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HIGH PERFORMANCE ISOTROPIC POLYMER/METAL COMPOSITE FOR FLIP CHIP ATTACH

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Material Development of Polymer/Metal Paste for
Flip-Chip Attach Interconnection Technology

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SUMMARY

Upon completion of the second year of this contract, we have delivered the next generation of polymer/metal composite, optimum paste II, to Endicott. We have done preliminary flip-chip type bonding at Universal Instruments, working closely with their personnel to enhance their equipment set and process. We have also shown that a PMC bond can withstand over 40% strain without effecting its electrical and mechanical properties. This resilience of the conductive polymer paste both under electrical and mechanical behavior, is a strong indication of the applicability of the material for Flip Chip Attach to organic laminates. We have also confirmed during this phase of the Contract that the Optimum Paste II can be processed and applied under normal ambient conditions, without special precautions of low temperature or inert atmospheres, a property which sets our system apart from many other commercial pastes. We would also like to remark the achievement of optimized paste properties and how these properties address the major issues and requirements for flip attach applications, in Table I and II of this report. Use of the PMC to build interposer for chip-testing.- Due to the high electrical conductivity of the PMC, a process was developed to use a thin film layer of the paste applied to a metal cathode of an electrochemical cell, to build fully metallized thru hole arrays containing a given C-4 chip foot print. This array interposers can be used for chip test (known-good-chip) applications. This process will be described in detail at the Year-End Review Meeting in Binghamton.

Mechanical and Electrical Compliance of PMC

One of the most important reliability concerns is the mechanical and electrical integrity of the PMC bond under thermal cycling. The origin of the stress on the bond is due to the thermal mismatch that induces a shear stress, ϵ given by,

$$\epsilon \sim \frac{\Delta\alpha \cdot \Delta T}{h} \quad (1)$$

where, $\Delta\alpha$ is the difference between the in-plane, linear thermal expansion coefficient of the chip and the substrate, ΔT is the temperature difference, and h is the height of the bond. We assume the chip is 1x1 cm. It is important to note that ϵ will increase if the substrate is organic instead of ceramic. Furthermore, to lower the ϵ , the bond height should be increased to the largest possible value. The h is fixed by the size, shape, and pitch of the features to be screened, the method for dispensing, and the bonding process. For a typical FCA geometry (1x1 cm chip, 75 μm bump height), ϵ ranges from <2% for typical glass ceramic substrates to as high as 18% for organic carrier, such as FR4.

Fig. 1 demonstrates the compliant behavior of PMC. A typical stress-strain curve of a PMC bond made at 220°C with a controlled thickness of $\sim 100\mu\text{m}$ show that the PMC is compliant well above 20% strain.

PMC is a composite material of silver particles dispersed in a polymer matrix. It is reasonable to expect that under tensile load the particles will tend to move farther apart which will increase the particle-to-particle and particle-contact pad contact resistance. To measure this behavior, we devised a special measurement to probe (the true four-point probe) contact resistance during tensile deformation. Fig. 2 shows a typical contact resistance versus strain behavior. Up to 50% strain, well above the required strain limit of 20%, the contact resistance is nominally constant (as seen from the % contact resistance change axis on the right hand side y-axis).

In most application, the chip is usually subjected to a thermal cycle: (a) during the bonding process, (b) as the appliance is turned on and off. Thus, the hysteresis behavior is also important. Fig. 3 shows the contact resistance characteristics as the paste is subjected to a loading-unloading cycle. We note that cycle up to 60% strain, the change is insignificant. This indicates that PMC is resilient both electrically and mechanically, under large strains. Furthermore, the reversibility for strain >40% suggests that FCA to organic substrates should be feasible.

Rheology

Fig. 4 compares the two Yorktown pastes I and II with two commercially available pastes. As discussed in the first annual report (2), Staystik has a very low η_0 resulting in a short shelf life and its screening properties are very poor due to its rheology. Ablebond rheologically is better but has the disadvantage of requiring storage at -40°C . We have improved upon the rheology of our Optimum Paste I as can be seen by the dramatic drop in viscosity with increasing shear rates. To note also is that the normal force of paste II is comparable with that of the two commercial pastes. Paste II is expected to screen better than any of the other pastes. As seen in the SEM's in Fig. 5, the "bumps" of this Optimum Paste II of a 10 on 20 mil array are very uniform and nicely shaped. The height of these bumps is quite high due to the rheology of the paste as well as by using an electroformed E-Fab XL nickel mask manufactured at AMTX(3). The trapezoidal shapes of the apertures in these masks allow for a larger volume of paste to be released. Fig. 6 shows a paste bump that has a cavity in the center. This cavity was formed during the release of the mask from the surface after screening. The material is pulled up and then flops over creating an air pocket upon subsequent bonding. Bonds made from this situation have poor adhesion and adhesive failure.

Bonding Experiments

For the bonding experiments, the paste was screened by doctor-blading the test vehicle pattern 10 mil diameters on 20 mil pitch (total 226 I/O's) through a 4 mil AMTX electroformed nickel mask on both a chip and 1 inch substrate. The chip and substrate were both Si wafer sputtered deposited with a barrier layer and 5000Å gold. The screened chip and substrate were dried to 70°C . Bonding was done at Universal Instruments on their prototype bonder. The chip and substrate were both heated simultaneously to 240°C as shown in Fig. 8. The whole bonding process was done in 10 or 30 seconds. The thermodes took ~ 3 seconds to heat to temperature with the remaining time for bonding. A force of 3 lbs was applied at the start of heating and released upon completion of the bonding cycle so cooling was done without pressure. The alignment of the chip to the wafer was improved by holding a vacuum throughout the travel steps of the machine. Bonds done at 10 seconds were subjected to a tensile stain at 0.25cm/min. The adhesion strength ranged from 10 - 19 lbs. The bond line was

measured to be ~5.5 mils by x-y registration before the pull-test. It is certain that if the applied load during the bonding is increased the adhesion strength will improve(2). Fig. 9 shows the chip and substrate after the adhesion test. The fracture is noted to be cohesive.

References

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- (2)R.F. Saraf, J.M Roldan, C.J. Sambucetti, C. Jahnes, R. Jagannathan, V. Brusic, Annual Report, DOE Contract No. DE-FC04-94AL98817, 11/95.
- (3)E-Fab XL Electroformed Stencil trademark of AMTX, Inc., 5450 Campus Drive, Canandaigua, NY 14425.

Figure Captions

Fig. 1: Stress-strain behavior of PMC bond at room temperature and at a constant pull speed of 0.25 cm/min.

Fig. 2: Change in contact resistance as a function of tensile strain for a PMC bond. The measurement was performed at room temperature in incremental elongations of 0.01mm.

Fig. 3: Hysteresis behavior of PMC bond contact resistance under conditions identical to those in Fig. 2.

Fig. 4: Shear rate response of Yorktown optimum pastes I and II and commercial pastes.

Fig. 5: SEM of optimum paste II screened through a 4 mil electroformed nickel mask. The pattern is the 10 mil diameter on 20 mil pitch array.

Fig. 6: SEM of a screened bump with a cavity inside.

Fig. 7: Experiments done at Universal Instruments.

Fig. 8: Typical temperature profile during a 30 second bond on Universal Instruments' bonder.

Fig. 9: SEM of a 10/20 array (same as Fig. 5) chip and substrate after pull-test. The chip and substrate are both Au coated Si material.

Fig.10: Summary of paste characteristics.

Mechanical Loading Behaviour of YKT-Paste BOND

Mechanical Loading Behaviour of YKT-Paste Bond

IBM/Yorktown

% Strain

Saraf/Roldan

% Contact Resistance Change

Mechanical Loading Behaviour of YKT-Paste Bond

Viscoelastic Effects of Silver Pastes

FIG-5
COTTE / ROLDAN

FIG 5
COTTE / ROLDAN

Experiments Conducted at Universal Instruments

- Test Vehicle: 10/20 mil pattern on blanket Au
Array screened on both chip and wafer, dry 70°C
- Alignment

- Temperature Control: heating from both thermodes, ambient to bonding temperature
- Bonding Parameters: 240°C, 10-30 secs., 3 lb force

coming up to

Force: 315
Time: 30 sec
CH1 500mV
CH2 500mV

A 5s -9.00 V VERT
1.815 V

Fig 8
Haruyama / Snyder
Holden / Saraf

18-15-96

chip

Chip

Properties of IBM Yorktown PMSP and PMC System

Bulk resistivity, ρ_b	20-50 $\mu\Omega$ -cm.
Contact resistance, ρ_c	$\leq 1.0 \mu\Omega$ -cm ²
Lamination temperature, T_{lam}	150 to 300 °C
Lamination pressure, P_{lam}	20 to 400 psi (based on feature area)
Adhesion strength, self	3000-5000 psi
Adhesion strength, Au pad	3000 psi
Screenability (paste)	75 μm features at 200 μm pitch
Syringe Dispensability	≥ 4 ml syringe, multiple passes
Thermal stability temp.	350 °C, <0.2% wt loss 30 min exposure
Reworkability	More than 10 cycles
Joining process (paste): Drying at 70 °C, Bonding at T_{lam} & P_{lam}	Time-Temperature-Pressure scheme No volatiles released No flux, no-clean process
T&H Stability	No change at 85 °C and 80% R.H. for 300 hrs.
G1 Environmental Test $H_2S/NO_2/SO_2/Cl_2$	300 hrs. exposure, 41/500/310/6 ppb, at 30 °C, Conductivity improved

FLIP-CHIP ATTACH USING CONDUCTIVE ADHESIVES

MAJOR ISSUES

- Paste Optimization
 - ◇ Electrical Conductivity
 - ◇ Rheology (Fine Screen Pitch)
 - ◇ Bondability (Adhesion; Reliability)
 - ◇ Reworkability
 - ◇ Manufacturing Capability (with Wafer BLM, and with Substrate Pads)
- Define Optimum Metallurgical Interface
 - ◇ Wafer BLM
 - ★ Al/Ni/Au - New BLM
 - ★ Cr/Cu/Ni/Au - Present BLM
 - ◇ Substrate Pads
 - ★ Cu/Ni-Au OR Pd/Ni
- Screenability
 - ◇ Bump Size (Curing/Shrinkage)
 - ◇ Whole Wafer Screening
- Bonding Parameters
 - ◇ Time - Temperature - Pressure
 - ◇ Ambient Conditions
- Functional Test Vehicle

TABLE I

KEY ISSUES AND OBJECTIVES

RESULTS

OPTIMIZED PASTE PROPERTIES

- Bulk Resistivity
 - 18 micro-ohm.cm (solder is 30 microohm.cm)
- Contact Resistance
 - Depends on Pad Metallurgy
 - Ni/Pd : 4.2 milliohm (the best)
 - Au 5-6 milliohm
 - These are Endicott Results on Statistical Sample Size on 30 bonds using Ni/Pd - Very similar to solder.
- Reliability
 - Passed G1 Exposure Testing
 - 300 HOURS (in H₂,SO₂,NO₂,Cl₂)
 - T&H : 1000 hours, 85 C,80% RH
 - No Change in Resistance
- Corrosion
 - Ag Migration detected between adjacent lines
 - Encapsulation stops Ag migration.
- Adhesion
 - Polymer-to-polymer - 3000-5000 psi
 - To Au pad - 3000 psi
- Screenability
 - 3 mil features in 8 mil center/center
- Thermal Stability
 - 350°C, less than 0.2% wt loss after 30 minutes.
- Bonding Temperature
 - Between 180°C to 300°C

TABLE II

RESULTS ACHIEVED ON PMC PROPERTIES.