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METALLIZATION WITH GENERIC METALLO-ORGANIC INKS

Geraldine M. Vest

Purdue University

West Lafayette, Indiana 47907

WHAT ARE METALLO-ORGANIC COMPOUNDS?

Metallo-organic compounds are ones in which a metal is linked to a long chain carbon ligand through a hetero atom such as O, S, N, P or As. Films formed by the thermal decomposition of these metallo-organics are called MOD films. In order that the products of decomposition contain only CO_2, H_2O, and in rare cases nitrogen compounds, and to avoid S containing products, Purdue's Turner Laboratory pioneered the use of a set of metallo-organic compounds for ink fabrication where the linking hetero atom was oxygen. These inks were made from commercially available carboxylates, or synthesized from commonly available reagents. The processing is described on page 3, and the molecular design critera on page 4. The particular carboxylates or amine carboxylates selected were the octoates or neodecanoates, and they are described on page 5 with examples given on pages 6, 7, and 8. Currently, metallo-organic compounds have been selected for 25 elements as listed on page 9.

WHAT ARE THE ADVANTAGES OF MOD FILMS?

Both the advantages and the problems involved with MOD films are listed on page 11. The chief advantage for metallizing photovoltaic systems is the low firing temperatures; for example, silver films have been fired on silicon wafers at temperatures as low as 250°C.

MOD PROCESSING AND PROPERTIES

The first step in formulating any ink was to assay the precursor materials and thermogravimetric analysis (TGA) results are given on page 15. Low firing silver films are more important in metallizing photovoltaic systems but more work was done on gold and copper films, and they will be discussed first. A very dense gold conductor film of near theoretical sheet resistivity was developed for firing on alumina substrates. The MOD gold films had adhesion and ultrasonic wire bonding properties that were better than conventional thick film gold. The processing of the MOD gold films is described on page 16.

Adhesion is measured in terms of the force required for detachment of two adhering phases. Separation may take place at the interface, or within the interfacial region, or in the bulk of the weaker phase. Different measurement techniques reflect different failure mechanisms and are, therefore, not directly comparable. For this study, the adhesion was measured by

a pull test performed in a similiar manner to the procedure developed by C. Kuo at CTS, by soldering nail head nickel wires to test pads on the substrates. The pretinned nail head wires were clamped perpendicular to the substrates and hand soldered with Indium Corp. of America flux #1 and 70Sn/18Pb/12In solder. The gold pads were not burnished or pretreated before soldering. An Instron Tensil Tester was used for the pull test, and the adhesion expressed in kg. The adhesion was conisdered to be excellent if the pull strength was 9.5 kg or above. After the pull test was completed, the pads were inspected for the failure mechanism. Each of the tensile test results were classified into the failure modes described on page 17.

The initial tests with gold MOD films showed very low adhesion, and on examining the fracture, it was determined that the solder had completely alloyed with the gold films. These results were not indicative of the adhesion between the gold MOD films and alumina, but rather the adhesion between a Sn-Pb-In-Au alloy and alumina. In order to circumvent this problem, a diffusion barrier layer of Ni or Pt was inserted between the gold and the solder. Metal films of platinum or nickel, approximately 5000 angstroms thick, were sputtered onto the adhesion test pads through metal masks. Before sputtering, the films were cleaned ultrasonically in acetone, methanol, and DI water. The coated conductor patterns were fluxed with Kester 15-44 solder flux and dipped for three seconds in a 60Sn/40Pb solder pot at 200^{o}C. Except for a different solder composition and flux, the previously described procedure for nail head pin attachment was used. Both small pins (diameter 0.05 cm) designated S and large pins (diameter 0.09 cm) designated L, each having a head diameter of 0.127 cm, were used because several of the initial failure modes involved breaking the pins. A summary of the adhesion data for the MOD films is presented on page 18 along with data for Engelhard's conventional mixed bonded gold ink A-3770 and their MOD (mercaptide chemistry) ink A-3725 for comparison.

Wire bonding data for the MOD gold films were obtained using a Kulicke and Soffa Ultrasonic Wedge Bonder. The semicircular loop geometry for attaching Al wires to the gold film is shown on page 19. Twenty five bonds were made on each sample. The test involved putting a small hook through the loop and pulling the wire to failure; the load and failure mode were then recorded. From a side view of the wire loop, the bonded ends look like feet; thus the failure modes were described as a "heel break" or a "foot lift". For a foot lift, the failure occurs by the aluminum wire lifting off of the gold conductor, and it may or may not bring the conductor with it. A heel break refers to a failure mode in which the aluminum wire breaks adjacent to the bonding area where its diameter was reduced during the bonding operation. In general, a heel break is the desirable failure mode because it indicates that the aluminum wire to gold conductor bond was stronger than the aluminum wire after bonding. However, both the mean pull strength and the failure mode are functions of the machine parameters and the bonded wire geometry. The wire bond results for 25 tests on each of the MOD gold films along with the results with conventional thin and thick films are presented on page 21. A summary of the effects of additions to gold in the films is given on page 21, and a summary of the Au film properties is given on page 22.

A screen printable copper ink, developed from an aqueous solution of copper nitrate trihydrate, produced solderable Cu films with good electrical conductivity and adhesion on POS substrates. The chemistry is listed on page 23 and the processing on page 24, and the Cu film properties are summarized on page 25.

Silver inks that could be screen printed or ink jet printed were formulated, and dense Ag films with good conductivity and good adhesion were obtained when they were fired on several substrates. The procedure for making silver neodecanoate is given on page 26, and the processing of screen printable and ink jet printable inks are given on page 27. Substitution of α-terpineol for xylene was necessary for the screen printable ink because of the high vapor pressure of xylene. A summary of the Ag film properties is given on page 28. It should be pointed out that 1 w/o Pt is adequate for solder leach resistance for conventional thick films, but the MOD films are so thin that 4 w/o Pt was required.

WHERE ARE WE?

The metallo-organic inks that have been formulated during the last three years in the Turner Laboratory at Purdue University along with the properties of the fired MOD films are summarized on pages 30 and 31. A great deal of additional work must be done in the area, and we have only scratched the surface of what might be accomplished with low firing temperature metallization.

Page 2.

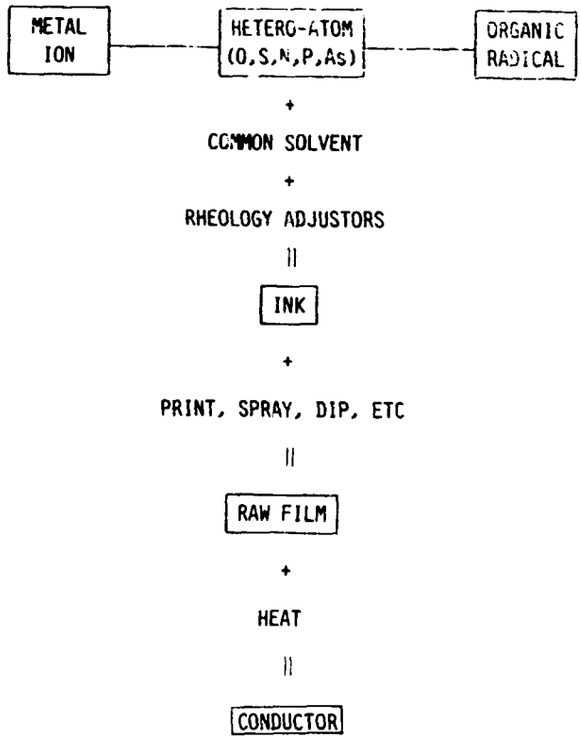
→ 1. WHAT ARE METALLO-ORGANIC COMPOUNDS?

2. WHAT ARE THEIR ADVANTAGES?

3. MOD PROCESSING AND PROPERTIES

4. WHERE ARE WE?

Page 3. MOD Film Processing



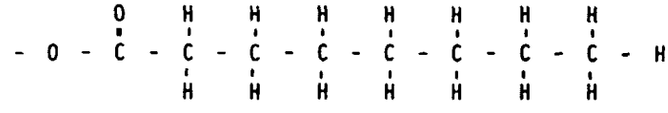
Page 4. Molecular Design Criterion

1. As the chain length of the organic radical increases:
   a) the solubility of the compound in organic solvents increases;
   b) the metal content of the compound decreases.

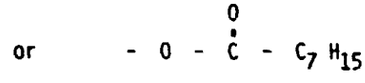
2. The solubility of the compound increases if the organic radical is branched.

Page 5.

NORMAL OCTOATE

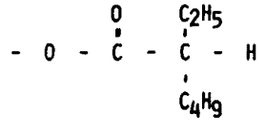


or

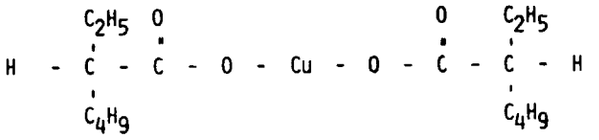


BRANCHED OCTOATE

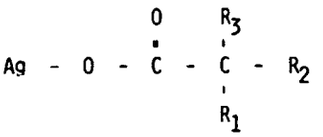
2-ethylhexoate



Page 6. Structural Formula for Copper 2-Ethylhexoate

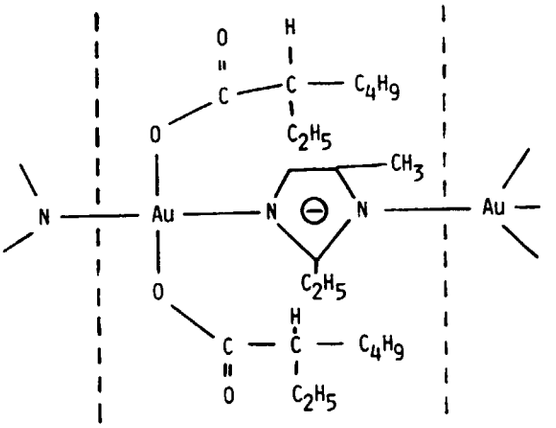


Page 7. Structural Formula for Silver Neodecanoate



The number of carbon atoms in $R_1 + R_2 + R_3 = 8$

Page 8. Structural Formula for Gold Amine 2-Ethylhexoate



Page 9. Turner Laboratory Compounds

2-ETHYLHEXOATES

Bi, Cd, Co, Cr, Cu, Ga, In, Ir, Ni, Pb, Rh, Ru, Si, Sn, Y, Zn, Zr

AMINE 2-ETHYLHEXOATES

Au, Pt

NEODECANOATES

Ag, Ba

OTHER

B	Pyridine
Pd	Acetate
Sb	Butoxide
Ti	2-Ethylhexoxide

Page 10.

1. WHAT ARE METALLO-ORGANIC COMPOUNDS?
2. WHAT ARE THEIR ADVANTAGES?
3. MOD PROCESSING AND PROPERTIES
4. WHERE ARE WE?

Page 11.

ADVANTAGES	FABRICATION	PROBLEMS
ELIMINATE VARIATIONS IN INGREDIENT MATERIALS	FORMULATION	LIMITED INFORMATION AVAILABLE ON PURE COMPOUNDS
ELIMINATE VARIATIONS DUE TO BLENDING	INK	LOW INORGANIC CONTENT
VARIETY OF PRINTING TECHNIQUES POSSIBLE	FILM	MORE DIFFICULT OT CONTROL VISCOSITY
LOWER FIRING TEMPERATURE	COMPONENTS	LARGE VOLUME OF VOLATILES
	PROPERTIES	
IMPROVED WIRE BONDING	CONDUCTORS	HIGHER SHEET RESISTANCE
REDUCED LASER TRIM EFFECTS	RESISTORS	RESISTANCE RANGE MAY BE LIMITED
PIN HOLE FREE	DIELECTRICS	DIELECTRIC CONSTANT VALUES MAY BE LIMITED

Page 12.

1. WHAT ARE METALLO-ORGANIC COMPOUNDS?

2. WHAT ARE THEIR ADVANTAGES?

→ 3. MOD PROCESSING AND PROPERTIES

4. WHERE ARE WE?

TO DEVELOP THICK FILM GOLD CONDUCTORS
TO INCREASE THE RELIABILITY OF ULTRA-
SONIC ALUMINUM WIRE BONDS.

APPLICATION

NEXT GENERATION OF HYBRID MANUFACTURING
TECHNOLOGY.

Page 13.

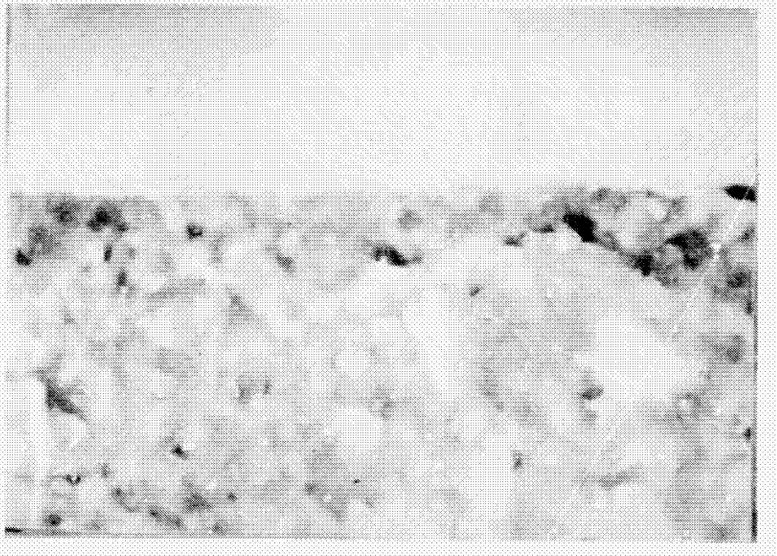
PROBLEM

TO DEVELOP THICK FILM GOLD CONDUCTORS
TO INCREASE THE RELIABILITY OF ULTRA-
SONIC ALUMINUM WIRE BONDS.

APPLICATION

NEXT GENERATION OF HYBRID MANUFACTURING
TECHNOLOGY.

Conventional 500X



MOD 500X

MOD 1000X

Page 15. TGA Results

Saturated solutions heated in air at 10°C/min.

Compound	Decomp.	w/o Product
Ag neodecanoate	250	15 Ag
Au amine 2-ethylhexoate	600	18 Au
Pt amine 2-ethylhexoate	400	18 Pt
Bi 2-ethylhexoate	350	16 Bi_2O_3
Cu 2-ethylhexoate	300	4 CuO
Rh 2-ethylhexoate	225	8 Rh
Pd acetate trimer	225	3 PdO

Page 16. Processing Gold Films

1. ASSAY MOD PRECURSORS

2. MIX MOD COMPOUNDS +3 w/o PENZOIL'S MINERAL JELLY #20

3. PLACE SOLUTION IN AN OPEN BEAKER AT 50°C UNDER A VACUUM OF 67 Pa FOR 24 HOURS

4. SCREEN PRINT WITH AREMCO 3100 ON 3M'S AlSiMag 838 SUBSTRATES, 325 MESH S.S. SCREEN

5. BATCH FIRE THE SAMPLES

   Sequence 1: 10 minutes each at the following temperatures: 120, 350, 500, 850°C

   Sequence 2: same as above except reducing the second temperature to 300°C and firing for 20 minutes

   Sequence 3: IR drying + 850°C/10 minutes

Page 17. Adhesion Failure Modes

A. Separation of the pad from the substrate

B. Separation within the solder fillet

C. Separation between the wire and the solder fillet

D. Fracture of the substrate

E. Pin breaks

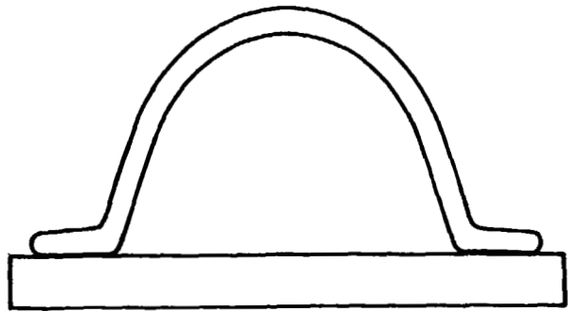
Page 18. Summary of Adhesion Data

Composition (w/o)*			Barrier	Pin	Load (kg)		Failure Mode				
Bi	Cu	Pd	Layer	Size	Mean	S.D.	A	B	C	D	E
1.5	-	1.5	Pt	S	9.1	0.6	1	-	-	-	4
			Pt	L	8.1	2.3	10	8	1	-	-
			Ni	L	8.8	1.8	1	1	-	-	-
1.0	-	1.5	Pt	S	7.0	1.1	9	1	-	-	-
			Pt	L	7.2	2.8	10	-	-	-	-
0.5	-	1.5	Ni	L	10.7	1.9	5	-	-	3	-
0.25	-	-	Ni	S	7.4	1.0	3	3	-	-	-
			Ni	L	8.7	1.0	1	2	-	-	-
-	-	1.5	Ni	S	3.1	1.5	6	-	-	-	-
1.5	0.1	1.5	Ni	L	9.5	1.2	3	7	-	2	-
1.0	0.1	1.5	Ni	L	7.6	1.8	3	5	3	12	2
0.25	1.0	-	Pt	S	7.3	1.2	9	1	-	3	-
A-3770			Ni	L	5.9	1.8	12	-	-	1	-
A-3770			none	L	5.9	1.5	10	-	-	3	-
A-3725			Ni	L	4.2	1.2	11	-	-	-	-

*Inks also contained 0.1 w/o Rh, balance Au.

Page 19. Ultrasonic Wedge Bonder

MODEL 484
KULICKE + SOFFA
S/N 1904



FOOT TO FOOT
LINEAR DISTANCE = .125 $\pm$ .001 cm
BONDED WIRE HEIGHT $\simeq$ .035 cm
Al WIRE (1 w/o Mg) 25 μm THICK

Page 20. Aluminum Wire Bond-Test Results

Firing Sequence	No. of Layers	w/o Bi*	Pull Strength (g) Mean	S.D.	Failure Mode H.B.	F.L.
#2	2	0.5	5.24	1.89	3	22
#2	2	1.0	5.24	1.79	9	16
#2	2	1.5	6.26	1.27	1	24
#2	2	2.5	6.78	1.03	19	6
#2	3	0.5	7.16	1.45	8	17
#2	3	1.0	9.58	1.28	20	5
#2	3	1.5	9.16	2.23	8	17
#2	3	2.5	8.28	1.15	25	-
#4	3	1.5	7.28	1.07	25	-
			8.04	1.23	25	-
#4	3	1.5	8.32	0.95	22	3
Conventional thin film			11.18	1.03	25	-
Conventional thick film			7.9	1.3	24	1

*All inks also contained 0.1 w/o Rh, 0.1 w/o Cu, 1.5 w/o Pt, balance Au.

Page 21. Additions to MOD Gold Films on Alumina Substrates

Rh — AT LEAST 0.1 w/o Rh IS NEEDED FOR FILM FORMATION.

Cu — ADDITIONS OF 1.0 w/o Cu DOUBLE THE ρ_s WITH NO SIGNIFICANT EFFECT ON ADHESION WHILE ADDITION OF 0.1 w/o IMPROVED ADHESION AND Al WIRE BONDING PROPERTIES WITHOUT DRASTIC EFFECTS ON ρ_s.

Pt or Pd — EITHER Pd OR Pt IMPROVES ROOM TEMPERATURE WIRE BONDING AND ADHESION PROPERTIES WITHOUT SIGNIFICANTLY CHANGING THE ρ_s. SINCE Pd OR Pt ALSO IMPROVE THE SOLDER LEACH RESISTANCE OF Au FILMS ≈1.5 w/o WAS ADDED.

Bi — BISMUTH INCREASES ADHESION AND WIRE BONDING PROPERTIES AND THE OPTIMUM MAY BE 1.5 w/o Bi.

Page 22. Au Film Properties

1. Raw materials are pure generic materials - anyone can fabricate films from the formulas.

2. Films can be conventionally processed.

3. Films have better adhesion and wire bonding properties than commercial thick film.

4. The film resistivities approach that expected for pure gold.

5. The microstructure shows that the films are very dense and thickness measurements show that the films are 0.5 μm/layer.

Page 23. Chemistry of the Copper Ink

COMPOUND	%
Cu nitrate trihydrate	67.4
water	28.8
methyl cellulose (4000 CP grade)	2.2
boron oxide	0.9
Ross Chem's Foam Burst 370	0.7

Page 24. Processing Copper Films

1. The B_2O_3 was added to the water. The methyl cellulose was then added, and several hours were necessary for it to dissolve. Next the Cu nitrate was added, and after it dissolved the Foam Burst was added. The ink was allowed to stand for one day.

2. The ink was screen printed through a 165 mesh S.S. screen on POS substrates.

3. The best firing sequence was to air dry at 50^0C/1 hour + air dry at 230^0C/20 minutes + fire in a 4% H_2/96% N_2 atmosphere at 650^0C/20 minutes. The samples were cooled to 100^0C before they were removed from the H_2/N_2 atmosphere.

Page 25. Cu Film Properties

1. A one layer film (8 μm thick) fired on POS gave 14 mΩ/sq/25 μm, another two layer film (9.9 μm thick) fired on POS gave 19 mΩ/sq/25 μm.

2. For room temperature aging, the sheet resistance increased by ≈0.5% in the first few hours, remained constant for times to 400 hours, increased to 5% after 1000 hours, then remained constant to 2000 hours.

3. Samples were dip soldered with 63% Sn - 37% Pb at 250^0C - films were completely tinned.

Page 26. Synthesizing Silver Neodecanoate

$$C_9H_{19}\ COOH + NH_4OH \rightarrow C_9H_{19}\ COONH_4 + H_2O$$

$$C_9H_{19}\ COONH_4 + AgNO_3 \rightarrow C_9H_{19}\ COOAg + NH_4NO_3$$

1. The acid was added to base and stirred, a clear solution resulted.

2. The $AgNO_3$ plus some H_2O was added and stirred and a white cloudy ppt resulted.

3. Xylene was added (25 cc for 10 g acid) and 2 immisible liquids were formed.

   Liquid 1 is C_9H_{19} COOAg in xylene
   Liquid 2 is NH_4NO_3 (aq)

4. The liquids were poured into a stoppered funnel and the bottom liquid was removed. This more dense liquid was the NH_4NO_3 (aq) solution.

5. The top solution was filtered and additional xylene was removed by bubbling air through the solution until a saturated solution was obtained.

Page 27. Processing Silver Films

1. After adding α-terpineol to a mixture of saturated xylene solutions of both Ag neodecanoate and Pt amine 2-ethyl-hexoate the solvents were exchanged.

2. Ethyl cellulose in α- terpineol was added to adjust the rheology for screen printing.

3. The ink was screen printed through a 325 mesh screen on various substrates.

4. The ink was dried at $150^{0}C$/10 minutes then fired at $150 \rightarrow 350^{0}C$ for various times.

INK JET PRINTING

1. Saturated xylene solutions of Ag neodecanoate and Pt amine 2-ethylhexoate were directly printable.

2. The alumina substrates were preheated to $30^{0}C$ and most of the xylene was removed during the printing.

3. The substrates were heated to $210^{0}C$/10 minutes then fired at $250^{0}C$/10 minutes.

Page 28. Ag Film Properties

Screen Printing

1. Silver films have been successfully printed and fired on alumina, POS, ITO, glass and Si at temperatures as low as 250^{0}C.

2. These films pass the "Scotch Tape" test for adhesion.

INK JET

1. Films have been successfully fired on alumina substrates at 250^{0}C/10 minutes.

2. Lines have been printed as narrow as 7 mils on AlSiMag 838 through a 3 mil orfice on the ink jet printer.

3. A film with composition 4 w/o Pt/96 w/o Ag remained after 30 seconds in 63 Sn - 37 Pb solder but if the Pt was reduced to 2 w/o solder leaching was observed.

4. Sheet resistance values as low as 0.06 Ω/sq have been obtained.

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1. WHAT ARE METALLO-ORGANIC COMPOUNDS?

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3. MOD PROCESSING AND PROPERTIES

→ 4. WHERE ARE WE?

Page 30. Where Are We

Au

A MOD gold ink containing Rh, Bi, Cu, and Pt or Pd has been developed for screen printing on alumina substrates and produces a very dense film with near theoretical sheet resistance. The MOD gold films had adhesion and ultrasonic aluminum wire bonding properties that were better than conventional thick film golds.

Cu

A screen printable copper ink was developed from an aqueous solution of copper nitrate trihydrate, boron oxide and methyl cellulose that produced solderable Cu films with good conductivity and good adhesion when fired in a reducing atmosphere on POS substrates.

Page 31. Ag

1. Silver inks that could be screen printed were formulated from Ag neodecanoate, Pt amine 2-ethylhexoate, ethyl cellulose and α-terpineol.

2. Silver inks that could be ink jet printed were formulated from a xylene solution of Ag neodecanoate and Pt amine 2-ethylhexoate.

3. The MOD inks were fired in air as low as 250^{0}C to produce a Ag film.

4. Adhesion was good on all substrates investigated - alumina, POS, ITO, glass, silicon.

5. Fired films containing 4 w/o Pt/96 w/o Ag were solderable.

DISCUSSION

WONG: You mentioned, I am referring to silver, about 250°C becomes a safe temperature. Is this the TGA data?

G. VEST: Right. Fired at 10° per minute.

WONG: OK, so 10° per minute is the heating range. What is the equilibrium deposition temperature?

G. VEST: We really haven't done that much with silver, but I do know that we fired, in air, just putting it in the furnace for 10 minutes at 220° and we got a silver film.

WONG: OK. Again, what is the sheet resistivity at that temperature -- 60 milliohm per square?

G. VEST: No, that was on the silicon; we just printed it very quickly on the silicon. I didn't know how to calculate how many squares and I was measuring it with a ruler, so it's about 60 milliohms per square, but that was very, very thin, it may be 1000 to 1500 Angstroms; again, I was measuring it with a ruler, so I hate giving very accurate sheet resistivities.

WONG: You think it is possible to go even lower than 220°C?

G. VEST: I don't know, we haven't tried.

WONG: Are you going to try?

G. VEST: Yes. My students say they were trying 210°C, but that's today.

NICOLET: I am very curious to know what scientific logic or inspiring intuition led you to pick rhodium to create a uniform thin foil rather than osmium or molybdenum or whatever.

G. VEST: We really haven't tried to optimize and look at some of those. Just like bismuth for chemical bonding, we wanted something that worked that had a small amount of foreign material in there. A lot of the literature had rhodium; we just picked it. It's the only one we've tried.

SOMBERG: Would you care to comment about the adhesion properties of silicon relative to what we know about thick-film materials, since there is no frit to bond the silver to the silicon? Would you expect anything different from that system?

G. VEST: With the silver, I don't know why, but it seems to bond to whatever we've tried without adding either any form of glass frit or metallo-organic to make an equivalent of a glass, or putting any chemical binders in there. It's great, but I don't really know why, and I'm just not that familiar with it. This is the first we've ever worked with silicon, as such. I did not clean the wafer; we are going to try

that when I get back. There were Monsanto wafers in a nice little supposedly clean container. We borrowed one, I guess we got one from the Physics Department or the E.E. Department; we just did this on Tuesday, just to see if we could get it to adhere, so it's probably dirty silicon. We haven't done any work with silicon.

TAYLOR: Were these Monsanto wafers epitaxial wafers with a smooth surface?

G. VEST: Yes. I have one, if you would like to see it.

GALLAGHER: Have you ever mixed any of these precursors with a standard thick-film ink and blended it to see, for example, in the problem we have with Spectrolab, that you would get adhesions to the substrate?

G. VEST: Yes, as you'll remember, Bob (R. Vest) was talking this morning about making the platinum ink. The lowest particles -- well, you couldn't call it particles, I suppose there was a platinum, a commercial resinate in there.

GALLAGHER: I meant silver, excuse me.

G. VEST: No, no, we've never had any funding on silver. The only reason why we've ever done anything is just that with the ink jet, it was cheaper than gold.

STEIN: Silver metallo-organics are often used in silver thick-film systems along with particles.

GALLAGHER: That's a standard technique?

STEIN: Yes.

GALLAGHER: We never knew they were there.

STEIN: Sorry?

GALLAGHER: We never knew they were there, they were just there.

STEIN: Yes. I don't know who you were talking to, but they are there.

G. VEST: We have played around a little bit. I shouldn't say we've done nothing, because we did do a silver film for an industrial application, though we did wind up having some silver metallo-organic in there.

WOLF: I notice that your prints were rather thin but close to bulk conductivity, and your copper prints were rather thick but in an order of magnitude away from bulk conductivity. Was it very spongy or what, have you noticed anything about those copper films?

G. VEST: No, we really haven't looked at them. The copper-film work was just done to test feasibility with using those solution inks to see if we could make a film. We didn't proceed with that any further.

PROVANCE: One of the severe limitations of the Midfilm process is that it puts the film down too thin to withstand the leaching effects of the solder.

I'm wondering if you have donc any tests with the silver, or any other metallization to see what the solder leak resistance might be of these films.

R. VEST: We really haven't done that much work with the silver.

PROVANCE: That might be one of the areas for fruitful further research, because the process is very interesting, but in actual application in the field that is one of the very important criteria. We found that once you go below that mininum thickness on any of these printed films you begin to lose both adhesion, because of the leaching effects of the solder, and the solder leaching system resistance. In other words, the film becomes part of the solder.

G. VEST: We did stick the silver film down into some solder for 30 seconds and they stayed there, but that was just a quick, dirty test. Again, had we had funding in silver -- maybe we will get that.

LANDEL: How much of the metallo-organic can you get into your system?

G. VEST: With the ink jet printer, that is a drop on demand, and again it will be computer-controlled. You could make them as thick as you would like to have them.

LANDEL: That's multiple coating. How much silver can you get in the original ink itself?

G. VEST: We have about 15%, but with the ink jet printing, which probably will be the great application for the silver, we mix up 15 weight percent silver in the xylene solution. We preheat the substrate; by the time the drop has arrived at the substrate, the bulk of the xylene is gone, so we will have, very shortly thereafter, silver neodecanoate. I forget what weight percent silver is in that.

LANDEL: But why isn't it 5%, why is it 18%? Why don't you have more in there?

G. VEST: We have to get the silver neodecanoate soluble in xylene.

LANDEL: Have you tried another solvent?

G. VEST: No, we haven't.

LANDEL: Because the decanoate would be relatively insoluble in the xylene, and straight chain hydrocarbon would be a much better solvent. I think there are some things that I would be happy to discuss with you in terms of calculating loading effects. It should be possible to make better than first-order calculations as to what is a good solvent for a given metallo-organic system.

G. VEST: I will say that the reason why we use silver neodecanoate in xylene is that is what GTE sold, and we really didn't want to start synthesizing this. We purchased it that way.

LANDEL: I have some papers from JPL, on other subjects, that would be very useful in optimizing the system. So you ought to be able to increase your concentration of the metallo-organics by quite a bit.

G. VEST: That would be very interesting.

SOMBERG: What are your intentions as far as further work with this is concerned? You mention you didn't have any funding. Maybe Brian Gallagher is the person to talk to here, but it seems very promising.

G. VEST: If we get money, we would be delighted to do whatever we are asked, to study any application. It does seem promising, it just doesn't have much data.

WONG: I'm thinking of the other side of your technique. Regardless solubility, what is the practical limit for you to lay down a thin film with your technique? What is the thinnest film you can deposit to form thin film?

G. VEST: We have always been worrying about how thick we can make, how thin, I really don't know right now. We can get the solubility in xylene; you can add quite a bit of xylene. I really don't know. I have never gone that way. At least, you would have to have a few molecules of silver neodecanoate to decompose, and again as they decompose they fire off the silver an atom at a time. I don't really know what the limit is for making the thinnest film. That would be interesting to work on.

WONG: Do you really need 4% of platinum to get decent solderability --

G. VEST: We tried two and that didn't quite work, so we tried four. We have made two quick attempts. We are just playing around with the silver. We haven't put anything in it.

STEIN: First, I'll make a comment about the question on solderability. You don't need any platinum for solderability, you need it for solder-leach resistance. You can solder to pure silver very readily, too readily. The other question that Wong asked about thin film: you can drop the thickness of these films in an almost infinitely continuous fashion. You can see it go through quarter wave length of light; you can get interference patterns; you can go down to discontinuous films. It is completely controllable.

WONG: In other words, you can make transparent, mechanical films.

STEIN: If you sandwich them, yes, but not by themselves. If you sandwich silver film of this sort between two dielectric layers and make a transparent film.