PROGRESS REPORT

ON

CONDUCTIVE PAINTS

May 1, 1993- August 15, 1993

Submitted by

R.J. Soukup

N.J. Ianno

Department of Electrical Engineering

University of Nebraska-Lincoln

Lincoln, NE 68588-0511

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

**Portions of this document may be illegible
electronic image products. Images are
produced from the best available original
document.**

This report covers the work performed from May 1, 1993, through August 15, 1993 under a subcontract from Sayles Enterprises entitled "A Study of Conductive Paints".

I. Solar Cell Contacts

The key factor in determining whether or not the paints can be utilized as solar cell contacts is the resistance between the paint and solar cell itself: the contact resistance.

While different methods exist to measure the contact resistance, we will initially employ one that relies on the geometry shown below in Figure 1:

Figure 1. Simple Geometry for Solar Cell Contact Resistance Measurement

The two rectangles are paint, the next layer is n+ silicon, and the thick bottom layer is p silicon. The n+-p structure forms the solar cell.

When current is injected through the contacts, the voltage across the contacts can be shown to be:

$$V = IR = (IR_s/Z)(S + 2L_t)$$

where R_s is the sheet resistance of the n+ layer, and L_t is the current transfer length, which is a function of ρ_c , the contact resistance. The quantities Z , the contact length and S , the contact spacing, are known dimensions. In order to measure R_s and L_t , a voltage versus spacing plot is generated, for a fixed current. This can be accomplished in a single pattern seen in Figure 2. The slope of the plot of the voltage vs contact spacing, S , yields R_s , while the intercept yields L_t . The contact resistance, ρ_c , is then determined from:

$$\rho_c = R_s L_t^2$$

Figure 2. Contact pattern, containing 4 sets of contacts, each with different spacing.

We have secured four 3 inch single crystal silicon solar cell wafers from Dr. Sopori at the National Renewable Energy Laboratory (NREL). The contact resistivity mask, as seen in Figure 2, has been obtained in metal foil form. The metal foil form has served as a mask for photographic generation of the contact mask pattern on a glass plate. This glass plate serves as the pattern for sample processing.

II. Sample Preparation

Solar cell samples are cut from the wafers supplied by NREL, cleaned, and undiluted paint is sprayed on as described previously. The paint is baked at 300 C for 30 minutes in a forming gas (80% N₂/20% H₂) atmosphere. The forming gas atmosphere minimizes oxidation. Three layers of negative photoresist are spun on the paint, where each layer is baked before the next layer is applied. The mask and sample are mounted in the photoresist processing system, exposed, and subsequently developed, resulting in the desired pattern being transferred to the photoresist/sample. The photoresist coated sample is immersed in a wet silver etch consisting of H₂O₂/HNO₃/H₂O, for approximately 30 minutes, or until the unwanted silver paint is removed. This leaves behind a carbon residue, which is removed along with the photoresist in an oxygen plasma asher.

III. Results

In order to test the experimental procedures and the contact mask, approximately 0.5 microns of pure silver was evaporated onto a solar cell sample, processed and measured. An ohmic contact will yield a fixed value of V/I for any value of current, and this will be a function of gap spacing. Figure 3 is a graph of V/I vs I as a function of gap spacing for the evaporated silver sample. As can be seen V/I is constant for a given gap spacing. Figure 4 is a graph of voltage vs gap spacing for a fixed value of current (I=0.01 A). An ohmic contact will yield a straight line. The smallest gap spacing does not lie on the line defined by the three larger spacings. A close examination of the pattern revealed that some silver bridged the small gap resulting in an erroneous reading. If the smallest gap is ignored, this data yields a contact resistance of $5.34 \times 10^{-4} \Omega\text{-cm}^2$. In view of these results we believe the experimental procedures, and contact pattern yield accurate results.

Paint samples were prepared as previously discussed, where it was determined that #3003 withstood the processing better than the other paints. Therefore, initial work centered on this formulation. Figure 5 is graph of V/I versus I as a function of gap spacing for #3003 baked at 300 C for 30 minutes in forming gas. This should be compared to Figure 3, the expected behavior obtained from evaporated silver. The paint sample exhibits non-linear V/I vs I , there is no correlation between gap spacing and V/I , and the V/I values are about 30 times larger than those obtained from evaporated silver. This result is representative of all results obtained with #3003, where samples were prepared at 100 C, and 200 C. The paint easily flaked off a sample baked at 600 C, so it could not be tested. We believe these results indicate a Schottky barrier contact exists between the paint and solar cell, which probably results from the binder forming a layer between the silver metal and solar cell. We are currently preparing samples designed to characterize the contact more directly. We have also produced paints without thinner, and will measure their contact properties as well.

IV. EMI Shielding

A small test fixture was constructed and the Hewlett-Packard Impedance meter was used to measure the change in impedance of paint films as a function of frequency up to 10 MHz. Figure 6 shows the impedance of a gold film, used to calibrate the system, measured against itself. This graph illustrates the sensitivity of the system at high frequency. An ideal system would show 0 for all frequencies. Figures 7 - 9 show the response of paints #1001-#4004, and paints cc#2002, and scc#2002. Paint cc#2002 is a copper paint based on graphite, while scc#2002 is a silver paint formulated like #2002 but with graphite instead of simple carbon. In all cases the frequency response is within the error of the measurement, thus we conclude that up to frequencies of 10 MHz the impedance of each paint is unchanged, and they all will provide excellent shielding.

SAMPLE P62

Figure 3. V/I vs I for evaporated silver.

—x— 1-2 GAP —*— 2-3 GAP —▲— 3-4 GAP —□— 4-5 GAP

SAMPLE P62

Figure 4. Voltage vs Gap Spacing, fixed current, evaporated silver.

SAMPLE P61

Figure 5. V/I vs current as a function of gap spacing for paint #3003 baked at 300 C for 30 minutes in forming gas.

—X— 1-2 GAP —*— 2-3 GAP —▲— 3-4 GAP —□— 4-5 GAP

Figure 6. Frequency response, gold vs. gold calibration.

GOLD W/ ZERO AT OSC=1.1V G&B

Figure 7. #1001, and #3003 frequency response.

2 RUNS SAME GOLD ZERO, G&B OSC=1.1V

Figure 8. Frequency response of #2002, and #4004.

2 RUNS SAME GOLD ZERO, G&B OSC=1.1V

Figure 9. Frequency response of cc#2002, and scc#2002.

2 RUNS SAME GOLD ZERO, G&B OSC=1.1V