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to: Distribution

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subject: Electrical and Thermal Conductivity of Two Silver-Loaded Adhesives

Conductive adhesives interest us as possible substitutes for solder. Although their electrical and thermal conductivities are more than an order of magnitude less than those of solder, they may be more resistant to thermal strain because of their high degree of flexibility. Calculations based on values of electrical and thermal conductivity specified by manufacturers show that electrical power loss and temperature drop across thin layers of these adhesives may be small.

I have completed thermal and electrical conductivity tests of silver-loaded two-part flexible adhesive Prima-Solder EG8050. Table I summarizes the results obtained.

Table I
Electrical Resistivity and Thermal Conductivity

	ρ, ohm-cm	k, W/m°C
Prima-Solder EG8050	.0006 to .9	1.8 to 8.9

The electrical resistivity of adhesive EG8050 depended strongly on the method of measurement (sheet resistance or joint resistance) thereby indicating significant electrical resistance at the bond interfaces. The thermal conductivity of adhesive EG8050 increased dramatically with curing at elevated temperature as compared to curing at ambient temperature. Unfortunately, for adhesive the thermal interface resistance was much larger than the thermal resistance within the adhesive.

Based on my experience with these adhesives, elevated temperature curing is mandatory. Samples cured at ambient temperature had much lower values of thermal and electrical conductivity than samples cured at elevated temperature. Also, the properties of samples cured at ambient temperature differed significantly from sample to sample for no obvious reason.

The adhesive 556 has better adhesion than the adhesive EG8050 as shown by greater mechanical strength and lower interfacial electrical resistance. The adhesive EG8050 has much lower bulk resistivity and slightly higher bulk thermal conductivity than the 556 adhesive. Difficulty of handling, pot life of one hour, and need to cure at elevated temperature offset the advantages of lower temperature processing and elimination of flux as compared to solder. Further developments are required before either adhesive can be used as a replacement for solder. Much uncertainty remains in the areas of interface resistance, bond-to-bond uniformity, and resistance changes with thermal cycling.

Electrical resistivity was determined using measurements of sheet resistance and joint resistance. Two different four-point probe instruments were used to measure the sheet resistance of layers of adhesive on glass slides. The instruments were a Veeco FPP-100 owned by Division 7475 and a Magnetron M800 owned by Division 7471. Table II shows results from these measurements.

Table II
Resistivity Determined by Sheet Resistance Method

	ρ sheet, ohms/sq.			ρ, ohm-cm
	Veeco	Magnetron	Average	
Aremco-Bond 556	.511	.79	.65	.013
Aremco-Bond 556	.370	.62	.50	.010
Prima-Solder EG8050	.040	.062	.051	.0011
Prima-Solder EG8050	.022	.036	.029	.0006

The four samples described in the table were cured at 100 degrees C for one hour. The bulk resistivity values in the last column of the table result from multiplying average sheet resistance by layer thickness. Aremco-Bond samples cured at room temperature had values of resistivity that were typically 10 times greater than values shown in Table II. The sheet resistance of Prima-Solder samples cured at room temperature could not be measured by either instrument.

Sheet resistance measurements do not include the influence of interface resistance. As as alternate method dependent on interface resistance, five joints between copper rods 2.61 mm in diameter were made using each type of adhesive. The resistance of these samples was then measured using our HP-3478A multimeter (four-wire method). Table III shows results from these measurements.

Table III
Resistivity Determined by Joint Resistance Method

	ℓ, cm	R, milliohms	ρ, ohm-cm
Aremco-Bond 556	.0688	20	.016
	.0879	20	.012
	.0589	10.	.009
	.0262	9.	.018
	.0269	8.	.016
Prima-Solder EG8050	.0098	16.	.087
	.0072	14.	.076
	.0028	50.	.96

All the samples described in Table III were cured at 100 degrees C for one hour. The resistivity values in the last column of the table result from multiplying the resistance values (R) by the area of the joint and dividing by the thickness of the adhesive layer (ℓ). Two of the Prima-solder samples broke before measurement had been accomplished. For the Aremco-Bond adhesive, the value of bulk resistivity determined by the joint resistance method was only slightly greater than the value of resistivity determined by the sheet resistance method. In contrast, the bulk resistivity of the Prima-Solder adhesive as determined by the joint-resistance method was roughly 100 times greater than the resistivity determined by the sheet-resistance method. Additionally, one of the Prima-Solder samples had a very high resistance value. Apparently the adhesion of the Aremco-Bond material to the copper rods was better than the adhesion of the Prima-Solder material to the copper rods.

Moss/Haseman of Division 1824 have measured thermal conductivity using their colora thermoconductometer. The samples that were tested consisted of aluminum disks 1.80 cm in diameter bonded with different thicknesses of each type of adhesive with and without elevated temperature cure. The method used to calculate thermal conductivity and interface resistance involved plotting total bond thermal resistance as a function of bond thickness. Table IV shows results from these measurements.

Table IV
Thermal Conductivity and Interface Resistance

	R Interface, °C/W	k, W/m°C	R .005" °C/W
Aremco-Bond 556	1.2	<0	<0
Aremco-Bond 556 Heat Cure	1.0	6.4	.078
Prima-Solder EG8050	.8	1.8	.28
Prima-Solder EG8050 Heat Cure	1.0	8.9	.056

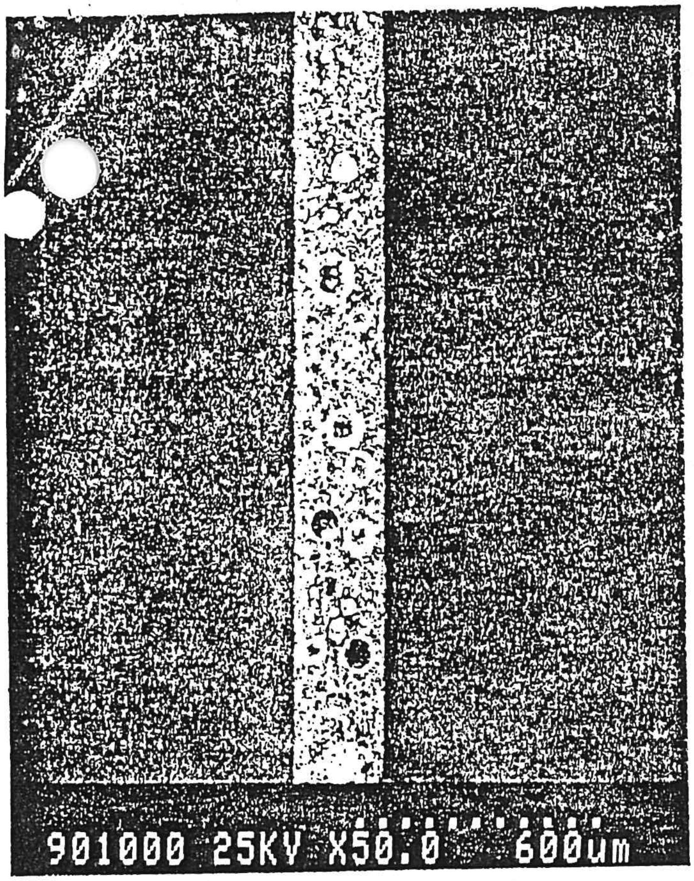
Incorrect negative values of thermal conductivity were obtained for the 556 adhesive without heat cure. The last column in the table lists values of bulk adhesive resistance for a bondline .005 inches in thickness. These values of resistance are much less than the values of interface resistance shown in Column 1 of the table. A solar cell having the area of the aluminum disks may require a cooling rate of 10 to 30 watts. Therefore, use of these materials as thermal conductors even in thin layers requires reduction of interface resistance.

Figure 1 shows magnified cross sections of bonds to aluminum made with both types of adhesives with and without elevated temperature curing. Judging from these micrographs, high values of interfacial resistance do not result from agglomeration of voids at the interfaces. Removal of the voids within the bulk of the adhesives will be difficult because of the high viscosity of the materials in their uncured state.

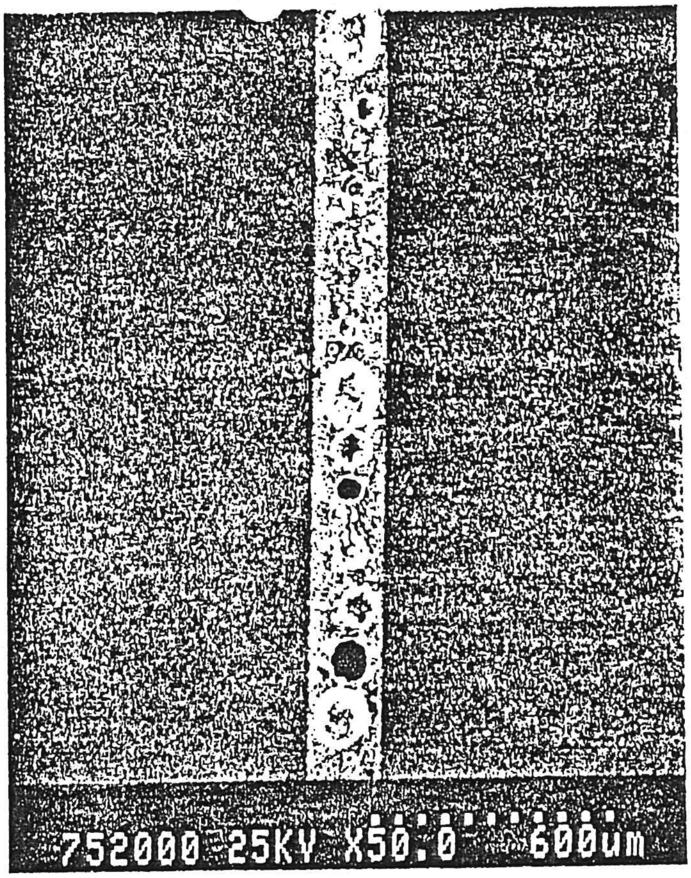
At this point, these conductive adhesives cannot be used as replacements for solder in solar cell assemblies. Their advantages of flexibility and low-temperature processing without flux are offset by high interface resistance, lower bulk conductivity, process control difficulty, limited pot and shelf lives, handling difficulty, and curing requirement. The greatest need for information lies in the area of resistance changes with thermal cycling. Manufacturers' specifications are listed in the attachment.

CJC:6224:gc

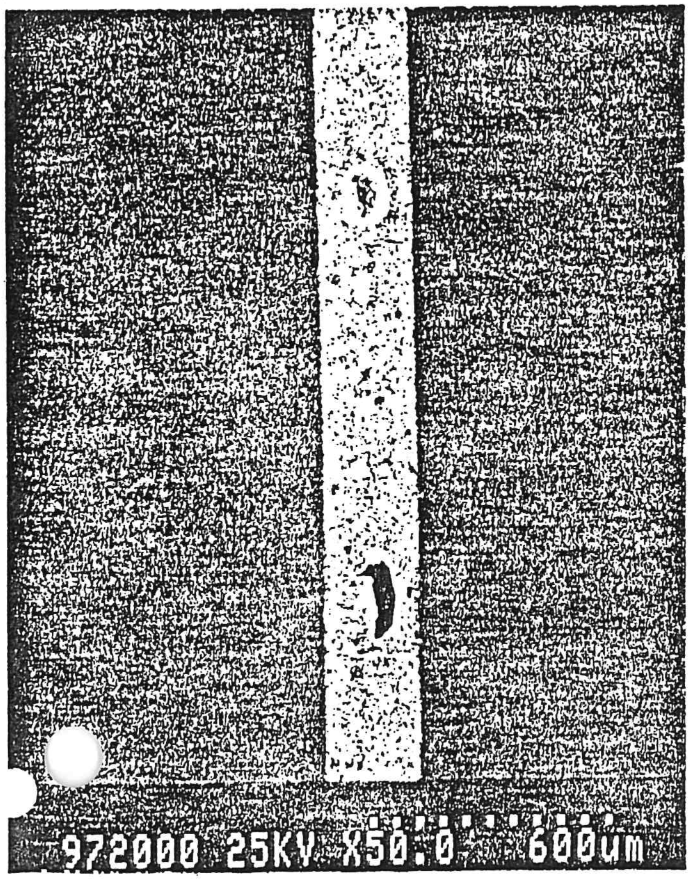
Enclosures



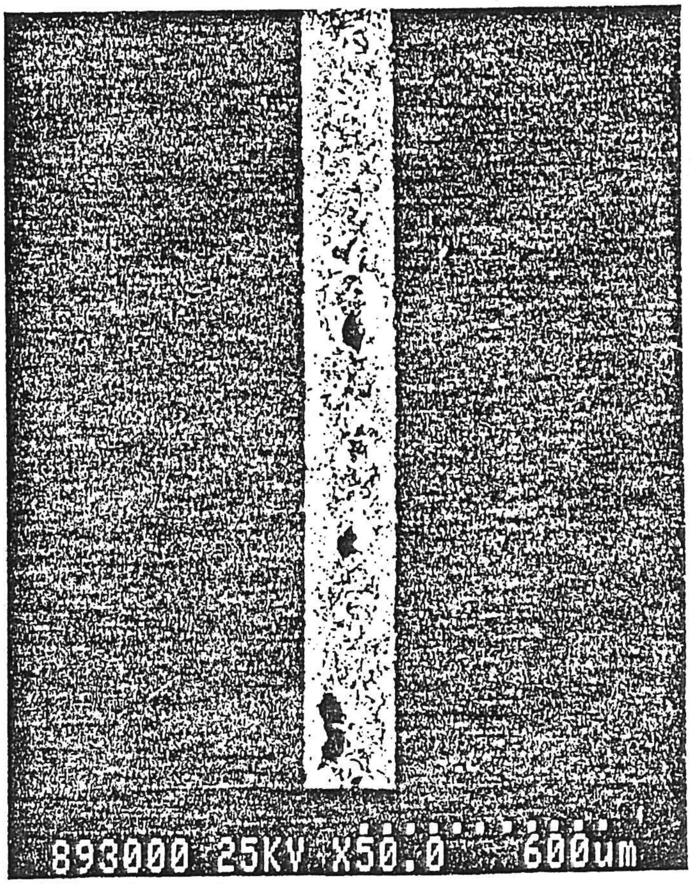
a. Adhesive 556



b. Adhesive 556 heat cured



c. Adhesive 8050



d. Adhesive 8050 heat cured