade. The lifetime median is about 3,000 7.52-cm diameter slices for the 15.24-cm blade and 5,000 10.16-cm diameter slices for the 20.32-cm blade.

A method being investigated, to increase the ID saw's productivity by a factor of two, is crystal rotation[7]. The cutting speed is doubled using a rotating crystal since the blade has to traverse only half-way through the crystal diameter. The half penetration in rotating crystal slicing permits the use of a cheaper, smaller diameter, and thinner inner diameter blade. For slicing 10-cm diameter wafers with this technique the wafer thickness and kerf are expected to be 225 μm and 210 μm respectively[7].

A UPPC format for slicing rotating 10-cm diameter crystals with the ID saw is attached to the Appendix. This process is expected to be in commercial use by 1982.

3. The Yasunaga YQ-100 Multiwire Saw System

The Yasunaga multiwire saw is a slurry slicing system which uses a single wire (600 to 30,000 m in length) routed around a rocker arm tensioning device, a wire guide catridge, and a take-up reel. The continuous wire forms up to 250 multiple loops around the three grooved wire guides, arranged in an equilateral triangle, that are the key parts of the wire guide catridge. During slicing, the wire guide catridge oscillates, while the workpiece is raised against the wires with a preset force. An abrasive slurry is sprayed on the cutting surface. The procedure for mounting the silicon crystal for multiblade slicing is similar to that described for multiblade slicing.

The chief potential benefit of the Yasunaga saw is its high area-mass conversion ratio by employing closely-spaced, small diameter wires. The current YQ-100 model has a workpiece capacity of 10×10×10 cm and as demonstrated by experiments,[8] results of which are listed on a UPPC format attached in the Appendix, it can slice 215, 212 ± 7 μm thick wafers with less than 200 μm kerf using 0.4 mm pitch guides, 0.16 mm diameter wire and 13 μm SiC abrasive. Under those conditions an area to unit mass ratio of 1.04 m^2/kg is obtained, which is about 50% higher than what anyother current production or experimental slicing system achieves. This higher area to mass ratio effectively reduces the consumption of single crystal silicon, to produce a given wafer area, by a third. It is projected that the Yasunaga saw can achieve an area-mass ratio of 1.42 m^2/kg by employing closer spaced pitch guides (0.3 mm), smaller diameter wire (0.08 mm) and a finer abrasive (5 μm). This would yield a 200 μm thick wafer with 100 μm kerf[11].

It is believed that the narrow lapping band of the wires of the Yasunaga saw results in wafers with less subsurface damage than with other commercial slicing techniques[11], and this is being investigated[8].

Currently, the Yasunaga saw is not used for the production of silicon wafers, at least not in the USA, although Solarex has recently obtained a machine for pilot line operation.

4. <u>The Multiwire Fixed Abrasive Slicing Technique ("FAST")</u>

This method is similar to multiblade slicing, except that the silicon is sliced with diamond-impregnated wires instead of steel blades and an abrasive slurry. In FAST, the diamond impregnated wires are mounted and evenly spaced, at a linear density expected to be up to 25 cm^{-1}, on a light weight frame that is reciprocated across a rocking workpiece[10]. The wires are coated with 22 to 45 μm diamonds imbedded in a metal matrix, and can be coated on their bottom halves only to reduce abrasive costs. Development is still proceeding towards finding an optimum wire composition, but it has been found that heat-hardened, tungsten core wire, diamond-impregnated, and nickel-plated, has a good lifetime, which means it could be used for about 10 loads before significantly losing its cutting ability[10].

Crystal Systems has conducted most of their experiments, pertaining to FAST, on a modified Varian 686 wafering machine. Consequently, the slicing potential of multiwire, fixed abrasive slicing has not been fully demonstrated. For example, workpiece size has been, for most of the experiments only 4 x 4 cm, and the reciprocating rate lower than required for optimum fixed-abrasive slicing. A slicing machine, built to Crystal Systems' specifications, have just been delivered to them and slicing with this machine has just been initiated. The new slicing machine has been designed to provide higher cutting rates and lower wafer and kerf thicknesses and operate with a much lighter blade carriage, at higher reciprocating frequencies, and reduced vibration than the Varian machine. It is expected that this multiwire, fixed abrasive slicing technique could have a cutting rate of 0.6 cm/h (twice the value previously achieved with good yields), with an area to mass ratio of 1.1 m^2/kg by producing wafers 200 μm thick with a 200 μm kerf.

The add-on prices for "FAST", detailed in one of the UPPC formats attached to the Appendix, have been projected for 1986 since the state of development of the system and the comparatively small base of experimental data available, making it unlikely that this slicing technique could be in significant commercial operation by 1982.

B. TABULATION OF OPERATION, LABOR, MATERIAL AND COST DATA

Tables I to III summarize the data provided by various organizations for the slicing techniques that are being used or developed. Included in these tables are production experience data from Spectrolab[1] for multi-

TABLE IA

SLICING OPERATION DATA FOR MULTIBLADE WAFERING

	Organization	Spectrolab (Production Experience) 2 cm Rectangular	Spectrolab 5.4 cm Diameter	Spectrolab 7.5 cm Diameter	OCLI (Experimental) 10.16 cm Diameter	Varian (Experiment no P-005) 10cm Diameter	Varian (Projection) 10cm Diameter	Varian (900 blade projection) 12cm Diameter	TI (Experimental incl. Projection) 12cm Diameter
1.	Workpiece size	8 x 17 cm	16 cm long	16 cm long	15 cm long	11.7 cm long	13.5 cm long	40.5 cm long	2, 13 cm long ingots
2.	No. of workpieces/ load	not applicable	3	2	1	1	1	1	2
3.	Slices/load	1750 (2x2 cm)	750	500	230	234	300	900	460
4.	Wafer thickness (mm)	0.35/0.45 cut 0.2/0.3 etched	0.4 cut 0.3 etched	0.4 cut 0.3 etched	0.33 ± 0.03	0.29 ± 0.04	0.25 ± 0.015	0.25	0.32
5.	Kerf thickness (mm)	0 275	0.275	0.275	0.33	0.22	0.2	0 2	0.24
6.	Practical Wafer Yield	0.95	0.95	0.95	0 84	0.83	0.95	0.95	1.00
7.	Fraction Silicon incorporated in wafer	0.53/0.59	0.56	0.56	0.42	0.47	0.53	0.53	0.57
8	Depth of Subsurface damage (µm)	75	75	75	n.a.	10-15	10-15	n.a.	10 severe 33 slight
9.	Abrasive	600 grit SiC	600 grit SiC	600 grit SiC	400 grit SiC	600 grit SiC	600 grit SiC	600 grit SiC	600 grit SiC
10.	Vehicle	PC oil	PC oil	PC oil	PC oil	PC oil	PC oil	PC oil	PC oil
11.	Concentration (kg/ℓ)	0.24	0 24	0.24	0.8	0.36	0 36	0.36	0.24
12.	Flow rate (ℓ/h)	low	low	low	n.a.	n.a.	n.a.	n.a.	18
13.	Type of Blade	1095* steel 0.2 mm thick	1095 steel 0 2 mm thick	1095 steel 0.2 mm thick	1095 steel 0.2 mm thick	1095 steel 0.15 mm thick	1095 steel 0.15 mm thick	1095 steel 0.15 mm thick	1095 steel 0.20 mm thick
14.	Blade dimensions	n.a.	n.a.	n.a.	6.35 mm high - 0.46 mm spacers	6.35 mm high 0.35 mm spacers	6.35 mm high 0.30 mm spacers	6.35 mm high 0 30 mm spacers	6.35 mm high 0.36 mm spacers
15.	Amount on machine	250 blade drill pin pack	250 blade drill pin pack	250 blade drill pin pack	230 blade epoxy package	300 blade package	300 blade package	900 blade package	230 blade package
16	No. of runs before blade change	7	2	1	1.5	1	1	2	1
17.	Wafer area/load (m^2)	0.69	1.63	2.10	1.57	1.53	2.24	9.67	5.20
18.	Area yield (m^2/kg)	0 65/0 56	0 60	0 60	0 54	0.71	0.90	0.90	0.76
19.	Effective cutting rate (cm/h)	0.36	0 25	0.34	0.5	0 31	0.34	0.41	0.66
20.	Slicing time segment/load (h)	5.5	22	22	20.5	32.0	29.5	29.5	18.2
21.	Load/Unload time (h/load)	0.25	0.25	0.25	0.45	0.5(p)	0.5	0.5	0.5
22.	Cutting tool change, machine service (h/load)	0.2	0 5	1 0	0 67	0.5(p)	0.5	0.5	0 6
23	Machine segment time (h/load)	5 95	22 75	23.25	21.6	33 0	30.5	30.5	20.0
24	Machine productivity (m^2/h)	0.115	0 071	0 090	0 07	0 046	0.074	0 317	0.24

TABLE IB

SLICING OPERATION DATA FOR MULTIWIRE AND INNER DIAMETER WAFERING

	Organization	Multiwire Wafering: Crystal Systems Fixed Abrasive Method (projection)	Multiwire Wafering: Yasunaga YQ-100 (Experimental) 7.6 cm diameter	Multiwire Wafering: Yasunaga YQ-100 (Projection) 10 cm diameter	Inner Diameter Slicing: OCLI (Experimental) 7.6 cm diameter	Inner Diameter Slicing: OCLI (Experimental) 10.16 cm diameter	Inner Diameter Slicing: HAMCO (Production exp.) 10.16 cm diameter
1.	Workpiece size	30x10x10 cm	10 cm long	10 cm long	50 cm long	25 mm long	46 cm long
2.	No. of workpieces/ load	1	1	1	1	1	1
3	Slices/load	250	215	333	725	350	555
4.	Wafer thickness (mm)	0.1	0.21 ± 0.01	0.2	0 36 ± 0.02	0.36 ± 0.02	0.50
5.	Kerf thickness (mm)	0.3	0 2	0.1	0.33	0.35	0.33
6.	Practical Wafer Yield	1.00	1.00	1.00	0.95	1.00	0.98
7.	Fraction Silicon Incorporated in Wafer	0.25	0.51	0.67	0.50	0.51	0.59
8.	Depth of Surface damage (μm)	Fissures extend 3 μm	~15	~6 5	n.a.	n.a.	n.a.
9.	Abrasive	none	GC 1200 (13 μm)	5 μm SiC	none	none	none
10.	Vehicle or coolant	1:1 water: ethylene glycol	lapping oil	n.a.	80.1 water: rust lick	80:1 water: rust lick	water
11.	Concentration (kg/ℓ)	-	~1.5	n.a.	-	-	-
12.	Flow rate (ℓ/h)	n a.	3600	3600	7.2	8.4	n.a.
13	Type of blade or wire	Ni plated, tungsten wire, diamond impregnated	Steel wire	Steel wire	Model STC-16 ID blade, diamond plated	Model STC-22, ID blade, diamond plated	ID blade diamond plated
14.	Blade or wire dimensions	0 125 mm core 0.25 mm total diameter 45 μm diamonds	0 16 mm diameter 0.4 mm pitch guides	0.08 mm diameter, 0.3 mm pitch guides	42 23 cm OD 15.24 cm ID 0.10 mm thick core, 0.28-0.30 total thickness	55.88 cm OD, 20.32 cm ID, 0.15 mm thick core, 0.33-0.36 total thickness	n.a.
15	Amount on machine	250 wire blade package	~17,000 m	~35,000 m	1	1	1
16.	No. of loads before blade change	9	3	3	4.1	14.3	1
17	Wafer area/load (m^2)	7.50	0.98	2.62	3.14	2.84	4.41
18.	Area yield (m^2/kg)	1.1	1.04	1.42	0.59	0.60	0.505
19	Effective cutting rate (cm/h)	0.6	0.84	0.3	305	305	305
20.	Slicing time segment/load (h)	16.67	9.0	30.0	23.9	14.7	23.12
21.	Load/Unload time (h/load)	1.33	n.a.	n.a.	1.23	0.735	0.083
22	Cutting tool change, machine service (h/load)	n a.	n a	n a	1.02	0.84	0.33
23	Machine segment time (h/load)	18.0	10.0(e)	3 1(e)	26.2	16.3	23 5
24	Machine productivity (m^2/h)	0 42	0 098	0.085	0.126	0.176	0.19

blade slicing and from HAMCO [2] for ID slicing, and experimental results for multiblade slicing, from OCLI[6], Varian[4] and TI[5] for multi slicing from JPL[8] and ID slicing from OCLI[6]. In addition, projections made by Varian for multiblade slicing[9], by Crystal Systems[10] for their "FAST" method, and by Solarex[11] for the Yasunaga saw are included. In the Appendix, UPPC formats containing the details of the information obtained, are shown for these principle applications or projections for the slicing techniques.

The operation data for multiblade slicing are listed in Table IA, while Table IB contains the corresponding data for the fixed abrasive and slurry multiwire and the inner diameter slicing processes. These tables contain the process attribute of slicing which are summarized on Figure 1. The first two lines of Table I are the dimensions of the workpiece and the number of workpieces per load, the product of which is the slicing machine's capacity. The wafer area produced in a load is related to the workpiece capacity through the wafer and kerf thicknesses and practical wafer yield. This wafer area per load (Table I, line 17) can also be calculated as the product of the theoretical number of slices cut per load (Table I, line 3), the "practical wafer yield" (Table I, line 5), and the area of the single wafers. The "practical wafer yield" fraction is the number of acceptable wafers divided by the theoretical number sliced per load. The wafer area per unit mass (Table I, line 18) is calculated by dividing the practical wafer yield by the product of the sum of the wafer and kerf thicknesses (Table I, lines 4 and 5) and the density of silicon, or

PROCESS ATTRIBUTES

WORKPIECE SIZE AND NUMBER/LOAD

WAFER THICKNESS

KERF THICKNESS

PRACTICAL YIELD

(DEPTH OF DAMAGE)

EFFECTIVE CUTTING RATE

LOAD/UNLOAD TIME (INCL. TOOL CHANGE)

MACHINE PRODUCTIVITY

MACHINE AVAILABILITY

Figure 1.

$$I.18 = \frac{10 * I.6}{(I.4 + I.5)*2.34} \quad m^2/kg ,$$

where I•n represents the value from Table I, line n.

The wafer thickness, kerf and practical wafer yield are necessary for finding the division of the input silicon crystal or workpiece into the silicon incorporated in the work-in-process wafer (Table I, line 7) and that silicon lost in kerf and broken wafers.

The procedures for determining the subsurface damage depths, listed in line 8 of Table I, were not consistent between organizations. The most accurate method for determining subsurface damage depth is to remove wafer surface material until the cell efficiency becomes independent of any further removal. Spectrolab's values reflect this procedure(1). The other subsurface damage depths were determined by chemical etching to remove surface material followed by Wright etching to reveal defects(4), by etching and x-ray topography(5), and by angle lapping and Sirtl etching(8).

Indirect material requirements, briefly summarized on Figure 2, in terms of the abrasive and vehicle, or coolant type, the slurry concentration and its flow rate or that of the coolant, are listed in lines 9-12 of Table I. Lines 13-16 describe the expendible tooling requirements such as the type of blade or wire, its dimensions, the size of the blade pack and its life expectancy. These data are necessary for determining the expendible tooling and material costs.

The effective cutting rate (Table I, line 19) is defined here as the workpiece diameter divided by the slicing time segment, which is the time the machine is actually sawing (Table I, line 20). The time periods when the machine is not actually slicing and cannot be used for slicing because of preparatory or service operations, are listed in lines 21 and 22. The sum of these lines and the slicing time segment is the machine segment time (Table I, line 23), or the average time needed for slicing a load, including loading, unloading and servicing. The machine segment time is needed for calculating the number of loads processed annually, and the machine productivity (Table 1, line 24) which is the wafer area sliced in a load divided by the machine segment time.

The requirements per machine load for labor, included that needed for service and repair, for indirect material needs, including electricity consumption, for capital expenses, which consists of machine and facility components, are included in Tables IIA and IIB. These data form the basis for calculating of the manufacturing cost components of labor, expendable tooling, indirect materials, and capital. Also listed in these tables are values necessary for calculating direct material or silicon costs: the proportion of silicon lost in grinding the cylindrical ingots to a uniform diameter, the unit mass of silicon incorporated in the wafer and that lost in kerf and broken wafers.

The labor times required for each part of the crystal slicing operation (see Fig. 2), that is crystal mounting, machine loading and machine monitoring are listed in lines 1-3 of Table II, with their total on line 4. The service labor time, which includes changing the blades or wires, is listed in line 5.

Table IIA

SLICING LABOR AND MATERIAL ANALYSIS FOR MULTIBLADE SLICING

	Organization	Spectrolab (Production Experience) 2 cm Rectangular	Spectrolab 5.4 cm Diameter	Spectrolab 7.5 cm Diameter	OCLI (Experimental) 10 16 cm Diameter	Varian (Experiment no. P-005) 10cm Diameter	Varian (Projection) 10cm Diameter	Varian (900 blade projection) 12cm Diameter	TI (Experimental incl. Projection) 12cm Diameter
1.	Crystal Mount time (h/load)	0.5	0.25	0.25	0.25	0.27	n.a.	n.a.	1.0
2	Machine load-unload labor (h/load)	0.25	0.25	0 25	0.45	0.4	0.67	0.67	n.a.
3.	Machine supervision during slicing (h/load)	0 58	5 1	5 2	0.45	0.67	0.67	1.60	0.07
4	Total direct labor time (h/load) (excluding maintenance)	1 33	5.6	5.7	1.15	1.33	1.33	2.27	1.07
5.	Cutting tool change, machine service labor (h/load)	0 4	1 4	1.4	0.87	0 67	0.67	0.67	0.6
6.	Blade or wire set cost ($)	~50	~50	~50	175	~50	23.50	39.45	6.90
7.	Vehicle or coolant consumption (ℓ/load)	7.6	7.6	7.6	6.8	7.6	7.6	15.0	n.a.
8.	Amount of abrasive consumed (kg/load)	1.8	1.8	1.8	5.45	2.74	2.74	5.4	n.a.
9	Power requirements (kW/machine)	1	1	1	1	1	0.75	1.67	1
10	Energy consumption (kWh/load)	5.5	22	22	20.5	32	22	49.3	18.2
11.	Machine availability (%)	90	90	90	90	90	90	90	90
12.	Potential no. of runs in a year (8280 h work year)	1250	325	320	345	225	245	245	370
13	Machine cost ($)	20,000	20,000	20,000	20,000	20,000	20,000	30,000	30,000
14	Annual machine cost ($/year)	4,280	4,280	4,280	4,280	4,280	4,280	6,420	6,420
15.	Allocatable building area (m^2/machine)	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
16.	Allocatable building cost ($/machine)	8,400	8,400	8,400	8,400	8,400	8,400	8,400	8,400
17	Annual building cost ($/y)	980	980	980	980	980	980	980	980
18	Fraction of silicon lost in grinding ingots (%) (100 x(0. 6/d))	-	11 1	8.0	5.9	6.0	6 0	5 0	5.0
19	Silicon incorporated into wafer (kg/m^2-wafer)	0.81/1 05	0.94	0.94	0.77	0.58	0 59	0.59	0.75
20.	Kerf and broken wafer loss (kg/m^2-wafer)	0.68 /0 73	0.73	0.73	1.07	0.76	0.52	0 52	0.56

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TABLE IIB

SLICING LABOR AND MATERIAL ANALYSIS FOR MULTIWIRE AND INNER DIAMETER WAFERING

	Organization	Multiwire Wafering: Crystal Systems Fixed Abrasive Method (Projection)	Multiwire Wafering: Yasunaga YQ-100 (Experimental) 7.6 cm diameter	Multiwire Wafering: Yasunaga YQ-100 (Projection) 10 cm diameter	Inner Diameter Slicing: OCLI (Experimental) 7.6 cm diameter	Inner Diameter Slicing: OCLI (Experimental) 10.16 cm diameter	Inner Diameter Slicing: HAMCO (Production exp.) 10.16 cm diameter
1	Crystal Mount time (h/load)	n.a.	n.a.	n.a.	0 41	0.23	0.25
2.	Machine load-unload labor (h/load)	n.a.	n a	n.a.	1 015	0.525	0.083
3.	Machine super-vision during slicing (h/load)	0.92	0.33(e)	1(e)	0.298	0.23	4.3
4.	Total direct labor time (h/load) (excluding main-tence)	1.75(e)	0 83(e)	1.5(e)	1.72	0.985	4.63
5.	Cutting tool change, machine service labor (h/load)	0.5(e)	0.5(e)	0.5(e)	1.015	0.875	0.8
6	Blade or wire set cost ($)	82	~97	143.50	60	150	55
7.	Vehicle or coolant con-sumption (ℓ/load)	n.a.	3 kg (~3.25ℓ)	n.a.	5.1	1.75	0
8.	Amount of abrasive con-sumed (kg/load)	0	5	n.a.	0	0	0
9	Power require-ments (kW/machine)	1.5	0.6	0.6	2(e)	2(e)	2(e)
10.	Energy con-sumption (kWh/load)	25	5.4	18	47.8	29.4	46.2
11.	Machine avail-ability (%)	90(e)	90(e)	90(e)	95	95	95
12.	Potential no. of runs in a year (8280 h work year)	415	745	240	300	480	325
13.	Machine cost ($)	30,000	30,000	30,000	40,000	40,000	40,000
14.	Annual ma-chine cost ($/y)	6,420	6,420	6,420	8,560	8,560	8,560
15.	Allocatable building area (m^2/machine)	11.2	8	8	18	18	18
16.	Allocatable building cost ($/machine)	8,400	6,000	6,000	13,500	13,500	13,500
17	Annual building cost ($/y)	980	700	700	1,580	1,580	1,580
18.	Fraction of silicon lost in grinding ingots (%) (100 x(0.6/d))	6.0(e)	8 0	6 0	8.0	6.0	6.0
19	Silicon in-corporated into wafer (kg/m^2-wafer)	0.23	0.49	0.46	0.84	0.84	1.17
20.	Kerf and broken wafer loss (kg/m^2-wafer)	0.70	0 47	0 23	0.86	0.82	0.81

Expendable tooling and indirect material requirements, in terms of the blade or wire set costs and the quantities of vehicle or coolant and abrasive consumed during a run, are listed in lines 6-8 of Table II. The electrical consumption for a run (Table II, line 10) is considered as an indirect material and is obtained by multiplying the slicer's power requirements by the slicing time segment (Table I, line 20).

In order to calculate the potential number of loads that can be sliced annually, shown in line 12, the machine segment time (Table I, line 23) is divided into 8280. This last value, 8280, is taken from SAMICS[12] and is the number of annual hours the wafer slicing plant operates. The plant operation schedule is continuous except for one 1-week vacation, two 4-day weekends, and one 3-day weekend, and was chosen to maximize annual production by minimizing slicer shutdowns during a run due to plant closings.

After dealing with expenses, the sum of the machine and facility costs, or the capital cost portion of the manufacturing costs needs to be considered. The capital costs are dependent on the factors listed on Figure 3. The annual machine cost (Table II, line 14) is the product of the initial cost of the slicing machine, including installation, taken from the data sources, and the standardized charge rate of 0.2135 y^{-1}. This charge rate was taken from SAMICS[12], using a depreciation schedule of 7 years, a state tax of 2% on one-half the capital, a 4% insurance premium, and a 12% interest-on-debt rate on one-twelfth the initial capital cost. The low ratio of dept to capital, or the low financial leverage, is due to the postulate that the photovoltaic industry would be

LABOR AND INDIRECT MATERIALS

LABOR TIMES:

- ATTACH SUPPORT BLOCK TO INGOT
- MACHINE LOAD/UNLOAD
- MACHINE MONITORING
- TOOL CHANGE/MACHINE SERVICING

INDIRECT MATERIAL COSTS:

- SLURRY (COOLANT) TYPE
  - UNIT COST
  - USAGE
- TOOL (BLADE) TYPE
  - COST
  - LIFE
- MACHINE REPLACEMENT PARTS
- PURCHASED MACHINE SERVICING
- MISC. (MOUNTING BLOCKS, ADHESIVE)
- ENERGY

Figure 2.

CAPITAL COSTS

MACHINE COST

(MACHINE LIFE)

ALLOCATABLE BUILDING AREA

(SPECIAL SERVICES)

Figure 3.

unable to raise large amounts of debt capital, without large interest rates, because it will be a rapidly evolving industry with appreciable risks[12].

The second capital cost contribution comes from the building. The allocatible building area, shown in line 15 of Table II, was taken, according to SAMICS[12], as twice the machine's operating area. The doubling accounts for indirect and overhead space needed e.g., for functions such as maintenance, administration and receiving/inventorying, as well as for aisles, washrooms, etc. The initial building cost (Table II, line 16) is taken as $\$1506.95/m^2$, according to SAMICS[12], and is based on the machine operating area only. This cost figure includes appropriate cost allocations for the additional building space needed as outlined above. The facilities charge rate used to calculate the annual building cost (Table II, line 17), from the initial cost, is 0.117 y^{-1}. This value was obtained in the same fashion as the equipment charge rate, except that a 40-year life expectancy is employed for determining the depreciation rate of the building. Also a 31% surcharge on the annual cost of capital is included, in the 0.117 y^{-1} factor, to account for special services which are the "indirect" utility consumption, that is for heating, air-conditioning, lighting, etc. for the building.

To properly calculate the direct material cost, that is the cost of the cylindrical slicing ingot, the amount of the silicon crystal lost in grinding is necessary. The grinding of the cylindrical ingots to a uniform outside diameter, previous to slicing, facilitates the slicing operation, as well as tooling and handling of the sliced wafers in subsequent device fabrication procedures. In calculating the mass fraction of silicon lost in grinding, shown in line 18 of Table II, the average diameter loss is assumed to be 0.6 cm. With this diameter loss, and the consequent loss of mass, the price per unit mass of silicon entering into the slicing operation can be determined. Since the grinding diameter loss stays constant with crystal diameter, the fraction of lost silicon is inversely proportional to the diameter of the crystal.

The difference between the add-on processing cost and the work-in-process cost is the cost of the direct material contained in the wafers. The latter value for a unit area can be obtained by multiplying line 19 of Table II by the unit mass silicon cost. To obtain the amount of silicon contained in a unit wafer area, the incorporated silicon fraction is divided by the wafer area per unit mass (Table I, line 18). The incorporated wafer fraction is the product of the yield fraction (taken from Table I, line 6) and wafer thickness (Table I, line 4) divided by the sum of the wafer and kerf thicknesses. In equation form, the fraction of silicon contained in the wafer is,

$$II.19 = \frac{I.6 * I.4}{(I.4 + I.5) * I.18} \quad \frac{kg}{m^2} ,$$

with the roman numerials representing the table numbers and the arabic numbers, the line numbers for that table. The kerf and broken wafer loss, necessary for differentiating the operating add-on cost from the specific add-on cost, is calculated in a similar fashion to line 19 of Table II, except that the kerf loss is represented by the kerf thickness and the broken wafer loss by the broken wafer fraction multiplied by the wafer thickness. Therefore

$$II.20 = \frac{(I.5 + (1 - I.6) * I.4)}{(I.4 + I.5) * I.18} \quad \frac{kg}{m^2} ,$$

From the operation data and expenses, listed in the first two tables, the add-on components of the slicing manufacturing slicing cost can be calculated. For the most part, the add-on cost components, shown in Table III, on a per unit area basis, are derived from the data of the proceeding tables using the relationships given in that table. The exceptions include the unit costs of the indirect materials which were taken from the sources footnoted in Table III. In addition, the purchased service cost for multi-blade slicing (Table III, line 4), which includes the cost of machine maintenance and overhaul performed on the outside or under contract, used was \$1529.3 y^{-1} and was obtained from Spectrolab[1]. HAMCO[2] supplied the purchased service cost for an inner diameter slicing as \$285.7 y^{-1}. The total material cost which is the sum of the first four lines of Table III was increased by 5.26%, in accordance to SAMICS charge factors[12], to account for handling and other miscellaneous expenses.

The labor costs were calculated using the labor times, listed in Table II and the labor rates shown in the Cost Account Catalog of the SAMICS Support Study[13]. For calculating the direct labor costs which involve crystal mounting, machine loading and supervision the wages paid an electronics semiconductor assembler, whose duties are described under SAMICS' occupation classification no. 726884 and wages under catalog no. B3096D[13] were employed. The maintenance labor rate of a maintenance mechanic II (occupation classification no. 726884, catalog no. B3736D) was used to find the labor cost of internal machine service and cutting tool charges. The listed labor rates were multiplied by 1.432 to take into consideration fringe benefits, such as vacations, medical health plans, social security benefits, etc, and miscellaneous expenses. A surcharge of 25% was added to the direct

TABLE IIIA

ADD-ON COST COMPONENTS FOR MULTIBLADE SLICING ($/m^2)

	Organization	2 cm Rectangular	Spectrolab (Production Experience) 5 4 cm Diameter	Spectrolab (Production Experience) 7 5 cm Diameter	OCLI (Experimental) 10 16 cm Diameter	Varian (Experiment no P-005) 10cm Diameter	Varian (Projection) 10cm Diameter	(900 blade projection) 12cm Diameter	TI (Experimental) incl Projection 12cm Diameter
1	Expendible tooling (IIA 6 ÷ IA 16* IA 17)	10.35	15 34	23 81	74 31	32 68	10 49	2 04	1.33
2	Materials	21.15 (a)	8 95 (a)	6.95 (a)	16 35 (b)	7.50 (c)	3 40 (c)	3.85 (c)	0 30 (d)
3.	Electrical energy cost ($0 032 *IIA.10 ÷ IA 17)	0 25	0.43	0 33	0.42	0 67	0 32	0.16	0 11
4	Replacement parts & purchased service	1 85	3 01	2.37	2.94	4.62	2 90	0 67	0 83
5	Total material costs (1.0526* (1 +2 +3 +4))	35 37	29 19	35 22	98 96	47.86	18 01	7.07	2 70
6	Direct Labor ($5 58*IIA 4 ÷ IA.17)	10.75	19.16	15.14	4.08	4 85	3 31	1.31	1 15
7	Maintenance labor ($ 8.12* IIA 4 ÷ IA.17)	4 71	6.98	5 42	4 50	3.55	2 43	0 56	0.94
8	Other indirect labor (25% of 6 + 7)	3 86	6 53	5 14	2 15	2 10	1 44	0 46	0 52
9	Total labor (6 + 7 + 8)	19 32	32 67	25 70	10 73	10.50	7 18	2.33	2 61
10	Equipment cost (IIA 14 - IIA.12 * IA.17)	4.96	8 08	6.37	7 90	12.43	7.80	2 71	2.22
11	Facilities cost (IIA 17 ÷ IIA 12 *IA 17)	1 14	1.85	1.46	1 81	2 85	1 79	0.41	0 34
12	Capital Cost (10 + 11)	6.10	9.93	7.83	0.71	15.28	9.59	4 50	2.56
13	Overhead (0 059 * (10.) + 0 168 *(11))	0 42	0 68	0 53	0 66	1.04	0 65	0 20	0.17
14.	Return on equity (0 192*(5.) + 0 192*(9.)+ 1.22 * (10) + 4 73*(11.))	21 94	30.49	26.37	39.26	39.85	22.82	7 05	5.34
15	Add-on price (Si price assumed zero) 5 +9 +12 +13. +14)	03.15	102.70	95.53	159.25	114.29	58.10	21.15	13.34
		Silicon Ingot Price (Unground) @ $139 15/kg (1978 estimation)							
16	Add-on cost of grinding ($/kg)	-	20.97	13.99	9.77	9.96	9.96	8.07	8 07
17	Cost of ground Si ($/kg)	-	160.12	153.14	148.92	149.11	149.11	147.22	147.22
18	Lost Silicon	-	116.89	111.79	158.80	113.21	78.05	77.05	82.68
19	Add-on price	-	219.59	207.31	318.14	227.50	136 15	98.20	96.02
20	Price	-	368.50	349.73	433.15	328.68	223 61	184.32	206.93
		Silicon Ingot Price (Unground) @ $65 98/kg (1982 projection)							
21	Add-on cost of grinding ($/kg)	-	12.84	8.13	5.45	5.56	5 56	4.41	4.41
22	Cost of ground Si ($/kg)	-	78.82	74.11	71.43	71.55	71.55	70.39	70.39
23	Lost Si	-	57.54	54.10	76.43	53.66	37.21	36.61	39.43
24	Add-on price	-	160 24	149.43	235.68	167.95	95.31	57.76	52.87
25	Price ($/m^2)		233.83	219.00	290 83	216.50	137 17	98 94	105 58
		Silicon Ingot Price (Unground) @ $24 46/kg (1986 projection)							
26.	Add-on cost of grinding ($/kg)	-	8.23	4.81	3.00	3.07	3.07	2.34	2.34
27	Cost of ground Si ($/kg)	-	32 69	29.27	27.46	27.53	27.53	26.80	26.80
28	Lost Silicon	-	23.86	21.37	29.38	20.65	14.32	13.94	15.05
29	Add-on Price	-	126.56	116.90	188.63	134.94	72.42	35.09	28.39
30	Price	-	157.16	144.30	209.83	153.62	88.53	50.77	48.46

(a) Calculated using $7/gallon for the slurry mixture and including $0.60/load for the ceramic base and bars.

(b) H I Yoo, "Assesment of Present State of the Art Sawing Technology," OCLI, DOE/JPL 954830-77/12, p 34 (12/77)

(c) S C Holden and J R Fleming, "Slicing of Silicon into Sheet Material" Varian Associates, ERDA/JPL 954374-77/2, p 22 (7/77)

(d) Samuel N Rea and Paul S Gleim, "Large Area Czochralski Silicon," Texas Instruments, ERDA/JPL-954475-76/2 p 17, (9/76)

TABLE IIIB

ADD-ON COST COMPONENTS FOR MULTIWIRE AND INNER DIAMETER SLICING ($/m²)

	Organization	Multiwire Wafering: Crystal Systems Fixed Abrasive Method (projection)	Multiwire Wafering: Yasunaga YQ-100 (Experimental) 7.6 cm diameter	Multiwire Wafering: Yasunaga YQ-100 (Projection) 10 cm diameter	Inner Diameter Slicing: OCLI (Experimental) 7.6 cm diameter	Inner Diameter Slicing: OCLI (Experimental) 10 16 cm diameter	Inner Diameter Slicing: HAMCO (Production exp.) 10 16 cm diameter
1	Expendible tooling (IIB.6 ÷ IB.16 *IB17)	1.25	33	18 25	4.65	3.70	12.45
2.	Materials	0.30 (a)	32.95 (b)	41.05 (d)	2.65 (e)	2.05 (e)	1 85 (f)
3.	Electrical energy cost ($0.0319* IIB.10 ÷ IB.17)	0.11	0.18	0.22	0.49	0.33	0.33
4.	Replacement parts and purchased service	n.a.	n.a.	n.a.	0 30 (g)	0 21 (g)	0.20 (g)
5	Total materials (1.0526*(1 + 2. + 3. +4.))	1 74	69.61	62.65	8 52	4 52	13.51
6.	Direct labor ($5.58* IIB 4 ÷ IB.17)	1.30	4.72	3.19	3.05	1.93	5.85
7.	Maintenance labor ($8.12*IIB.5 ÷ IB.17)	0.54	4.14	1.55	2.63	2.50	1.47
8	Other indirect labor (25% of (6 + 7.))	0.45	2.22	1.19	1.42	1.11	1 83
9	Total labor (6. + 7. + 8)	2.30	11 08	5 93	7.10	6.54	9.15
10.	Equipment cost (IIB.14 ÷ IIB.12 IB.17)	2.06	8.79	10 21	9.09	6.28	5.97
11.	Facilities cost (IIB.17 ÷ IIB.12 IB.17)	0.32	0.96	1 12	1.67	1 15	1.10
12.	Capital Cost (10 + 11.)	2.38	9.75	11.33	10 76	7 43	7.07
13.	Overhead (0.059* (10.) + 0.108 *(11.))	0.16	0.57	0.66	0.72	0.49	0.471
14	Return on equity (0.192* (5.)+0.192*(9.) + 1.22* (10.) + 4.73*(11.))	4.80	30.57	30.92	21.99	15.22	16.84
15.	Add-on price (Si price assumed zero) (5. +9. +12. +13. +14.)	11.38	121.57	111.62	49.06	36.29	47.04
		Silicon Ingot Price (Unground) @ $139 15/kg (1978 estimation)					
16.	Add-on cost of grinding ($/kg)	9.94	13.77	9.96	13.77	9.77	9.77
17.	Cost of ground silicon ($/kg)	149.09	152.92	149.11	152.92	148.92	148.92
18.	Lost Silicon ($/m²)	104.66	71.57	34.30	131.09	122.17	120.96
19.	Add on price ($/m²)	116.04	193.14	145 92	180.15	158.46	168.00
20.	Price ($/m²)	150.93	268 45	215.70	309.02	280.48	342.31
		Silicon Ingot Price (Unground) @ $65.98/kg (1982 projection)					
21.	Add on cost of grinding ($/kg)	5.55	7.99	5 56	7.99	5.45	5.45
22.	Cost of ground Si ($/kg)	71.53	73.97	71 55	73.97	71.43	71 43
23.	Lost Si	50.21	34.03	16.46	62.87	58.57	57.99
24.	Add-on price	61.59	155.60	128.08	111.93	94.86	104.83
25.	Price ($/m²)	78.33	192.03	161.57	174 24	155.03	188.40
		Silicon Ingot Price (Unground) @ $24.46/kg (1986 projection)					
26.	Add-on cost of grinding ($/kg)	3.06	4.71	3.07	4.71	3.00	3.00
27.	Cost of ground Si ($/kg)	27.52	29 17	27.53	29.17	27.46	27.46
28.	Lost Si	19.32	13.42	6.33	24.79	22.52	22.29
29.	Add-on Price	30 70	134.99	117.95	73.85	58.80	69.33
30	Price	37.14	149.16	130.83	94.65	79.60	101.48

(a) F. Schmid and C.P. Khattack, "Heat Exchanger-Ingot Casting/Slicing Process" Crystal Systems, ERDA/JPL 954373-77/3, pp 78-79 (10/77).

(b) Calculated using $12.10/kg [c] for the abrasive and $1.25/ℓ [c] for the PC oil and assuming the slurry is used twice.

(c) LSSA Project Report, "Multiwire Slurry Wafering Demonstrations," Jet Propulsion Laboratory, DOE/JPL-1012-7817, (2/78).

(d) Estimated from materials cost of Yasunaga's 7.6 cm diameter ingot

(e) H.I. Yoo, "Assesment of Present State-of-the-Art Sawing Technology," OCLI, DOE/JPL 954830-77/12, p. 38 (12/77)

(f) Estimated from OCLI's material cost data

(g) Assuming total purchased service is $2,000 for the machine's lifetime.

labor and maintenance labor costs to account for the cost of supervisory, management, and other support personnel.

The unit area equipment and facility costs, which constitute the capital cost, were obtained by dividing the respective annual costs by the annual area factory output. The overhead, listed in line 13 of Table III, is defined as the insurance, state taxes, and interest-on-debt payments on the working capital. As suggested by SAMICS[12], the working capital was taken as 15% of the equipment plus facility cost, or 15% of the capital cost.

The profit and the amortization of one-time costs is represented by the return-on-equity (ROE), shown in line 14 of Table III. This value is equal to the SAMICS' return-on-equity (EQR), which is 20% of the equity portion of the book value[12], plus the amortization of the start-up costs (AOC), minus the income tax investment credit (ITC) on 10% of the annual equipment depreciation divided by the product of one minus the federal income tax credit ($1 - \tau$) and one minus the miscellaneous expense fraction, $(1 - x)$, or

$$\text{ROE (III.14)} = \frac{\text{EQR} + \text{AOC} - \text{ITC}}{(1-x) * (1-\tau)} \quad \$/\text{m}^2.$$

The add-on cost components described above can be used to calculate a unit area wafer price that ignores the cost of the silicon ingots. This add-on price shown in line 15 of Table III, is the sum of the material, labor, capital, overhead and return-on-equity. To convert this value into a wafer price, the unit mass cylindrical crystal price, and the add-on grinding cost must be added to it. The unground silicon crystal or ingot prices shown for 1978, 1982 and 1986 are taken from our previous evaluations.[14] For 1978, the ingot price is based on pulling 7.8-cm diameter ingots with a Leybold-Heraeus single charge puller. The silicon ingot prices employed for the years 1982 and 1986 are projections for multi-pulling Cz-grown 10.2-cm and 15.2-cm diameter ingots, respectively.

Previous to slicing, the silicon ingots must be ground to a uniform diameter and this cost has to be included in the cost of the direct material. The add-on cost of grinding, listed in line 16 of Table III, consists of two parts: a) the cost of the grinding operation which is projected to be \$0.20/cm-crystal length, based on industry data[1], and b) the cost of the silicon lost from grinding, which is equal to $\frac{II.18}{(100 - II.18)}$ * (Si ingot price (\$/kg)), where II.18 is the percentage of material lost in grinding. Summing the add-on grinding cost to the Si ingot price yields the cost of ground silicon prices (Table II, lines 17, 22, 27) which are used to calculate silicon wafer prices.

Also of interest in our analysis is the cost of the silicon lost in kerf and broken wafers. These values, shown in line 18, 23, 28 of Table III, are the product of the unit area kerf and wafer loss mass (Table II, line 20) and the ground silicon prices. The add-on wafer prices, shown in lines 19, 24 and 29 of Table III, are defined, here, as the sum of add-on wafer price, assuming a zero silicon price (Table III, line 15) and the cost of the lost silicon.

To arrive at a unit area wafer price listed in lines 20, 25, and 30 of Table III, the add-on price and the cost of silicon incorporated in the wafer are summed. The latter value is the cost of the ground silicon ingot multiplied by unit area silicon mass contained in the wafers (Table II, line 19).

C. COST STRUCTURES OF THE SLICING PROCESSES

The more important unit area manufacturing cost components for selected current production or experimental slicing capabilities, using 1978 silicon prices, and projected future capabilities, using 1982 and 1986 projected silicon proces are summarized in Table IV. These silicon prices apply to single crystal ingots grounded to a uniform diameter. Also included in this table are the costs of the lost silicon and that contained in the wafer. In Table IV, one can observe the decreases in expendible tooling, indirect materials, labor and capital costs that are expected for 1982 in ID, multiblade and slurry multiwire slicing. Illustrated in Figure 4 are the more relevant data of Tables III and IV, in a bar graph format. In Figure 4, the relative impacts of the material, labor and capital costs can be readily compared to each other for the current multiblade and ID slicing processes and for the near future (1982) projected multiblade, ID, and slurry multiwire processes.

As evidenced in Table IV, the indirect material costs (primarily slurry) and the costs for expendible tooling (the steel blades or wires) are much higher for the slurry sawing processes (multiblade and Yasunaga multiwire) than those for the fixed abrasive approaches (ID saw and FAST wire saw). This is a consequence of the more effective utilization of the abrasive in the fixed abrasive system, coupled with longer tool life. Reductions of these expendible tooling costs for the multiblade and slurry multiwire slicing processes are expected in the future through lower cost tool fabrication techniques[9,11] and through improved lifetimes[9]. The lower tool cost fabrication techniques are expected to result from larger

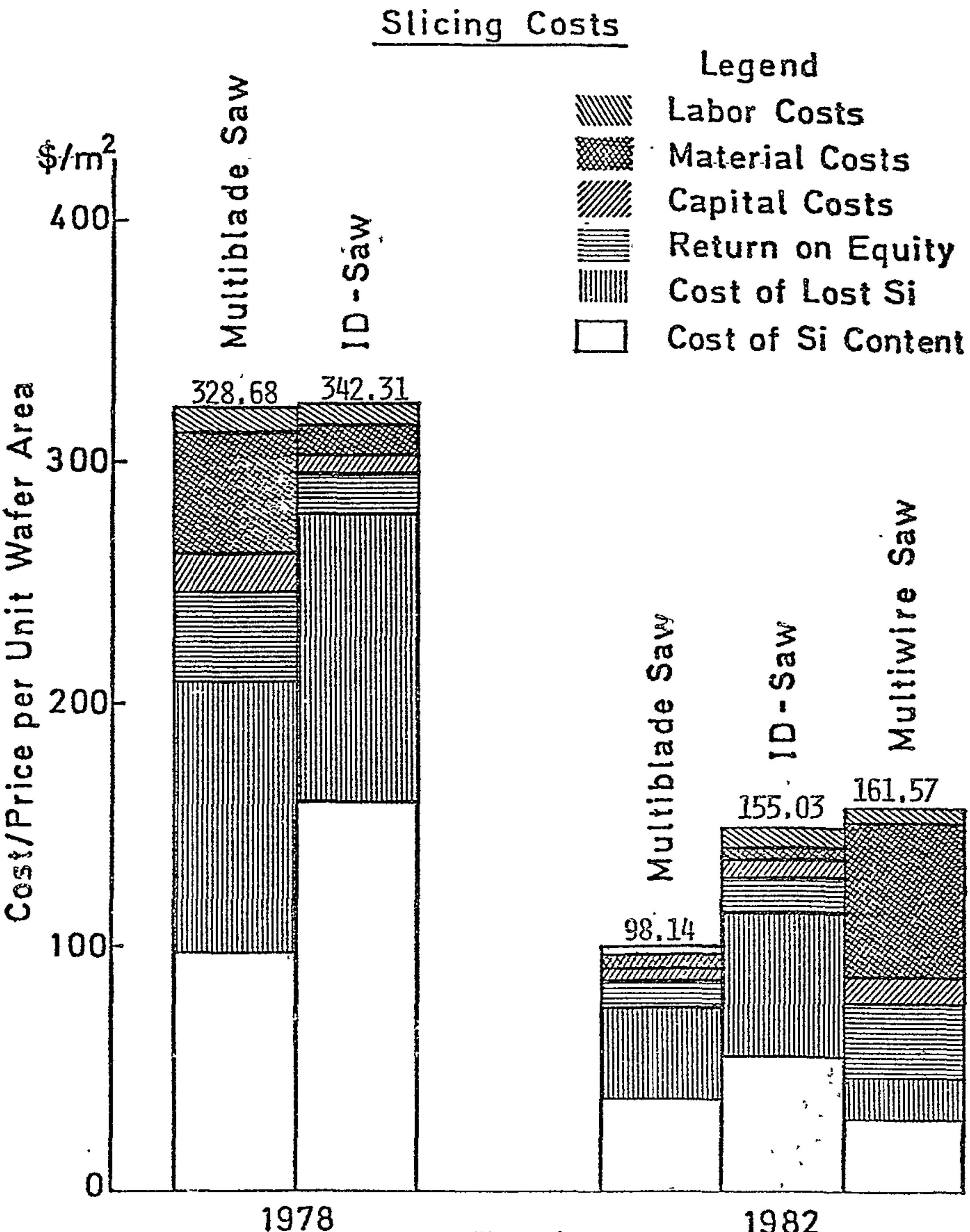

Figure 4

Costs of silicon wafer production in the years 1978 and 1982 by the slicing cost components, including the cost of the single crystal silicon content.

TABLE IV

KEY COSTS ($/m^2)

Type	ID Saw		Multiblade			Multiwire		
Source	OCLI	STC	Spectrolab	Varian		Yasunaga		Cryst. Systems*
X-tal Dia (cm)	7.6	10	7.5	10	12	7.6	10	10 x 10 rect.
Data Type	Exper. 1978	Projected 1982	Product.	Exper.	Projected 1982	Exper.	Projected 1982	Projected 1986
Tooling	4.65	1.46	23.81	32.68	2.04	33.00	18.25	0.33
Ind. Materials	2.65	-	6.95	7.50	3.85	32.95	41.05	0.35
Dir. Labor	3.05	1.48	15.14	4.85	0.77	4.72	3.19	1.67
Maint. Labor	2.63	0.15	5.42	3.55	0.56	4.14	1.55	0.54
Equip't Cost	9.09	3.66	6.37	12.43	2.71	8.79	10.21	2.55
Facil. Cost	1.67	0.50	1.46	2.85	0.41	0.96	1.12	0.47
Add-On Cost	27.07	7.25	69.16	74.44	13.43	91.00	80.70	7.61
Ret. on Equity	21.99	7.68	28.37	39.85	6.92	30.57	30.92	6.18
Lost Si	131.09	38.97	111.79	113.21	36.61	71.57	16.46	12.88
Add-On Price	180.15	53.90	207.32	227.50	56.96	193.14	128.08	26.67
Si Content	128.87	37.65	142.41	101.18	41.18	75.14	33.49	12.88
Price	309.02	91.55	349.73	328.68	98.14	268.14	161.57	39.55
Si ground X-tal ($/kg)	152.92	71.55	153.14	149.11	70.39	152.92	71.55	27.52

*Calculated using an effective cutting rate of 0.4 cm/h.

scale, automated assembly[9] and a simplification of the assembly process[11]. Investigations are currently being conducted into possibilities for the slurry costs, for instance by reclycling the slurry or substituting a cheaper vehicle (e.g. mineral oil) for the PC oil. In spite of these projected reductions, the indirect material and expendible tooling costs for the multiblade and the Yasunaga multiwire techniques remain sizable components of the total add-on costs for those processes. In the near-term projections, these components are 44% and 73% of the add-on cost for the multiblade and slurry multiwire processes, respectively. This compares to 20% and 9% of the 1982 projections for the add-on costs in the ID and fixed abrasive multiwire saws, respectively.

The current prices are essentially equal for production wafers cut by either the Varian multiblade or the ID sawing processes, although the ID saw has twice the productivity (Table I, line 24) and experiences lower indirect material and tooling costs. The higher productivity directly results in lower labor, capital, and return-on-equity costs, as shown in Figure 4. These lower processing costs for the ID slicing are counter-balanced, however, by a higher silicon consumption resulting from the practice to cut the wafers to greater thickness with higher kerf than achieved with the slurry saws. At the current silicon prices, this has a considerable cost impact.

The 1978 wafer prices shown here are somewhat lower than the contemporary commerical wafer and the 1978 values of the LSA Interim Price Allocation Guidelines[14]. This difference results from two facts: a) the data of this report do not include the cleaning, etching, or polishing process steps usually included in commercially sold wafers; and b) the standardized indirect cost model (SAMICS-IPEG) purposely omits several indirect charges on partially processed items such as wafers. Since the indirect cost structure models a vertically integrated industry, marketing costs for wafers, e.g. are not incurred.

3. CONCLUSIONS

The cost-analysis data, and particularly the projections, which include reduced expendible tooling and indirect material cost components, show that the dominant influence on the add-on price of sliced wafers is the productivity of the slicing machine. The machine productivity (the time rate of output unit expressed in wafer area) has a direct inversely proportional impact on the capital cost allocation to the wafer area produced of the cost components for equipment and facility, and on that part of the labor expenditures which are devoted to machine monitoring and maintenance, as shown in Figure 5. Figure 5 shows that the effective linear cutting rate (the workpiece diameter divided by the slicing time-segment) is 0.55 $\pm$ 0.3 cm/h for the multiblade and multiwire processes. The inner diameter diamond-coated blade process has an effective linear cutting rate of approximately 300 cm/h, a nearly 550 times larger value than that for the other processes. To achieve comparable machine productivities, the low linear cutting rates have to be compensated by simultaneous multiple slicing. The current efforts of Crystal Systems, Solarex, and Varian are therefore directed at increasing the number of wafers sliced during a run. Current multiblade packages contain about 250 blades. Varian has built an experimental slicer incorporating a blade pack of over 900 blades. Similarly, the wire package proposed by Crystal Systems[10] is projected to have 750 cutting wires. Solarex hopes to slice[11] 333 wafers at a time with the Yasunaga YQ-100 slicing machine.

The slicing technology improvements projected for the 1982 production lines are based on the results of recent experimental runs and on

CUTTING RATES:

ID SAW ~300 CM/H

ALL OTHER SAWS ~0.55 ± 0.3 CM/H

↓

IMPACTS:

PRODUCTIVITY

↓

CAPITAL COST: EQUIPMENT
FACILITY
LABOR (?)

REMEDY: MULTIPLE CUTTING

Figure 5.

developments in progress (Table IV, Fig. 5). For the multiblade saw, the primary advancement will be a nearly four-fold productivity increase via Varian's development of a machine using a 900-blade-pack. Simultaneously, a 25% blade thickness reduction in combination with a 37.5% wafer thickness decrease, while maintaining a wafer yield of 95%, is projected to result in an area yield of 0.9 m^2/kg-Si crystal, a 50% increase from Spectrolab's mass to area conversion ratio in slicing round wafers.

Slice and kerf thickness reductions to values similar to those projected for the multiblade slurry process, are also expected for the ID-sawing method. Recently acquired data from STC are reflected in a 1982 projection for 10-cm diameter crystals using ID slicing with ingot rotation, as shown in Table IV and in a UPPC format attached to the appendix. The wafers from this process are expected to be 225 μm thick with 210 μm kerf. In addition, crystal rotation is expected to double the effective cutting rate of the ID process. This essentially doubles the productivity of the ID saw, and results in comparable projected productivities for the 900-blade multiblade and the ID sawing processes. Remaining differences in the costs of these two processes are, however, overshadowed by the cost of the silicon incorporated into the wafer or lost. At the projected 1982 price for ground single crystal ingots, the cost of this silicon still amounts to nearly 80% of the wafer price.

One slicing method has been projected to 1986, primarily, because only a comparatively small base of experimental data is available, so that this method cannot be expected to be in significant commercial operation by 1982. This method is Crystal Systems' fixed abrasive multiwire sawing. The current projections are contained in Table IV, while Table IIIB is based on earlier inputs. The difference results primarily from a recently communicated reduction in tooling costs based on wirehead fabrication improvements, and from the use in Table IV of a more conservative effective cutting rate corresponding to the experimentally found rates averaged over the life of the bladehead. The process add-on costs are comparable to those of the two previously discussed processes. If the silicon price of 1982 would have been used, an approximately $11/m^2 lower wafer price would have resulted in comparison to the ID process. While the fixed abrasive multiwire process currently projects the lowest wafer price, it is also the one with the least experience data. It is therefore of great importance to gain a significant data base through pilot line operation.

Considering the uncertainties in the projections, the data indicate no considerable differences in the competitiveness of the three approaches, and a reasonable potential for all three to meet the 1986 guideline goal.

4. NEW TECHNOLGY

No new technology was developed during this quarter.

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6. APPENDIX

The University of Pennsylvania Characterization Formats for Production, Experimental and Projected Slicing Processes

Process No. [2].[4].[0 1]-[0 1] Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Sheet Generation

Subprocess: Wafer Generation

Option: Mounting of crystal ingots on ceramic base with wax (Spectrolab)

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14	1 to 0			
15	1 to 1			
16	1 to 0			

Form 2

Revision ______ Date 3/78

Process No. 2 . 4 . 0 1 - 0 1

0.1 Value Added:	$/

Process Description: Mounting of two, 7.5 cm diameter, 16 - cm long single crystal, silicon ingots on a ceramic base with wax. Material and labor requirements supplied by Spectrolab.

1. Input Specification:

Name of Item: Single crystal silicon ingots (two); grounded.

Dimensions: 7.5 cm in diameter, 16.875 cm in length, and 1.744 kg.

Material: high purity silicon

Other Specifications:

1.1 Quantity Required: 3.49 kg / load Unit Cost: 153.14 $/ kg

1.2 Input Value:	$/
1.3 Input Cost:	534.31 $/ load

Note to Item 1.3: Use price, if input produced in own plant.

Process No. 2 . 4 . 0 1 - 0 1

Form 3

Page 1 of 1

2.1 Direct Materials:

Revision ______ Date 3/78

2.11 Type: Ceramic base;

Specification: ;

Quantity Required: ___/___; Unit Cost: 0.60 $/ load; Cost: 0.60 $/ load

2.12 Type: Mounting wax;

Specification: Cost is estimated. Can be recycled.;

Quantity Required: ___/___; Unit Cost: 0.10 $/ load; Cost: 0.10 $/ load

2.1_ Type: ;

Specification: ;

Quantity Required: ___/___; Unit Cost: ___ $/___; Cost: ___ $/___

2.1 Subtotal Direct Materials:	0:70 $/load

Process No. 2 . 4 . 0 1 – 0 1

Form 5

Revision ____ Date 3/78

2.3 Expendable Tooling:

2.3 _ Type: ______

______ Quantity Required: ______ ____/____: Unit Cost: ____$/____ Cost: ______$/______

2.3 _ Type: ______

______ Quantity Required: ______ ____/____: Unit Cost: ____$/____ Cost: ______$/______

2.3 _ Type: ______

______ Quantity Required: ______ ____/____: Unit Cost: ____$/____ Cost: ______$/______

2.3 _ Type: ______

______ Quantity Required: ______ ____/____: Unit Cost: ____$/____ Cost. ______$/______

2.3 Subtotal Expendable Tooling: ______$/______

2.4 Energy

2.4 1 Type: Electricity (2 kW power rating)

______ Quantity Required: 0.50 kWh/ load : Unit Cost: 0.0319 $/kWh Cost: 0.02 $/ load

2.4 _ Type: ______

______ Quantity Required: ______ ______: Unit Cost: ____$/____ Cost: ______$/______

2.4 Subtotal Energy Costs: ______$/______

2.5 Subtotal 2.1 to 2.4:	0.72 $/ load
2.6 Handling Charge: 5.26 % of item 2.5	0.03 $/ load
2.7 Subtotal Materials and Supplies: (2.5 + 2.6)	0.75 $/ load

Process No. 2.4.01-01

Form 6
Page 1 of 1
Revision ____ Date 3/78

3.1 Direct Labor:

3.11 Category: Semiconductor assembler (SAMICS B3096D) Activity: Workpiece mounting
Amount Required: 0.25 h/ load; Rate: $ 3.894 /h; Load 36.0 %; Cost: 1.34 $/ load

3.1_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.1_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.1 Direct Labor Subtotal: ____ $/ ____

3.2 Indirect Labor: Taken as 25% of direct labor

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2 Indirect Labor Subtotal: 0.33 $/ load

3.3 Subtotal 3.1 and 3.2	1.67	$/ load
3.4 Overhead on Labor: 5.26 %	0.09	$/ load
3.5 Subtotal Labor	1.76	$/ load

Form 7
Page 1 of 1
Revision ____ Date 3/78

Process No. 2 . 4 . 0 1 - 0 1

4.1 Equipment

4.1_1 Type: Hot plate (25 x 40 cm) with bench.

Cost: 2,000 $; Installation Cost: ______ $; Throughput: 2 loads /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 99 %; Machine Oper'g Time 8200 h/y

Servicing Costs: Labor ______ h/y at ______ $/h; Parts or Outside Service: ______ $/y

Useful Life: ______ y; Charge Rate. ______ % of Cost/y; Capital Cost: 430 $/y | 0.03 $/ load

4.1_ Type: ______

Cost: ______ $; Installation Cost: ______ $, Throughput: ______ /h;

Plant Oper'g Time ______ h/y; Machine Avail'ty: ______ %; Machine Oper'g Time ______ h/y

Servicing Costs: Labor ______ h/y at ______ $/h; Parts or Outside Service: ______ $/y

Useful Life: ______ y; Charge Rate: ______ % of Cost/y; Capital Cost: ______ $/y | ______ $/ ______

4.1_ Type: ______

Cost: ______ $; Installation Cost: ______ $; Throughput: ______ /h;

Plant Oper'g Time ______ h/y; Machine Avail'ty: ______ %; Machine Oper'g Time ______ h/y

Servicing Costs· Labor ______ h/y at ______ $/h; Parts or Outside Service: ______ $/y

Useful Life: ______ y; Charge Rate: ______ % of Cost/y; Capital Cost: ______ $/y | ______ $/ ______

4.1 Subtotal Equipment Cost:	0.03 $/ load

Process No. 2 . 4 . 0 1 - 0 1

4.2 Facilities:

4.21 Type: Bench area Floor Area: 2.0 m^2; Throughput: 16,400 loads /y

Charge Rate: 179.13* $/($m^2$·y):

Energy Use:

Heating		/y at	$/	
Air Cond'g		/y at	$/	
Lighting		/y at	$/	

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: 360 $/y — 0.02 $/load

4.2_ Type: ____ Floor Area: ____ m^2; Throughput: ____ ____ /y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

Heating		/y at	$/	
Air Cond'g		/y at	$/	
Lighting		/y at	$/	

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: ____ $/y — ____ $/____

4.2_ Type: ____ Floor Area: ____ m^2; Throughput: ____ ____ /y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

Heating		/y at	$/	
Air Cond'g		/y at	$/	
Lighting		/y at	$/	

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: ____ $/y — ____ $/____

4.2 Subtotal Facilities:	0.02 $/load
4.3 Equipment and Facilities Subtotal :	0.05 $/load

*INCLUDES ENERGY USE

Process No. 2 . 4 . 0 1 – 0 1

Revision ______ Date 3/78

7. Process Cost Computation

7.11 Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.)	2.56	\$/ load
7.22 Other Indirect Costs: (0.059 x 4.1 + 0.108 + ~~4.2~~) ______ % of 7.11	0.00	\$/ load
7.21 Total Operating Add-on Costs of Process:	2.56	\$/ load
7.22 G & A ______ % of 7.21		\$/
7.31 Total Gross Add-On Cost of Process	2.56	\$/ load
7.32 Credit for Salvaged Material (5.8)		\$/
7.33 Cost of Work-in-Process Lost (5.3)		\$/
7.34 Specific Add-On Cost of Process (7.31 + 7.33)-(7.32)	2.56	\$/ load
7.35 Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4)	534.31	\$/ load
7.36 Loading on Item 7.35 at Rate ______ %		\$/
7.37 Cost of Output Work-in-Process (7.34 + 7.35 + 7.36)	536.87	\$/ load

7.41 Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units)	3.49 kg	/ load
7.42 Practical Yield	100 %	
7.43 Effective Yield (7.41 x 7.42)		/
7.44 Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35	3.49 kg	/ load

7.51 Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44)	153.84	\$/ kg
7.52 Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44)	0.74	\$/ kg

Process No. 2 . 4 . 0 1 - 0 1

Form 13-1
Page 1 of 1

Revision ____ Date 3/78

8. Price Computation

8.1 Alternate 1

8.11 Profit at Expected Rate of 20 %: 0.15 $/ kg
(Profit before income taxes; applied to 7.52)

8.12 Price of Process (7.52 + 8.11) 0.89 $/ kg

8.13 Price of Work-in-Process (7.51 + 8.11) 153.99 $/ kg

8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274* 0.026 $/ load from Subtotal 4.1 = 0.024 $/ load

1.946* 0.022 $/ load from Subtotal 4.2 = 0.043 $/ load

Subtotal = 0.067 $/ load

8.22 Costs of Amortization of the One-Time Cost:

0.192* 0.75 $/ load from Subtotal 2.7 = 0.145 $/ load

0.192* 1.76 $/ load from Subtotal 3.5 = 0.338 $/ load

0.2958* 0.026 $/ load from Subtotal 4.1 = 0.008 $/ load

2.77* 0.022 $/ load from Subtotal 4.2 = 0.061 $/ load

Subtotal = 0.551 $/ load

8.23 Total Net Cost of Equity (8.21 + 8.22): 0.62 $/ load

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 3.49 kg / load from 7.44)

0.18 $/ kg

8.25 Price of Process (7.52 + 8.24) 0.92 $/ kg

8.26 Price of Work-in-Process (7.51 + 8.24) 154.02 $/ kg

Process No. 2.4.01-01

Revision ____ Date 3/79

0. Output Specification:

Name of item: Mounted silicon ingots.

Dimensions: 15.2 - cm in diameter, 7.62 - cm high and 16.875 - cm long

Material: Silicon on ceramic mounting block

Other Specifications: The capital cost for mounting an ingot for MBS is proportional to $\ell * r$. Therefore the unit mass capital cost for mounting is inversely proportional to r. Since the capital cost is a small part of the total cost, the mounting cost is essentially independent of ingot size. For MBS, the mounting cost is $3.18/load.

Process No. 2 . 4 . 0 1 - 0 3 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Sheet Generation

Subprocess: Wafer Generation

Option: Mounting of ingot on graphite block with epoxy for use on ID-blade machines.

Data supplied by OCLI.

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Revision ____ Date 3/78

Process No. 2 . 4 . 0 1 - 0 3

0.1 Value Added:	$/

Process Description: Mounting of ingot on its end with epoxy on a graphite block, for ID- blade slicing. Data supplied by OCLI.

1. Input Specification:

Name of Item: Single crystal, silicon ingot

Dimensions: 10.16 - cm in diameter, 25 - cm in length, and mass is 4.74 kg

Material: High purity silicon

Other Specifications:

1.1 Quantity Required: 4.74 kg /load Unit Cost: 71.43 $/ kg

1.2 Input Value:	$/
1.3 Input Cost:	338.58 $/ load

Note to Item 1.3: Use price, if input produced in own plant.

Process No. 2 . 4 . 0 1 - 0 3

Form 3

2.1 Direct Materials:

Revision ______ Date 3/78

2.11 Type: Ingot mounting material;

Specification: Includes epoxy and graphite.

Data taken from OCLI.

Quantity Required: ______ ___/___, Unit Cost: 1.36 $/ load; Cost: 1.36 $/load

2.1_ Type: ______;

Specification: ______;

Quantity Required: ______ ___/___; Unit Cost: ______ $/______; Cost: ______ $/______

2.1_ Type: ______;

Specification: ______;

Quantity Required: ______ ___/___; Unit Cost: ______ $/______; Cost: ______ $/______

2.1 Subtotal Direct Materials: 1.36 $/ load

Process No. 2 . 4 . 0 1 - 0 3

Revision ____ Date 3/78

2.3 Expendable Tooling:

2.3 _ Type: ____

____ Quantity Required: ____ ____/____: Unit Cost: ____$/____ Cost: ____$/____

2.3 _ Type: ____

____ Quantity Required: ____ ____/____: Unit Cost: ____$/____ Cost: ____$/____

2.3 _ Type: ____

____ Quantity Required: ____ ____/____: Unit Cost: ____$/____ Cost: ____$/____

2.3 _ Type: ____

____ Quantity Required: ____ ____/____: Unit Cost: ____$/____ Cost: ____$/____

2.3 Subtotal Expendable Tooling:	____$/____

2.4 Energy

2.4 1 Type: Power rating of hot plate is estimated to be 2 kW

____ Quantity Required: 0.23 kWh / load : Unit Cost: 0.0319 $/kWh Cost: 0.007 $/ load

2.4 _ Type: ____

____ Quantity Required: ____ ____: Unit Cost: ____$/____ Cost: ____$/____

2.4 Subtotal Energy Costs:	0.007 $/ load
2.5 Subtotal 2.1 to 2.4:	1.37 $/ load
2.6 Handling Charge: 5.26 % of item 2.5	0.07 $/ load
2.7 Subtotal Materials and Supplies: (2.5 + 2.6)	1.44 $/ load

Process No. 2 . 4 . 01 - 03

Form 6
Page 1 of 1
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3.1 Direct Labor:

3.1_1 Category: Semiconductor Assembler (SAMICS B3096D) Activity: Ingot mounting

Amount Required: 0.23 h/ load ; Rate: $ 3.895 /h; Load 36.0 %; Cost: 1.22 $/ load

3.1_ Category: ____ Activity: ____

Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.1_ Category: ____ Activity: ____

Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.1 Direct Labor Subtotal: 1.22 $/ load

3.2 Indirect Labor: Taken as 25% of direct

3.2_ Category: ____ Activity: ____

Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____

Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____

Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2 Indirect Labor Subtotal: 0.30 $/ load

3.3 Subtotal 3.1 and 3.2 1.52 $/ load

3.4 Overhead on Labor: 5.26 % 0.08 $/ load

3.5 Subtotal Labor 1.60 $/ load

Process No. 2.4.01-03

4.1 Equipment

4.1_1 Type: Hot plate (20 x 20 cm) with work bench

Cost: 1,000 $; Installation Cost: ____ $; Throughput: 2 loads /h;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 95 %; Machine Oper'g Time 7866 h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 213.50 $/y | 0.01 $/load

4.1_ Type: ____

Cost: ____ $; Installation Cost: ____ $; Throughput: ____ /h;

Plant Oper'g Time ____ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ____ h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: ____ % of Cost/y; Capital Cost: ____ $/y | ____ $/____

4.1_ Type: ____

Cost: ____ $; Installation Cost: ____ $; Throughput: ____ /h;

Plant Oper'g Time ____ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ____ h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: ____ % of Cost/y; Capital Cost: ____ $/y | ____ $/____

4.1 Subtotal Equipment Cost: 0.01 $/load

Process No. 2 . 4 . 01 - 03

4.2 Facilities:

4.21 Type: Bench area Floor Area: 1 m^2; Throughput: 15,732 loads /y

Charge Rate: 179.13* $/($m^2$·y);

Energy Use:

Heating ________ ______/y at ______$/______

Air Cond'g ________ ______/y at ______$/______

Lighting ________ ______/y at ______$/______

Maintenance Costs:

Labor: ________h/y at ________$/h

Supplies: ________$/y

Outside Services: ________$/y

Total Cost: 179 $/y — 0.01 $/ load

4.2_ Type: ________ Floor Area: ________ m^2; Throughput: ________ ________/y

Charge Rate: ________ $/($m^2$·y);

Energy Use:

Heating ________ ______/y at ______$/______

Air Cond'g ________ ______/y at ______$/______

Lighting ________ ______/y at ______$/______

Maintenance Costs:

Labor: ________h/y at ________$/h

Supplies: ________$/y

Outside Services: ________$/y

Total Cost: ________$/y — ________$/______

4.2_ Type: ________ Floor Area: ________ m^2; Throughput: ________ ________/y

Charge Rate: ________ $/($m^2$·y);

Energy Use:

Heating ________ ______/y at ______$/______

Air Cond'g ________ ______/y at ______$/______

Lighting ________ ______/y at ______$/______

Maintenance Costs:

Labor: ________h/y at ________$/h

Supplies: ________$/y

Outside Services: ________$/y

Total Cost: ________$/y — ________$/______

4.2 Subtotal Facilities:	0.01 $/ load
4.3 Equipment and Facilities Subtotal :	0.02 $/ load

* Includes energy use

Process No. 2 . 4 . 0 1 – 0 3

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7. Process Cost Computation

7.11 Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.)	3.06 $/load
7.22 Other Indirect Costs: ______% of 7.11 (0.059*4.1+0.108*4.2)	0 $/load
7.21 Total Operating Add-on Costs of Process:	3.06 $/load
7.22 G & A ______% of 7.21	$/
7.31 Total Gross Add-On Cost of Process	3.06 $/load
7.32 Credit for Salvaged Material (5.8)	$/
7.33 Cost of Work-in-Process Lost (5.3)	$/
7.34 Specific Add-On Cost of Process (7.31 + 7.33)-(7.32)	3.06 $/load
7.35 Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4)	338.58 $/load
7.36 Loading on Item 7.35 at Rate ______%	$/
7.37 Cost of Output Work-in-Process (7.34 + 7.35 + 7.36)	341.64 $/load

7.41 Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units)	4.74 kg / load
7.42 Practical Yield	100 %
7.43 Effective Yield (7.41 x 7.42)	______ / ______
7.44 Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35	4.74 kg / load

7.51 Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44)	72.08 $/kg
7.52 Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44)	0.65 $/kg

Process No. 2 . 4 . 0 1 - 0 3

Form 13-1
Page 1 of 1

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8. Price Computation

8.1 Alternate 1

8.11 Profit at Expected Rate of 20 %: 0.13 $/ kg
(Profit before income taxes; applied to 7.52)

8.12 Price of Process (7.52 + 8.11) 0.78 $/ kg

8.13 Price of Work-in-Process (7.51 + 8.11) 72.21 $/ kg

Process No. 2.4.01-03

Form 13-2
Page 1 of 1

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8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274* 0.01 $/ load from Subtotal 4.1 = 0.01 $/ load

1.946* 0.01 $/ load from Subtotal 4.2 = 0.02 $/ load

Subtotal = 0.03 $/ load

8.22 Costs of Amortization of the One-Time Cost:

0.192* 1.44 $/ load from Subtotal 2.7 = 0.28 $/ load

0.192* 1.60 $/ load from Subtotal 3.5 = 0.31 $/ load

0.2958* 0.01 $/ load from Subtotal 4.1 = 0.00 $/ load

2.77* 0.01 $/ load from Subtotal 4.2 = 0.03 $/ load

Subtotal = 0.62 $/ load

8.23 Total Net Cost of Equity (8.21 + 8.22): 0.65 $/ load

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 4.74 kg / load from 7.44)

0.14 $/ kg

8.25 Price of Process (7.52 + 8.24) 0.79 $/ kg

8.26 Price of Work-in-Process (7.51 + 8.24) 72.22 $/ kg

Process No. 2 . 4 . 0 1 - 0 3

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9. Process Economic Evaluation:

9.1 Process Cost Balance (7.52 - 0.1)	______ $/ ______
9.2 Relative Process Performance (9.1 - 0.1)	______
9.3 Output Cost (7.51)	72.08 $/ kg
9.4 Output Value (0.2 + 0.1)	______ $/ ______
9.5 Relative Excess Cost [(9.3 - 9.4) ÷ 9.4]	______

Process No. 2 . 4 . 0 1 - 0 3

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0. Output Specification:

Name of item: Mounted silicon ingot

Dimensions: 10.16-cm in diameter, 25-cm in length

Material: Silicon with graphite base

Other Specifications: The capital cost of mounting an ingot for ID-slicing is proportioned to r^2, therefore this unit mass cost for mounting is inversely proportioned to the length of the crystal. Since the capital cost is small compared to material and labor costs, the absolute mounting cost is essentially independent of crystal size. For ID-slicing, it is $3.71/load.

Process No. 2 . 4 . 0 2 - 0 1 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Sheet generation

Subprocess: Ingot slicing

Option: Multiblade slurry slicing of 5.4-cm diameter ingots (Spectrolab)

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Process No. 2 . 4 . 0 2 - 0 1

0.1 Value Added: ________ $/ ________

Process Description: Multiblade slurry slicing.
Data listed in this format were derived from Spectrolab's production line experience in slicing 5.4-cm diameter ingots. Three ingots are sliced per load with a 250 blade-pack.

1. Input Specification:

Name of Item: Prepared machine load from 2.4-01-01

Dimensions: Each ingot is 5.4-cm in diameter and 16.875-cm long. Three ingots per load.

Material: Silicon (high purity)

Other Specifications: See 2.4-02-01 , three ingots are mounted on a ceramic block.
Mass of ingot is 0.903 kg
Mass of load is 2.71 kg

1.1 Quantity Required: 2.71 kg / load Unit Cost: 161.30 $/ kg

1.2 Input Value:	________ $/ ________
1.3 Input Cost:	437.11 $/ load

Note to Item 1.3: Use price, if input produced in own plant.

Process No. 2 . 4 . 0 2 - 0 1

Form 4

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2.1 Type: Abrasive slurry;

Specification: PC oil with 600 grit SiC abrasive

Concentration is 0.24 kg/ℓ, slurry cost given by Spectrolab.

Quantity Required: 7.6 ℓ / load; Unit Cost: 1.85 $/ ℓ ; Cost: 14.06 $/ load

2.2_ Type: ______

Specification: ______

Quantity Required: ______ / ______; Unit Cost: ______ $/ ______; Cost: ______ $/ ______

2.2_ Type: ______

Specification: ______

Quantity Required: ______ / ______; Unit Cost: ______ $/ ______; Cost: ______ $/ ______

2.2 Subtotal Indirect Materials: 14.06 $/ load

Process No. 2 . 4 . 0 2 – 0 1

Form 5

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2.3 Expendable Tooling:

2.3 1 Type: 250 blade drill-pin pack, consisting of 0.2 mm thick 1095 steel blades.

Quantity Required: 0.5 Pack /load: Unit Cost: 50 $/ Pack Cost: 25 $/ load

2.3 _ Type: ____

Quantity Required: ____ /____: Unit Cost: ____ $/____ Cost: ____ $/____

2.3 _ Type: ____

Quantity Required: ____ /____: Unit Cost: ____ $/____ Cost: ____ $/____

2.3 _ Type: ____

Quantity Required: ____ /____: Unit Cost: ____ $/____ Cost: ____ $/____

2.3 Subtotal Expendable Tooling:	25 $/ load

2.4 Energy

2.4 1 Type: Electrical, 1kW main and auxiliary motors

Quantity Required: 22 kWh/ load: Unit Cost: 0.0319 $/ kWh Cost: 0.70 $/ load

2.4 _ Type: ____

Quantity Required: ____ ____: Unit Cost: ____ $/____ Cost: ____ $/____

2.4 Subtotal Energy Costs:	0.70 $/ load
2.5 Subtotal 2.1 to 2.4.	39.78 $/ load
2.6 Handling Charge: 5.26 % of item 2.5	2.09 $/ load
2.7 Subtotal Materials and Supplies: (2.5 + 2.6)	41.87 $/ load

Process No. 2.4.02-01

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3.1 Direct Labor:

3.11 Category: Semiconductor Assembler (SAMICS B3096D) Activity: mounting/demounting
Amount Required: 0.25 h/ load ; Rate: $ 3.89 /h; Load 36.0 %; Cost: 1.32 $/load

3.12 Category: Semiconductor Assembler (SAMICS B3096D) Activity: machine supervision
Amount Required: 5.1 h/ load ; Rate: $ 3.89 /h; Load 36.0 %; Cost: 27.06 $/load

3.13 Category: Maintenance Mechanic II (SAMICS B3736D) Activity: blade head changing/adjusting
Amount Required: 1.4 h/ load ; Rate: $ 5.67 /h; Load 36.0 %; Cost: 10.80 $/load

3.1 Direct Labor Subtotal 39.18 $/load

3.2 Indirect Labor: Taken as 25% of direct

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2 Indirect Labor Subtotal: 9.80 $/ load

3.3 Subtotal 3.1 and 3.2 48.98 $/ load

3.4 Overhead on Labor: 5.26 % 2.57 $/ load

3.5 Subtotal Labor 51.55 $/ load

Process No. 2 . 4 . 0 2 - 0 1

4.1 Equipment

4.1.1 Type: Multiblade slicing machine

Cost: 20,000 $; Installation Cost: ________ $; Throughput: 327 loads /h;y

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 90 %; Machine Oper'g Time 7452 h/y

Servicing Costs: Labor ______ h/y at ______ $/h; Parts or Outside Service: 1592 $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 4270 $/y — 17.92 $/load

4.1_ Type: ________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ______ h/y at ______ $/h; Parts or Outside Service: ______ $/y

Useful Life: ______ y; Charge Rate: ______ % of Cost/y; Capital Cost: ________ $/y — ______ $/______

4.1_ Type: ________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ______ h/y at ______ $/h; Parts or Outside Service: ______ $/y

Useful Life: ______ y; Charge Rate: ______ % of Cost/y; Capital Cost: ________ $/y — ______ $/______

4.1 Subtotal Equipment Cost:	17.92 $/load

Process No. 2 . 4 . 02 - 01

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4.2 Facilities:

4.21 Type: Slicing machine area Floor Area: 5.6 m^2; Throughput: 327 loads /y

Charge Rate: 179.13* \$/(m^2·y):

Energy Use:				
Heating	____	____/y at	____\$/____	
Air Cond'g	____	____/y at	____\$/____	
Lighting	____	____/y at	____\$/____	

Maintenance Costs:

Labor: ____ h/y at ____ \$/h

Supplies: ____ \$/y

Outside Services: ____ \$/y

Total Cost: 1003.13 \$/y — 3.07 \$/ load

4.2_ Type: ____ Floor Area: ____ m^2; Throughput: ____ /y

Charge Rate: ____ \$/(m^2·y);

Energy Use:				
Heating	____	____/y at	____\$/____	
Air Cond'g	____	____/y at	____\$/____	
Lighting	____	____/y at	____\$/____	

Maintenance Costs:

Labor: ____ h/y at ____ \$/h

Supplies: ____ \$/y

Outside Services: ____ \$/y

Total Cost: ____ \$/y — ____ \$/____

4.2_ Type: ____ Floor Area: ____ m^2; Throughput: ____ /y

Charge Rate: ____ \$/(m^2·y);

Energy Use:				
Heating	____	____/y at	____\$/____	
Air Cond'g	____	____/y at	____\$/____	
Lighting	____	____/y at	____\$/____	

Maintenance Costs:

Labor: ____ h/y at ____ \$/h

Supplies: ____ \$/y

Outside Services: ____ \$/y

Total Cost: ____ \$/y — ____ \$/____

*Includes energy use

4.2 Subtotal Facilities:	3.07 \$/ load
4.3 Equipment and Facilities Subtotal :	20.49 \$/ load

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Process No. 2 . 4 . 0 2 – 0 1

5. Salvaged Material (Work-in-process)

5.1	Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit)	1.52 kg / load	
5.21	Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1)	1.19 kg / load	
5.22	Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ – ☐☐	______ ______ / ______	
5.23	Credit for 5.22 at the Market Value of ______ $/ ______ :	______ $/ ______	
5.24	Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ______ $/ ______ :	______ $/ ______	
5.25	Net Credit for 5.22 (5.23 minus 5.24):		______ $/ ______
5.26	Material of Type 1. Lost in Process (5.21 minus 5.22)	1.19 kg/ load	
5.3	Cost of Work-in-Process Lost (Amount 5.26 Times Unit Cost 1.1)		191.95 $/ load
5.4	Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.2 Times Unit Cost from 1.1)		245.18 $/ load

Salvaged Materials Summary:

5.8	Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76)	______ $/ ______

Process No. 2 . 4 . 0 2 - 0 1

Form 13-1
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Revision ____ Date 3/78

8. Price Computation

8.1 Alternate 1

8.11 Profit at Expected Rate of 20 %: 37.70 \$/ m^2
(Profit before income taxes; applied to 7.52)

8.12 Price of Process (7.52 + 8.11) 227.20 \$/ m^2

8.13 Price of Work-in-Process (7.51 + 8.11) 376.61 \$/ m^2

8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274*	17.90 $/ load	from Subtotal 4.1 =	16.60 $/ load		
1.946*	3.07 $/ load	from Subtotal 4.2 =	5.97 $/ load		
		Subtotal =	22.57 $/ load		

8.22 Costs of Amortization of the One-Time Cost:

0.192*	41.87 $/ load	from Subtotal 2.7 =	8.04 $/ load		
0.192*	51.55 $/ load	from Subtotal 3.5 =	9.90 $/ load		
0.2958*	17.90 $/ load	from Subtotal 4.1 =	5.29 $/ load		
2.77*	3.07 $/ load	from Subtotal 4.2 =	8.50 $/ load		
		Subtotal =	31.73 $/ load		

8.23 Total Net Cost of Equity (8.21 + 8.22): 54.30 $/load

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 1.63 m^2 / load from 7.44)

33.31 $/ m^2

8.25 Price of Process (7.52 + 8.24) 221.81 $/ m^2

8.26 Price of Work-in-Process (7.51 + 8.24) 372.22 $/ m^2

Process No. 2.4.02-01

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9. Process Economic Evaluation:

9.1	Process Cost Balance (7.52 - 0.1)	______ $/ ______
9.2	Relative Process Performance (9.1 ÷ 0.1)	______
9.3	Output Cost (7.51)	338.91 $/ m^2
9.4	Output Value (0.2 + 0.1)	______ $/ ______
9.5	Relative Excess Cost [(9.3 - 9.4) ÷ 9.4]	______

Process No. 2 . 4 . 0 2 - 0 1

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0. Output Specification:

Name of item: Silicon wafer, as-cut

Dimensions: 5.4-cm in diameter, 0.4 mm thick

Material:

Other Specifications: Depth of subsurface damage is 75 μm

Process No. 2 . 4 . 0 2 - 0 1

Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Sheet Generation

Subprocess: Ingot Slicing

Option: Multiblade Slurry slicing of 7.5-cm diameter ingots (Spectrolab)

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Process No. 2 . 4 . 0 2 - 0 1

0.1 Value Added:	$/

Process Description: Multiblade slurry slicing

Data listed here were obtained from Spectrolab's production experience.

Blade head has 250 blades and two ingots are sliced per load.

1. Input Specification:

Name of Item: Prepared machine load from 2.4 . 01 - 01

Dimensions: 7.5 cm diameter 17 cm long, 3.57 kg/load

Material: High purity silicon

Other Specifications: Two single crystal silicon ingots mounted on a ceramic block.

see 2.4 .01 - 01

1.1 Quantity Required: 3.49 kg /load   Unit Cost: 154.04 $/ kg

1.2 Input Value:	$/
1.3 Input Cost:	537.57 $/load

Note to Item 1.3: Use price, if input produced in own plant.

Process No. 2 . 4 . 02 - 01

Form 5

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2.3 Expendable Tooling:

Item	Type / Quantity Required	Unit Cost	Cost
2.3 1	Type: 250 blade drill pin pack consisting of 0.2 mm thick 1095 steel blades		
	Quantity Required: 1 pack / load	Unit Cost: 50 $/pack	Cost: 50 $/load
2.3 _	Type:		
	Quantity Required: /	Unit Cost: $/	Cost: $/
2.3 _	Type:		
	Quantity Required: /	Unit Cost: $/	Cost: $/
2.3 _	Type:		
	Quantity Required: /	Unit Cost: $/	Cost: $/
2.3	Subtotal Expendable Tooling:		50.00 $/load

2.4 Energy

Item	Type / Quantity Required	Unit Cost	Cost
2.4 1	Type: Electrical, 1 kW main and auxiliary motors		
	Quantity Required: 22 kWh/load	Unit Cost: 0.0319 $/kWh	Cost: 0.70 $/load
2.4 _	Type:		
	Quantity Required:	Unit Cost: $/	Cost: $/
2.4	Subtotal Energy Costs:		0.70 $/load

2.5 Subtotal 2.1 to 2.4:	64.76 $/load
2.6 Handling Charge: 5.26 % of item 2.5	3.41 $/load
2.7 Subtotal Materials and Supplies: (2.5 + 2.6)	68.17 $/load

Process No. 2 . 4 . 0 2 - 0 1

Form 6
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3.1 Direct Labor:

3.1 1 Category: Semiconductor Assembler (SAMICS B3096D) Activity: Loading/unloading
Amount Required: 0.25 h/load; Rate: $ 3.90 /h; Load 36.0 %; Cost: 1.32 $/load

3.1_ Category: Semiconductor Assembler (SAMICS B3096D) Activity: machine supervision
Amount Required: 5.2 h/load; Rate: $ 3.90 /h; Load 36.0 %; Cost: 27.59 $/load

3.1_ Category: Maintenance Mechanic II (SAMICS B3736D) Activity: blade head changing/adjusting
Amount Required: 1.4 h/ load; Rate: $ 5.67 /h; Load 36.0 %; Cost: 10.80 $/load

3.1 Direct Labor Subtotal: 39.71 $/load

3.2 Indirect Labor: 25% of direct

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2 Indirect Labor Subtotal: 9.93 $/load

3.3 Subtotal 3.1 and 3.2 49.64 $/load

3.4 Overhead on Labor: 5.26 % 2.61 $/load

3.5 Subtotal Labor 52.25 $/load

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Revision ____ Date 3/78

Process No. 2 . 4 . 0 2 - 0 1

4.1 Equipment

4.1.1 Type: Multiblade slicing machine

Cost: 20,000 $; Installation Cost: ________ $; Throughput: 320 loads /y;

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 90 %; Machine Oper'g Time 7452 h/y

Servicing Costs: Labor ______ h/y at ______ $/h; Parts or Outside Service: 1592.30 $/y

Useful Life: 7 y, Charge Rate: 21.35 % of Cost/y; Capital Cost. 4270 $/y | 18.31 $/load

4.1_ Type: ____________

Cost: ________ $, Installation Cost: ________ $; Throughput: ________ /h,

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs. Labor ______ h/y at ______ $/h; Parts or Outside Service: ______ $/y

Useful Life: ______ y; Charge Rate: ______ % of Cost/y; Capital Cost. ________ $/y | ______ $/______

4.1_ Type: ____________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ______ h/y at ______ $/h; Parts or Outside Service: ______ $/y

Useful Life: ______ y; Charge Rate: ______ % of Cost/y; Capital Cost: ________ $/y | ______ $/______

4.1 Subtotal Equipment Cost:	18.31 $/load

Process No. 2 . 4 . 02 - 01

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4.2 Facilities:

4.2.1 Type: Slicing machines area Floor Area: 5.6 m^2; Throughput: 320 loads /y

Charge Rate: 179.13* $/(m^2·y);

Energy Use:

Heating ____ ____ /y at ____ $/____

Air Cond'g ____ ____ /y at ____ $/____

Lighting ____ ____ /y at ____ $/____

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: 1003.13 $/y — 3.13 $/load

4.2._ Type: ____ Floor Area: ____ m^2; Throughput: ____ ____ /y

Charge Rate: ____ $/(m^2·y);

Energy Use:

Heating ____ ____ /y at ____ $/____

Air Cond'g ____ ____ /y at ____ $/____

Lighting ____ ____ /y at ____ $/____

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: ____ $/y — ____ $/____

4.2._ Type: ____ Floor Area: ____ m^2; Throughput: ____ ____ /y

Charge Rate: ____ $/(m^2·y);

Energy Use:

Heating ____ ____ /y at ____ $/____

Air Cond'g ____ ____ /y at ____ $/____

Lighting ____ ____ /y at ____ $/____

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: ____ $/y — ____ $/____

4.2 Subtotal Facilities:	3.13 $/load
4.3 Equipment and Facilities Subtotal :	21.45 $/load

*Includes energy use

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Process No. 2 . 4 . 0 2 – 0 1

5. Salvaged Material (Work-in-process)

5.1	Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit)	1.97 kg / load	
5.21	Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1)	1.53 kg / load	
5.22	Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ – ☐☐	______ ______ / ______	
5.23	Credit for 5.22 at the Market Value of ______ $/ ______ :	______ $/ ______	
5.24	Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ______ $/ ______ :	______ $/ ______	
5.25	Net Credit for 5.22 (5.23 minus 5.24):		______ $/ ______
5.26	Material of Type 1. Lost in Process (5.21 minus 5.22)	1.53 kg / load	
5.3	Cost of Work-in-Process Lost (Amount 5.26 Times Unit Cost 1.1)		235.67 $/ loa
5.4	Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.2 Times Unit Cost from 1.1)		303.44 $/ loa

Salvaged Materials Summary:

5.8	Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76)	______ $/ ______

Process No. 2 . 4 . 0 2 - 0 1

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6. Byproducts and Wastes

6.1 Solid Byproducts/Wastes

6.11 Type (Composition): Silicon chips and dust Quantity Produced: 0.175 kg/ load

Physical Shape/Size: ______ Energy Content: ______ kWh/ ______

Density: 2.34 g/cm^3; Water Solubility: ______ g/l at ______ °C; pH: ______

Toxicity: ______ Biodegradable: ______ Other Remarks: ______

Type of Disposal: ______

Input Material for: ______ Cost/(Credit) ______ $/ ______, Cost: ______ $/ ______

6.2 Liquid Byproducts/Wastes (inorganic):

6.2.1 Type (Composition): PC oil slurry Quantity Produced: 7.6 ℓ / load

Density: 0.95 g/cm^3; Suspended Solids: SiC abrasive Amount: 0.24 kg/l pH: N.A.

Toxicity: ______ Heavy Metal Content: ______ mg/l Other Remarks: ______

Kerf; 1.425 kg/load, concentration 187.6 g/ℓ

Type of Disposal: can be stored in drums

Input Material for: ______ Cost/(Credit) 0 $/ 0 Cost: ______ $/ ______

Carry: ______ $/ ______

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Process No. 2 . 4 . 0 2 – 0 1 Revision ______ Date 3/78

7. Process Cost Computation

7.11 Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.)		141.87 $/load
7.22 Other Indirect Costs: (0.059 x (4.1) + 108x(4.2)) ______ % of 7.11		1.418 $/load
7.21 Total Operating Add-on Costs of Process:		143.29 $/load
7.22 G & A ______ % of 7.21		$/
7.31 Total Gross Add-On Cost of Process		143.29 $/ load
7.32 Credit for Salvaged Material (5.8)		- $/ -
7.33 Cost of Work-in-Process Lost (5.3)		235.67 $/ load
7.34 Specific Add-On Cost of Process (7.31 + 7.33)-(7.32)		378.96 $/ load
7.35 Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4)		303.44 $/ load
7.36 Loading on Item 7.35 at Rate ______ %		- $/ -
7.37 Cost of Output Work-in-Process (7.34 + 7.35 + 7.36)		682.40 $/ load
7.41 Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units)	0.63 m^2 / kg	
7.42 Practical Yield	95 %	
7.43 Effective Yield (7.41 x 7.42)	0.60 m^2 / kg	
7.44 Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35	2.10 m^2 / load	
7.51 Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44)		324.95 $/ m^2
7.52 Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44)		180.46 $/ m^2

Process No. 2 . 4 . 0 2 - 0 1

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8. Price Computation

8.1 Alternate 1

8.11 Profit at Expected Rate of 20 %: 36.09 \$/ m^2
(Profit before income taxes; applied to 7.52)

8.12 Price of Process (7.52 + 8.11) 216.55 \$/ m^2

8.13 Price of Work-in-Process (7.51 + 8.11) 361.04 \$/ m^2

Process No. 2.4.02-01

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.8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274* 18.31 $/load from Subtotal 4.1 = 16.98 $/ load

1.946* 3.13 $/load from Subtotal 4.2 = 6.10 $/ load

Subtotal = 23.08 $/ load

8.22 Costs of Amortization of the One-Time Cost:

0.192* 68.17 $/ load from Subtotal 2.7 = 13.09 $/ load

0.192* 52.25 $/ load from Subtotal 3.5 = 10 03 $/ load

0.2958* 18.31 $/ load from Subtotal 4.1 = 5.42 $/ load

2.77* 3.13 $/ load from Subtotal 4.2 = 8.68 $/ load

Subtotal = 37.22 $/ load

8.23 Total Net Cost of Equity (8.21 + 8.22): 60.30 $/load

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 2.1 m^2 /load from 7.44)

28.71 $/ m^2

8.25 Price of Process (7.52 + 8.24) 209.17 $/ m^2

8.26 Price of Work-in-Process (7.51 + 8.24) 353.66 $/ m^2

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9. Process Economic Evaluation:

9.1	Process Cost Balance (7.52 - 0.1)	$/
9.2	Relative Process Performance (9.1 ÷ 0.1)	
9.3	Output Cost (7.51)	324.95 $/ m^2
9.4	Output Value (0.2 + 0.1)	$/
9.5	Relative Excess Cost [(9.3 - 9.4) ÷ 9.4]	

Process No. 2.4.02-01

Form 15

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0. Output Specification:

Name of item: Silicon wafer, as-cut

Dimensions: 7.5-cm in diameter and 0.4 mm thick

Material: high purity silicon

Other Specifications:

subsurface damage depth is 75 μm

Process No. 2 . 4 . 0 2 - 0 3 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Sheet generation

Subprocess: Ingot slicing

Option: ID fixed - abrasive slicing, 10.16 cm diameter ingots (HAMCO)

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Form 2

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Process No. 2 . 4 . 0 2 - 0 3

0.1 Value Added: ______ $/ ______

Process Description: Inner diameter slicing of 10.16 cm diameter ingots. Analysis derived from data supplied by HAMCO. 555 slices made per load.

1. Input Specification:

Name of Item: Prepared machine load from 2.4 : 01 : 03

Dimensions: 10.16-cm in diameter, 46-cm long, 8.72 kg/load

Material: High purity silicon

Other Specifications: See 2.4-01-03

1.1 Quantity Required: 8.726 kg / load   Unit Cost: 149.31 $/ kgr-s

1.2 Input Value:	1302.90 $/ load
1.3 Input Cost:	______ $/ ______

Note to Item 1.3: Use price, if input produced in own plant.

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2.1 Type: Coolant;

Specification: Filtered domestic wafer with Rust-Lick
80:1 water to Rust-Lick ratio

Quantity Required: 1 gallon /load; Unit Cost: 3.65 $/ gallons; Cost: 3.65 $/ load

2.2.2 Type: Blade dressing

Specification: Alumina stick

Quantity Required: 4.41 m^2 /load; Unit Cost: 0.71 $/ m^2; Cost: 3.15 $/ load

2.2._ Type: ______

Specification: ______

Quantity Required: ______ /____; Unit Cost: ____ $/____; Cost: ____ $/____

2.2 Subtotal Indirect Materials: 6.80 $/ load

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2.3 Expendable Tooling:

2.3 1 Type: ID blade, diamond-plated

Quantity Required: 1 blade /load Unit Cost: 55 $/blade Cost: 55 $/ load

2.3 _ Type:

Quantity Required: ____ /____: Unit Cost: ____ $/____ Cost: ____ $/____

2.3 _ Type:

Quantity Required: ____ /____: Unit Cost: ____ $/____ Cost: ____ $/____

2.3 _ Type:

Quantity Required: ____ /____: Unit Cost: ____ $/____ Cost: ____ $/____

2.3	Subtotal Expendable Tooling:	55 $/ load

2.4 Energy

2.4 1 Type: Electrical, 2 kW main and auxiliary motors

Quantity Required: 46.2 kWh/load : Unit Cost: .032 $/ kWh Cost: 1.48 $/ load

2.4 _ Type:

Quantity Required: ____ ____: Unit Cost: ____ $/____ Cost: ____ $/____

2.4	Subtotal Energy Costs:	1.48 $/ load
2.5	Subtotal 2.2 to 2.4:	63.28 $/ load
2.6	Handling Charge: 5.26 % of item 2.5	3.32 $/ load
2.7	Subtotal Materials and Supplies: (2.5 + 2.6)	66.30 $/ load

3.1 Direct Labor:

3.1 1 Category: Semiconductor Assembler (SAMICS B3096D) Activity: Loading/unloading

Amount Required: 0.083 h/load; Rate: $ 3.89 /h; Load 36.0 %; Cost: 0.439 $/load

3.1 2 Category: Semiconductor Assembler (SAMICS B3096D) Activity: Machine supervision

Amount Required: 4.3 h/load; Rate: $ 3.89 /h; Load 36.0 %; Cost: 22.81 $/load

3.1 3 Category: Maintenance Mechanic (SAMICS B3736D) Activity: Blade head changing

Amount Required: 0.80 h/load; Rate: $ 5.67 /h; Load 36.0 %; Cost: 6.17 $/load

3.1 Direct Labor Subtotal: 29.42 $/load

3.2 Indirect Labor: Taken as 25% of direct

3.2_ Category: ____ Activity: ____

Amount Required: ____ h/____; Rate: $____ /h; Load ____ %; Cost: ____ $/____

3.2_ Category: ____ Activity: ____

Amount Required: ____ h/____; Rate: $____ /h; Load ____ %; Cost: ____ $/____

3.2_ Category: ____ Activity: ____

Amount Required: ____ h/____; Rate: $____ /h; Load ____ %; Cost: ____ $/____

3.2 Indirect Labor Subtotal: 7.35 $/load

3.3 Subtotal 3.1 and 3.2	36.77 $/load
3.4 Overhead on Labor: 5.26 %	1.93 $/load
3.5 Subtotal Labor	38.70 $/load

Process No. 2 . 4 . 0 2 - 0 3

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4.1 Equipment

4.1_1 Type: ID saw slicing machine

Cost: 40,000 $; Installation Cost: ________ $; Throughput: 325 /h;y

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 95 %; Machine Oper'g Time 7866 h/y

Servicing Costs: Labor ______ h/y at ______ $/h; Parts or Outside Service: 285.71 $/y

Useful Life: 7 y; Charge Rate: 21.4 % of Cost/y; Capital Cost: 8560 $/y | 27.21 $/load

4.1_ Type: ________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ______ h/y at ______ $/h; Parts or Outside Service: ______ $/y

Useful Life: ______ y; Charge Rate: ______ % of Cost/y; Capital Cost: ________ $/y | ______ $/______

4.1_ Type: ________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ______ h/y at ______ $/h; Parts or Outside Service: ______ $/y

Useful Life: ______ y; Charge Rate: ______ % of Cost/y; Capital Cost: ________ $/y | ______ $/______

4.1 Subtotal Equipment Cost: 27.21 $/load

Process No. 2 . 4 . 02 - 03

4.2 Facilities:

4.2.1 Type: Machine area Floor Area: 9.0 m^2; Throughput: 325 loads /y

Charge Rate: 179.13* $/(m^2·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: 1612 $/y   4.96 $/load

4.2_ Type: ______ Floor Area: ______ m^2; Throughput: ______ ______/y

Charge Rate: ______$/(m^2·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: ______$/y   ______$/______

4.2_ Type: ______ Floor Area: ______ m^2; Throughput: ______ ______/y

Charge Rate: ______$/(m^2·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: ______$/y   ______$/______

4.2 Subtotal Facilities: 4.96 $/load

4.3 Equipment and Facilities Subtotal : 32.17 $/load

*Includes energy use

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Process No. 2 . 4 . 0 2 — 0 3

5. Salvaged Material (Work-in-process)

5.1	Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit)	5.15 kg / load	
5.21	Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1)	3.57 kg / load	
5.22	Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ — ☐☐	______ ______ / ______	
5.23	Credit for 5.22 at the Market Value of ______ $/ ______ :	______ $/ ______	
5.24	Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ______ $/ ______ :	______ $/ ______	
5.25	Net Credit for 5.22 (5.23 minus 5.24):		______ $/ ______
5.26	Material of Type 1. Lost in Process (5.21 minus 5.22)	______ ______ / ______	
5.3	Cost of Work-in-Process Lost (Amount 5.26 Times Unit Cost 1.1)		533.04 $/ loa
5.4	Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.2 Times Unit Cost from 1.1)		768.95 $/ loa

Salvaged Materials Summary:

5.8	Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76)	______ $/ ______

Process No. 2 . 4 . 0 2 - 0 3

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6. Byproducts and Wastes

6.1 Solid Byproducts/Wastes

6.1.1 Type (Composition): Silicon chips and dust   Quantity Produced: 0.105 kg/ load

Physical Shape/Size: ____________   Energy Content: ______ kWh/ ______

Density: 2.34 g/cm^3; Water Solubility: 0 g/l at ______ °C;   pH: ______

Toxicity: ______ Biodegradable: ______ Other Remarks: ______

Type of Disposal: ______

Input Material for: ______ Cost/(Credit) ______ $/ ______;   Cost: ______ $/ ______

6.2 Liquid Byproducts/Wastes (inorganic):

6.2.1 Type (Composition): water and silicon kerf   Quantity Produced: 300 ℓ/ load

Density: ____ g/cm^3; Suspended Solids: 3.47 kg/load   Amount: 11.6 g/l   pH: ______

Toxicity: ______ Heavy Metal Content: ____ mg/l   Other Remarks: ______

Type of Disposal: ______

Input Material for: ______ Cost/(Credit) ____ $/ ______   Cost: ______ $/ ______

Carry: ______ $/ ______

Process No. 2 . 4 . 0 2 — 0 3

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7. Process Cost Computation

7.11	Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.)	137.17 $/load
7.22	Other Indirect Costs: ________% of 7.11 0.059*(4.1)+0.108*(4.2)	2.15 $/load
7.21	Total Operating Add-on Costs of Process:	139.32 $/load
7.22	G & A ________% of 7.21	$/
7.31	Total Gross Add-On Cost of Process	141.36 $/load
7.32	Credit for Salvaged Material (5.8)	$/
7.33	Cost of Work-in-Process Lost (5.3)	533.04 $/load
7.34	Specific Add-On Cost of Process (7.31 + 7.33)-(7.32)	674.40 $/load
7.35	Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4)	768.95 $/load
7.36	Loading on Item 7.35 at Rate ________%	$/
7.37	Cost of Output Work-in-Process (7.34 + 7.35 + 7.36)	1443.35 $/load

7.41	Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units)	0.515 m^2 / kg
7.42	Practical Yield	98 %
7.43	Effective Yield (7.41 x 7.42)	0.505 m^2/ kg
7.44	Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35	4.41 m^2 / load

7.51	Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44)	327.29 $/ m^2
7.52	Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44)	152.92 $/ m^2

Process No. 2 . 4 . 0 2 - 0 3

8. Price Computation

8.1 Alternate 1

8.11 Profit at Expected Rate of 20 %: 30.58 $/ m^2
(Profit before income taxes; applied to 7.52)

8.12 Price of Process (7.52 + 8.11) 183.50 $/ m^2

8.13 Price of Work-in-Process (7.51 + 8.11) 357.86 $/ m^2

8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274* 27.21 $/ load	from Subtotal 4.1 =	25.23 $/ load		
1.946* 4.96 $/ load	from Subtotal 4.2 =	9.65 $/ load		
	Subtotal =	34.89 $/ load		

8.22 Costs of Amortization of the One-Time Cost:

0.192* 66.30 $/ load	from Subtotal 2.7 =	12.73 $/ load		
0.192* 38.70 $/ load	from Subtotal 3.5 =	7.43 $/ load		
0.2958* 27.21 $/ load	from Subtotal 4.1 =	8.05 $/ load		
2.77* 4.96 $/ load	from Subtotal 4.2 =	13.74 $/ load		
	Subtotal =	41.95 $/ load		

8.23 Total Net Cost of Equity (8.21 + 8.22): 76.84 $/ load

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 4.41 m^2 / load from 7.44)

17.42 $/ m^2$

8.25 Price of Process (7.52 + 8.24) 170.34 $/ m^2$

8.26 Price of Work-in-Process (7.51 + 8.24) 344.71 $/ m^2$

Process No. 2.4.02-03

Revision ____ Date 4/78

9. Process Economic Evaluation:

9.1 Process Cost Balance (7.52 - 0.1)	$/
9.2 Relative Process Performance (9.1 ÷ 0.1)	
9.3 Output Cost (7.51)	327.29 $/ m^2
9.4 Output Value (0.2 + 0.1)	$/
9.5 Relative Excess Cost [(9.3 - 9.4) ÷ 9.4]	

Process No. 2.4.02-03

Revision ____ Date 4/78

0. Output Specification:

Name of item: Silicon wafers, as cut

Dimensions: 10.16 cm in diameter, 0.50 mm thick

Material: Silicon

Other Specifications:

Process No. 2 . 4 . 0 2 - 0 3 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Sheet generation

Subprocess: Wafer generation

Option: STC Current Production

ID Slicing (10-cm diameter wafers)

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Process No. 2 . 4 . 02 - 03

0.1 Value Added:	$/

Process Description: Inner diameter slicing as performed commercially by STC's ID slicing machine

1. Input Specification:

Name of Item: Single crystal silicon ingot, prepared as specified in 2.4-01-17

Dimensions: 10-cm diameter, 60 cm long, 11.027 kg

Material: high purity silicon

Other Specifications:

1.1 Quantity Required: 11.027 kg/ load   Unit Cost: 149.45 $/ kg

1.2 Input Value:	$/
1.3 Input Cost:	1647.45 $/ load

Note to Item 1.3: Use price, if input produced in own plant.

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2.1 Type: Misc. materials ;

Specification: Includes: alumina sticks, mounting epoxy, graphite mounting bar, etc.

Quantity Required: ______ ___/___; Unit Cost: 4.00 $/ load ; Cost: 2.50 $/ load

2.2.2 Type: Coolant

Specification: 80:1 water to Rustlick

Coolant is recycled and filtered so that consumption/load is negligible. Flow rate is 7 ℓ/h

Quantity Required: negligible ___/___; Unit Cost: ___$/___; Cost: -- $/ --

2.2._ Type: ______

Specification: ______

Quantity Required: ______ ___/___; Unit Cost: ___$/___; Cost: ___$/___

2.2 Subtotal Indirect Materials: 2.50 $/ load

Process No. 2 . 4 . 02 – 03

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2.3 Expendable Tooling:

2.3 1 Type: STC-22 ID diamond coated blade

Quantity Required: 0.1667 blade /load: Unit Cost: 110 $/blade Cost: 18.33 $/load

2.3 _ Type: ____

Quantity Required: ____ /____: Unit Cost: ____ $/____ Cost: ____ $/____

2.3 _ Type: ____

Quantity Required: ____ /____: Unit Cost: ____ $/____ Cost: ____ $/____

2.3 _ Type: ____

Quantity Required: ____ /____: Unit Cost: ____ $/____ Cost: ____ $/____

2.3 Subtotal Expendable Tooling: 18.33 $/load

2.4 Energy

2.4 1 Type: Power consumption is 2 kW, running time is 35.7 h.

Quantity Required: 71.4 kWh/load : Unit Cost: 0.0319 $/kWh Cost: 2.28 $/load

2.4 _ Type: ____

Quantity Required: ____ ____: Unit Cost: ____ $/____ Cost: ____ $/____

2.4 Subtotal Energy Costs: 2.28 $/load

2.5 Subtotal 2.2 to 2.4:	23.11 $/load
2.6 Handling Charge: 5.26 % of item 2.5	1.22 $/load
2.7 Subtotal Materials and Supplies: (2.5 + 2.6)	24.33 $/load

Process No. 2.4.02-03

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3.1 Direct Labor:

3.1 1 Category: Semiconductor Assembler (SAMICS B3096D) Activity: Machine mounting/demounting
Amount Required: 0.5 h/ load; Rate: $ 3.89 /h; Load 36.0 %; Cost: 2.65 $/ load

3.1 2 Category: Semiconductor Assembler (SAMICS B3096D) Activity: Machine supervision
Amount Required: 2.5 h/ load; Rate: $ 3.89 /h; Load 36.0 %; Cost: 13.23 $/ load

3.1 3 Category: Maintenance Mechanic (SAMICS B3736D) Activity: Cutting tool change
Amount Required: 0.5 h/ load; Rate: $ 5.67 /h; Load 36.0 %; Cost: 3.86 $/ load

3.1 Direct Labor Subtotal: 19.74 $/ load

3.2 Indirect Labor: Taken as 25% of direct

3.2_ Category: ______ Activity: ______
Amount Required: ______ h/ ______; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2_ Category: ______ Activity: ______
Amount Required: ______ h/ ______; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2_ Category: ______ Activity: ______
Amount Required: ______ h/ ______; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2 Indirect Labor Subtotal:	4.93	$/ load
3.3 Subtotal 3.1 and 3.2	24.67	$/ load
3.4 Overhead on Labor: 5.26 %	1.30	$/ load
3.5 Subtotal Labor	25.97	$/ load

Process No. 2 . 4 . 0 2 - 0 3

4.1 Equipment

4.1_1 Type: STC ID slicing machine

Cost: 40,000 $; Installation Cost: ________ $; Throughput: 224 loads /y

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 99 %; Machine Oper'g Time 8197.2 h/y

Servicing Costs: Labor 52 h/y at 8.12 $/h; Parts or Outside Service: 300 $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 9262.25 $/y — 41.34 $/load

4.1_ Type: ________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ______ $/h; Parts or Outside Service: ________ $/y

Useful Life: ________ y; Charge Rate: ______ % of Cost/y; Capital Cost: ________ $/y — ______ $/ ______

4.1_ Type: ________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ______ $/h; Parts or Outside Service: ________ $/y

Useful Life: ________ y; Charge Rate: ______ % of Cost/y; Capital Cost: ________ $/y — ______ $/ ______

4.1 Subtotal Equipment Cost:	41.34 $/ load

Process No. 2 . 4 . 02 - 0 3

4.2 Facilities:

4.21 Type: ID machine area Floor Area: 7.5 m^2; Throughput: 224 loads /y

Charge Rate: 179.13* $/($m^2$·y);

Energy Use:

Heating	____	____/y at	____$/	____
Air Cond'g	____	____/y at	____$/	____
Lighting	____	____/y at	____$/	____

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: 1343.48 $/y — 6.00 $/load

4.2_ Type: ____ Floor Area: ____ m^2; Throughput: ____ /y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

Heating	____	____/y at	____$/	____
Air Cond'g	____	____/y at	____$/	____
Lighting	____	____/y at	____$/	____

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: ____ $/y — ____ $/____

4.2_ Type: ____ Floor Area: ____ m^2; Throughput: ____ /y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

Heating	____	____/y at	____$/	____
Air Cond'g	____	____/y at	____$/	____
Lighting	____	____/y at	____$/	____

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: ____ $/y — ____ $/____

4.2 Subtotal Facilities:	6.00 $/load
4.3 Equipment and Facilities Subtotal :	47.35 $/load

* Includes energy use

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5. Salvaged Material (Work-in-process)

5.1	Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit)	5.453 kg / load	
5.21	Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1)	5.574 kg / load	
5.22	Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ – ☐☐	____ ____ / ____	
5.23	Credit for 5.22 at the Market Value of ____ $/ ____ :	____ $/ ____	
5.24	Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ____ $/ ____ :	____ $/ ____	
5.25	Net Credit for 5.22 (5.23 minus 5.24):		____ $/ ____
5.26	Material of Type 1. Lost in Process (5.21 minus 5.22)	5.574 kg / load	
5.3	Cost of Work-in-Process Lost (Amount 5.26 Times Unit Cost 1.1)		833.03 $/ load
5.4	Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.2 Times Unit Cost from 1.1)		814.95 $/ load

Salvaged Materials Summary:

5.8	Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76)	____ $/ ____

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Process No. 2 . 4 . 0 2 — 0 3 Revision ______ Date 8/78

7. Process Cost Computation

7.11	Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.)	97.65 $/ load
7.22	Other Indirect Costs: (0.059*(4.1)+0.108*(4.2)) % of 7.11	2.98 $/ load
7.21	Total Operating Add-on Costs of Process:	100.63 $/ load
7.22	G & A ______ % of 7.21	$/
7.31	Total Gross Add-On Cost of Process	100.63 $/ load
7.32	Credit for Salvaged Material (5.8)	$/
7.33	Cost of Work-in-Process Lost (5.3)	833.03 $/ load
7.34	Specific Add-On Cost of Process (7.31 + 7.33)-(7.32)	933.66 $/ load
7.35	Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4)	814.95 $/ load
7.36	Loading on Item 7.35 at Rate ______ %	$/
7.37	Cost of Output Work-in-Process (7.34 + 7.35 + 7.36)	1748.61 $/ load

7.41	Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units)	0.585 m^2 / kg
7.42	Practical Yield	95 %
7.43	Effective Yield (7.41 x 7.42)	0.556 m^2 / kg
7.44	Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35	6.133 m^2 / load

7.51	Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44)	285.11 $/ m^2
7.52	Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44)	152.24 $/ m^2

Process No. 2 . 4 . 0 2 - 0 3

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8. Price Computation

8.1 Alternate 1

8.11 Profit at Expected Rate of 20 %: 30.44 $/ load
(Profit before income taxes; applied to 7.52)

8.12 Price of Process (7.52 + 8.11) 182.69 $/ m^2

8.13 Price of Work-in-Process (7.51 + 8.11) 315.56 $/ m^2

8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274* 41.34 $/ load from Subtotal 4.1 = 38.34 $/ load

1.946* 6.00 $/ load from Subtotal 4.2 = 11.68 $/ load

Subtotal = 50.02 $/ load

8.22 Costs of Amortization of the One-Time Cost:

0.192* 24.33 $/ load from Subtotal 2.7 = 4.67 $/ load

0.192* 25.47 $/ load from Subtotal 3.5 = 4.98 $/ load

0.2958* 41.34 $/ load from Subtotal 4.1 = 12.23 $/ load

2.77* 6.00 $/ load from Subtotal 4.2 = 16.62 $/ load

Subtotal = 38.50 $/ load

8.23 Total Net Cost of Equity (8.21 + 8.22): 88.52 $/ load

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 6.133 m^2 / load from 7.44)

14.43 $/ m^2

8.25 Price of Process (7.52 + 8.24) 166.67 $/ m^2

8.26 Price of Work-in-Process (7.51 + 8.24) 299.54 $/ m^2

Process No. 2 . 4 . 02 - 01

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6. Byproducts and Wastes

6.1 Solid Byproducts/Wastes

6.1.1 Type (Composition): Silicon chips Quantity Produced: 0.14 kg/ load

Physical Shape/Size: ________ Energy Content: ________ kWh/ ________

Density: 2.34 g/cm^3; Water Solubility 0 g/l at ________ °C: pH: ________

Toxicity ________ Biodegradable: ________ Other Remarks: ________

Type of Disposal: ________

Input Material for ________ Cost/(Credit) ________ $/ ________; Cost ________ $/ ________

6.2 Liquid Byproducts/Wastes (inorganic):

6.2.1 Type (Composition): PC oil with abrasive Quantity Produced: 7.6 ℓ/ load

Density: ~0.95 g/cm^3; Suspended Solids: SiC abrasive Amount: ________ mg/l pH: ________

Toxicity: ________ Heavy Metal Content: ________ mg/l Other Remarks: ________

Slurry oil also contains Si kerf at a concentration of 145 g/ℓ

Type of Disposal: ________

Input Material for: ________ Cost/(Credit) ________ $/ ________ Cost: ________ $/ ________

Carry: ________ $/ ________

Process No. 2 . 4 . 0 2 – 0 1

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7. Process Cost Computation

7.11	Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.)	113.91 $/ load
7.22	Other Indirect Costs: (0.59 *(4.1) + 0.108 *(4.2)) % of 7.11	1.39 $/ load
7.21	Total Operating Add-on Costs of Process:	115.30 $/ load
7.22	G & A ______ % of 7.21	______ $/ ______
7.31	Total Gross Add-On Cost of Process	115.30 $/ load
7.32	Credit for Salvaged Material (5.8)	______ $/ ______
7.33	Cost of Work-in-Process Lost (5.3)	191.95 $/ load
7.34	Specific Add-On Cost of Process (7.31 + 7.33)-(7.32)	307.25 $/ load
7.35	Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4)	245.18 $/ load
7.36	Loading on Item 7.35 at Rate ______ %	______ $/ ______
7.37	Cost of Output Work-in-Process (7.34 + 7.35 + 7.36)	552.42 $/ load

7.41	Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units)	0.63 m^2 / kg
7.42	Practical Yield	95 %
7.43	Effective Yield (7.41 x 7.42)	0.6 m^2 / kg
7.44	Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35	1.63 m^2 / load

7.51	Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44)	338.91 $/ m^2
7.52	Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44)	188.50 $/ m^2

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Form 15

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0. Output Specification:

Name of item: Silicon wafers

Dimensions: 10 cm diameter, 380 μm thick,

Material:

Other Specifications: 350 μm kerf, 822 wafers/load

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University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Sheet generation

Subprocess: Ingot Slicing

Option: ID fixed abrasive slicing of 10.16 cm diameter ingots as performed by OCLI and projected for 1982

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Process No. 2 . 4 . 02 - 03

0.1 Value Added:	$/

Process Description: Inner diameter slicing as demonstrated by OCLI using a STC-22 diamond impregnated blade (55.88-cm OD, 20.32-cm ID, 0.15 mm thick core with a 0.33-.36 mm total thickness).

1. Input Specification:

Name of Item: Prepared machine load from 2.4 : 01 : 03

Dimensions: 10.16 cm in diameter, 25 cm long, 4.74 kg silicon crystal ingots

Material: High purity silicon.

Other Specifications: Single crystal ingot

1.1 Quantity Required: 4.74 kg / load Unit Cost: 72.22 $/ kg

1.2 Input Value:	$/
1.3 Input Cost:	342.32 $/ load

Note to Item 1.3: Use price, if input produced in own plant.

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Form 4

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2.1 Type: Blade dressing materials. ;

Specification: Alumina stick.

Quantity Required: ____ ___/___; Unit Cost: 2.02 $/ load ; Cost: 2.02 $/ load

2.2.2 Type: Coolant

Specification: Rust lick

80:1 water to Rust-lick ratio

Quantity Required: 0.66 gallon /load; Unit Cost: 3.65 $/gallon ; Cost: 2.414 $/load

2.2._ Type: ____

Specification: ____

Quantity Required: ____ ___/___ Unit Cost: ___ $/___; Cost: ___ $/___

2.2 Subtotal Indirect Materials: 4.44 $/ load

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Form 5

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2.3 Expendable Tooling:

2.3 1 Type: Model STC-22, ID diamond-plated blade

Quantity Required: 0.07 blade/ load Unit Cost: 150 $/blade Cost: 10.49 $/ load

2.3 _ Type: ____

Quantity Required: ____ ___/___: Unit Cost: ___$/___ Cost: ___$/___

2.3 _ Type: ____

Quantity Required: ____ ___/___: Unit Cost: ___$/___ Cost: ___$/___

2.3 _ Type: ____

Quantity Required: ____ ___/___: Unit Cost: ___$/___ Cost: ___$/___

2.3	Subtotal Expendable Tooling:	10.49 $/ load

2.4 Energy

2.4 1 Type: Electrical, 2kW main and auxiliary motors

Quantity Required: 29.4 kWh/load : Unit Cost: 0.0319 $/ kWh Cost: 0.94 $/ load

2.4 _ Type: ____

Quantity Required: ____ ____: Unit Cost: ___$/___ Cost: ___$/___

2.4	Subtotal Energy Costs:	0.94 $/ load
2.5	Subtotal 2.1 to 2.4.	15.87 $/ load
2.6	Handling Charge: 5.26 % of item 2.5	0.84 $/ load
2.7	Subtotal Materials and Supplies: (2.5 + 2.6)	16.71 $/ load

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3.1 Direct Labor:

3.1 1 Category: Semiconductor Assembler (SAMICS B3096D) Activity: Mounting and loading

Amount Required: 0.525 h/ load ; Rate: $ 3.90 /h; Load 36.0 %; Cost: 2.78 $/ load

3.1 2 Category: Semiconductor Assembler (SAMICS B3096D) Activity: Machine supervision

Amount Required: 0.23 h/ load ; Rate: $ 3.90 /h; Load 36.0 %; Cost: 1.22 $/ load

3.1 3 Category: Maintenance Mechanic (SAMICS B3736D) Activity: Blade head changing

Amount Required: 0.875 h/ load ; Rate: $ 5.67 /h; Load 36.0 %; Cost: 6.75 $/ load

3.1 Direct Labor Subtotal: 10.75 $/ load

3.2 Indirect Labor: Taken as 25% of direct

3.2 _ Category: ____ Activity: ____

Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2 _ Category: ____ Activity: ____

Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2 _ Category: ____ Activity: ____

Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2 Indirect Labor Subtotal: 2.59 $/ load

3.3 Subtotal 3.1 and 3.2: 13.44 $/ load

3.4 Overhead on Labor: 5.26 %: 0.71 $/ load

3.5 Subtotal Labor: 14.15 $/ load

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Revision ____ Date 3/78

Process No. 2 . 4 . 0 2 - 0 3

4.1 Equipment

4.1_1 Type: ID saw slicing machine

Cost: 40,000 $; Installation Cost: ____ $; Throughput: 480 /h;y

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 95 %; Machine Oper'g Time 7866 h/y

Servicing Costs: Labor ____ h/y at ____ $/h;Parts or Outside Service: 285.71 $/y

Useful Life: ____ y, Charge Rate: 21.4 % of Cost/y; Capital Cost: 8560 $/y | 18.43 $/ load

4.1_ Type: ____

Cost: ____ $; Installation Cost: ____ $; Throughput: ____ /h;

Plant Oper'g Time ____ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ____ h/y

Servicing Costs: Labor ____ h/y at ____ $/h;Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: ____ % of Cost/y; Capital Cost: ____ $/y | ____ $/ ____

4.1_ Type: ____

Cost: ____ $; Installation Cost: ____ $; Throughput: ____ /h;

Plant Oper'g Time ____ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ____ h/y

Servicing Costs: Labor ____ h/y at ____ $/h;Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: ____ % of Cost/y; Capital Cost: ____ $/y | ____ $/ ____

4.1 Subtotal Equipment Cost: 18.43 $/load

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4.2 Facilities:

4.21 Type: Machine area Floor Area: 9.0 m^2; Throughput: 480 loads /y

Charge Rate: 179.13* $/($m^2$·y);

Energy Use:			Maintenance Costs:	
Heating	____ /y at	$/ ____	Labor: ____ h/y at ____ $/h	
Air Cond'g	____ /y at	$/ ____	Supplies: ____ $/y	
Lighting	____ /y at	$/ ____	Outside Services: ____ $/y	
			Total Cost: 1612 $/y	3.36 $/load

4.2_ Type: ____ Floor Area: ____ m^2; Throughput: ____ /y

Charge Rate: ____ $/($m^2$·y);

Energy Use:			Maintenance Costs:	
Heating	____ /y at	$/ ____	Labor: ____ h/y at ____ $/h	
Air Cond'g	____ /y at	$/ ____	Supplies: ____ $/y	
Lighting	____ /y at	$/ ____	Outside Services: ____ $/y	
			Total Cost: ____ $/y	____ $/ ____

4.2_ Type: ____ Floor Area: ____ m^2; Throughput: ____ /y

Charge Rate: ____ $/($m^2$·y);

Energy Use:			Maintenance Costs:	
Heating	____ /y at	$/ ____	Labor: ____ h/y at ____ $/h	
Air Cond'g	____ /y at	$/ ____	Supplies: ____ $/y	
Lighting	____ /y at	$/ ____	Outside Services: ____ $/y	
			Total Cost: ____ $/y	____ $/ ____

* Includes energy use

4.2 Subtotal Facilities:	3.36 $/load
4.3 Equipment and Facilities Subtotal :	21.79 $/load

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5. Salvaged Material (Work-in-process)

5.1	Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit)	2.40 kg / load	
5.21	Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1)	2.34 kg / load	
5.22	Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ – ☐☐	______ ______ / ______	
5.23	Credit for 5.22 at the Market Value of ______ $/ ______ :	______ $/ ______	
5.24	Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ______ $/ ______ :	______ $/ ______	
5.25	Net Credit for 5.22 (5.23 minus 5.24):		______ $/ ______
5.26	Material of Type 1. Lost in Process (5.21 minus 5.22)	2.34 kg / load	
5.3	Cost of Work-in-Process Lost (Amount 5.26 Times Unit Cost 1.1)		168.99 $/load
5.4	Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.2 Times Unit Cost from 1.1)		173.33 $/load

Salvaged Materials Summary:

5.8	Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76)	______ $/ ______

Process No. 2 . 4 . 02 – 03

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6. Byproducts and Wastes

6.1 Solid Byproducts/Wastes

6.1.1 Type (Composition): Silicon chips and dust Quantity Produced: 0. kg / load

Physical Shape/Size: ________ Energy Content: ________ kWh/ ________

Density: 2.34 g/cm^3; Water Solubility: ________ g/l at ________ °C; pH: ________

Toxicity: ________ Biodegradable: ________ Other Remarks: ________

Type of Disposal: ________

Input Material for: ________ Cost/(Credit) ________ \$/ ________; Cost: ________ \$/ ________

6.2 Liquid Byproducts/Wastes (inorganic):

6.2.1 Type (Composition): 80:1 water: rust lick Quantity Produced. 123 ℓ/ load

Density: ________ g/cm^3; Suspended Solids: silicon kerf Amount: 19 g/l pH: ________

Toxicity: ________ Heavy Metal Content: ________ mg/l Other Remarks: ________

Type of Disposal: Can be stored in drums

Input Material for: ________ Cost/(Credit) ________ \$/ ________ Cost: ________ \$/ ________

Carry: ________ \$/ ________

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7. Process Cost Computation

7.11 Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.)	52.64 $/load
7.22 Other Indirect Costs: (0.059*(4.1)+0.108*4.2) % of 7.11	1.45 $/load
7.21 Total Operating Add-on Costs of Process:	54.09 $/load
7.22 G & A ______ % of 7.21	$/
7.31 Total Gross Add-On Cost of Process	54.09 $/load
7.32 Credit for Salvaged Material (5.8)	$/
7.33 Cost of Work-in-Process Lost (5.3)	168.99 $/load
7.34 Specific Add-On Cost of Process (7.31 + 7.33)-(7.32)	223.08 $/load
7.35 Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4)	173.33 $/load
7.36 Loading on Item 7.35 at Rate ______ %	$/
7.37 Cost of Output Work-in-Process (7.34 + 7.35 + 7.36)	396.40 $/load

7.41 Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units)	0.6 m^2 / kg
7.42 Practical Yield	100 %
7.43 Effective Yield (7.41 x 7.42)	0.6 m^2/ kg
7.44 Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35	2.84 m^2/ load

7.51 Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44)	139.58 $/ m^2
7.52 Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44)	78.55 $/ m^2

Process No. 2 . 4 . 0 2 - 0 3

Form 13-1

Revision ____ Date 3/78

8. Price Computation

8.1 Alternate 1

8.11 Profit at Expected Rate of 20 %: 15.71 $/ m^2
(Profit before income taxes; applied to 7.52)

8.12 Price of Process (7.52 + 8.11) 94.76 $/ m^2

8.13 Price of Work-in-Process (7.51 + 8.11) 155.29 $/ m^2

Process No. 2.4.02-03

Form 13-2
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Revision ______ Date 3/78

8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274* 18.43 $/ load from Subtotal 4.1 = 17.09 $/ load

1.946* 3.36 $/ load from Subtotal 4.2 = 6.54 $/ load

Subtotal = 23.63 $/ load

8.22 Costs of Amortization of the One-Time Cost:

0.192* 16.70 $/ load from Subtotal 2.7 = 3.21 $/ load

0.192* 14.15 $/ load from Subtotal 3.5 = 2.72 $/ load

0.2958* 18.43 $/ load from Subtotal 4.1 = 5.45 $/ load

2.77* 3.36 $/ load from Subtotal 4.2 = 9.31 $/ load

Subtotal = 20.68 $/ load

8.23 Total Net Cost of Equity (8.21 + 8.22): 44.32 $/ load

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 2.84 m^2 / load from 7.44)

15.60 $/ load

8.25 Price of Process (7.52 + 8.24) 94.15 $/ m^2

8.26 Price of Work-in-Process (7.51 + 8.24) 155.18 $/ m^2

Process No. 2.4.02-03

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9. Process Economic Evaluation:

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9.1 Process Cost Balance (7.52 - 0.1)	$/
9.2 Relative Process Performance (9.1 ÷ 0.1)	
9.3 Output Cost (7.51)	139.58 $/ m^2
9.4 Output Value (0.2 + 0.1)	$/
9.5 Relative Excess Cost [(9.3 - 9.4) ÷ 9.4]	

Process No. 2.4.02-03

Form 15

Revision ____ Date 3/78

0. Output Specification:

Name of item: Silicon wafers, 95 cut

Dimensions: 10.16 cm in diameter, 0.36 ± 0.02 mm thick

Material: High purity silicon

Other Specifications: Kerf thickness is 0.35 mm

Process No. 2 . 4 . 0 2 - 0 4

Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Sheet Generation

Subprocess: Ingot Slicing

Option: Multiblade Slurry Slicing of 10-cm diameter ingots with 234 blades per pack as demonstrated experimentally by Varian in Exp. P-005.

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Form 2

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Process No. 2 . 4 . 0 2 - 0 4

0.1 Value Added:	________ $/ ________

Process Description: Multiblade slurry slicing as performed experimentally by Varian using a blade-head with 234 blades.

1. Input Specification:

Name of Item: Silicon ingot, prepared as specified in 2.4-01-01

Dimensions: 10-cm in diameter, 11.9 cm long, mass is 2.19 kg

Material: high purity silicon

Other Specifications: Silicon single crystal ingot mounted on ceramic block.

1.1 Quantity Required: 2.19 kg / load   Unit Cost: 150.56 $/ kg

1.2 Input Value:	________ $/ ________
1.3 Input Cost:	329.73 $/ load

Note to Item 1.3: Use price, if input produced in own plant.

Process No. 2.4.02-04

Form 4

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2 1 Type: PC oil;

Specification: PC oil for abrasive vehicle

Quantity Required: 7.6 ℓ/load; Unit Cost: 0.66 $/ℓ; Cost: 5.02 $/load

2.2 2 Type: Abrasive

Specification: 600 grit SiC abrasive;

concentration in PC oil is 0.36 kg/ℓ;

mass consumed per load is 2.736 kg.

Quantity Required: 2.736 kg /load; Unit Cost: 4.29 $/kg; Cost: 7.03 $/load

2.2_ Type:

Specification:

Quantity Required: ____/____; Unit Cost: ____$/____; Cost: ____$/____

2.2 Subtotal Indirect Materials: 12.05 $/load

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2.3 Expendable Tooling:

2.3.1 Type: Blade pack with 300 blades of 1095 steel, 0.15 mm thick, 6.35 mm high

Quantity Required:	1 pack / load:	Unit Cost: 50 $/pack	Cost:	50 $/load

2.3_ Type: ______

Quantity Required:	___/___:	Unit Cost: ___$/___	Cost:	___$/___

2.3_ Type: ______

Quantity Required:	___/___:	Unit Cost: ___$/___	Cost:	___$/___

2.3_ Type: ______

Quantity Required:	___/___:	Unit Cost: ___$/___	Cost:	___$/___

2.3 Subtotal Expendable Tooling:	50 $/load

2.4 Energy

2.4.1 Type: Electricity for 1 kW main and auxiliary motors

Quantity Required:	32 kWh / load:	Unit Cost: 0.0319 $/kWh	Cost:	1.02 $/load

2.4_ Type: ______

Quantity Required:	______:	Unit Cost: ___$/___	Cost:	___$/___

2.4 Subtotal Energy Costs:	1.02 $/load
2.5 Subtotal 2.1 to 2.4:	63.07 $/load
2.6 Handling Charge: 5.26 % of item 2.5	3.32 $/load
2.7 Subtotal Materials and Supplies: (2.5 + 2.6)	66.39 $/load

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3.1 Direct Labor:

3.11 Category: Semiconductor assembler (SAMICS B3096D) Activity: Machine loading
Amount Required: 0.5 h/ load; Rate: $3.90 /h; Load 36.0 %; Cost: 2.65 $/load

3.12 Category: Semiconductor assembler (SAMICS B3096D) Activity: machine supervision
Amount Required: 0.67 h/ load; Rate: $ 3.90 /h; Load 36.0 %; Cost: 3.55 $/load

3.13 Category: Maintenance mechanic (SAMICS B3736D) Activity: Adjustments, blade head changing
Amount Required: 0.67 h/ load; Rate: $ 5.67 /h; Load 3.60 %; Cost: 5.17 $/load

3.1 Direct Labor Subtotal: 11.37 $/load

3.2 Indirect Labor: 25% of direct

3.2_ Category: ______ Activity: ______
Amount Required: ______ h/ ______; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2_ Category: ______ Activity: ______
Amount Required: ______ h/ ______; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2_ Category: ______ Activity: ______
Amount Required: ______ h/ ______; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2 Indirect Labor Subtotal: 2.84 $/load

3.3 Subtotal 3.1 and 3.2: 14.21 $/load

3.4 Overhead on Labor: 5.26 %: 0.75 $/load

3.5 Subtotal Labor: 14.96 $/load

Process No. 2 . 4 . 0 2 - 0 4

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4.1 Equipment

4.11 Type: Multiblade slicing machine

Cost: 20,000 $; Installation Cost: - $; Throughput: 225 loads /h; y

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 90 %; Machine Oper'g Time 7452 h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: 1592.3 $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 4270 $/y — 20.05 $/load

4.1_ Type: ____

Cost: ____ $; Installation Cost: ____ $; Throughput: ____ /h,

Plant Oper'g Time ____ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ____ h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: ____ % of Cost/y; Capital Cost: ____ $/y — ____ $/____

4.1_ Type: ____

Cost: ____ $; Installation Cost: ____ $; Throughput: ____ /h;

Plant Oper'g Time ____ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ____ h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: ____ % of Cost/y; Capital Cost: ____ $/y — ____ $/____

4.1 Subtotal Equipment Cost:	20.05 $/load

Process No. 2 . 4 . 0 2 - 0 4

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4.2 Facilities:

4.21 Type: Slicing machine area Floor Area: 5.6 m^2; Throughput: 225 load /y

Charge Rate: 179.13* $/($m^2$·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: 1003.13 $/y — 4.46 $/load

4.2_ Type: ______ Floor Area: ______ m^2; Throughput: ______ ______/y

Charge Rate: ______$/($m^2$·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: ______$/y — ______$/______

4.2_ Type: ______ Floor Area: ______ m^2; Throughput: ______ ______/y

Charge Rate: ______$/($m^2$·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: ______$/y — ______$/______

4.2 Subtotal Facilities: 4.46 $/load

4.3 Equipment and Facilities Subtotal : 24.51 $/load

* Includes energy use

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5. Salvaged Material (Work-in-process)

5.1	Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit)	1.035 kg / load	
5.21	Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1)	1.158 kg / load	
5.22	Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ – ☐☐	______ ______ / ______	
5.23	Credit for 5.22 at the Market Value of ______ $/ ______ :	______ $/ ______	
5.24	Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ______ $/ ______ :	______ $/ ______	
5.25	Net Credit for 5.22 (5.23 minus 5.24):		______ $/ ______
5.26	Material of Type 1. Lost in Process (5.21 minus 5.22)	1.158 kg / load	
5.3	Cost of Work-in-Process Lost (Amount 5.26 Times Unit Cost 1.1)		174.35 $/ load
5.4	Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.2' Times Unit Cost from 1.1)		155.83 $/ load

Salvaged Materials Summary:

5.8	Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76)	______ $/ ______

Process No. 2.4.02-04

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6. Byproducts and Wastes

6.1 Solid Byproducts/Wastes

6.11 Type (Composition): Silicon chips with dust Quantity Produced: 0.21 kg/ load

Physical Shape/Size: ______ Energy Content: ______ kWh/ ______

Density: 2.34 g/cm^3; Water Solubility: 0 g/l at ______ °C; pH: ______

Toxicity: ______ Biodegradable: ______ Other Remarks: ______

Type of Disposal: ______

Input Material for: ______ Cost/(Credit) ______ $/ ______; Cost: ______ $/ ______

6.2 Liquid Byproducts/Wastes (inorganic):

6.21 Type (Composition): Abrasive oil slurry with kerf Quantity Produced: 7.6 ℓ/ load

Density: ~0.95 g/cm^3; Suspended Solids: SiC abrasive Amount: 0.36 kg/l pH: ______

Toxicity: ______ Heavy Metal Content: ______ mg/l Other Remarks: ______

contains 0.95 kg of kerf (0.12 kg/ℓ - slurry)

Type of Disposal: ______

Input Material for: ______ Cost/(Credit) ______ $/ ______ Cost: ______ $/ ______

Carry: ______ $/ ______

Process No. 2 . 4 . 02 – 04

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7. Process Cost Computation

7.11 Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.)	105.86 $/load
7.22 Other Indirect Costs: ______ % of 7.11 0.59 x (4.1) + 0.108x(4.2)	1.66 $/load
7.21 Total Operating Add-on Costs of Process:	107.52 $/load
7.22 G & A ______ % of 7.21	$/
7.31 Total Gross Add-On Cost of Process	107.52 $/load
7.32 Credit for Salvaged Material (5.8)	$/
7.33 Cost of Work-in-Process Lost (5.3)	174.35 $/load
7.34 Specific Add-On Cost of Process (7.31 + 7.33)-(7.32)	281.87 $/load
7.35 Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4)	155.83 $/load
7.36 Loading on Item 7.35 at Rate ______ %	$/
7.37 Cost of Output Work-in-Process (7.34 + 7.35 + 7.36)	437.70 $/load

7.41 Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units)	0.838 m^2 / kg
7.42 Practical Yield	83 %
7.43 Effective Yield (7.41 x 7.42)	0.695 m^2 / kg
7.44 Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35	1.525 m^2 / load

7.51 Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44)	287.02 $/ m^2
7.52 Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44)	184.83 $/ m^2

Process No. 2.4.02-04

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8. Price Computation

8.1 Alternate 1

8.11 Profit at Expected Rate of 20 %: 36.97 $/ m^2
(Profit before income taxes; applied to 7.52)

8.12 Price of Process (7.52 + 8.11) 323.98 $/ m^2

8.13 Price of Work-in-Process (7.51 + 8.11) 221.80 $/ m^2

Process No. 2.4.02-04

Form 13-2

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8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274* 20.05 $/ load from Subtotal 4.1 = 18.59 $/load

1.946* 4.46 $/ load from Subtotal 4.2 = 8.68 $/load

Subtotal = 27.27 $/load

8.22 Costs of Amortization of the One-Time Cost:

0.192* 66.39 $/ load from Subtotal 2.7 = 12.75 $/load

0.192* 14.96 $/ load from Subtotal 3.5 = 2.87 $/load

0.2958* 20.05 $/ load from Subtotal 4.1 = 5.93 $/load

2.77* 4.46 $/ load from Subtotal 4.2 = 12.35 $/load

Subtotal = 33.90 $/load

8.23 Total Net Cost of Equity (8.21 + 8.22): 61.17 $/load

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 1.525 m^2 /load from 7.44)

40.11 $\$/m^2$

8.25 Price of Process (7.52 + 8.24) 224.94 $\$/m^2$

8.26 Price of Work-in-Process (7.51 + 8.24) 327.13 $\$/m^2$

Process No. 2 . 4 . 0 2 - 0 4

Form 15

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0. Output Specification:

Name of item: Wafer, as-cut

Dimensions: 10-cm diameter, 0.294 ± 0.04 mm thick

Material: high purity silicon

Other Specifications: Depth of subsurface damage 10-15 μm

Process No. 2 . 4 . 0 2 - 0 4 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Sheet generation

Subprocess: Ingot slicing

Option: Multiblade slurry slicing using the 900 blade-head machine as proposed by Varian for use in 1986.

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Process No. 2 . 4 . 0 2 - 0 4

0.1 Value Added:	______ $/ ______

Process Description: Multiblade slurry slicing

Projection for Varian's slicing machine with 900 blades per head,

Blades are 0.15 mm thick with 0.30 mm spacers

1. Input Specification:

Name of Item: Prepared machine load from 2.4 : 01 : 04

Dimensions: 12-cm in diameter, 40·5 cm long, 10·72 kg single crystal ingots

Material: High purity silicon

Other Specifications: One silicon crystal mounted on ceramic block

1.1 Quantity Required: 10·72 kg / load Unit Cost: 70.98 $/ kg Si

1.2 Input Value:	______ $/ ______
1.3 Input Cost:	760.94 $/ load

Note to Item 1.3: Use price, if input produced in own plant.

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2.1 Type: Abrasive slurry;

Specification: PC oil with 600 grit abrasive

Concentration 0.24 kg/ℓ

Quantity Required: 15 ℓ/load; Unit Cost: 1.85 $/ℓ. Cost: 27.75 $/load

2.2.2 Type: Misc. materials

Specification: Not given; estimated

Quantity Required: ____ /____; Unit Cost: ____ $/____; Cost: 9.48 $/load

2.2._ Type: ____

Specification: ____

Quantity Required: ____ /____; Unit Cost: ____ $/____; Cost: ____ $/____

2.2 Subtotal Indirect Materials:	37.23 $/load

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2.3 Expendable Tooling:

2.3 1 Type: 900-blade drill pin pack consisting of 0.15 mm thick, 1095 steel blades

Quantity Required: 0.5 Pack / load: Unit Cost: 39.45 $/Pack Cost: 19.73 $/load

2.3 _ Type: ____

Quantity Required: ____ ___/___: Unit Cost: ___$/___ Cost: ___$/___

2.3 _ Type: ____

Quantity Required: ____ ___/___: Unit Cost: ___$/___ Cost: ___$/___

2.3 _ Type: ____

Quantity Required: ____ ___/___: Unit Cost: ___$/___ Cost: ___$/___

2.3	Subtotal Expendable Tooling:	19.73 $/pack

2.4 Energy

2.4 1 Type: Electrical, 1.67 kW in main and auxiliary motors

Quantity Required: 49.3 kWh/load: Unit Cost: 0.032 $/kWh Cost: 1.57 $/load

2.4 _ Type: ____

Quantity Required: ____ ____: Unit Cost: ___$/___ Cost: ___$/___

2.4 Subtotal Energy Costs:	1.57 $/load
2.5 Subtotal 2.1 to 2.4:	58.53 $/load
2.6 Handling Charge: 5.26 % of item 2.5	3.07 $/load
2.7 Subtotal Materials and Supplies: (2.5 + 2.6)	61.60 $/load

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3.1 Direct Labor:

3.1 1 Category: Semiconductor Assembler (SAMICS B3096D) Activity: loading/unloading

Amount Required: 0.67 h/ load ; Rate: $ 3.90 /h; Load 36.0 %; Cost: 3.55 $/ load

3.1_ Category: Semiconductor Assembler (SAMICS B3096D) Activity: Machine supervision

Amount Required: 0.67 h/ load ; Rate: $ 3.90 /h; Load 36.0 %; Cost: 3.55 $/ load

3.1_ Category: Maintenance Mechanic (SAMICS B3704D) Activity: blade head changing and adjusting

Amount Required: 0.67 h/ load ; Rate: $ 5.67 /h; Load 36.0 %; Cost: 5.17 $/ load

3.1 Direct Labor Subtotal: 12.27 $/ load

3.2 Indirect Labor: 25% of direct

3.2_ Category: ______ Activity: ______

Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2_ Category: ______ Activity: ______

Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2_ Category: ______ Activity: ______

Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2 Indirect Labor Subtotal: 3.07 $/ load

3.3 Subtotal 3.1 and 3.2 15.34 $/ load

3.4 Overhead on Labor: 5.26 % 0.81 $/ load

3.5 Subtotal Labor 16.15 $/ load

Process No. 2 . 4 . 0 2 - 0 1

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4.1 Equipment

4.1 1 Type: Multiblade slicing machine

Cost: 30,000 $; Installation Cost: ________ $; Throughput: 245 /h; y

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 90 %; Machine Oper'g Time 7452 h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: 1592.3 $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 6420 $/y — 32.70 $/load

4.1_ Type: ________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: ________ $/y

Useful Life: ________ y; Charge Rate: ________ % of Cost/y; Capital Cost: ________ $/y — ________ $/________

4.1_ Type: ________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: ________ $/y

Useful Life: ________ y; Charge Rate: ________ % of Cost/y; Capital Cost: ________ $/y — ________ $/________

4.1 Subtotal Equipment Cost:	32.70 $/load

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4.2 Facilities:

4.2_1 Type: Slicing machine area Floor Area: 5.6 m^2; Throughput: 245 loads /y

Charge Rate: 179.13* $/($m^2$·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: 1003.13 $/y — 4.09 $/ load

4.2_ Type: ______ Floor Area: ______ m^2; Throughput: ______ /y

Charge Rate: ______ $/($m^2$·y);

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: ______$/y — ______$/______

4.2_ Type: ______ Floor Area: ______ m^2; Throughput: ______ /y

Charge Rate: ______ $/($m^2$·y).

Energy Use:

Heating ______ ______/y at ______$/______

Air Cond'g ______ ______/y at ______$/______

Lighting ______ ______/y at ______$/______

Maintenance Costs:

Labor: ______h/y at ______$/h

Supplies: ______$/y

Outside Services: ______$/y

Total Cost: ______$/y — ______$/______

4.2 Subtotal Facilities:	4.09 $/ load
4.3 Equipment and Facilities Subtotal :	35.79 $/ load

*Includes energy use

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5. Salvaged Material (Work-in-process)

5.1	Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit)	5.66 kg / load	
5.21	Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1)	5.06 kg / load	
5.22	Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ – ☐☐	______ ______ / ______	
5.23	Credit for 5.22 at the Market Value of ______ $/ ______ :	______ $/ ______	
5.24	Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ______ $/ ______ :	______ $/ ______	
5.25	Net Credit for 5.22 (5.23 minus 5.24):		______ $/ ______
5.26	Material of Type 1. Lost in Process (5.21 minus 5.22)	5.06 kg / load	
5.3	Cost of Work-in-Process Lost (Amount 5.26 Times Unit Cost 1.1)		359.18 $/ load
5.4	Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.2 Times Unit Cost from 1.1)		401.76 $/ load

Salvaged Materials Summary:

5.8	Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76)	______ $/ ______

Process No. 2 . 4 . 0 2 - 0 4

Revision ________ Date 5/78

6. Byproducts and Wastes

6.1 Solid Byproducts/Wastes

6.1.1 Type (Composition): Silicon chips and dust Quantity Produced: 0.536 kg/ load

Physical Shape/Size: ________ Energy Content: ________ kWh/ ________

Density: 2.34 g/cm^3; Water Solubility: ________ g/l at ________ °C. pH: ________

Toxicity: ________ Biodegradable: ________ Other Remarks: ________

Type of Disposal: ________

Input Material for: ________ Cost/(Credit) ________ $/ ________ ; Cost: ________ $/ ________

6.2 Liquid Byproducts/Wastes (inorganic):

6.2.1 Type (Composition): PC oil slurry Quantity Produced: 15 ℓ / load

Density: 0.95 g/cm^3; Suspended Solids: SiC abrasive Amount: 0.24 kg/l pH: ________

Toxicity: ________ Heavy Metal Content: ________ mg/l Other Remarks: ________

Oil also contains 4.76 kg of kerf/load; concentration is 0.32 kg/ℓ.

Type of Disposal: ________

Input Material for: ________ Cost/(Credit) ________ $/ ________ Cost: ________ $/ ________

Carry: ________ $/ ________

Process No. 2.4.02-04

Revision ______ Date 5/78

7. Process Cost Computation

7.11	Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.)	114.46 $/load
7.22	Other Indirect Costs: (0.59*(4.1) + .108(4.2)) ______ % of 7.11	2.37 $/load
7.21	Total Operating Add-on Costs of Process:	116.83 $/load
7.22	G & A ______ % of 7.21	$/
7.31	Total Gross Add-On Cost of Process	116.83 $/load
7.32	Credit for Salvaged Material (5.8)	$/
7.33	Cost of Work-in-Process Lost (5.3)	359.18 $/load
7.34	Specific Add-On Cost of Process (7.31 + 7.33)-(7.32)	476.01 $/load
7.35	Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4)	398.40 $/load
7.36	Loading on Item 7.35 at Rate ______ %	$/
7.37	Cost of Output Work-in-Process (7.34 + 7.35 + 7.36)	874.41 $/load

7.41	Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units)	0.947 m^2 / kg
7.42	Practical Yield	95 %
7.43	Effective Yield (7.41 x 7.42)	0.9 m^2 / kg
7.44	Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35	9.67 m^2 / load

7.51	Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44)	90.42 $/ m^2
7.52	Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44)	49.22 $/ m^2

Process No. 2 . 4 . 0 2 - 0 4

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8. Price Computation

8.1 Alternate 1

8.11 Profit at Expected Rate of 20 %: 9.85 \$/ m^2
(Profit before income taxes; applied to 7.52)

8.12 Price of Process (7.52 + 8.11) 59.06 \$/ m^2

8.13 Price of Work-in-Process (7.51 + 8.11) 100.28 \$/ m^2

8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274* 32.70 $/ load	from Subtotal 4.1 =	30.33 $/ load
1.946* 4.09 $/ load	from Subtotal 4.2 =	7.96 $/ load
	Subtotal =	38.29 $/ load

8.22 Costs of Amortization of the One-Time Cost:

0.192* 61.60 $/ load	from Subtotal 2.7 =	11.82 $/ load
0.192* 16.075 $/ load	from Subtotal 3.5 =	3.09 $/ load
0.2958* 32.70 $/ load	from Subtotal 4.1 =	9.67 $/ load
2.77* 4.09 $/ load	from Subtotal 4.2 =	11.34 $/ load
	Subtotal =	35.92 $/ load

8.23 Total Net Cost of Equity (8.21 + 8.22): 74.21 $/ load

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 9.67 m^2 / load from 7.44)

7.67 $/ m^2

8.25 Price of Process (7.52 + 8.24) 56.89 $/ m^2

8.26 Price of Work-in-Process (7.51 + 8.24) 98.10 $/ m^2

Process No. 2.4.02-04

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9. Process Economic Evaluation:

9.1 Process Cost Balance (7.52 - 0.1)	____ $/ ____
9.2 Relative Process Performance (9.1 ÷ 0.1)	____
9.3 Output Cost (7.51)	90.42 $/ m^2
9.4 Output Value (0.2 + 0.1)	____ $/ ____
9.5 Relative Excess Cost [(9.3 - 9.4) ÷ 9.4]	____

Process No. 2 . 4 . 02 - 04

Revision ____ Date 5/78

0. Output Specification:

Name of item: Silicon wafer, as cut

Dimensions: 12 cm in dia., 0.25 mm thickness

Material: High purity silicon

Other Specifications: Kerf thickness 0.2 mm

Process No. 2 . 4 . 0 2 – 0 6 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Sheet generation

Subprocess: Wafer generation

Option: Crystal Systems' Fixed Abrasive Multiwire Slicing

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Process No. 2 . 4 . 0 2 - 0 6

0.1 Value Added: ______ $/ ______

Process Description: Multiwire fixed abrasive slicing as projected by Crystal Systems

1. Input Specification:

Name of Item: Sectioned from a 30 x 30 x 30 cm boule, grown by heat exchange ingot-casting

Dimensions: Two 30 x 10 x 10 cm ingots, each weighing 7.02 kg

Material: Silicon crystal (high purity)

Other Specifications: Two blade carriages are used for each load

1.1 Quantity Required: 14.04 kg / load

Unit Cost: 27.75 $/ kg

1.2 Input Value:	______ $/ ______
1.3 Input Cost:	389.56 $/ load

Note to Item 1.3: Use price, if input produced in own plant.

Process No. 2 . 4 . 0 2 - 0 6

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.21 Type: Coolant water;

Specification: Filtered domestic water flowing at a rate of about 20 ℓ/h (SAMICS C1016B)

Quantity Required: 333 ℓ/load; Unit Cost: 0.113 $/1000 ℓ; Cost: 0.04 $/load

2.22 Type: Misc. materials: eg. slicer parts, etc.

Specification:

Quantity Required: ___/___; Unit Cost: 0.30 $/load; Cost: 0.30 $/load

2.2_ Type:

Specification:

Quantity Required: ___/___; Unit Cost: ___$/___; Cost: ___$/___

2.2 Subtotal Indirect Materials: 0.34 $/load

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2.3 Expendable Tooling:

2.3.1 Type: 2, 750 wire-blade package sets

Quantity Required: 0.2 sets/load: Unit Cost: 25 $/set Cost: 5 $/load

2.3_ Type: ____

Quantity Required: ____ ____/____: Unit Cost: ____$/____ Cost: ____$/____

2.3_ Type: ____

Quantity Required: ____ ____/____: Unit Cost: ____$/____ Cost: ____$/____

2.3_ Type: ____

Quantity Required: ____ ____/____: Unit Cost: ____$/____ Cost: ____$/____

2.3 Subtotal Expendable Tooling:	5 $/load

2.4 Energy

2.4.1 Type: 2 kW motors

Quantity Required: 33.3 kWh/load : Unit Cost: 0.0319$/kWh Cost: 1.06 $/load

2.4_ Type: ____

Quantity Required: ____ ____: Unit Cost: ____$/____ Cost: ____$/____

2.4 Subtotal Energy Costs:	1.06 $/load
2.5 Subtotal 2.1 to 2.4:	6.40 $/load
2.6 Handling Charge: 5.26% of item 2.5	0.34 $/load
2.7 Subtotal Materials and Supplies: (2.5 + 2.6)	6.74 $/load

Process No. 2 . 4 . 0 2 - 0 6

Form 6
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3.1 Direct Labor:

3.1_1 Category: Semiconductor Assembler (SAMICS B3096D) Activity: machine loading and unloading

Amount Required: 0.50 h/ load ; Rate: $ 3.90 /h; Load 36.0 %; Cost: 2.65 $/ load

3.1_2 Category: Semiconductor Assembler (SAMICS B3096D) Activity: Machine supervision

Amount Required: 1.1 h/ load ; Rate: $ 3.90 /h; Load 36.0 %; Cost: 5.83 $/ load

3.1_3 Category: Maintenance Mechanic II (SAMICS B3704D) Activity: Service and repair, cutting tool change

Amount Required: 1.0 h/ load ; Rate: $ 5.67 /h; Load 36.0 %; Cost: 7.71 $/ load

3.1 Direct Labor Subtotal: 16.19 $/ load

3.2 Indirect Labor: 25% of direct

3.2_ Category: ______ Activity: ______

Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2_ Category: ______ Activity: ______

Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2_ Category: ______ Activity: ______

Amount Required: ______ h/ ______ ; Rate: $ ______ /h; Load ______ %; Cost: ______ $/ ______

3.2 Indirect Labor Subtotal: 4.05 $/ load

3.3 Subtotal 3.1 and 3.2	20.24	$/ load
3.4 Overhead on Labor: 5.26 %	1.06	$/ load
3.5 Subtotal Labor	21.30	$/ load

Process No. 2 . 4 . 0 2 - 0 6

4.1 Equipment

4.1_1 Type: FAM slicing machine with two blade heads

Cost: 35,000 $; Installation Cost: ________ $; Throughput: 385 loads /y

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 85 %; Machine Oper'g Time 7038 h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: 1592.3 $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y; Capital Cost: 7472.50 $/y — 23.54 $/ load

4.1_ Type: ________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: ________ $/y

Useful Life: ________ y; Charge Rate: ________ % of Cost/y; Capital Cost: ________ $/y — ________ $/ ________

4.1_ Type: ________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: ________ $/y

Useful Life: ________ y; Charge Rate: ________ % of Cost/y; Capital Cost: ________ $/y — ________ $/ ________

4.1 Subtotal Equipment Cost:	23.54 $/ load

Process No. 2 . 4 . 02 - 06

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4.2 Facilities:

4.2 1 Type: Slicing machine area Floor Area: 7.43 m^2; Throughput: 385 loads /y

Charge Rate: 179.13* $/($m^2$·y);

Energy Use:

Heating		/y at	$/	
Air Cond'g		/y at	$/	
Lighting		/y at	$/	

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: 1330.94 $/y — 3.46 $/load

4.2_ Type: ____ Floor Area: ____ m^2; Throughput: ____ /y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

Heating		/y at	$/	
Air Cond'g		/y at	$/	
Lighting		/y at	$/	

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: ____ $/y — ____ $/____

4.2_ Type: ____ Floor Area: ____ m^2; Throughput: ____ /y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

Heating		/y at	$/	
Air Cond'g		/y at	$/	
Lighting		/y at	$/	

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: ____ $/y — ____ $/____

4.2 Subtotal Facilities: 3.46 $/load

4.3 Equipment and Facilities Subtotal: 27.00 $/load

* Includes energy use

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Process No. 2 . 4 . 0 2 – 0 6

5. Salvaged Material (Work-in-process)

5.1	Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit)	7.02 kg / load	
5.21	Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1)	7.02 kg / load	
5.22	Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ – ☐☐	____ ____/____	
5.23	Credit for 5.22 at the Market Value of ____$/____:	____$/____	
5.24	Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ____$/____:	7.02 kg $/ load	
5.25	Net Credit for 5.22 (5.23 minus 5.24):		____$/____
5.26	Material of Type 1. Lost in Process (5.21 minus 5.22)	____ ____/____	
5.3	Cost of Work-in-Process Lost (Amount 5.26 Times Unit Cost 1.1)		194.78 $/ load
5.4	Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.2 Times Unit Cost from 1.1)		194.78 $/ load

Salvaged Materials Summary:

5.8	Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76)	____$/____

Process No. 2 . 4 . 02 - 06

Revision ________ Date ________

6. Byproducts and Wastes

6.1 Solid Byproducts/Wastes

6.1_1 Type (Composition): Silicon-broken wafers Quantity Produced: 0 / load

Physical Shape/Size: ________ Energy Content: ________ kWh/________

Density: ________ g/cm^3, Water Solubility: ________ g/l at ________ °C: pH: ________

Toxicity: ________ Biodegradable: ________ Other Remarks: ________

Type of Disposal: ________

Input Material for: ________ Cost/(Credit) ________ $/________ ; Cost: ________ $/________

6.2 Liquid Byproducts/Wastes (inorganic):

6.2_1 Type (Composition): water and silicon kerf Quantity Produced: 333 ℓ/ load

Density: 1 g/cm^3; Suspended Solids: silicon Amount: 21.08 g/l pH: >7

Toxicity: ________ Heavy Metal Content: 21.08 g/l Other Remarks: ________

Possible to separate the silicon from water and recycle it.

Type of Disposal: Silicon filtered out and water recycled thru cooling tower

Input Material for: ________ Cost/(Credit) ________ $/________ Cost: ________ $/________

Carry: ________ $/________

Process No. 2 . 4 . 0 2 – 0 6

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7. Process Cost Computation

Item	Description	$	Unit
7.11	Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.)	55.04	$/load
7.22	Other Indirect Costs: (0.059*(4.1) + 0.108*4.2) ______ % of 7.11	1.76	$/
7.21	Total Operating Add-on Costs of Process:	56.80	$/load
7.22	G & A ______ % of 7.21		$/
7.31	Total Gross Add-On Cost of Process	56.80	$/load
7.32	Credit for Salvaged Material (5.8)		$/
7.33	Cost of Work-in-Process Lost (5.3)	194.78	$/load
7.34	Specific Add-On Cost of Process (7.31 + 7.33)-(7.32)	251.58	$/load
7.35	Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4)	194.78	$/load
7.36	Loading on Item 7.35 at Rate ______ %		$/
7.37	Cost of Output Work-in-Process (7.34 + 7.35 + 7.36)	446.36	$/load

Item	Description	Value
7.41	Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units)	1.06 m^2 / kg
7.42	Practical Yield	100 %
7.43	Effective Yield (7.41 x 7.42)	1.06 m^2 / kg
7.44	Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35	15 m^2 / load

Item	Description	$	Unit
7.51	Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44)	29.77	$/ m^2
7.52	Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44)	16.79	$/ m^2

Process No. 2 . 4 . 0 2 - 0 6

8. Price Computation

8.1 Alternate 1

8.11 Profit at Expected Rate of 20 %: 3.36 $/ m^2
(Profit before income taxes; applied to 7.52)

8.12 Price of Process (7.52 + 8.11) 20.15 $/ m^2

8.13 Price of Work-in-Process (7.51 + 8.11) 33.13 $/ m^2

8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274* 23.54 $/ load from Subtotal 4.1 = 21.83 $/ load

1.946* 3.46 $/ load from Subtotal 4.2 = 6.73 $/ load

Subtotal = 28.56 $/ load

8.22 Costs of Amortization of the One-Time Cost:

0.192* 6.74 $/ load from Subtotal 2.7 = 1.31 $/ load

0.192* 21.30 $/ load from Subtotal 3.5 = 4.08 $/ load

0.2958* 23.54 $/ load from Subtotal 4.1 = 6.96 $/ load

2.77* 3.46 $/ load from Subtotal 4.2 = 9.58 $/ load

Subtotal = 21.94 $/ load

8.23 Total Net Cost of Equity (8.21 + 8.22): 50.50 $/ load

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 15 m^2 / load from 7.44)

3.37 $/ load

8.25 Price of Process (7.52 + 8.24) 20.16 $/ m^2

8.26 Price of Work-in-Process (7.51 + 8.24) 33.14 $/ m^2

Process No. 2.4.02-06

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0. Output Specification:

Name of item: Wafer

Dimensions: 10 x 30 cm

Material: Solar grade silicon

Other Specifications: 200 μm thick, 3 μm deep fissures

Process No. 2 . 4 . 0 2 - 1 6 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Sheet generation

Subprocess: Ingot slicing

Option: Multiwire slicing

Yasunaga YQ-100 (Experimental 1978)

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Form 2

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Process No. 2 . 4 . 0 2 - 1 6

0.1 Value Added:	$/

Process Description: Multiwire slurry wafering

Data obtained from a JPL conducted demonstration run.

215 slices were made per load and 0.4 mm pitch guides were used

1. Input Specification:

Name of Item: Prepared machine load from 2.4:01:16

Dimensions: 7.6 cm-diameter, 8.8cm long, 0.94 kg/load

Material: High purity silicon

Other Specifications: Ingots are mounted on ceramic block.

1.1 Quantity Required: 1.061 kg / load Unit Cost: 155.98 $/ kg

1.2 Input Value:	$/
1.3 Input Cost:	165.50 $/ load

Note to Item 1.3: Use price, if input produced in own plant.

Process No. 2 . 4 . 0 2 - 1 6

Form 4

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2.1 Type: Abrasive;

Specification: 13 μm GC 1200 abrasive, concentration 1.5 kg/ℓ;

Is used twice. 5 kg needed per load or 2.5 kg consumed per load

Quantity Required: 2.5 kg / load; Unit Cost: 12.10 $/ kg ; Cost: 30.25 $/ 2 loads

2.2.2 Type: Lapping oil vehicle for abrasive

Specification: Is used for two loads;

3.25 ℓ used in each load and 1.625

ℓ consumed in each load

Quantity Required: 1.625 ℓ /load; Unit Cost: 1.25 $/ ℓ ; Cost: 2.031 $/ 2 loads

2.2._ Type: ______

Specification: ______

Quantity Required: ______ ___/___; Unit Cost: ______$/______; Cost: ______$/______

2.2 Subtotal Indirect Materials:	32.28 $/ load

Process No. 2 . 4 . 0 2 - 1 6

Form 5

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2.3 Expendable Tooling:

2.3 1 Type: Steel wire, 0.16 mm dia. Can be used three times

Quantity Required: 5667 m / load Unit Cost: 5.7×10^{-3} $/ m Cost: 32.30 $/ load

2.3 _ Type: ____

Quantity Required: ____ / ____ : Unit Cost: ____ $/ ____ Cost: ____ $/ ____

2.3 _ Type: ____

Quantity Required: ____ / ____ : Unit Cost: ____ $/ ____ Cost: ____ $/ ____

2.3 _ Type: ____

Quantity Required: ____ / ____ : Unit Cost: ____ $/ ____ Cost: ____ $/ ____

2.3 Subtotal Expendable Tooling: 32.30 $/ load

2.4 Energy

2.4 1 Type: Electrical, 0.6 kW total power for main and auxiliary motors

Quantity Required: 5.4 kWh/load : Unit Cost: 0.0319 $/ kWh Cost: 0.172 $/ load

2.4 _ Type: ____

Quantity Required: ____ ____ : Unit Cost: ____ $/ ____ Cost: ____ $/ ____

2.4 Subtotal Energy Costs: 0.172 $/ load

2.5 Subtotal 2.1 to 2.4: 64.75 $/load

2.6 Handling Charge: 5.26 % of item 2.5 3.40 $/load

2.7 Subtotal Materials and Supplies: (2.5 + 2.6) 68.15 $/load

Process No. 2 . 4 . 0 2 - 1 6

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3.1 Direct Labor:

3.11 Category: Semiconductor Assembler (SAMICS B3096D) Activity: Machine loading/unloading
Amount Required: 0.25 h/ load ; Rate: $ 3.89 /h; Load 36.0 %; Cost: 1.32 $/ load

3.12 Category: Semiconductor Assembler (SAMICS B3096D) Activity: machine supervision
Amount Required: 0.33 h/ load ; Rate: $ 3.89 /h; Load 36.0 %; Cost: 1.763 $/ load

3.13 Category: Maintenance Mechanic (SAMICS B3736D) Activity: wire changing/adjusting
Amount Required: 0.5 h/ load ; Rate: $ 5.67 /h; Load 36.0 %; Cost: 3.855 $/ load

3.1 Direct Labor Subtotal: 6.40 $/ load

3.2 Indirect Labor: 25% of direct

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____ ; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2 Indirect Labor Subtotal: 1.73 $/ load

3.3 Subtotal 3.1 and 3.2 8.13 $/ load

3.4 Overhead on Labor: 5.26 % 0.43 $/ load

3.5 Subtotal Labor 8.56 $/ load

Process No. 2 . 4 . 0 2 - 1 6

Form 7
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4.1 Equipment

4.1 1 Type: Yasunaga YQ-100 Slicing machine

Cost: 30,000 $; Installation Cost: n.a. $; Throughput: 745 loads /~~h~~;y

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 90 %; Machine Oper'g Time 7452 h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: n.a. $/y

Useful Life: 7 y; Charge Rate: 21.4 % of Cost/y; Capital Cost: 6420 $/y | 8.61 $/ load

4.1_ Type: ____

Cost: ____ $; Installation Cost: ____ $; Throughput: ____ /h;

Plant Oper'g Time ____ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ____ h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: ____ % of Cost/y; Capital Cost: ____ $/y | ____ $/ ____

4.1_ Type: ____

Cost: ____ $; Installation Cost: ____ $; Throughput: ____ /h;

Plant Oper'g Time ____ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ____ h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: ____ % of Cost/y; Capital Cost: ____ $/y | ____ $/ ____

4.1 Subtotal Equipment Cost:	8.61 $/ load

Process No. 2.4.02-16

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4.2 Facilities:

4.2_1 Type: Slicing machine area Floor Area: 4.0 m^2; Throughput: 745 loads /y

Charge Rate: 179.13* $/($m^2$·y);

Energy Use:

Heating ____ ____/y at ____$/____

Air Cond'g ____ ____/y at ____$/____

Lighting ____ ____/y at ____$/____

Maintenance Costs:

Labor: ____h/y at ____$/h

Supplies: ____$/y

Outside Services: ____$/y

Total Cost: 716.52 $/y | 0.96 $/ load

4.2_ Type: ____ Floor Area: ____ m^2; Throughput: ____ ____/y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

Heating ____ ____/y at ____$/____

Air Cond'g ____ ____/y at ____$/____

Lighting ____ ____/y at ____$/____

Maintenance Costs:

Labor: ____h/y at ____$/h

Supplies: ____$/y

Outside Services: ____$/y

Total Cost: ____$/y | ____$/____

4.2_ Type: ____ Floor Area: ____ m^2; Throughput: ____ ____/y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

Heating ____ ____/y at ____$/____

Air Cond'g ____ ____/y at ____$/____

Lighting ____ ____/y at ____$/____

Maintenance Costs:

Labor: ____h/y at ____$/h

Supplies: ____$/y

Outside Services: ____$/y

Total Cost: ____$/y | ____$/____

* Includes energy use

4.2 Subtotal Facilities: 0.96 $/ load

4.3 Equipment and Facilities Subtotal : 9.57 $/ load

Process No. 2 . 4 . 0 2 — 1 6

5. Salvaged Material (Work-in-process)

5.1	Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit)	0.479 kg / load	
5.21	Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1)	0.456 kg / load	
5.22	Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process □ . □ . □□ — □□	____ ____/____	
5.23	Credit for 5.22 at the Market Value of ____$/____:	____$/____	
5.24	Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ____$/____:	____$/____	
5.25	Net Credit for 5.22 (5.23 minus 5.24):		____$/____
5.26	Material of Type 1. Lost in Process (5.21 minus 5.22)	0.456 kg / load	
5.3	Cost of Work-in-Process Lost (Amount 5.26 Times Unit Cost 1.1)		71.13 $/load
5.4	Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.2 Times Unit Cost from 1.1)		74.72 $/load

Salvaged Materials Summary:

5.8	Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76)	____$/____

Process No. 2 . 4 . 0 2 – 1 6

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6. Byproducts and Wastes

6.1 Solid Byproducts/Wastes

6.1_ Type (Composition): ______ Quantity Produced: ____/____

Physical Shape/Size: ______ Energy Content: ____ kWh/____

Density: ____ g/cm^3; Water Solubility: 0 g/l at ____ °C; pH: ____

Toxicity: ____ Biodegradable: ____ Other Remarks: ____

Type of Disposal: ______

Input Material for: ______ Cost/(Credit) ____ $/____; Cost: ____ $/____

6.2 Liquid Byproducts/Wastes (inorganic):

6.2_1 Type (Composition): GC oil slurry Quantity Produced: 1.63 ℓ/ load

Density: ~0.95 g/cm^3; Suspended Solids: GC abrasive Amount: 1.5 kg/l pH: ____

Toxicity: ____ Heavy Metal Content: ____ mg/l Other Remarks: ____

Slurry also contains silicon kerf at a concentration of 0.48 kg/ℓ (790 g/load)

Type of Disposal: ______

Input Material for: ______ Cost/(Credit) ____ $/____ Cost: ____ $/____

Carry: ____ $/____

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Page 1 of 1

Process No. 2 . 4 . 0 2 – 1 6

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7. Process Cost Computation

7.11 Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.)	86.28 $/ load
7.22 Other Indirect Costs: (0.059*(4.1)+ .108*(4.2)) % of 7.11	0.61 $/ load
7.21 Total Operating Add-on Costs of Process:	86.89 $/ load
7.22 G & A ______% of 7.21	$/
7.31 Total Gross Add-On Cost of Process	86.89 $/ load
7.32 Credit for Salvaged Material (5.8)	$/
7.33 Cost of Work-in-Process Lost (5.3)	71.13 $/ load
7.34 Specific Add-On Cost of Process (7.31 + 7.33)-(7.32)	158.01 $/ load
7.35 Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4)	74.72 $/ load
7.36 Loading on Item 7.35 at Rate ______%	$/
7.37 Cost of Output Work-in-Process (7.34 + 7.35 + 7.36)	232.74 $/ load
7.41 Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units)	1.04 m^2 / kg
7.42 Practical Yield	100 %
7.43 Effective Yield (7.41 x 7.42)	0.936 kg/ load
7.44 Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35	0.975 m^2 / load
7.51 Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44)	238.69 $/ m^2
7.52 Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44)	163.07 $/ m^2

Process No. 2 . 4 . 0 2 - 1 6

Form 13-1
Page 1 of 1
Revision ____ Date 4/78

8. Price Computation

8.1 Alternate 1

8.11 Profit at Expected Rate of 20 %: 32.61 $/ m^2
(Profit before income taxes; applied to 7.52)

8.12 Price of Process (7.52 + 8.11) 195.68 $/ m^2

8.13 Price of Work-in-Process (7.51 + 8.11) 271.30 $/ m^2

8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274* 8.61 $/ load from Subtotal 4.1 = 7.98 $/ load

1.946* 0.96 $/ load from Subtotal 4.2 = 1.87 $/ load

Subtotal = 9.85 $/ load

8.22 Costs of Amortization of the One-Time Cost:

0.192* 68.15 $/ load from Subtotal 2.7 = 13.08 $/ load

0.192* 8.56 $/ load from Subtotal 3.5 = 1.64 $/ load

0.2958* 8.61 $/ load from Subtotal 4.1 = 2.55 $/ load

2.77* 0.96 $/ load from Subtotal 4.2 = 2.66 $/ load

Subtotal = 19.93 $/ load

8.23 Total Net Cost of Equity (8.21 + 8.22): 29.78 $/ load

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 0.975 m^2 / load from 7.44)

30.55 $/ load

8.25 Price of Process (7.52 + 8.24) 193.62 $/ m^2

8.26 Price of Work-in-Process (7.51 + 8.24) 269.24 $/ m^2

Process No. 2 . 4 . 0 2 – 1 6

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9. Process Economic Evaluation:

9.1	Process Cost Balance (7.52 - 0.1)	____ $/ ____
9.2	Relative Process Performance (9.1 ÷ 0.1)	____
9.3	Output Cost (7.51)	238.69 $/ m^2
9.4	Output Value (0.2 + 0.1)	____ $/ ____
9.5	Relative Excess Cost [(9.3 - 9.4) ÷ 9.4]	____

Process No. 2.4.02-16

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0. Output Specification:

Name of item: Silicon wafer, as cut

Dimensions: 7.6 cm in dia., 0.21 ∓ 0.01 mm thickness

Material: High purity silicon

Other Specifications: Kerf thickness, 0.2mm

Subsurface damage depth is approximately 15 μm

C-3

Process No. 2 . 4 . 0 2 - 1 6 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Sheet Generation

Subprocess: Ingot Slicing

Option: Multiwire Slicing - 1982 projection using the Yasunaga YQ-100 Slicing System

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Form 2

Revision ______ Date 4/78

Process No. 2 . 4 . 0 2 — 1 6

0.1 Value XXXXX:	128 $/ m^2

Process Description: Multiwire slurry wafering as performed by the Yasunaga slicing system data projected from using a 0.3 mm pitch roller, (333 slices per load).

1. Input Specification:

Name of Item: Prepared machine load from 2·4:01:0

Dimensions: 10-cm diameter, 10-cm long, 1.837 kg/load.

Material: 1 silicon crystal mounted on ceramic block

Other Specifications:

See 2·4:01:0

1.1 Quantity Required: 1.837 kg /load Unit Cost: 73.31 $/ kg

1.2 Input Value:	$/
1.3 Input Cost:	134.07 $/load

Note to Item 1.3: Use price, if input produced in own plant.

Process No. 2 . 4 . 02 – 16

Form 4

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2 1 Type: Abrasive slurry;

Specification: 5 μm SiC abrasive, concentration is not available

Estimated from materials cost given for slicing a 7.6 cm diameter ingot with the Yasunaga saw by JPL and using the relationship $C_2 = C_1\left(\frac{T_2}{T_1} \cdot \frac{A_1}{A_2}\right)$ (T = slicing time, A = water area).

Quantity Required: ______ ___/___; Unit Cost: ______ $/______; Cost: 107.55 $/load

2.2_ Type: ______

Specification: ______

Quantity Required: ______ ___/___; Unit Cost: ______ $/______; Cost: ______ $/______

2.2_ Type: ______

Specification: ______

Quantity Required: ______ ___/___; Unit Cost: ______ $/______; Cost: ______ $/______

2.2 Subtotal Indirect Materials:	107.55 $/load

Process No. 2.4.02-16

Form 5

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2.3 Expendable Tooling:

2.3 1 Type: Steel wire; 0.08 mm diameter.

Quantity Required: 12,000 m /load	Unit Cost: 0.004 $/m	Cost:	47.83 $/load
2.3 _ Type:			
Quantity Required: ____ /____	Unit Cost: ____ $/____	Cost:	____ $/____
2.3 _ Type:			
Quantity Required: ____ /____	Unit Cost: ____ $/____	Cost:	____ $/____
2.3 _ Type:			
Quantity Required: ____ /____	Unit Cost: ____ $/____	Cost:	____ $/____
2.3	Subtotal Expendable Tooling:		47.83 $/load

2.4 Energy

2.4 1 Type: Electrical, 0.6 kW total power for main and auxiliary motors

Quantity Required: 18 kWh / load	Unit Cost: 0.0319 $/kWh	Cost:	0.57 $/load
2.4 _ Type:			
Quantity Required:	Unit Cost: ____ $/____	Cost:	0.57 $/load
2.4	Subtotal Energy Costs:		0.57 $/load
2.5 Subtotal 2.1 to 2.4:			155.44 $/load
2.6 Handling Charge: 5.26 % of item 2.5			8.18 $/load
2.7 Subtotal Materials and Supplies: (2.5 + 2.6)			163.61 $/load

Process No. 2.4.02-16

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3.1 Direct Labor: (Estimated)

3.1 1 Category: Semiconductor Assembler (SAMICS B3096D) Activity: Machine loading/unloading
Amount Required: 0.25 h/load; Rate: $ 3.90 /h; Load 36.0 %; Cost: 1.32 $/load

3.1 2 Category: Semiconductor Assembler (SAMICS B3096D) Activity: machine supervision
Amount Required: 1.00 h/ load; Rate: $ 3.90 /h; Load 36.0 %; Cost: 5.30 $/load

3.1 3 Category: Maintenance Mechanic (SAMICS B3704D) Activity: ____
Amount Required: 0.5 h/ load; Rate: $ 5.67 /h; Load 36.0 %; Cost: 3.86 $/load

3.1 Direct Labor Subtotal: 10.48 $/load

3.2 Indirect Labor: 25% of direct

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2 Indirect Labor Subtotal: 2.62 $/load

3.3 Subtotal 3.1 and 3.2: 13.10 $/load

3.4 Overhead on Labor: 5.26 %: 0.69 $/load

3.5 Subtotal Labor: 13.79 $/load

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4.1 Equipment

4.1 1 Type: Yasunaga YQ-100 Slicing Machine

Cost: 30,000 $; Installation Cost: n.a. $; Throughput: 240 loads /~~h~~; y

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 90 %; Machine Oper'g Time 7452 h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: ____ $/y

Useful Life: 7 y; Charge Rate: 21.4 % of Cost/y; Capital Cost: .6420 $/y | 26.75 $/load

4.1_ Type: ____

Cost: ____ $; Installation Cost: ____ $; Throughput: ____ /h;

Plant Oper'g Time ____ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ____ h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: ____ % of Cost/y; Capital Cost: ____ $/y | ____ $/____

4.1_ Type: ____

Cost: ____ $; Installation Cost: ____ $; Throughput: ____ /h;

Plant Oper'g Time ____ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ____ h/y

Servicing Costs: Labor ____ h/y at ____ $/h; Parts or Outside Service: ____ $/y

Useful Life: ____ y; Charge Rate: ____ % of Cost/y; Capital Cost: ____ $/y | ____ $/____

4.1 Subtotal Equipment Cost: 26.75 $/load

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4.2 Facilities:

4.2.1 Type: Slicing machine area Floor Area: 4.0 m^2; Throughput: 240 loads /y

Charge Rate: 179.13* \$/(m^2·y);

Energy Use:

Heating ______ ______/y at ______\$/______

Air Cond'g ______ ______/y at ______\$/______

Lighting ______ ______/y at ______\$/______

Maintenance Costs:

Labor: ______h/y at ______\$/h

Supplies: ______\$/y

Outside Services: ______\$/y

Total Cost: 716.52 \$/y — 2.985 \$/ load

4.2.__ Type: ______ Floor Area: ______ m^2; Throughput: ______ ______/y

Charge Rate: ______ \$/(m^2·y);

Energy Use:

Heating ______ ______/y at ______\$/______

Air Cond'g ______ ______/y at ______\$/______

Lighting ______ ______/y at ______\$/______

Maintenance Costs:

Labor: ______h/y at ______\$/h

Supplies: ______\$/y

Outside Services: ______\$/y

Total Cost: ______\$/y — ______\$/______

4.2.__ Type: ______ Floor Area: ______ m^2; Throughput: ______ ______/y

Charge Rate: ______ \$/(m^2·y);

Energy Use:

Heating ______ ______/y at ______\$/______

Air Cond'g ______ ______/y at ______\$/______

Lighting ______ ______/y at ______\$/______

Maintenance Costs:

Labor: ______h/y at ______\$/h

Supplies: ______\$/y

Outside Services: ______\$/y

Total Cost: ______\$/y — ______\$/______

4.2 Subtotal Facilities:	2.985 \$/ load
4.3 Equipment and Facilities Subtotal :	29.735 \$/ load

*Includes energy use

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5.	Salvaged Material (Work-in-process)		
5.1	Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit)	1.227 kg / load	
5.21	Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1)	0.613 kg / load	
5.22	Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ – ☐☐	____ ____ / ____	
5.23	Credit for 5.22 at the Market Value of ____ $/ ____ :	____ $/ ____	
5.24	Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ____ $/ ____ :	____ $/ ____	
5.25	Net Credit for 5.22 (5.23 minus 5.24):		____ $/ ____
5.26	Material of Type 1. Lost in Process (5.21 minus 5.22)	0.613 kg / load	
5.3	Cost of Work-in-Process Lost (Amount 5.26 Times Unit Cost 1.1)		44.94 $/load
5.4	Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.2 Times Unit Cost from 1.1)		89.95 $/load
	Salvaged Materials Summary:		
5.8	Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76)		____ $/ ____

Process No. 2 . 4 . 02 - 16

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6. Byproducts and Wastes

6.1 Solid Byproducts/Wastes

6.11 Type (Composition): Silicon chips and dust Quantity Produced: 0 kg / load

Physical Shape/Size: ________ Energy Content: - kWh/ ____

Density: 2.34 g/cm^3; Water Solubility: 0 g/l at - °C; pH: -

Toxicity: ________ Biodegradable: no Other Remarks: ________

Type of Disposal: ________

Input Material for: ________ Cost/(Credit) ____ $/ ____; Cost: ____ $/ ____

6.2 Liquid Byproducts/Wastes (inorganic):

6.21 Type (Composition): Abrasive suspended in PC oil Quantity Produced: 5.4 ℓ / load

Density: ____ g/cm^3; Suspended Solids: abrasive and kerf Amount: ____ mg/l pH: ____

Toxicity: ________ Heavy Metal Content: ____ mg/l Other Remarks: ________

abrasive concentration is approximately 1.5 kg/ ℓ

Type of Disposal: ________

Input Material for: ________ Cost/(Credit) ____ $/ ____ Cost: ____ $/ ____

Carry: ____ $/ ____

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7. Process Cost Computation

7.11 Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.)	207.135	$/load
7.22 Other Indirect Costs: ______ % of 7.11 (0.059*4.1+0.108*4.2)	1.90	$/ load
7.21 Total Operating Add-on Costs of Process:	209.03	$/ load
7.22 G & A ______ % of 7.21		$/
7.31 Total Gross Add-On Cost of Process	209.03	$/ load
7.32 Credit for Salvaged Material (5.8)		$/
7.33 Cost of Work-in-Process Lost (5.3)	49.94	$/ load
7.34 Specific Add-On Cost of Process (7.31 + 7.33)-(7.32)	253.97	$/ load
7.35 Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4)	89.95	$/ load
7.36 Loading on Item 7.35 at Rate ______ %		$/
7.37 Cost of Output Work-in-Process (7.34 + 7.35 + 7.36)	343.92	$/ load

7.41 Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units)	1.42 m^2 / kg
7.42 Practical Yield	100 %
7.43 Effective Yield (7.41 x 7.42)	1.42 m^2 / kg
7.44 Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35	2.62 m^2 / load

7.51 Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44)	131.27	$/ m^2
7.52 Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44)	96.93	$/ m^2

Process No. 2.4.02-16

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8. Price Computation

8.1 Alternate 1

8.11 Profit at Expected Rate of 20 %: 19.39 $/$m^2$
(Profit before income taxes; applied to 7.52)

8.12 Price of Process (7.52 + 8.11) 116.32 $/$m^2$

8.13 Price of Work-in-Process (7.51 + 8.11) 150.66 $/$m^2$

Process No. 2.4.02-16

Form 13-2
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Revision 6/78 Date 4/78

8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274* 26.75	$/ load	from Subtotal 4.1 =	24.81	$/ load
1.946* 2.985	$/ load	from Subtotal 4.2 =	5.81	$/ load
		Subtotal =	30.62	$/ load

8.22 Costs of Amortization of the One-Time Cost:

0.192* 163.61	$/ load	from Subtotal 2.7 =	31.41	$/ load
0.192* 13.79	$/ load	from Subtotal 3.5 =	2.65	$/ load
0.2958* 26.75	$/ load	from Subtotal 4.1 =	7.91	$/ load
2.77* 2.985	$/ load	from Subtotal 4.2 =	8.27	$/ load
		Subtotal =	50.57	$/ load

8.23 Total Net Cost of Equity (8.21 + 8.22): 80.86 $/ load

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 2.62 m^2 / load from 7.44)

30.86 $/ m^2

8.25 Price of Process (7.52 + 8.24) 127.79 $/ m^2

8.26 Price of Work-in-Process (7.51 + 8.24) 162.13 $/ m^2

Process No. 2.4.02-16

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9. Process Economic Evaluation:

9.1 Process Cost Balance (7.52 - 0.1)	\$/
9.2 Relative Process Performance (9.1 - 0.1)	
9.3 Output Cost (7.51)	131.27 \$/ m^2
9.4 Output Value (0.2 + 0.1)	\$/
9.5 Relative Excess Cost [(9.3 - 9.4) ÷ 9.4]	

Process No. 2 . 4 . 0 2 - 1 6

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0. Output Specification:

Name of item: Silicon wafers, as-cut

Dimensions: 10 cm in dia., 0.2mm Thickness

Material: high purity silicon

Other Specifications: 0.1 mm kerf Thickness

333 wafers sliced per load

Process No. 2 . 4 . 0 2 – 1 7 Form 1

University of Pennsylvania

PROCESS CHARACTERIZATION

(UPPC)

Process: Sheet generation

Subprocess: Wafer generation

Option: Inner-diameter slicing of a rotating crystal as proposed by STC for 1982.

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Process No. 2 . 4 . 0 2 - 1 7

0.1 Value Added:	\$/

Process Description: Inner-diameter slicing of a rotating crystal as projected by STC for 1982.

1. Input Specification:

Name of Item: Single, crystal, grounded silicon ingot

Dimensions: 10-cm diameter, 100-cm long and mass is 18.378 kg

Material: High purity silicon

Other Specifications: Grounded ingot, see 2.4-01-01

1.1 Quantity Required: 18.378 kg / load Unit Cost: 71.75 \$/ kg

1.2 Input Value:	\$/
1.3 Input Cost:	1318.66 \$/load

Note to Item 1.3: Use price, if input produced in own plant.

Process No. 2 . 4 . 0 2 - 1 7

Form 4

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2.2 Indirect Materials (incl. supplies and non-energy utilities):

2.2.1 Type: Alumina dress stick, etc.;

Specification: ______

Quantity Required: ______ ___/___; Unit Cost: ______ $/______; Cost: n.a. $/ load

2.2_ Type: ______

Specification: ______

Quantity Required: ______ ___/___; Unit Cost: ______ $/______; Cost: ______ $/______

2.2_ Type: ______

Specification: ______

Quantity Required: ______ ___/___; Unit Cost: ______ $/______; Cost: ______ $/______

2.2 Subtotal Indirect Materials: 0 $/ load

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2.3 Expendable Tooling:

2.3 1 Type: STC-16 ID diamond-coated blade

____ Quantity Required: 0.5 blades/load Unit Cost: 50 $/blade Cost: ____ $/____

2.3 _ Type: ____

____ Quantity Required: ____ ____/____: Unit Cost: ____ $/____ Cost: ____ $/____

2.3 _ Type: ____

____ Quantity Required: ____ ____/____: Unit Cost: ____ $/____ Cost: ____ $/____

2.3 _ Type: ____

____ Quantity Required: ____ ____/____: Unit Cost: ____ $/____ Cost: ____ $/____

2.3	Subtotal Expendable Tooling:	25 $/load

2.4 Energy

2.4 1 Type: Power requirement is 2 kW

____ Quantity Required: 102 kWh/load ____: Unit Cost: 0.0319 $/kWh Cost: 3.25 $/load

2.4 _ Type: ____

____ Quantity Required: ____ ____: Unit Cost: ____ $/____ Cost: ____ $/____

2.4 Subtotal Energy Costs:	3.25 $/load
2.5 Subtotal 2.1 to 2.4:	28.25 $/load
2.6 Handling Charge: 5.26 % of item 2.5	1.49 $/load
2.7 Subtotal Materials and Supplies: (2.5 + 2.6)	29.74 $/load

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3.1 Direct Labor:

3.1 1 Category: Semiconductor assembler (SAMICS B3096D) Activity: Machine loading/unloading
Amount Required: 0.50 h/ h; Rate: $ 3.90 /h; Load 36 %; Cost: 2.65 $/ load

3.1 2 Category: Semiconductor assembler (SAMICS B3096D) Activity: machine supervision
Amount Required: 2.81 h/ h; Rate: $ ____ /h; Load 36 %; Cost: 14.90 $/ load

3.1 3 Category: Maintenance Mechanic (SAMICS B3736D) Activity: Cutting tool change
Amount Required: 0.5 h/ h; Rate: $ 5.67 /h; Load 36 %; Cost: 3.86 $/ load

3.1 Direct Labor Subtotal: 21.41 $/ load

3.2 Indirect Labor: Taken as 25% of direct

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2_ Category: ____ Activity: ____
Amount Required: ____ h/ ____; Rate: $ ____ /h; Load ____ %; Cost: ____ $/ ____

3.2 Indirect Labor Subtotal: 5.35 $/ load

3.3 Subtotal 3.1 and 3.2	26.76	$/ load
3.4 Overhead on Labor: 5.26 %	1.41	$/ load
3.5 Subtotal Labor	28.17	$/ load

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4.1 Equipment

4.1_1 Type: STC ID slicing machine with capacity to rotate ingot

Cost: 45,000 $; Installation Cost: ________ $; Throughput: 158 loads /h;y

Plant Oper'g Time 8280 h/y; Machine Avail'ty: 99 %; Machine Oper'g Time 8197.2 h/y

Servicing Costs: Labor 52 h/y at 8.12 $/h; Parts or Outside Service: 300 $/y

Useful Life: 7 y; Charge Rate: 21.35 % of Cost/y, Capital Cost: 10,329.74 $/y | 65.38 $/ load

4.1_ Type: ________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: ________ $/y

Useful Life: ________ y; Charge Rate: ________ % of Cost/y; Capital Cost: ________ $/y | ________ $/ ________

4.1_ Type: ________

Cost: ________ $; Installation Cost: ________ $; Throughput: ________ /h;

Plant Oper'g Time ________ h/y; Machine Avail'ty: ____ %; Machine Oper'g Time ________ h/y

Servicing Costs: Labor ________ h/y at ________ $/h; Parts or Outside Service: ________ $/y

Useful Life: ________ y; Charge Rate: ________ % of Cost/y; Capital Cost: ________ $/y | ________ $/ ________

4.1 Subtotal Equipment Cost: 65.38 $/ load

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4.2 Facilities:

4.21 Type: Slicing machine area Floor Area: 7.5 m^2; Throughput: 158 loads /y

Charge Rate: 179.13* $/($m^2$·y);

Energy Use:

Heating	____	____/y at	____	$/____
Air Cond'g	____	____/y at	____	$/____
Lighting	____	____/y at	____	$/____

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: 1343.48 $/y — 8.50 $/ load

4.2_ Type: ____ Floor Area: ____ m^2; Throughput: ____ /y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

Heating	____	____/y at	____	$/____
Air Cond'g	____	____/y at	____	$/____
Lighting	____	____/y at	____	$/____

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: ____ $/y — ____ $/____

4.2_ Type: ____ Floor Area: ____ m^2; Throughput: ____ /y

Charge Rate: ____ $/($m^2$·y);

Energy Use:

Heating	____	____/y at	____	$/____
Air Cond'g	____	____/y at	____	$/____
Lighting	____	____/y at	____	$/____

Maintenance Costs:

Labor: ____ h/y at ____ $/h

Supplies: ____ $/y

Outside Services: ____ $/y

Total Cost: ____ $/y — ____ $/____

*Includes energy use

4.2 Subtotal Facilities:	8.50 $/ load
4.3 Equipment and Facilities Subtotal :	73.87 $/ load

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5. Salvaged Material (Work-in-process)

5.1	Quantity of Work-in-Process 1. Contained in Good Output Work-in-Process (per Computation Unit)	9.030 kg / load	
5.21	Input Work-in-process 1. Not Contained in Good Output Work-in-Process ("Amount Required" from 1.1 minus 5.1)	9.347 kg / load	
5.22	Net Amount of 5.21 which is sold for Credit As-Is or After Applying Re-Process ☐ . ☐ . ☐☐ – ☐☐	____ ____ / ____	
5.23	Credit for 5.22 at the Market Value of ____ $/ ____ :	____ $/ ____	
5.24	Cost of Reprocessing Material of 5.22 at the Average Reprocessing Cost of ____ $/ ____ :	____ $/ ____	
5.25	Net Credit for 5.22 (5.23 minus 5.24):		____ $/ ____
5.26	Material of Type 1. Lost in Process (5.21 minus 5.22)	9.347 kg / load	
5.3	Cost of Work-in-Process Lost (Amount 5.26 Times Unit Cost 1.1)		670.66 $/load
5.4	Cost of Work-in-Process Contained in Good Output Work-in-Process (Amount 5.2 Times Unit Cost from 1.1)		647.92 $/load

Salvaged Materials Summary:

5.8	Total Net Credits for All Salvaged Materials (5.25 + 5.67 + 5.76)	____ $/ ____

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7. Process Cost Computation

7.11	Manufacturing Add-On Costs (sum of 2.7, 3.5, 4.3, 6.)	131.69 $/ load
7.22	Other Indirect Costs: (0.059*(4.1)+0.108*(4.2)) % of 7.11	4.62 $/ load
7.21	Total Operating Add-on Costs of Process:	136.31 $/ load
7.22	G & A ______ % of 7.21	$/
7.31	Total Gross Add-On Cost of Process	136.31 $/ load
7.32	Credit for Salvaged Material (5.8)	$/
7.33	Cost of Work-in-Process Lost (5.3)	670.66 $/ load
7.34	Specific Add-On Cost of Process (7.31 + 7.33)-(7.32)	806.97 $/ load
7.35	Cost of Input Work-in-Process Contained in Good Output Work-in-Process (5.4)	647.92 $/ load
7.36	Loading on Item 7.35 at Rate ______ %	$/
7.37	Cost of Output Work-in-Process (7.34 + 7.35 + 7.36)	1454.89 $/ load

7.41	Theoretical Yield (or Conversion Rate, if output units of work-in-process do not equal input units)	0.982 m^2 / kg
7.42	Practical Yield	95 %
7.43	Effective Yield (7.41 x 7.42)	0.933 m^2/ kg
7.44	Number of Units of Good Output Work-in-Process per Computation Unit Used up to 7.35	17.161 m^2 / load

7.51	Cost of Unit of Good Output Work-in-Process (7.37 ÷ 7.44)	84.77 $/ m^2
7.52	Specific Add-On Cost per Unit of Good Output Work-in-Process (7.34 ÷ 7.44)	47.02 $/ m^2

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8. Price Computation

8.1 Alternate 1

8.11 Profit at Expected Rate of 20 %: 9.40 $/ load
(Profit before income taxes; applied to 7.52)

8.12 Price of Process (7.52 + 8.11) 56.42 $/ m^2

8.13 Price of Work-in-Process (7.51 + 8.11) 94.17 $/ m^2

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8.2 Alternate 2 (SAMICS Methodology):

8.21 Profit Computation:

0.9274*	65.38 $/ load	from Subtotal 4.1	=	60.63	$/ load
1.946*	8.50 $/ load	from Subtotal 4.2	=	16.54	$/ load
		Subtotal	=	77.17	$/ load

8.22 Costs of Amortization of the One-Time Cost:

0.192*	29.74 $/ load	from Subtotal 2.7	=	5.71	$/ load
0.192*	28.17 $/ load	from Subtotal 3.5	=	5.40	$/ load
0.2958*	65.38 $/ load	from Subtotal 4.1	=	19.33	$/ load
2.77*	8.50 $/ load	from Subtotal 4.2	=	23.55	$/ load
		Subtotal	=	54.00	$/ load

8.23 Total Net Cost of Equity (8.21 + 8.22): 131.17 $/ load

8.24 Profit and Amortization of Start-up Costs per Unit of Good Output Work-in-Process:
(Divide Subtotal 8.23 by 17.161 m^2 / load from 7.44)

7.64 $/ m^2$

8.25 Price of Process (7.52 + 8.24) 54.66 $/ m^2$

8.26 Price of Work-in-Process (7.51 + 8.24) 92.41 $/ m^2$

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0. Output Specification:

Name of item: Silicon wafers as cut

Dimensions: 10-cm diameter, 225 μm thick, 210 μm kerf, 350 wafers/load

Material: High purity silicon

Other Specifications: