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FINAL REPORT

SOLAR CELL COVER GLASS DEVELOPMENT

A. R. Kirkpatrick, F. T. C. Bartels, G. A. Tripoli

Contract Number NAS5-10236

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland

Technical Monitor: Luther W. Slifer, Jr.

March, 1971

ION PHYSICS CORPORATION IPC

A Subsidiary of High Voltage Engineering Corporation

BURLINGTON, MASSACHUSETTS

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SECTION 1
SUMMARY AND RECOMMENDATIONS

The content of this report describes the successful development of a practical integral coverslip technology for solar cell utilization. The course of the program has been:

(1) Identification of design considerations associated with integral coverslip optimization.

(2) Development of procedures for deposition of high quality limited thickness fused silica integral covers.

(3) Identification of the stress mechanisms responsible for thickness limitations of fused silica covers.

(4) Examination of alternative candidate materials for thick covers.

(5) Fabrication and evaluation of thick integral coverslips of low stress materials.

Current status of IPC integral coverslipping capability using high vacuum ion beam sputtering technology can be summarized:

(1) All major technical obstacles to successful integral coverslip deposition have been overcome.

(2) Fused silica integral coatings exhibiting excellent physical and optical characteristics can be deposited with usable thickness limited to approximately 0.002 inch by inherent film stress.

(3) High quality integral coatings of radiation resistant borosilicate glass can be deposited to any required thickness; these covers exhibit low stress, excellent optical transmission, thermal and environmental stability and low susceptibility to ultraviolet or ionizing particle degradation.

(4) Present high vacuum ion beam sputtering techniques result in integral coatings which provide significant technological and potential economic advantages over equivalent conventionally applied coverglasses.

The integral covering process allows thickness tailoring for specific mission requirements, elimination of adhesives and UV rejection filters, total surface protection (including cell edges and contact areas) and capability for cell in-space anneal. The low stress integral coverslip can be effectively utilized in the design of extremely high power/weight panel configurations utilizing very thin cells and flexible substrates and has made feasible integral coverslipping of entire pre-assembled panels for total protection of all surfaces including interconnects.

At present, low volume integral coverglassing costs are comparible to those of conventional attached coverglassing. Study indicates that production volume costs will be reduced to as low as 10% of conventional glued coverglassing costs.

Further integral covering study is recommended in the following areas:

(1) Determination of reliability and radiation resistance improvement relative to conventional covers to be achieved because of edge protection and the absence of protective gaps.
(2) Development of post-assembly coverslipping procedures for entire panel segments.
(3) Investigation of coverslipping for very thin cells.
(4) Development of volume process facility and procedures with associated minimization of costs.

SECTION 2
PREVIOUSLY REPORTED PROGRESS

This integral cover development program has been active on a non-continuous basis since June 1966. Periodically issued Technical Progress Reports No. 1 through No. 6[1] have detailed development effort up to the end of 1968. The previously reported work has included study of optimum design parameters for the integral cover cell, investigation of several deposition techniques, examination of the stress in the initial successful fused silica integral covers and evaluation of environmental performance of cells with limited thickness fused silica covers. Development was, during this period, confined to use of fused silica as the cover material. All major problems related to successful application of integral covers to silicon solar cells were solved with the single important exception that no method was found to allow deposition of high quality fused silica coatings thicker than 2 mils.

IPC investigated the following methods for deposition of solar cell integral covers:

(1) high vacuum ion beam sputtering (HVIBS)
(2) electron beam evaporation
(3) DC reactive sputtering
(4) RF and RF + DC sputtering

High vacuum ion beam sputtering is a proprietary IPC process which utilizes a focused ion beam (usually argon) propagating through a high vacuum region to sputter from a target onto substrates located in a line-of-sight position relative to the target. The HVIBS facility put into operation during and used for most of this program utilizes a 20 kV 250 mA argon ion beam impacting upon a target area of roughly 40 in^2. Developmental cell substrate holders mounted in this facility are positioned such that only approximately 10% of sputtered target material is collected on a 500 cm^2 solar cell area which experiences a deposition rate of 12,000 Å/hr, that is, 1 mil in approximately 21 hours.

Following elimination of contamination of deposited films by sputtered material from the facility chamber stainless steel walls and development of adequate pre-deposition cell cleaning procedures, excellent SiO_2 film quality was obtained by the HVIBS process. Wide variation in the deposition process parameters had no appreciable effect on the high as-deposited stress level in the fused silica covers. Although cells with fused silica covers as thick as 8 mils were fabricated, usable cover thickness of fused silica was and has remained at approximately 2 mils.

Electron beam evaporation was investigated by IPC with the hope that higher deposition rates and lower stress could be obtained. While high deposition rates were easily obtained, stress in fused silica covers was found to be as high or higher than that resulting with HVIBS deposition. IPC was unable to establish adequate control over the evaporation process and the deposited fused silica was relatively soft, had low refractive index and contained a high density of optical scattering centers. The technique was dropped from further consideration.

DC reactive sputtering from a silicon cathode in an oxygen atmosphere was investigated at some length because of process simplicity and potentially high deposition rate. Actual SiO_2 deposition rates never exceeded 25,000 Å/hr and deposited films were of very poor physical quality. Continued lack of success in improving quality led to discontinuation of investigation of this process.

RF and RF plus DC sputtering were found to result in SiO_2 film quality approximately equivalent to that from the HVIBS process only when deposition rates did not exceed that of the HVIBS process. The films were also highly stressed. High quality coatings were not produced under high rate conditions. Results were not considered to be sufficiently promising to warrant further investigation.

Limitation of further IPC development of integral covers to the HVIBS process was based upon the results of the technical investigations. Of the processes considered prior to this decision, the HVIBS process requires the most sophisticated and expensive facility. However, it was determined that

a large machine designed for high volume utilization and fabricated at a cost of less than $75K could deposit integral covers for a small fraction of conventional glued cover costs.

Continued development of integral covering using fused silica and the HVIBS process resulted in fabrication of cells which exhibited no degradation under proton and ultraviolet irradiation, temperature-humidity storage, high vacuum storage and repeated thermal cycling. However, continued lack of success in reducing stress and increasing usable cover thickness resulted in the decision to expand the development program to include consideration of feasible integral cover materials other than fused silica. Investigation of other materials has been in progress since July 1969.

SECTION 3
RECENT PROGRESS

3.1 Materials Selection

Following the decision to consider materials other than fused silica for thick integral cover utilization, a review was made to identify feasible materials among the commercially available glasses. Choice of a protective material for the silicon solar cell is governed by a number of technical considerations. Many of these considerations are those which also dictate selection of the conventional glued coverglass and demand that the cover material must exhibit the following characteristics:

(1) Must transmit essentially all incident photon energy in the silicon solar cell response band between 0.4 and 1.2 microns. Due to a lack of adequate antireflective coating-materials with refractive index >2.4, this requires not only that the cover material be non-absorbing over the 0.4 to 1.2 micron band but also that its refractive index should be low, preferably below 1.5.

(2) Must be resistant to darkening as a result of exposure to ultraviolet and ionizing particle radiations.

(3) Must be highly emissive for wavelengths greater than 5 microns.

(4) Must be chemically and mechanically stable under ambient atmosphere and high vacuum storage and/or temperature cycling conditions.

These requirements are best satisfied by fused silica and are met, to varying lesser degrees, by alumina (sapphire) and a number of silicate glasses. The unsurpassed optical characteristics, physical stability and resistance to photon and ionizing particle induced transmission degradation of fused silica make it the best material for the conventional coverglass. Economic considerations have resulted in the selection of less expensive silicate glass covers of Corning 0211 Microsheet for certain mission applications.

Fused silica would be an optimum material for the integral cover but unfortunately, in addition to satisfying the requirements listed above, a material to be employed in an integral cover must possess two characteristics not necessary to the conventional cover:

(1) Must have thermal expansion coefficient reasonably similar to that of silicon (10 to 30 x 10^{-7} $°C^{-1}$) over a temperature range from well below room temperature to a few hundred degrees centigrade.

(2) Must be compatible with some integral glass deposition process which can be accomplished at temperature not exceeding the thermal limitation of the solar cell (~500 °C).

Fused silica is not compatible with requirements (1) and (2). IPC is able to deposit fused silica integral covers by high vacuum ion beam sputtering which exhibit excellent, even outstanding, physical and performance characteristics. But the fused silica is deposited in a highly stressed condition sufficient to result in significant cell fragility when coating thickness exceeds 2 mils and to result in certain cell failure at approximately 6 mils. All deposition techniques, high vacuum ion beam sputtering, RF sputtering, electron beam evaporation, for fused silica tried at IPC and elsewhere have resulted in very high deposited layer stress. Wide variation of process deposition parameters has resulted in no appreciable reduction of the stress severity.

Alumina has also been considered to be a potential integral cover material because of its excellent darkening resistance but is less acceptable than fused silica because of its high refractive index (n = 1.68). Deposited alumina integral coatings have been found to be accompanied by the same high stress incompatibility with thicker layer requirements that resulted with fused silica.

Preliminary experimental work demonstrated that among the commercially produced silicate glasses there exist many compositions which can be deposited by high vacuum ion beam sputtering in a low stress condition. Most serious disadvantage of many of these glasses for the solar cell cover is that

they are badly darkened by exposure to radiation environments equivalent to those experienced by solar cells under typical mission conditions. However, it is possible to select from among the glasses compositions exhibiting very good radiation resistance which are potentially also compatible with an integral deposition process.

Silicate glasses are produced by adding other metallic oxides to silica in order to modify its properties. Silica is an extremely refractory oxide, and at temperatures sufficiently high to permit fabrication by glass-working techniques, it is extremely corrosive. In order to make practical glasses, modifying oxides are chosen which reduce the melting temperature so that glass can be melted in oxide refractories. In ordinary soda-lime glass, oxides from Group I (Na_2O, K_2O) and Group II (CaO, MgO) are used. These glasses are unsuitable for coverslip applications because of their high thermal expansion, and because the presence of metallic ions (Na^+, K^+, Ca^{++}, Mg^{++}) in the glass results in the formation of "color centers" when the glass is exposed to intense UV and/or particle radiation. Silica can be considered as a semiconductor with a bandgap of $\sim$8 eV and a large density of states approximately 2 eV above the valence band. When glass containing metallic ions is irradiated with photons of at least 6 eV energy (0.2 micron), free electrons are produced which are then trapped by the positive metallic ion. The trapped electron can absorb energy in the visible region, leading to coloration of the glass.

There are a few metallic oxides which, when added to silica, do not produce color centers because the metal atoms do not exist as positive ions in the glass but instead substitute for silicon atoms in the SiO_2 network. Of these oxides, the most important is B_2O_3, leading to the family of borosilicate glasses. The Corning tradename for this family of glasses is "Pyrex". Pure binary B_2O_3/SiO_2 glasses are impractical as commercially melted glasses because the addition of B_2O_3 to SiO_2 does not substantially reduce melt viscosity, so a small amount of alkali oxides must also be added to improve melt characteristics. The best known Pyrex glass is 7740 ("chemical Pyrex"), used for chemical glassware. In addition to B_2O_3 and SiO_2, it contains 2.2% Al_2O_3 to improve

corrosion resistance, and 4.2% alkali oxides (Na_2O + K_2O) to improve melting characteristics.

Corning 7070 is a Pyrex glass originally developed for electrical insulators. The positive metal ions in glass contribute to electrical conductivity and dielectric loss, so the objective in formulating 7070 was to reduce the alkali content to the lowest level consistent with adequate meltability. 7070 contains only 0.5% alkali, 0.3% (CaO + MgO), and 1.2% Li_2O, which is not objectionable in a coverslip because the color centers produced by Li^+ absorb in the near UV.

Another useful group of glasses is the aluminosilicates, originally developed for high temperature applications. Alumina additions to silica raise the melt viscosity, annealing point, and elastic modulus of glass substantially. In order to retain an adequate level of meltability, large additions of alkali and alkaline earth oxides are necessary. Corning 1720, a typical glass of this group, contains 18.5% (Na_2O + CaO + MgO).

Corning Microsheet is a unique glass developed with the objective of attaining the largest possible working temperature range, so that the glass could be drawn into thin sheets directly from the melt. The composition of the glass is quite complex, including significant percentages of TiO_2 and ZnO, as well as a very high (Na_2O + K_2O) content (15%).

As resistance to radiation induced darkening is an essential characteristic of the solar cell cover material, glasses were selected for study which either exhibited excellent darkening resistance or moderate darkening resistance which could be expected to be improved by the addition of a small percentage of CeO_2 for color center modification. The potential use of CeO_2 doping of solar cell covers has been reported elsewhere.[2] Glass compositions selected for study were required to have thermal expansion coefficient comparable to that of silicon and preferably were to be stress annealable at temperatures not greatly

above 500 °C. Three materials investigated and their relative characteristics are given in Table 1.

Corning code 7070 borosilicate glass was considered to be the best potential integral cover material available; 7740 was selected for its good expansion coefficient match to that of silicon, its negligible cost and its potential for improved radiation resistance through introduction of CeO_2 into the sputtered coating; 0211 Microsheet was investigated because of its known performance characteristics as a conventional cover material and known darkening improvement through addition of CeO_2. Although the radiation induced darkening characteristics of 7740 and 0211 are only marginally acceptable, their physical properties and the possibilities for CeO_2 doping made these materials possible choices for the integral cover. Compositions of the three glasses are tabulated in Table 1.

In addition to the three silicate glasses, a silicon 'oxynitride' composition was included for study. The stress in pure SiO_2 sputtered layers on silicon is compressive while similarly deposited Si_3N_4 coatings are found to be under high tensile stress. It has been reported [3] that a portion of the oxygen of SiO_2 can be replaced by divalent nitrogen to result in an inorganic polymer silicon 'oxynitride' structure with as-deposited stress determined by the fractional oxygen content replaced by nitrogen. An unstressed composition is expected for a correctly selected component ratio. A single attempt to deposit this composition as an integral cover coating was made as part of this program.

3.2 Electron Irradiation of Cover Materials

Silicate glasses are more susceptible to optical degradation as a result of exposure to ionizing particle radiation than is fused silica. The glass composition selected for the integral cover must exhibit a high degree of

Table 1. Material Parameters

Material	Thermal Expansion Coefficient ($^{\circ}C^{-1}$)	Annealing Point ($^{\circ}C$)	Relative Radiation Resistance	Constituents (weight percent)	
7070	32×10^{-7}	495	good	SiO_2	70.0
				B_2O_3	28.0
				Li_2O	1.2
				Al_2O_3	1.1
				K_2O	0.5
				MgO	0.2
				CaO	0.1
7740	33×10^{-7}	565	fair	SiO_2	80.5
				B_2O_3	12.9
				Na_2O	3.8
				Al_2O_3	2.2
				K_2O	0.4
0211	72×10^{-7}	539	fair	SiO_2	65.5
				B_2O_3	10.0
				Na_2O	7.1
				K_2O	7.1
				ZnO	5.1
				TiO_2	2.7
				Al_2O_3	2.3
Silicon	$10\text{-}30 \times 10^{-7}$				

resistance to darkening under exposure to the space environment in which the solar cell is to operate. Technical goal for the integral coverglass is that performance loss of the integral coverslip cell under typical mission radiation exposures will not exceed that to be experienced by cells having equivalent thickness conventionally applied fused silica coverglasses. Degradation of the integral coverslip is limited to darkening of the coverslip material while the glued coverglass is vulnerable to darkening of the required adhesive and the ultraviolet rejection filter necessary to minimize adhesive degradation.

In order to evaluate darkening under electron irradiation of the three selected silicate glasses, 0.006" unfiltered slides of 7070, 7740 and 0211 glasses, 7940 fused silica and 1723 aluminosilicate glass were subjected to 1 MeV electron fluences of 2.5×10^{14} and then 5×10^{15} electrons/cm^2. Transmission spectra of these materials after irradiation are shown in Figures 1 and 2. It is evident that serious darkening occurred in the 0211, 7740 and 1723 glasses while much smaller losses resulted in 7070 glass and the 7940 fused silica remained virtually unchanged. The relative degradations observed are consistent with anticipated results which can be crudely predicted on the basis that the greater the alkali oxide content of the glass, the greater the darkening to be expected. Type 7070 glass is the least susceptible to darkening of all practical candidate silicate glasses for thick integral cover use.

Based upon the results of electron irradiation of glass slide samples it was concluded that type 7070 glass represented an optimum choice as a material exhibiting excellent radiation resistance and potential ability to be deposited in thick low stress integral layers. In order to confirm that material deposited by the HVIBS process would retain the excellent darkening resistance of the bulk material, a sample with 3 mils of HVIBS 7070 integral cover deposited onto a 12 mil fused silica slide was irradiated to 5×10^{15} e/cm^2 fluence of 1 MeV electrons. The post-irradiation transmission spectrum of this sample is in Figure 3 compared to that of a similarly irradiated bare 12 mil fused silica slide. Wide band transmission loss due to the 7070 HVIBS layer over the 400 - 1100 nm band usually associated with response of the silicon solar cell is seen to be less than 2% at 5×10^{15} e/cm^2 fluence.

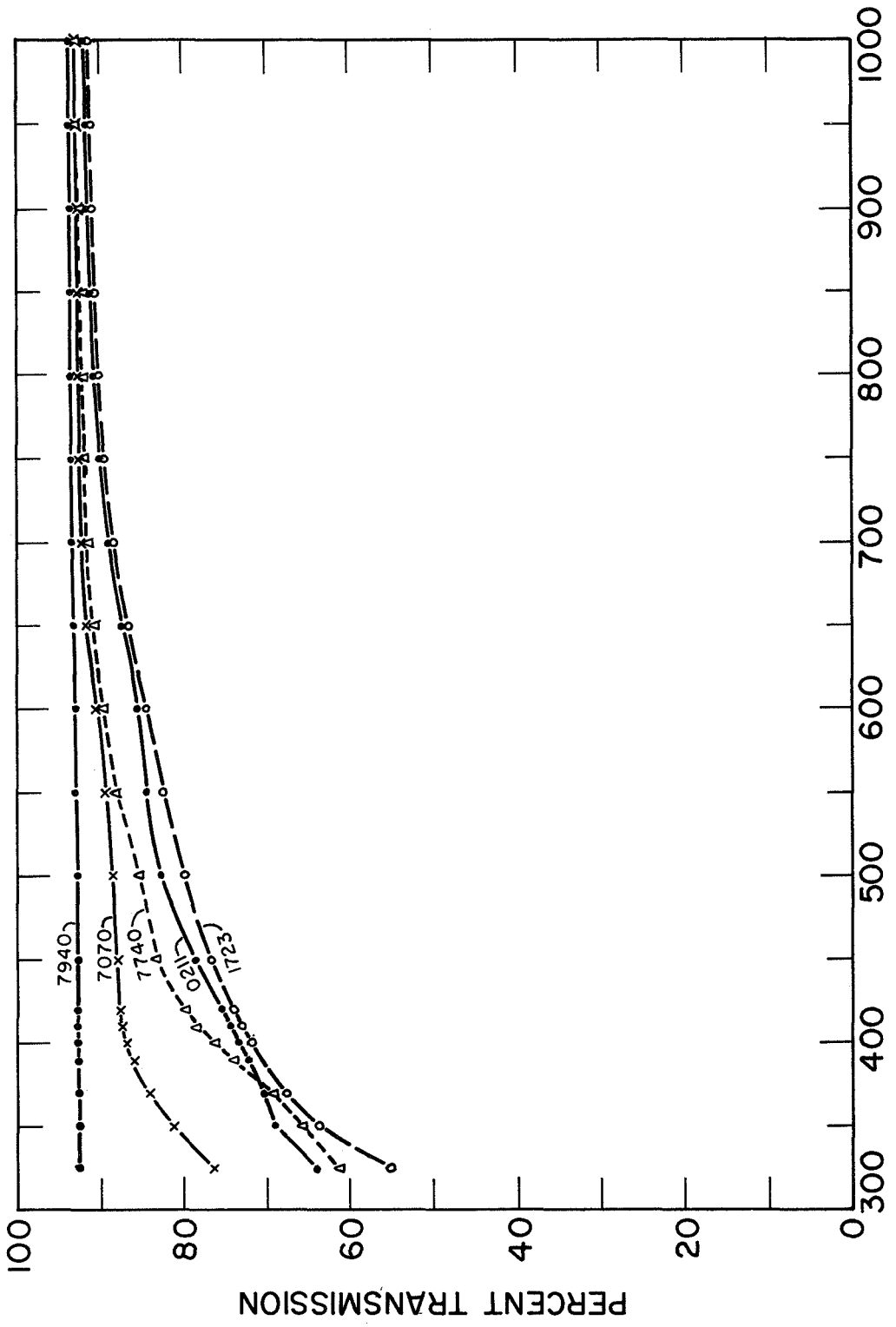

Figure 1. Transmission of 0.006" Slides After 2.5×10^{14} 1 MeV Electrons.

1-6128

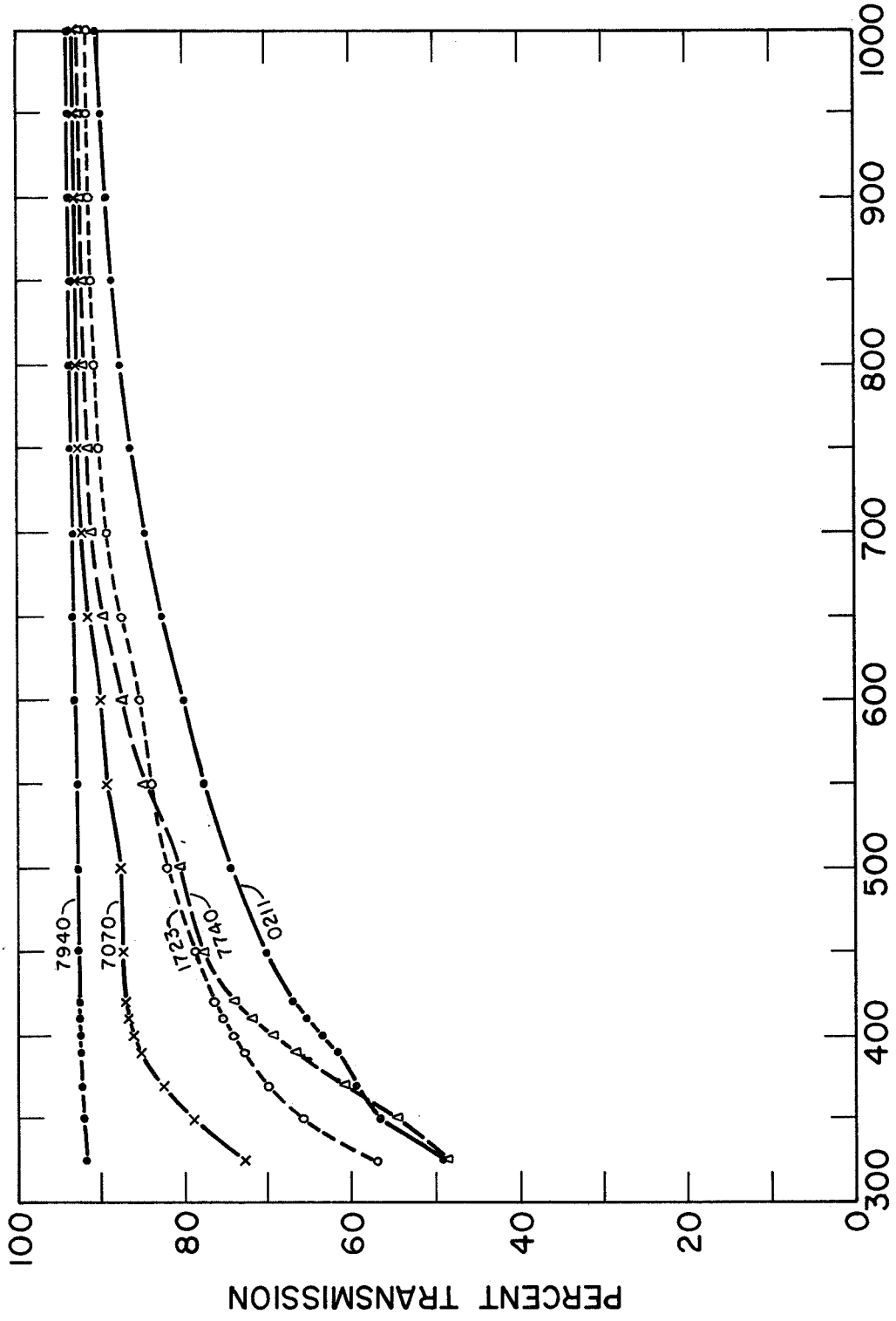

Figure 2. Transmission of 0.006" Slides After 5 x 10^{15} 1 MeV Electrons.

1-6129

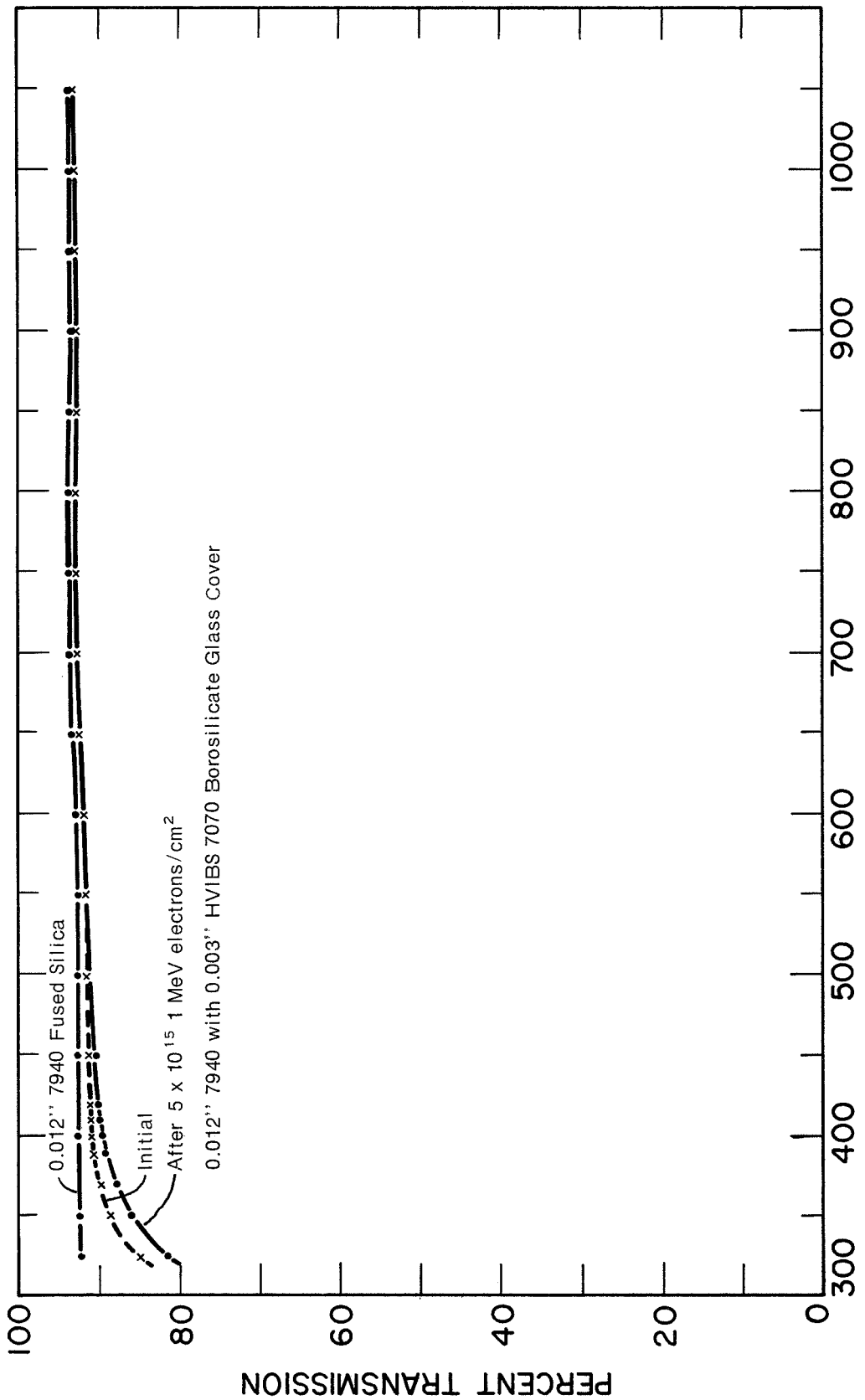

Figure 3. Transmission of HVIBS 7070 Integral Cover.

1-6130

3.3 The Stress Problem

Excessive stress in the deposited coating has been the most difficult obstacle to integral coverslip development. Reduction of the stress included in the HVIBS integral coverslip to acceptably low level has been accomplished through careful control of process parameters and utilization of the selected silicate glass compositions compatible with the deposition process. Examination of developmental data accumulated throughout this program has suggested that coverslip stress can be attributed to at least three distinct component mechanisms. In the order in which they occur during coating deposition and subsequent cell exposure to ambient environment, these components are:

(1) as-deposited stress due to molecular impact
(2) thermal stress due to expansion coefficient mismatch
(3) environmentally-induced stress due to interaction of water vapor with coating porosity.

Relative importance and degree of these three stress contributions are dependent upon parameters of the deposition process employed and the characteristics of the coverslip material composition.

As-deposited stress associated with molecular impact is anticipated to be directly dependent upon the energy of the molecular or atomic material as it impacts upon the growing coating surface. All attempted integral deposition processes involve energetic particle collision at the growth surface and penetration of the surface by these deposited particles. As suggested by the representation of Figure 4, penetrating molecules expand the lattice structure below the immediate surface to generate a compressive coating stress. As high vacuum ion beam sputtering results in higher particle energy than does RF sputtering or electron beam evaporation, this stress component is probably highest with the HVIBS process. However, this component is also found to be of relatively minor importance and is compensated by the fact that greater penetration produces increased bond strength.

Integral coverslipping procedures involve at least moderately elevated cell temperatures during coating deposition. Completed cells are required to be

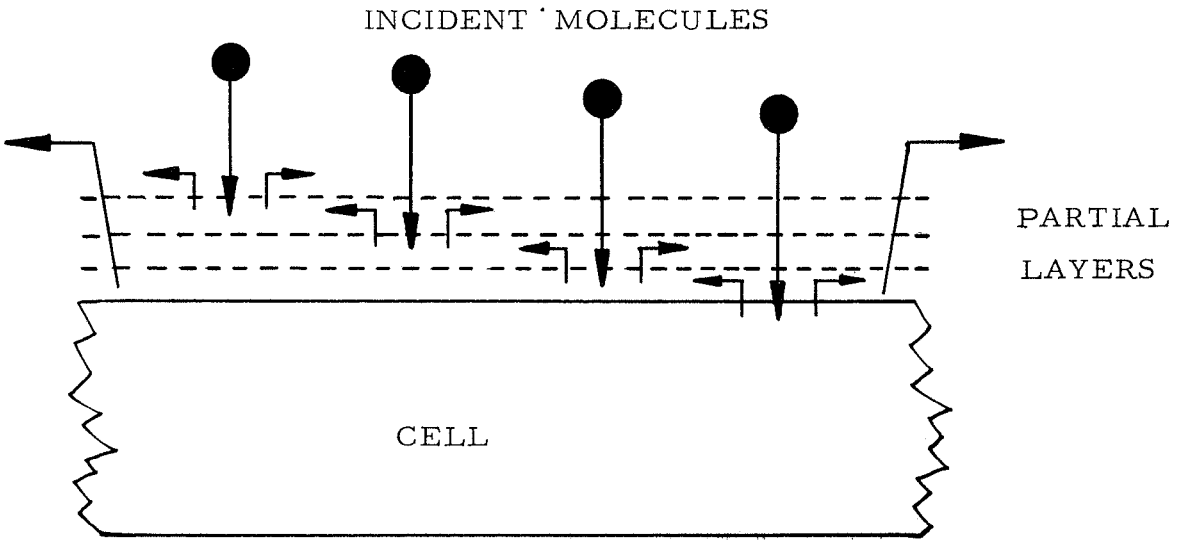

Figure 4. Formation of Molecular Impact Stress.

stable through exposure to wide temperature excursions. Mismatch of thermal expansion coefficient of the coverslip material with that of silicon will, at temperatures other than that of deposition, result in significant resultant stress. If the expansion coefficient of the coverslip is less than that of silicon ($\sim 30 \times 10^{-7}$ $^{\circ}C^{-1}$) as is the case with fused silica ($\sim 5 \times 10^{-7}$ $^{\circ}C^{-1}$), the room temperature stress component in the coverslip will be compressive. Correct coefficient match as in the cases of 7070 and 7740 glasses will result in no net thermal stress, and a high coverslip coefficient such as the 72×10^{-7} $^{\circ}C^{-1}$ value of 0211 will produce a room temperature tensile stress in the coating. This tensile stress, when it exists, will subtract from the as-deposited molecular impact stress for a net stress reduction.

Although the molecular impact phenomena is responsible for what might be considered microscopic overdensification, the deposited material carries with it high kinetic energy which upon impact is transformed into thermal energy which can be responsible for coating porosity. Other causes of porosity are gas occlusion in sputtering processes, and the ejection of droplets of glass from the melt due to gas evolution during thermal evaporation. The result is a deposited film with a density lower than the bulk value, containing microscopic voids. It is also common for the deposited film to be somewhat oxygen deficient. This is avoided in the HVIBS process by maintaining a controlled oxygen pressure in the deposition chamber; this approach is not as compatible with other deposition processes. Oxygen-deficient silica will react chemically with water vapor, and the incorporation of hydroxyl groups into the silica lattice will cause it to expand. Upon introduction of the completed coverslip cell to ambient environment, water vapor is absorbed into voids of the porous structure to create compressive coating stress. The HVIBS process is conducted at a low deposition rate which minimizes porosity. As this water vapor/porosity problem is apparently the dominant stress factor and is accented by temperature-humidity environmental conditions, the HVIBS integral coverslip which is least susceptible to it has exhibited superior environmental stability.

Fused silica is highly susceptible to all three stress components and for this reason has been limited to 2 mil practical integral coverslip thickness.

Borosilicate 7070 and 7740 glasses have good expansion coefficient match to that of silicon and, at least under HVIBS deposition, are found to exhibit little tendency to experience porosity problems. Type 0211 glass also exhibits resistance to porous deposition and because of its higher than silicon expansion coefficient and associated reduction of net room temperature stress has been found to be deposited in exceptionally low stress conditions. Net coverslip stress is most easily characterized by measurement of cell bow (2 x 2 cm cell center deflection above a plane surface). Shown in Figure 5 are experimental cell curvature data from 7940, 7740, 7070 and 0211 depositions. The borosilicate glass stresses are considered to be further reducible from indicated values by thermal annealing. However even in the absence of annealing the stress levels of these glasses are seen to be greatly reduced from the 7940 fused silica levels.

3.4 Experimental Cover Depositions

During the final year of this program, integral covers of the following materials were investigated:

Material	Deposited Stress	Integral Coating Physical Quality	Integral Coating Optical Quality
7940 fused silica	high	excellent	excellent
SiO_2/Si_3N_4	very high	poor	poor
7740	moderate	excellent	excellent
7740 + CeO_2 doping	low	excellent	good
0211 + CeO_2 doping	very low	excellent	good
7070	low	initially fair/ improved to excellent	excellent

An HVIBS integral coating of excellent physical quality is expected to be uniformly transparent and must not exhibit any evidence of delamination, flecks, voids, etc. Experience has shown that most glasses are normally

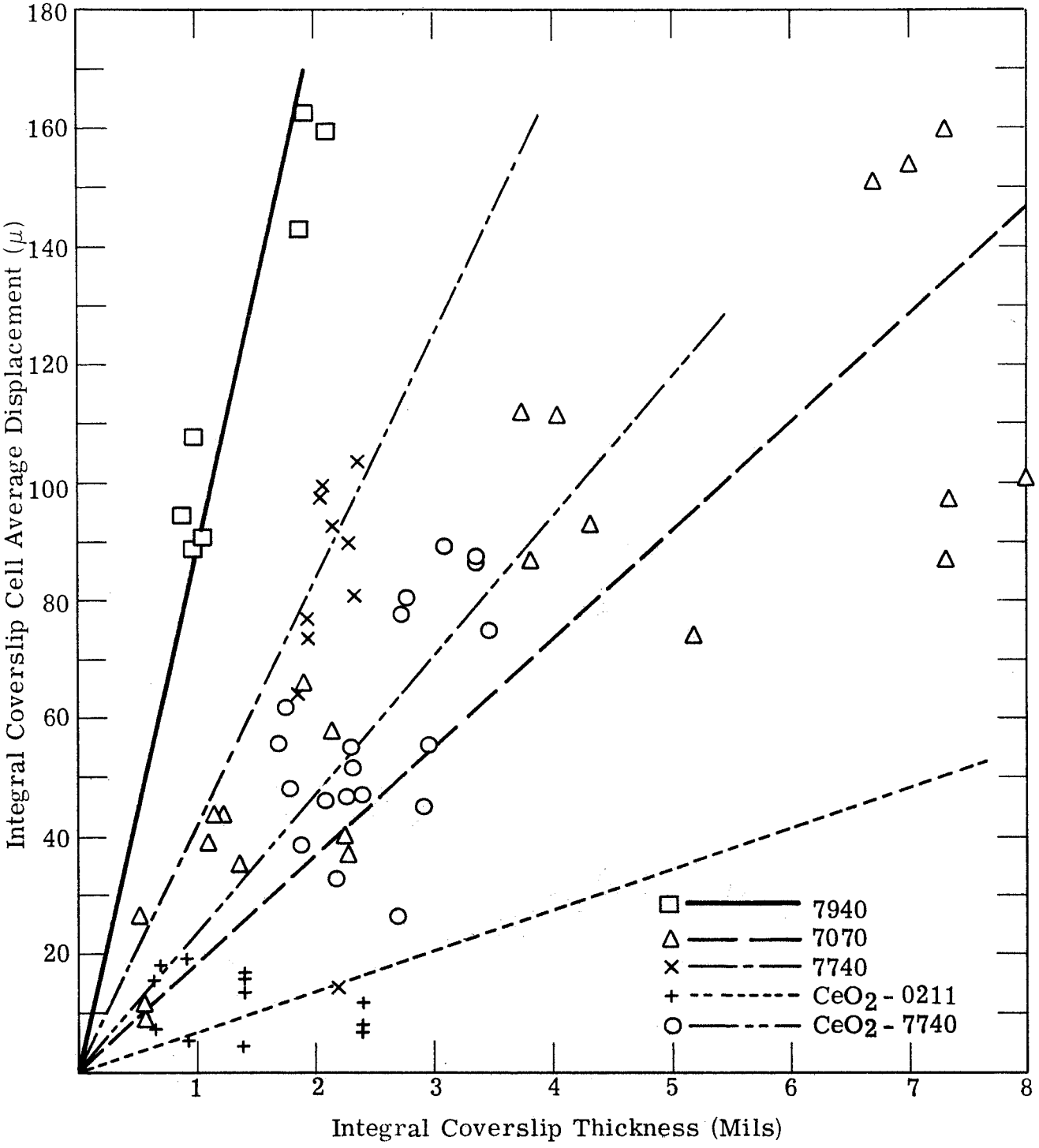

Figure 5. Integral Coverslip Cell Bow versus Integral Coverslip Thickness

deposited with excellent physical appearance. However, the SiO_2/Si_3N_4 'oxynitride' and initial 7070 coatings were exceptions. The extreme stress levels in the SiO_2/Si_3N_4 resulted in incidence of cover delamination from small cells. The early 7070 covers, although they were transparent, colorless and stable under environmental testing, were characterized by serious cosmetic deficiencies in the form of flecked, irregular surfaces. Improvement in control of the HVIBS process was found to eliminate the cosmetic faults of the integral 7070 covers.

Materials deposited by the high vacuum ion beam sputtering process are found to have optical characteristics almost identical to those of the bulk sputtering target material. In the case of a colorless glass these can be considered excellent. The SiO_2/Si_3N_4 and CeO_2 doped glasses were sputtered simultaneously from two target materials in the sputtering ion beam. In the case of the SiO_2/Si_3N_4 oxynitride material, the target was 7940 fused silica with a small additional piece of Si_3N_4 laying on the fused silica. The resulting deposited integral coating, although only 2 mils thick, was brown in color and exhibited strong optical absorption. The CeO_2 doping of 7740 and 0211 glasses was for the purpose of improving the radiation darkening resistance of these materials and was also introduced into the sputtered integral coatings by overlaying the respective glass targets with small pieces of CeO_2 during sputtering. The deposited glass materials were estimated to be approximately 5 to 15% CeO_2 by weight and as expected from known results,[2] had slight but noticeably yellow appearance. The minor optical attenuation resulting from the presence of the CeO_2 is a penalty which must be accepted in order to realize the radiation resistance improvement attributed to the CeO_2. Concentrations under 5% should be adequate.

Prior to selection of 7070 glass as the best material for use in very thick integral covers, evaluation samples of the integral cover materials were deposited in thickness 2 to 4 mils. Thickness of 7940 fused silica covers was purposely limited to 2 mils because of previous unsuccessful experience with thicker coatings. Stress in the SiO_2/Si_3N_4 'oxynitride' material was found to be even greater than that in fused silica such that a 2 mil deposited thickness of this material was sufficient to cause fracture of many cells. Stress levels

in the 7740 and 0211 materials were sufficiently low to allow very thick coatings to be deposited if desired, but covers of thickness 2 to 4 mils were adequate for evaluation purposes. Initial depositions of 7070 glass were of 2 and 4 mils in thickness. Preliminary evaluation of the low deposited stress condition, excellent darkening resistance and stability under environmental conditions of the 7070 material indicated it to have the greatest potential for high quality thick integral covers and further development was devoted exclusively to the 7070.

Integral 7070 covers of thickness to beyond 10 mils were deposited. No obstacle to achieving greater thickness was observed. No cell losses were experienced even with the thickest coatings. In these initial depositions, the thicker coatings also had rough, fleck covered surfaces which were observed to be the result of local overheating of the 7070 sputtering target leading to boiling type ejection of small globules of glass. The local overheating was due to 'hot spots' in the large area ion beam created by the design of the ion source. However, the flecking was a cosmetic problem only which was found to have no appreciable effect on performance of the covered cells. The evaluation testing data on 7070 covers given in Section 4.2 were obtained on cells with the rough covers.

Following conclusive demonstration that 7070 integral covers of any required thickness could be deposited, effort was made to eliminate the cosmetic flecking problem. Reduction of sputtering beam current from 250 mA to approximately 125 mA was observed to eliminate the problem but of course was accompanied by a 50% reduction in cover deposition rate. A subsequent modification to the focusing aperture of the ion source resulted in a more uniform ion beam at the sputtering target and eliminated flecking while allowing the higher beam current level to be maintained. The cosmetic problem of the 7070 material is considered to have been solved and covers now exhibit excellent physical quality.

Tabulated in Table 2 are pre- and post-covering electrical data from groups of cells integrally covered with materials under consideration. Cells with optimized CeO_2 antireflective coatings generally exhibit a small, slightly less than ideal,[4] increase in output current following application of an undoped integral cover. Cells with SiO_x antireflective coatings experience a current loss

Table 2. Test Data Summary — Influence of Integral Cover Deposition on Cell Electrical Performance.

AR Coating	Cover Material	No. of Cells in Test	Mean Cover Thickness (mils)	Mean Initial Performance			Change After Covering		
				I_{sc} (mA)	$I_{0.43}$ (mA)	V_{oc} (volt)	(mA)	$I_{0.43}$ (mA)	V_{oc} (volt)
CeO_2	7070	36	3.1	138	132	.549	-1	-2	0
	7070	20	3.5	138	132	.549	+3	-1	-0.005
	7070	10	~4	138	134	.564	+2	+1	-0.010
	7070	32	6.4	138	132	.550	+1	-2	-0.015
	7940	6	~1	136	130	.551	+3	+2	0
	7940	6	~2	143	131	.546	+1	-3	-0.010
	7740	40	2.1	136	130	.553	+3	+3	0
	CeO_2 doped 7740	24	2.5	138	132	.552	-1	-2	-0.005
	5% CeO_2 doped 0211	8	1.2	138	131	.548	+1	+1	+0.005
	10% CeO_2 doped 0211	10	2.4	136	129	.553	-1	0	0
	15% CeO_2 doped 0211	9	1.3	138	132	.549	-2	-2	+0.005
SiO_x	7070	9	~4	134	127	.551	-2	-1	0
	7940	5	~1	138	132	.551	-6	-7	0
	7940	5	~2	138	129	.551	-8	-7	0

due to integral covering ranging from approximately the predicted ideal level[4] to several milliamperes greater in the case of fused silica which is intentionally deposited in an oxygen rich condition and interacts with the SiO_x layer. Covers doped with CeO_2 to improve their darkening resistance are faintly yellow colored and result in slightly lower cell currents. Application of covers thicker than approximately 3 mils is generally accompanied by a small degradation in V_{oc}.

3.5 Experience with Centralab and Heliotek Cells

Centralab and Heliotek cells supplied by GSFC have been integrally covered using the HVIBS process. Experience demonstrated that these normally handled cells required more thorough pre-covering cleaning than that employed on IPC cells from as-fabricated stock. Cover quality on properly cleaned Centralab and Heliotek cells is apparently identical to that obtained on IPC cells. However, unlike the IPC cells which are routinely anti-reflected with CeO_2, the Centralab and Heliotek cells had SiO_x anti-reflection coatings which are modified to some extent by interaction with the HVIBS cover to result in greater than ideal cell current losses. As discussed in Section 3.4, similar losses occur with IPC cells having SiO_x coatings.

Under a service arrangement IPC has deposited 7070 and 7940 HVIBS integral covers onto Heliotek cells for the ATS-F Solar Cell Radiation Damage Experiment being conducted by Hughes Aircraft Company under NASA Contract NAS5-11677. Before and after cover deposition cell electrical data supplied by Hughes[11] are summarized in Table 3. The current losses in these Heliotek cells due to covering are consistent with losses observed in IPC cells with SiO_x anti-reflection coatings. A 2 x 2 cm cell with good SiO_x coating will lose approximately 4 mA and 2 mW of output due to application of a conventional glued cover. It can be seen that an additional 4 mA and 2 mW is lost when a 7070 glass HVIBS integral cover is applied and even more when the cover is 7940 fused silica. The integral cover-SiO_x AR coating loss is characteristic of the deposition process and indicates the additional desirability of stable CeO_2 coatings on cells to be integrally covered.

Table 3. Electrical Data Summary. Cells Integrally Covered for ATS-F Radiation Damage Experiment.

Cover Material	Mean Thickness (mils)	Number of Cells	Initial Output			Change After Covering		
			I_{sc} (mA)	P_{max} (mW)	V_{oc} (volt)	I_{sc} (mA)	P_{max} (mW)	V_{oc} (volt)
7070	1.4	35	138.5	57.8	0.559	-8.6	-4.4	-0.005
7070	3.0	35	138.4	57.8	0.561	-8.3	-4.3	-0.006
7070	1.8	35	137.8	57.8	0.561	-11.4	-6.3	-0.010

Cells: 2 x 2 cm, 10Ω-cm, N/P, 13 mils thick, SiO_x anti-reflective coatings.

Measurements: X25L solar simulator, 140 mW/cm^2, 25 ℃. Data taken by Heliotek for Hughes Aircraft Company under NASA Contract NAS5-11677.[11]

SECTION 4

ENVIRONMENTAL EVALUATIONS OF HVIBS INTEGRAL COVERS

4.1 Evaluation by External Organizations

During this program and an earlier Air Force sponsored[5] integral cover development program, evaluations have been made by IPC and periodically by external organizations of the environmental stability of silicon solar cells protected by HVIBS integral covers. All available data indicate high performance of HVIBS integral covers under laboratory and flight test conditions. Applicable testing other than that at IPC has concerned fused silica covers and has included the following:

	Author	Reference	Date	Tests
(i)	Wise, J., Air Force Aero Propulsion Laboratory	(6)	1967	Thermal cycling UV-Vacuum Storage
(ii)	Fairbanks, J., NASA Goddard Space Flight Center	(7)	1969	Temperature-Humidity Storage, Proton Irradiation
(iii)	Seaman, J., Air Force Aero Propulsion Laboratory	(8)	1969	Thermal Cycling UV Exposure
(iv)	Luft, W., TRW	(9)	1970	Thermal Cycling
(v)	Sarles, F. W., Stanley, A. G., MIT Lincoln Laboratory	(10)	1970	Flight Test

Wise - AFAPL

Wise has reported the results of vacuum thermal-cycle and vacuum-ultraviolet irradiation storage on integrally covered cells. IPC cells with 1 and 2 mil HVIBS 7940 fused silica integral covers survived 300 cycles between temperature limits of -275 to +250 °F without failure and withstood 1000 hours of ultraviolet exposure at 60 °C and 10^{-6} torr without degradation.

Fairbanks - GSFC

Fairbanks conducted 2-week 70 °C, 95% relative humidity exposure and proton irradiations on integrally covered cells. IPC cells with 2 mil 7940 fused silica integral covers exhibited no degradation due to the temperature-humidity storage and showed no I_{sc} or P_{max} degradation following exposure to high fluence levels of 2 MeV protons. Under 500 keV proton irradiation similar cells experienced no I_{sc} degradation but approximately 10% P_{max} loss after 10^{14} protons/cm^2.

Seaman - AFAPL

In AFAPL thermal cylcing tests, 5 IPC cells with 1.5 mil 7940 fused silica HVIBS integral covers were subjected to 3645 cycles between -275 and +250 °F without incidence of cover or cell failure. This test represents the longest thermal cycling evaluation reported on IPC integral cover cells and the absence of failure is consistent with all test data from other sources. No HVIBS integral cover cell is known by IPC to have failed under any thermal cycle or thermal shock test.

Under the equivalent of more than 5500 hours in the ultraviolet component of the AMO spectrum, 3 IPC cells with 1.5 mil 7940 fused silica HVIBS integral covers exhibited no physical or electrical degradation.

Luft - TRW

In TRW thermal cycling tests, 12 IPC cells with 1.5 mil 7940 fused silica integral covers were subjected to 437 cycles between -175 °C and +65 °C. No failures were observed

Sarles and Stanley - MIT Lincoln Laboratory

A solar cell flight experiment is in progress aboard Lincoln Laboratory LES-6 satellite in synchronous orbit. Ten types of silicon N/P and P/N lithium doped cells with various combinations of coverglass protection are included. Identical cell pairs are mounted with and without picture-frame edge

protection mask. Included in this test are IPC N/P cells with 1 mil HVIBS 7940 fused silica integral covers. The protection provided by 1 mil of cover is not quite adequate against the synchronous altitude environment and it is inevitable that eventually the IPC cells will show greater degradation than those with thicker glued covers. However, from data after 18 months in orbit it is possible to draw a number of conclusions regarding effectiveness of the HVIBS integral covers:

(1) In spite of the thickness inadequacy of their 1 mil protection, the integrally covered IPC cells were at the end of 18 months the most efficient cells in the test.

(2) Among the 10 Ω-cm N/P cells not provided with metal window frame masking to protect cell edges, the IPC cell with integral cover showed the least normalized P_{max} degradation as well as greatest absolute P_{max}.

(3) During the first 6 months of flight the integrally covered IPC cells exhibited substantially less degradation than other cells with glued covers. It is during this early period that surface effects, filter degradation, adhesive darkening, etc., to which the integrally covered cell is least susceptible, occur most strongly in other cell structures.

(4) Contrary to the performance of all other types, the integrally covered IPC cell with picture frame mask exhibited degradation identical to that of the similar IPC cell without edge mask. This result indicates the importance of the edge protection afforded by the HVIBS process which deposits integral coating onto the cell edge.

4.2 Testing by IPC

IPC has conducted assessment testing on its HVIBS integral cover cells for the purpose of determining acceptability of the HVIBS process and of candidate cover materials. As the development of HVIBS integral covers of materials other than fused silica is recent, the only available data at present is that which has been obtained by IPC.

4.2.1 Proton Irradiations

The results of 400 keV proton irradiations of cells with 2 mils or less of 7940 fused silica cover have been reported previously on this program.[1] No degradation has been observed in cells exposed to high fluence levels except when solderless contact bars or unprotected gaps were left exposed during irradiation.

Irradiation with 1 MeV protons has been performed on a number of small sample groups of cells with HVIBS integral covers of the materials investigated during the latter portion of this program. The results of the irradiations are tabulated in Table 4. Except for cell B-12 which was accidentally irradiated on its solderless contact bar, no covered cell has been observed to have been degraded by the protons which had energy insufficient to allow penetration of any of the covers. Minor performance changes are the result of reproducibility errors experienced with the IPC carbon arc AMO solar simulator.

4.2.2 Temperature-Humidity Storage

Temperature-humidity storage for 30 days at 45 ℃, 90% relative humidity has been performed on small sample quantities of cells with HVIBS integral covers of each candidate material. The test data are summarized in Table 5. No visible physical degradation occurred in any cell. The electrical data exhibit some scatter but, with the possible exception of the fused silica covered cells, no tendency of any cover type toward degradation was observed. Actually in the absence of observable physical changes in the covers, variations

Table 4. 1 MeV 10^{14} p/cm^2 Proton Irradiation Data.

Cell	Integral Cover Material	Nominal Thickness (mils)	Initial Performance			Change After 10^{14} 1 MeV p/cm^2		
			I_{sc} mA	$I_{0.43}$ mA	V_{oc} V	I_{sc} mA	$I_{0.43}$ mA	V_{oc} V
FS155	7070	2	135	128	0.552	0	0	0
478-21	7070	2	139	133	0.560	0	0	0
478-24	7070	2	138	134	0.563	0	0	+0.005
478-22	7070	2	137	131	0.560	-1	+1	+0.005
D4	7070	2	137	133	0.562	+3	+2	0
G45	7070	2	140	135	0.562	0	0	0
G16	7070	6	139	132	0.547	+3	-2	-0.010
G27	7070	6	137	132	0.561	+3	+4	+0.005
B-12*	7940	2	140	134	0.556	-32*	-134*	-0.240
TA90	7940	1	144	138	0.570	-1	0	0
P29	7740	2	139	135	0.566	+3	0	-0.020
P9	7740	2	143	134	0.538	+1	0	0
CD10	CeO_2 doped 0211	2	132	127	0.552	+2	+3	+0.010
CD30	CeO_2 doped 0211	2	138	132	0.560	0	+1	+0.005
CD31	CeO_2 doped 7740	2	140	132	0.560	+1	0	-0.010
CD33	CeO_2 doped 7740	2	142	136	0.556	0	+1	+0.010
ET13	None	-	137	124	0.562	-101	-124	-0.200

*Solderless contact bar mask lost during test with resulting irradiation of bar area.

Table 5. Temperature - Humidity Storage Test Data
45°C, 90 RH, 30 days.

Cell	Integral Cover Material	Nominal Thickness (mils)	Initial Performance			Post-Exposure Change		
			I_{sc} mA	$I_{0.43}$ mA	V_{oc} V	I_{sc} mA	$I_{0.43}$ mA	V_{oc} V
G44	7070	2	139	134	0.536	0	-3	0
G45	7070	2	138	134	0.544	+2	-2	0
G46	7070	2	138	130	0.539	+2	0	0
G23	7070	6	139	126	0.530	+3	0	-0.005
G24	7070	6	140	134	0.550	+4	+3	-0.005
G25	7070	6	141	133	0.546	+1	-3	-0.005
AA1	7940	1	130	120	0.546	-1	-4	-0.005
AA4	7940	1	125	113	0.541	+1	-2	-0.005
AT5	7940	1	143	134	0.531	0	-7	0
P9	7740	2	136	129	0.541	+3	-1	-0.005
P10	7740	2	138	133	0.543	+2	-2	-0.005
P11	7740	2	139	128	0.539	+1	0	0
CD1	CeO_2 doped 0211	2	134	128	0.548	0	0	0
CD2	CeO_2 doped 0211	2	133	129	0.548	+4	+1	-0.005
CD3	CeO_2 doped 0211	2	134	129	0.549	+5	+4	0
CD34	CeO_2 doped 7740	2	136	130	0.539	Broken in Electrical Test		
CD36	CeO_2 doped 7740	2	136	130	0.549	+3	0	-0.005
CD38	CeO_2 doped 7740	2	138	128	0.534	+1	+1	+0.005
ET1	None	-	141	129	0.549	0	+2	0
ET2	None	-	140	128	0.540	+2	+1	+0.005
ET3	None	-	138	126	0.543	+3	-2	0

Cells: 2 x 2 cm
Ti/Ag contacts
CeO_2 AR coating

of electrical performance in a temperature-humidity test are more likely to have been associated with the Ti/Ag contacts.

4.2.3 Ultraviolet-Vacuum Storage

Cells of the same type included in the temperature-humidity storage test have also been subjected to ultraviolet irradiation-vacuum storage for 30 days at 10^{-7} torr under 20 mW/cm^2 of continuous ultraviolet irradiation. Light source was a General Electric UVIARC lamp with ultraviolet spectral content in the range 2200 to 4000 Å.

The test data are summarized in Table 6. No electrical changes larger than possible measurement error were observed. Close visual inspection indicated slight discoloration of the antireflective coating particularly in the vicinity of contact fingers in most of the cell types. Mechanism of the discoloration has not been investigated and no observable performance changes can be attributed to it.

4.2.4 Thermal Shock Test -196 °C to +100 °C

The data from a thermal shock test are summarized in Table 7. Cells were immersed in liquid nitrogen for 15 seconds, removed and immersed immediately in boiling water for 15 seconds, then returned to the liquid nitrogen and so on for a total of 10 cycles. No physical failures or changes of any kind occurred in cells coated with any integral cover material as a result of the thermal shock cycles and no significant electrical changes were observed. Repetition of this thermal shock test on a larger quantity of cells with 7070 integral covers of thicknesses from 1 to more than 10 mils resulted in no degradation in appearance or performance of any cell.

4.2.5 Thermal Anneal Test

Cells with each type of integral cover were subjected to a series of 20 minute anneals at 250 °C, 300 °C, and then 350 °C. No physical change or

Table 6. Ultraviolet - Vacuum Storage Test Data
10^{-7} torr, 20 mW/cm^2 - 350 mμ
Illumination 30 days.

Cell	Integral Cover Material	Nominal Thickness (mils)	Initial Performance			Post-Exposure Change		
			I_{sc} mA	$I_{0.43}$ mA	V_{oc} V	I_{sc} mA	$I_{0.43}$ mA	V_{oc} V
G42	7070	2	134	130	0.545	+2	0	0
G43	7070	2	135	129	0.540	-2	-3	0
G32	7070	6	140	130	0.532	-3	-2	0
G34	7070	6	135	126	0.531	+1	0	+0.005
AT2	7940	1	141	118	0.526	0	0	+0.010
AT3	7940	1	141	127	0.531	+2	+3	+0.005
P13	7740	2	137	127	0.551	-1	0	0
P14	7740	2	133	124	0.545	+1	+2	0
CD4	CeO_2 doped 0211	2	133	126	0.546	+1	+1	+0.005
CD6	CeO_2 doped 0211	2	134	128	0.541	+1	0	+0.005
CD40	CeO_2 doped 7740	2	138	127	0.534	-2	0	+0.010
CD42	CeO_2 doped 7740	2	136	128	0.547	-1	+1	0
ET4	None	-	138	127	0.546	+5	+4	0
ET5	None	-	137	125	0.548	+2	+3	+0.005

Cells: 2 x 2 cm
Ti/Ag contacts
CeO_2 AR coating

Table 7. Thermal Shock Test Data - 10 Cycles Direct Immersion Liquid Nitrogen 15 Seconds to Boiling Water 15 Seconds

Cell	Integral Cover Material	Nominal Thickness (mils)	Initial Performance			Post-Test Change		
			I_{sc} mA	$I_{0.43}$ mA	V_{oc} V	I_{sc} mA	$I_{0.43}$ mA	V_{oc} V
D1	7070	2	138	128	0.546	Broken in Electrical Test		
D4	7070	2	137	132	0.557	-2	-2	0
G16	7070	6	139	130	0.537	-1	-2	-0.005
G27	7070	6	138	133	0.546	0	-3	0
BGT-12	7940	2	138	130	0.550	0	0	-0.005
TA90	7940	1	140	133	0.557	0	0	0
P29	7740	2	139	135	0.557	0	-1	0
P30	7740	2	138	130	0.546	0	0	0
CD10	CeO_2 doped 0211	2	132	127	0.549	-1	-3	0
CD30	CeO_2 doped 0211	2	137	131	0.553	-1	-1	0
CD31	CeO_2 doped 7740	2	138	131	0.551	-1	-1	0
CD33	CeO_2 doped 7740	2	139	132	0.551	-1	-1	0
ET13	None	-	138	130	0.554	0	-5	0

Cells: 2 x 2 cm
Ti/Ag contacts
CeO_2 AR coatings

performance degradation occurred in any cell. Initial and final electrical performance are summarized in Table 8.

The cells used in this test, and virtually all the cells covered in this program, had CeO_2 optimized antireflective coatings. As reported previously,[1] CeO_2 coatings will result in bubbling delamination failure at 400 °C unless special precautions are taken immediately prior to integral cover deposition. No attempt has been made to apply these precautions with CeO_2 in normal practice as at present there is no requirement for cell annealability and because normally applied SiO_x antireflective coatings are annealable. After the 350 °C anneal the anneal test cells were subjected to 400 °C for 20 minutes. As expected, all cells showed incidence of bubbling delamination at the CeO_2-cover interface.

Table 8. Anneal Test Data - Effect of Consecutive 20 minute Anneals at 250, 300, 350 °C.

Cell	Integral Cover Material	Nominal Thickness (mils)	Initial Performance			Change in Performance After Three Anneals		
			I_{sc} mA	$I_{0.43}$ mA	V_{oc} V	I_{sc} mA	$I_{0.43}$ mA	V_{oc} V
G37	7070	2	141	133	0.544	0	+2	+0.005
G15	7070	6	136	130	0.531	0	+1	+0.010
G18	7070	6	137	124	0.529	+1	+5	+0.010
G29	7070	6	137	129	0.529	+1	+3	+0.010
G31	7070	6	133	126	0.533	+3	+5	+0.010
BGT9	7940	2	138	134	0.557	-1	-1	0
BGT10	7940	2	136	130	0.547	0	0	+0.005
BGT11	7940	2	138	131	0.546	-2	0	+0.005
P21	7740	2	138	131	0.551	+3	+3	+0.005
P22	7740	2	138	132	0.553	0	+2	0
P23	7740	2	136	130	0.554	0	0	0
CD7	CeO_2 doped 0211	2	138	133	0.552	-1	-1	+0.005
CD27	CeO_2 doped 0211	2	139	134	0.548	0	-2	0
CD29	CeO_2 doped 0211	2	138	131	0.546	-1	-1	0
CD51	CeO_2 doped 7740	2	137	130	0.545	+1	+2	+0.005
CD54	CeO_2 doped 7740	2	137	130	0.542	+1	+1	+0.005
ET10	None	-	137	131	0.550	-3	-2	+0.005
ET11	None	-	137	131	0.547	-2	-1	0
ET12	None	-	137	120	0.544	0	+1	0

SECTION 5
ECONOMICS OF HVIBS INTEGRAL COVER DEPOSITION

5.1 Present Capability

The HVIBS facility which has been used for most of the effort of this program is a research machine with sufficient volume capability to be employed for limited pilot production purposes. The system as it presently exists can be operated in either of two modes to coverslip 125 2 x 2 cm cells simultaneously at a rate of 22 hours per mil or 1200 2 x 2 cm cells simultaneously at a rate of approximately 150 hours/mil. These rates assume continuous operation of the machine and are consequently somewhat optimistic. The system is shut down periodically by failures such as sparking within the ion source or filament burn-out and is not equipped for automatic restart during non-working hours. Non-optimized internal geometry results in inefficient utilization of sputtered material and is responsible for unnecessarily low deposition rates. Value of this facility is approximately $50 K.

Until such time as the present facility is modified to increase throughput and reduce costs, IPC is providing integral covering service on evaluation quantities of cells supplied by the purchaser of the service. Price of this service is approximately $2 per cell plus $1 per mil of cover per cell on a minimum quantity of 100 2 x 2 cm cells.

5.2 Modified Facility Capability

Because of its limited volume capability and inefficient operation, the existing research facility results in high integral cover cost and low volume throughput and is not adequate for a production volume coverslipping program. IPC has initiated design of modification to this existing facility which will result in capability to cover 2000 cells simultaneously at a rate of 10 hours/mil with cell removal, replacement and system evacuation accomplished in 4 hours. The system design is considered to be proprietary and will not be detailed here. Basis of design improvement is increase of sputtering target area, increase of

beam current from 0.25 amp to 2.0 amps and inversion of system geometry to effect efficient utilization of sputtering area. Automated handling procedures could allow the facility to operate continuously on a three-shift five day week basis with a single technician/operator present during each shift to conduct all required process operations. Estimated cost of a new system fabricated to the modified design is $75 K.

Assuming the anticipated capabilities of the production volume system, high volume utilization and amortization of the facility over 18 months or 60 months, integral cover application costs of Table 9 are predicted. It is seen that assuming the 18 month amortization, covering cost for individual 2 x 2 cm cells will range between $0.18 for 1 mil up to $0.48 for 10 mils. With amortization over 60 months, costs for the same covers could decrease to $0.13 and $0.22 respectively.

Production process integral covering yield can be expected to approach 100%. Although failures should be totally eliminated in the actual HVIBS deposition of the cover, occasional inevitable handling losses will prevent a real 100% yield from being obtained.

Table 9. Production Volume Costs.

Coverslip Thickness →	Coverslipping Cost Per Cell							
	Individual Cells				Panel Segments			
	1 mil	2 mil	6 mil	10 mil	1	2	6	10
Burdened Labor:								
Cell Preparation	$0.04	$0.04	$0.04	$0.04	$0.04	$0.04	$0.04	$0.04
Platen Load	0.04	0.04	0.04	0.04	0.01	0.01	0.01	0.01
System Operation	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Materials	$0.02	$0.02	$0.02	$0.02	$0.02	$0.02	$0.02	$0.02
Facility Amortization $75,000 - 18 months	0.07	0.10	0.23	0.37	0.07	0.10	0.23	0.37
TOTAL	$0.18	$0.21	$0.34	$0.48	$0.15	$0.18	$0.31	$0.45
With Facility Amortization $75,000 - 60 months	$0.02	$0.03	$0.07	$0.11	$0.02	$0.03	$0.07	$0.11
TOTAL	$0.13	$0.14	$0.18	$0.22	$0.10	$0.11	$0.15	$0.19

SECTION 6

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