N82

FIELD EXPERIENCE WITH VARIOUS SLICING METHODS

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ABSTRACT

Slicing methods used are internal diameter (ID) saw, multi-blade slurry (MBS) saw and multi-wire slurry (MWS) saw. Slicing parameters inlfuencing final wafer cost are reviewed based on field experience and interaction between the parameters are discussed.

1.0 INTRODUCTION

Substrate preparation in sheet form is a first step in solar cell fabrication. Sheets for silicon solar cells are often prepared from ingots sliced by mechanical means. This slicing step results in loss of silicon (called kerf loss), and this loss adds considerably to the overall cost because already much expense has accrued in forming the ingots. A number of different techniques for slicing silicon have beer tried and some have been limited to production use. Methods tried include:

- Internal or outer diameter (I.D. or O.D.) wheel saw.
- Multiblade saw, using slurry, or diamond particles plated to the blade.
- Spark discharge with wires or blades.
- Pulsed laser discharge.
- Electro-chemical removal with current (etch-cutting)
- Ultra-high pressure (100,000 PSI) water jet.

Among these techniques, the I.D. saw is the most extensively used in industry and is a well developed method for preparing large area sheets from silicon ingots for solar cells. Typical shortcomings of other techniques include excessive taper, unpredictable work damage, low mechanical yield, and lack of machine productivity (mainly because of slow cutting rate). The objective of this paper is to identify slicing parameters influencing wafering cost of silicon ingots for solar sheet materials. Slicing method used were I.D. saw, multi-blade slurry saw (MBS) and multi-wire slurry saw (MWS) with an emphasis on I.D. saw

2.0 SLICING TESTS

Slicing conditions used for both I.D. and MBS saw were chosen based on field experience at ASEC, in such a way that reasonably high wafer yield (~90%) can be obtained reproducibly. MWS slicing was carried out at Yusunaga Engineering Co., LTD. and slicing conditions were chosen to provide reliable operation.

Slicing Conditions

MBS slicing tests were conducted using a Norton 686 wafering machine (same as Varian 686). A pre-assembled blade package from Varian was loaded in the blade head and aligned and tensioned. NOTE; Difficulty in alignment and tensioning, especially in tensioning, forced ASEC to stop using pin type blade packages which are cheaper than pre-assembled blade packages. Detailed slicing conditions are given in Table 1.

A MWS slicing test was performed at Yasunaga Engineering Co., Ltd., useing their YQ-100 wafering machine. Detailed slicing information is given in Table 2.

I.D. slicing was carried out using wafering machines from Silicon Technology Corporation; Model STC-16 for 3" ingots. Table 3 shows slicing conditions used in the test.

Comparison of Wafer Parameters

The parameters obtained from the wafers of three different slicing types, MBS saw, MWS saw, and I.D. saw, were compared for the evaluation of the mechanical quality of the sliced wafers. After the wafers were demounted, degreased and cleaned, thickness, bow and roughness (RMS) were measured. Their average values, standard deviations, and ranges were obtained. Thickness was measured at seven points on each slice using a dial gauge (Mitutoyo, Model DGS-E), one at the center and six at points 120 degrees apart, and an average of these seven points data represented a thickness of a single wafer. Bow is measured by supporting a wafer on three points 120 degrees apart in the periphery. The center position of the slice relative to the three points is defined as bow. Bow was measured by a Brown & Sharp bow gauge. Taper was determined by taking the difference between the maximum and minimum slice thickness measured. Surface roughness (RMS) was measured in parallel to the cutting direction, using a Metro-surf (Model 181, Airtronics, Illinois)

Comparison of the measured parameters for different slicing types is given in Figure 1. Thickness variation, from wafer to wafer and within a single wafer, of the MBS wafer were higher than those of the I.D. saw and MWS saw. Bow and roughness (RMS) also indicated that the MBS saw wafers showed about a factor of two higher values than those with the I.D. saw wafers. In general, comparison of the parameters indicated that the wafers sliced with the I.D. saw and MWS saw had much smaller values and variations, than those with the MBS saw. Wafers sliced by the I.D. saw (cut at or below 2 IPM of cut rate) showed slightly better mechanical quality than those with MWS saw.

Add-On Slicing Cost

Input data for SAMICS were obtained from the slicing experiments performed and the costs were estimated based on SAMICS Workbook (September, 1977). Cost assessment on wire saw slicing was obtained from the information supplied by the manufacturer who did a slicing test.

Add-on slicing cost of three slicing types is shown in Table 4. MBS saw suffered from direct material cost, in which the blade package and slurry (P.C. oil and abrasive) form a major portion of the cost. Direct material cost forms a major portion of MWS slicing, which comes from expensive wire and slurry. Analysis of I.D. saw shows relatively uniform distribution in cost between equipment, direct labor and direct material. High equipment cost is mainly due to low wafer productivity per dollars invested for I.D. saw.

3.0 SENSITIVE SLICING PARAMETERS INFLUENCING WAFER COST

Slicing experience showed that the most important factors controlling final wafer cost are silicon cost (wafer thickness + kerf loss), add-on slicing cost, and finally mechanical yield. Wafer cost can be written in simple expression:

$$W = \frac{M + S}{Y}$$

Where, W: Wafer Cost
M: Material Cost (Silicon)
S: Add-on Slicing Cost
Y: Yield
and, $M = f\ (T + K)$
T: Wafer Thickness
K: Kerf Loss

Most importantly, there is a very strong interaction between these parameters, i.e., an effort to reduce silicon cost by decreasing either wafer thickness or kerf loss, results in increase of add-on slicing cost and reduction in wafer yield.

Slicing parameters for both MBS and I.D. saw influencing these three parameters are given in Table 5 for material (silicon) cost, Table 6 for add-on slicing cost, and Table 7 for yield. The tables show that there is a very strong interaction between the parameters; i.e., an effort to reduce silicon cost by reducing either wafer thickness or kerf loss, results in increase of add-on slicing cost and reduction in wafer yield, suggesting a necessity of optimization between these parameters. This procedure is illustrated in Figure 2, in which silicon cost (M) and add-on slicing cost (S) are shown as a function of wafer thickness and kerf loss. Final wafer cost is an addition of M and S, and cross mark (X) indicates minimum wafer cost. NOTE: Yield is considered in the figure.

4.0 CONCLUSION

Wafer parameters such as bow, taper, and roughness which may not be important factors for solar cell fabrication, were considerably better for I.D. saw than those of the MBS and MWS saw.

Analysis of add-on slicing cost indicated that machine productivity seems to be a major limiting factor for I.D. saw, while expendible material costs are a major factor for both MBS and MWS saw.

Slicing experience indicated that the most important factors controlling final wafer cost are 1) silicon cost (wafer thickness + kerf loss), 2) add-on slicing cost,and 3) mechanical yield. There is a very strong interaction between these parameters, suggesting a necessity of optimization of these parameters.

ACKNOWLEDGEMENT

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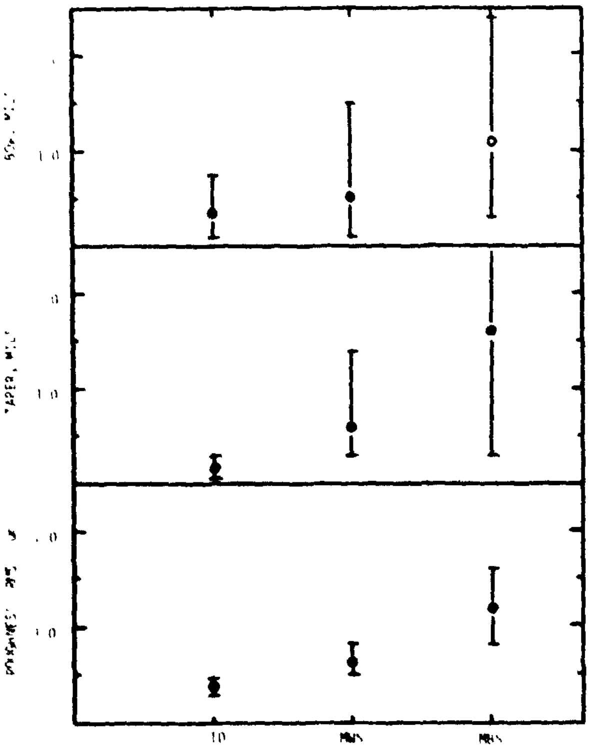

FIGURE 1

PARAMETERS OF WAFERS SLICED BY
THREE DIFFERENT SLICING METHODS

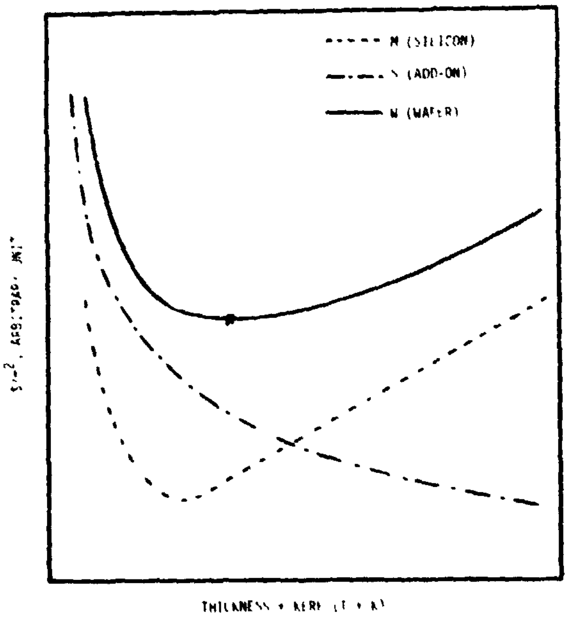

FIGURE 2

AN ILLUSTRATION OF FINDING AN
OPTIMUM WAFER COST

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TABLE 1

MBS SAW SLICING CONDITIONS

BLADE PACKAGE	
Number of Blades	230
Spacer Thickness, mm (mils)	0.457 (18)
Blade Thickness, mm (mils)	0.203 (8)
Blade Width, mm (inch)	6.35 (¼)
SLURRY	
Abrasive (400,SiC), Kg (lb)	5.4 (12)
Suspension Oil (P.C Oil), liter (gallon)	6.8 (1.8)
Mix, kg/liter (lb/gallon)	0.79 (6.7)
Load on Blade, gram/blade	100
Blade Speed, cm/sec.	57
Wear Ratio	---
PRODUCTIVITY (WAFER)	
cm^2/Machine/Hour	1,005
cm^2/Blade/Hour	4.33

TABLE 3

I.D.SAW SLICING CONDITIONS

BLADE		
I.D., cm (inch)	15.24 (6)	
O.D., cm (inch)	42.23(16-5/8)	
Core Thickness, mm (mils)	0.10 (4)	
Diamond Thickness, mm (mils)	0.28 0.30(11-12)	
Blade Rotation, R.P.M	2,100	
Blade Return Speed, cm/min (inch/min)	38.1(15)	
Blade Stroke, cm (inch)	8.13(3.2)	
Blade Dressing, After Number of Slices	50	
COOLANT		
Flow Rate, cc/min	120	
Mix Ratio, Water : Rust-Lick	80:1	
Cut Rate, Inch/Minute	1	2
Slicing Cycle, Minute/Wafer	3.4	1.8
Productivity(wafer), cm^2/Machine/Hr	800	1,510

TABLE 2

MWS SAW SLICING CONDITIONS

WIRE	
Roller Pitch, mm (mils)	0.47(18.5)
Diameter of Wire, mm (mils)	0.16(6.3)
Number of Wires Under Cutting	163
Mean Unit Weight, g/cm/wire	13
Total Wire Tension, kg	1.7
Breaking Point of Wire, Kg	5.7
Wire Feed Rate, m/min	8
Reciprocation of Wire, Cycle/min.	65
Wears of Wire, um	12
SLURRY	
Abrasive, GC #1000 (16um), Kg	5
Lapping Oil, P.C. Oil, Kg	3
Wafer Thickness, mm (mils)	0.27(10.6)
Kerf Width, mm (mils)	0.20(7.9)
Slicing Time Hours	8.35
Mechanical Yield, %	97
Yielded Wafer Area, m^2	0.72
Productivity, cm^2/machine/hour	840

TABLE 4

ANALYSIS OF ADD-ON SLICING COST (SAMICS, 1977 DOLLARS) OF THREE INCH CZ INGOT. (PARENTHESIS NUMBERS IN UNIT OF $/m²).

	MBS		MWS		I.D.	
	$/Wafer	%	$/Wafer	%	$/Wafer	%
EQUIPMENT	0.066	8.2	0.091	10.7	0.060	34.3
SPACE	0.029	3.6	0.028	3.3	0.030	17.1
DIRECT LABOR	.158	19.6	0.197	23.2	0.044	25.1
DIRECT MATERIALS	0.552	68.6	0.531	62.6	0.039	22.3
UTILITIES	0.001		0.001	0.2	0.002	1.2
TOTAL	0.806 (177)	100	0.848 (186)	100	0.175 (38)	100

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TABLE 5

SLICING PARAMETERS INFLUENCING WAFER THICKNESS AND KERF LOSS

	MBS SAW	I.D. SAW
WAFER THICKNESS	INGOT DIAMETER CUT RATE BLADE PACKAGE - Spacer Thickness - Number of Blades - Alignment and Tensioning SLURRY - Abrasive Size - Density of Abrasive in Suspension Oil	INGOT DIAMETER CUT RATE BLADE - Tensioning
KERF LOSS	BLADE PACKAGE - Spacer Thickness - Number of Blades - Alignment and Tensioning SLURRY - Abrasive Size - Density of Abrasive in Suspension Oil	BLADE - Thickness of Diamond Plated Edge Tensioning MACHINE Accuracy of Travel Between Blade and Ingot

TABLE 6

SLICING PARAMETERS INFLUENCING ADD-ON SLICING COST

	MBS SAW	I.D. SAW
EQUIPMENT	CUT RATE BLADE PACKAGE - Number of Blades	CUT RATE
DIRECT LABOR	BLADE PACKAGE - Alignment and Tensioning INGOT - Mounting and Demounting DEGREASE - Sliced Wafers OPERATOR ATTENTION	BLADE Tensioning - Dressing INGOT - Mounting & Demonting CLEANING - Sliced Wafers OPERATOR ATTENTION
DIRECT MATERIALS	BLADE PACKAGE SLURRY - Abrasive - Suspension Oil DEGREASER - SOLVENT INGOT MOUNT	BLADE INGOT MOUNT COOLANT

TABLE 7

SLICING PARAMETERS INFLUENCING MECHANICAL WAFER YIELD

MBS SAW	ID SAW
INGOT DIAMETER WAFER THICKNESS - Spacer Thickness CUT RATE - Travel Speed - Load on Blade BLADE PACKAGE - Thickness of Blade - Number of Blades - Alignment and tensioning INGOT MOUNTING WAFER DEMOUNTING - Handling (slippery) OPERATOR'S SKILL - Blade Alignment and Tensioning - Special attention of last moment of cutting	INGOT DIAMETER WAFER THICKNESS CUT RATE BLADE AND HEAD - Core Material - Diamond Plating Condition - Dressing - Blade History - Tensioning - Accuracy of Travel between blade and ingot - Relative vibration between blade edge and ingot (centering) INGOT MOUNTING OPERATOR'S SKILL - Blade Mounting (Alignment and Tensioning) - Blade Dressing

DISCUSSION:

WOLF: I'll make one comment at this point, to keep the multiblade and multiwire people from walking out. I have found that the best performance of a machine is usually obtained in a real production environment. Often the manufacturers of the equipment themselves don't get the best performance out of their equipment because they don't get the experience in running it. There's always an exception to these generalizations, but this is frequently the experience.

This seems to be a general thing. People take time learning with a particular piece of equipment, and find out how to use it right. They make modifications on equipment frequently, to make it easier to use, to get better yield and so on. It's often very difficult, therefore, to make exact comparisons between methods because we often don't find out exactly what the experience is of the people who really have it down pat and are running it day in and day out under all optimized conditions. So I think we have to, in these comparisons, be a little bit careful with how we use these numbers.