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MODULE FLAMMABILITY RESEARCH

JET PROPULSION LABORATORY

R.S. Sugimura
D.H. Otth

ARCO SOLAR, INC.

J. Arnett
K. Lewis

Introduction

- **Objective:** **Develop the technology base required to construct fire-ratable modules**
- **Approach:** **Explore new materials of construction and module configurations to achieve increased fire resistance**
  - **Phase I:** **Assess fire-resistance capability of current PV module designs**
  - **Phase II:** **Perform parametric tests to characterize flammability**
  - **Phase III:** **Hypothesize and test improved construction techniques that lead to increased fire resistance**

Background

- Tests for Fire Resistance of Roof Covering Materials, UL-790
  - Spread-of-flame test—distance that flame has spread. No flaming or glowing brands of roof material
  - Burning-brand test—until flame, glow and smoke disappear. No sustained flaming on underside, production of flaming or glowing brands of roof material

	Spread-of-Flame		Burning Brand
	Time	Distance	Size
Class A	10 min	6 ft	12 x 12 x 2 1/4 in.
Class B	10 min	8 ft	6 x 6 x 2 1/4 in.
Class C	4 min	13 ft	1 1/2 x 1 1/2 x 25/32 in.

Chronology

Exploratory testing (June, 1980; August, 1981)

- Glass/silicone/CRES pan (Blk III)
- Sylgard/FRP back (Blk III)
- Glass/silicone/Pan-L-Board (Blk IV)
- Glass/EVA/T (Blk IV)
- Findings
  - Silicone modules are inherently fire resistant
  - EVA modules are highly flammable, may not be fire ratable

Manufacturers' testing (1983)

Parametric testing (January, 1984)

- 27 burning-brand tests
- 9 different manufacturers
- 3 different encapsulants/8 different back surfaces

Parametric testing: findings

- Difficult to maintain module integrity
  - Glass shatters due to thermal stress
  - Penetration of back-surface material is disastrous
- Hydrocarbon encapsulants are highly flammable
- Heating from brand is highly localized

Joint ARCO/JPL test program (February, 1984)

- Fabricate and test experimental modules
  - High-temperature back-surface materials
  - Improved module construction techniques

ARCO-JPL Flame Retardant Test Program

Material Description	Cost ($/ft^2)	Configuration	Adhesive	Result
Unfilled Kapton (2 mils)	1.05	Add-on	TS	F
			PS	P
		Substitute	–	P
Fiberglass – fine-woven (stabilized)	0.85	Add-on	TS	P
–			PS	F
–		Substitute	–	F
– (unstabilized)	< 0.20	Add-on	PS	F
– coarse-woven (unstabilized)			TS	F*
Neoprene Rubber (mineral-filled) –				
Latex (≈8 mils)	≈ 0.25		–	F
Sheet (93 mils)	≈ 1.50		TS	P
Stainless-Steel Foil (2 mils)	0.45		TS	P
			PS	AP*
Aluminum Foil (3 mils) in 4-layer laminate	0.06	Substitute	–	P
			–	AF

Summary

- Temperature measurements indicate that materials with high thermal stability are required to maintain back-surface integrity
- Available high-temperature materials are potentially effective in this application

Future Work

- Complete burning-brand effort
  - Analyze data
  - Nominate candidate materials
  - Identify cost tradeoffs
- Start spread-of-flame research

PROCESS DEVELOPMENT AND ADVANCED PROCESSES

M.H. Leipold and D.B. Bickler, Chairmen

Presentations on 11 on-going process developments were made during the technology session. Areas being investigated are metallization, junction formation, thick- and thin-film deposition and hydrogen passivation.

Westinghouse Electric Corp. Advanced Energy Systems Division reported on simultaneous junction formation using liquid dopants. A p+nn+ cell was fabricated using n-type dendritic web. Cross-doping of phosphorus into the front junction was a major problem. Earlier formation of a harder glass will be one approach to a solution. Desired diffusion profiles were obtained during simultaneous firing. Efficiencies up to 12% were found when simultaneously fired cells were measured.

The amount of LBIC (laser-beam induced-current)-imaged grain-boundary activity has little or no effect on space-charge recombination or fill factor, according to Solarex Corp. Continuing work on large-grain polycrystalline silicon (Semix and Wacker) has also shown that there is a strong correlation between quasi-neutral recombination and electrically active grain and subgrain boundaries. Additional findings were: V_{OC} of polycrystalline cells is 20 to 60 mV lower than that of single-crystal cells; large data scatter correlates with inclusions; most V_{OC} scatter is accounted for by J_{QNO} variation. Another contractual effort, hydrogen passivation of polycrystalline cells, was just starting.

Caltech diffusion barrier studies continue to produce results and have attracted interest from industry and other R&D laboratories. Certain amorphous metallic layers can be very stable at high temperatures. Areas of concern in selecting amorphous metallic layer constituents are crystallization, reaction with underlying silicon or reaction with overlying metal. Rules for selecting amorphous film constituents are: Use a transition metal plus a metalloid; use two transition metals with low solubility and that have a deep eutectic; use two transition metals of different crystallographic structure. Films are formed by ensuring a random atomic arrangement and using low-temperature deposition with high heat dissipation. Potential solutions to reactivity of amorphous metallic films are: Use an intermediate layer; use early transition metals with high reaction temperatures with silicon; nitrogen containing alloys show promise; ternary alloys show promise.

The MOD (metallo-organic decomposition) work at Purdue University continues to provide interesting results. Many organic compounds and rheology adjusters can be used to form the MOD inks. Experimental work has shown the need for fairly high-purity organic precursors so that all organics break down at essentially the same temperature. Ink requirements for screen printing are: have very low vapor pressure; have viscosity in the range of 100-500 Pa at low shear rate; be pseudoplastic and thixotropic. Available solvents are also being studied for compatibility and boiling point. Three different baseline processes with silver neodecanoate are being pursued: solution with xylene and solvent exchange, solution with toluene and solvent exchange, and

solid compound plus additive. Different furnaces and air flows are also being investigated. Important parameters are: purity of ingredients, heating rate between 70°C and 225°C, and air flow. Although the mechanism of adhesion is not fully understood, dense films with good adhesion and conductivity have been produced.

Spectrolab Division of Hughes Aircraft Co. has continued research into the non-noble front metallization system of molybdenum-tin-titanium hydride. Some interim conclusions are: molybdenum-tin combination has adequate conductivity; shunting is never a problem; solderability is a major problem; more work is needed on wetting phenomena; a cellulosic vehicle is best. A new analytical technique is being used to obtain real-time and videotaped visual SEM data that can be used to examine ink behavior during firing. More control of research findings has been gained by using fully described inks from Electrink, Inc., instead of proprietary formulations from vendors.

Electrink, Inc., has been examining viscosity measurements as a means of process control of thick-film printing. Generally, viscosity measurements are convenient to make and can be reproducible. The measurements do relate to production application and are a means of correlating composition and condition of the ink. Three different viscosity conditions can be found: Newtonian (viscosity is constant with varying shear rates); plastic (viscosity decreases with increasing shear rate); dilatent (viscosity increases with increasing shear rate). Thixotropic materials have an additional constant to define liquid structure restoration rate for disrupted states. Good reproducibility of viscosity measurements for thixotropic materials requires scheduled measurements and close temperature control. Constants relating to material rheology may be calculated from three or more measurements at different shear rates with an iterative computer program.

Ion implantation of non-Cz silicon sheet materials was studied by Spire Corp. Materials examined were: Wacker Silso; Solarex Semix; Crystal Systems, Inc. HEM, Mobil Solar EFG, and Cz controls. The ion-implantation process was held constant; annealing processes tried were one-step thermal, two-step thermal, three-step thermal and pulsed electron beam annealing (PEBA). Analysis of the one-step anneal at 850°C shows EFG improved; Semix relatively unchanged and HEM, Cz and Silso somewhat degraded. Analysis of the two-step anneal at 850°C shows EFG much improved; Semix, Cz and HEM relatively unchanged and Silso slightly degraded. Conclusions are: use of ion implantation allows tailoring of thermal annealing process to a specific material; ion implantation and rapid thermal annealing can be used successfully for junction formation.

Laser-assisted solar-cell metallization processes are being developed by the R&D Division of Westinghouse Electric Corp. Potential advantages of laser deposition techniques are high resolution, no photolithography, clean and contamination-free, in-situ sintering, and low contact resistance. Three processes are being investigated: pyrolytic deposition (thermal decomposition of liquid or gas phase), photolytic deposition (photodissociation of vapors and solutions), and laser-assisted electroplating. Results of laser pyrolysis were encouraging; lines of silver were formed by decomposition of a spun-on silver neodecanoate film provided by Purdue University. Adhesion is still a possible problem in this process. Laser-assisted gas-phase photolysis equipment is ready to use for titanium and tin depositions. Early results of

laser-enhanced electroplating of copper have been exciting. A 25-micrometer-wide line has been achieved with a 12 micrometer/second local plating rate.

Ion cluster beam (ICB) deposition research is being pursued at JPL. The intent of the research is verification of Japanese work, investigation of PV applications other than metallization (such as dielectric and semiconductor deposition), and characterization of ICB as a function of source parameters. A number of changes have been made in the ionizer chamber to achieve more reliable operation. A crucible nozzle is being considered for better collimation of the beam. Other changes being investigated are cluster detector, substrate heater, and operation of ionizer at higher temperatures.

Another JPL research effort is a program for SERI. The parameters governing large-area deposition of amorphous silicon are being established. Tests have been run on plasma stability while voltage, pressure and electrode spacing are varied. Deposition uniformity is also being studied with regard to corner effects, electrode spacing, silane feed rate and velocity, and substrate influence (aluminum, silicon or glass).

New contracts to explore the technology of advanced processes have been let for two excimer laser energy sources and one microwave source. The ability to apply energy selectively to achieve process improvements has already been seen in other research efforts. An additional benefit is the ability to get a detailed assessment of a new technology and thereby validate claims of large processing improvements or cost reductions.