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Thin Gold to Gold Bonding for Flip Chip Applications

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Outline

- Introduction
- Experimental Procedure
- Results and Discussion
- Conclusions
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Fine Pitch Flipchip

- **Motivation: A flip chip bonding process that enables bonding of devices with higher interconnect densities and finer pitches than can be bonded with solder bumps.**
- **Direct flip chip interconnects using ENIG/ENEPIG bump metallization.**
- **Two standard under bump metallization technologies:**
  - **Electroless Nickel Immersion Gold (ENIG).**
  - **Electroless Nickel, Electroless Palladium, Immersion Gold (ENEPIG).**
  - **Electroless plating processes are typically maskless.**

Thermosonic Au Wire Bonding

- Thermosonic gold wire bonding to ENIG and ENEPIG pads having 100nm immersion gold is routinely done for PCB.
- ENIG and ENEPIG are now low-cost, maskless alternatives to 400nm to 1μm thick, soft gold electrolytic metallization.
- Plasma cleaning was found to be essential in achieving consistent adhesion with a wider wire bonding process window and reduced bonding temperatures for thermosonic gold wire bonding to ENIG and ENEPIG metallization.
- Argon or argon-oxygen plasmas cleaning:
  - Plasma power, exposure time, and hold time prior to bonding are the key parameters.
  - A short duration (1 to 3 minutes) exposure to a 100W plasma has been found to be sufficient to remove the organic contaminants from gold surfaces.
  - Wire bonding is typically done within 1 to 8 hours of plasma cleaning.

Au to Au Flipchip Bonding –Thick Au

- Gold bumps ranging from 2μm to 50μm tall have been used to integrate optoelectronic devices.
- These studies report that surface activation with argon plasma enables strong bonds at 150°C.
- Plasma treatment also enabled bonding of 600nm gold films to 150nm gold films at 100°C to150°C.
- As with gold thermosonic wire bonding, 100W argon or argon-oxygen plasmas have been found to be effective at reducing the temperature for gold to gold flip chip bonding.

SAMs Coatings on Au

- **Gold coated with dodecanethiol self-assembled monolayers (SAMs).**
  - **Dodecanethiol can act as a lubricant and a passivation layer.**
  - **Treated gold surfaces, gold to gold bonding can be done at lower temperatures than are possible with untreated gold.**
  - **X-ray photoelectron spectroscopy studies have shown that gold surfaces coated with dodecanethiol shows lLess oxygen and carbon contaminants than uncoated gold surfaces.**
  - **Explains why dodecanethiol coated copper bond pads can be wire bonded after longer storage times than uncoated bond pads.**
  - **There is no reason to suspect that dodecanethiol will result in stronger gold to gold bonds considering that it desorbs at ~117°C, which is below the typical bonding temperature of 160°C .**

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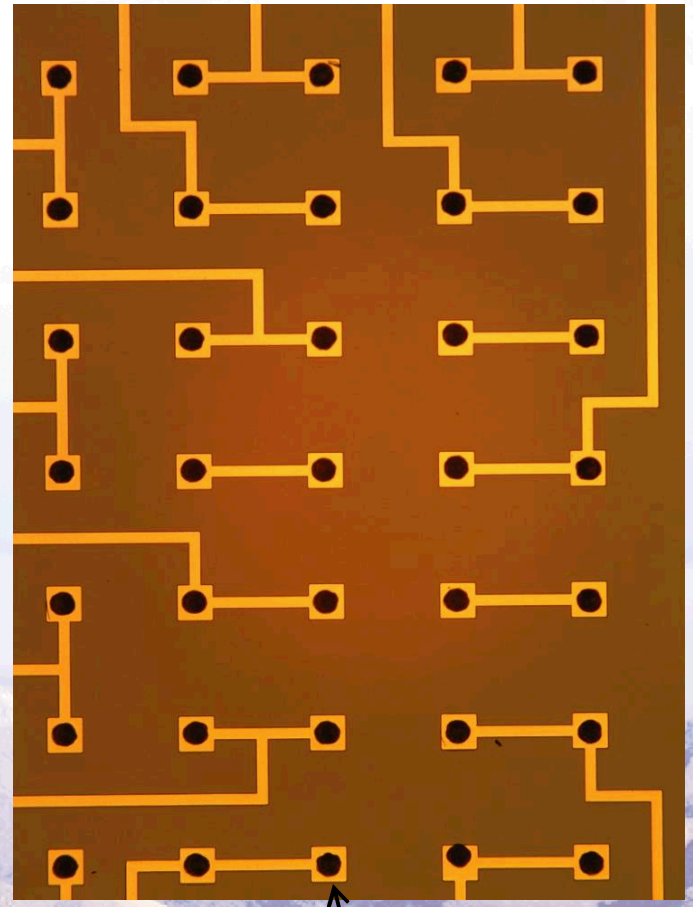
Gold Stud Bump Samples

- **Our experiments used several different flip chip bump test samples.**
  - **The first type of bumped test flip chip die consist of ~1cm square silicon die with an 8x8 array of gold stud bumps.**
  - **These 8x8 arrays were made by wire bonding 25µm gold wire on to 100µm square pads with 1µm thick gold on a 200nm thick titanium adhesion layer.**

Partial test die

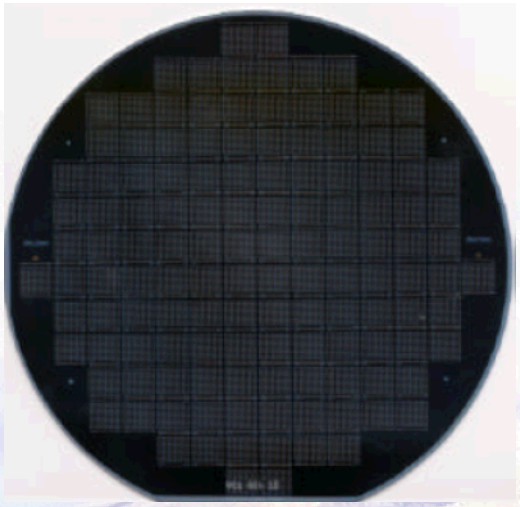


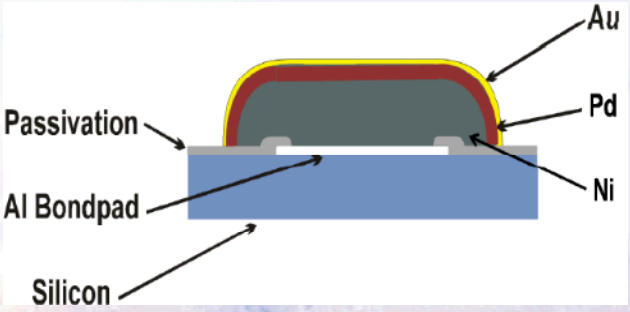
ENIG or ENEPIG Bump Metallization on Aluminum Pads

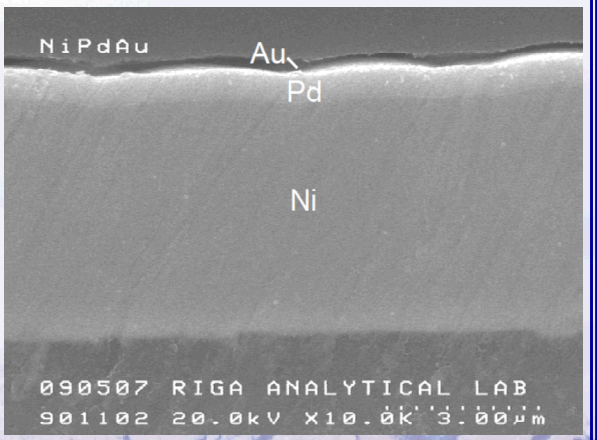
- The second and third type of bumped test flip chip die consist of 24x40 arrays of ENIG or ENEPIG bump metallization on aluminum pads.
  - The ENIG/ENEPIG metallization on 150mm wafers were made by Pac Tech USA Inc.
  - The aluminum pad size on the test die was 100μm and octagonal in shape. The pad passivation openings are ~80μm and octagonal in shape on 400μm pitch in the x direction and 200μm pitch in the y direction.
  - The ENIG bump metallization consists of 5μm, 10μm, 15μm, 20μm, or 25μm thick nickel and 100nm thick of gold on aluminum pads.
  - The ENIG bump metallization consists of 5μm, 10μm, 15μm, 20μm, or 25μm thick nickel,0.35μm thick layer of palladium, and 100nm thick of gold on aluminum pads.
  - The ENIG or ENEPIG bumped arrays were bonded together (ENEG to ENIG, ENEG to ENEPIG, ENEPIG to ENEPIG) or were bonded to 10mm x 10mm silicon substrates coated with a blanket film of 1μm thick evaporated gold on a 200nm titanium adhesion layer (ENEG to gold, ENEPIG to gold).

ENIG or ENEPIG Bump Metallization on Aluminum Pads

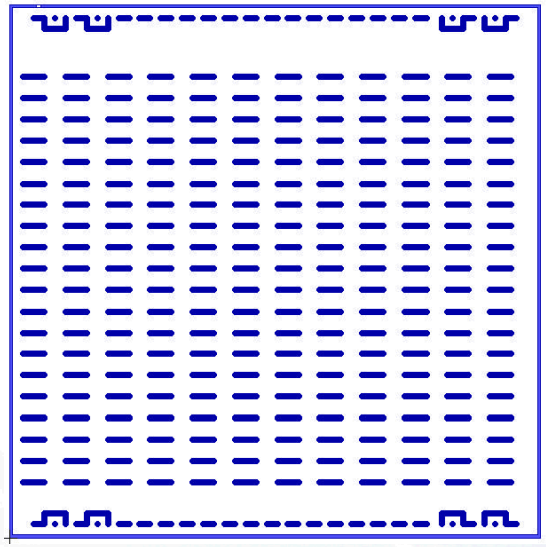
- ENIG or ENEPIG bumped wafer.
- Cross section of ENEPIG bump.
- SEM image of an ENEPIG bump in cross section.

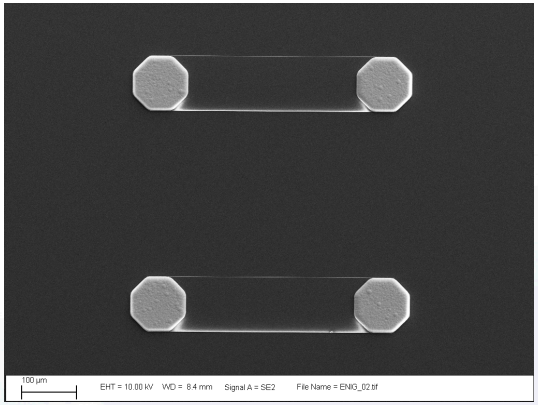






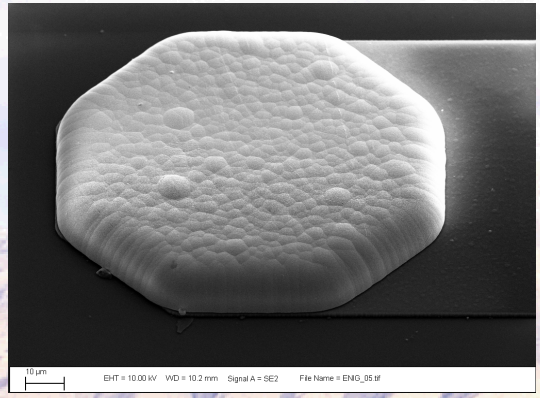
ENIG or ENEPIG Test Die

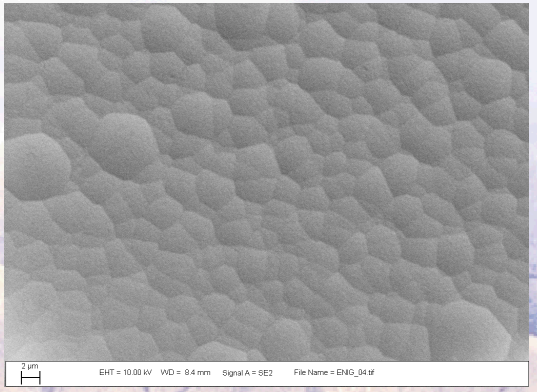




pitch	200/400 µm
pad size	100 µm
passivation opening	80 µm
bump size*	90 µm
pad configuration	area
pad geometry	octagonal
number of pads	572 I/O´s
pad material	1 µm AlSi

*size of Ni/Au UBM: 5 µm





Surface Treatment of Au Pads

- The gold surfaces of the test die were:
- Coated with dodecanethiol SAMs
  - Before SAM coating, the gold was cleaned in dilute piranha solution for 5 minutes, rinsed in water, air-jet dried, then immersed in a 1mM solution of dodecanethiol in ethanol for 24 hours, rinsed in ethanol, and air-jet dried.
- Argon plasma cleaned for 5 minutes (375W, 15 psi).
- Argon plasma cleaned for 1 minutes (100W, 15 psi).
- Cleaned in a dilute piranha solution (5:1:1 solution of deionized water, H_2SO_4, and 30% H_2O_2) for 5 minutes.
- The time till bonding ranged from 0 to 8 days for the SAM coated parts.

Flipchip Bonding for Treated Au Bumps

- The bonds were made using a Finetech Lambda flip chip bonder.
- For the gold stud bumps.
  - 150-155°C.
  - 30-45 seconds.
  - 20N of force.
- For the ENIG / ENEPIG arrays.
  - 185°C - 300°C.
  - 1 - 20 minutes.
  - 25N - 200N of force.
- The bonds were sheared using a Dage 4000 shear tester.

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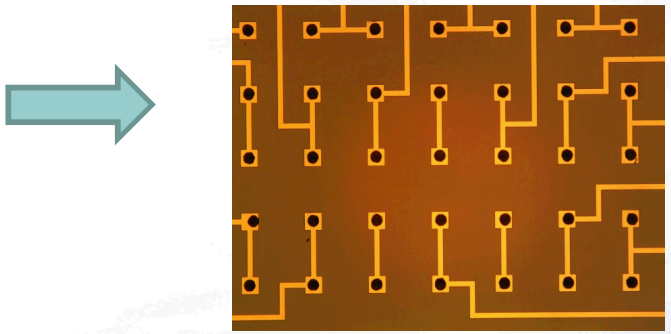
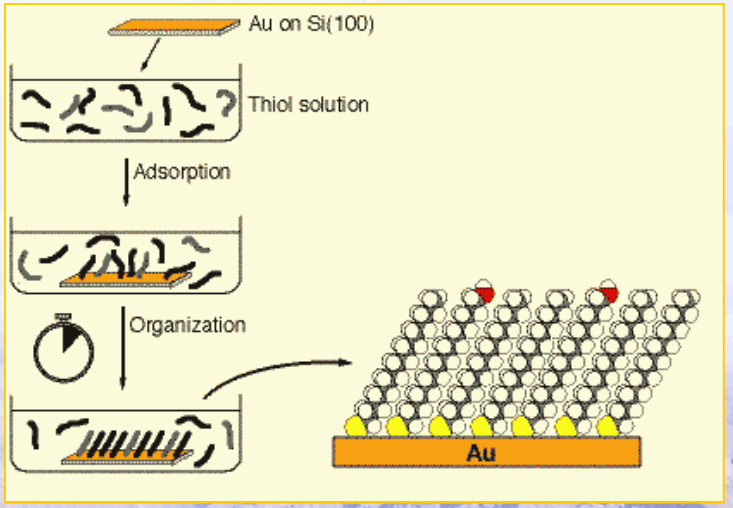
Bonding SAM-coated Au stud bumps

- 8 x 8 array of 25 μm-tall stud bumps.



- Three surface treatments:
  - Argon plasma (1 min., 100W)
  - 5:1:1 DI-H_2O:H_2SO_4:H_2O_2 5 min.
  - SAM coating (1mM dodecanethiol in ethanol for 24 h).



- Bonding was done at 150-155°C for 40-45 seconds under 20N.

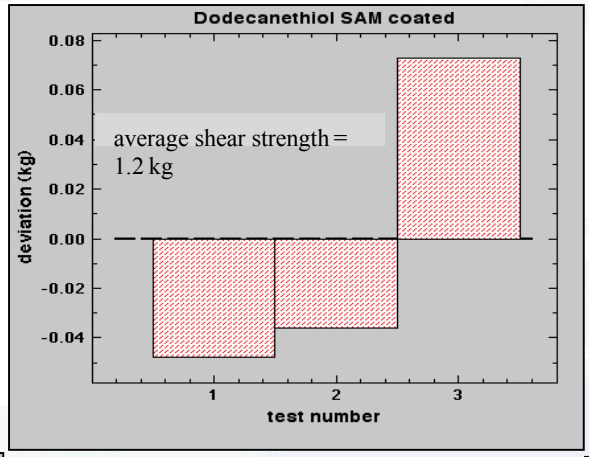
Gold Stud Bumping

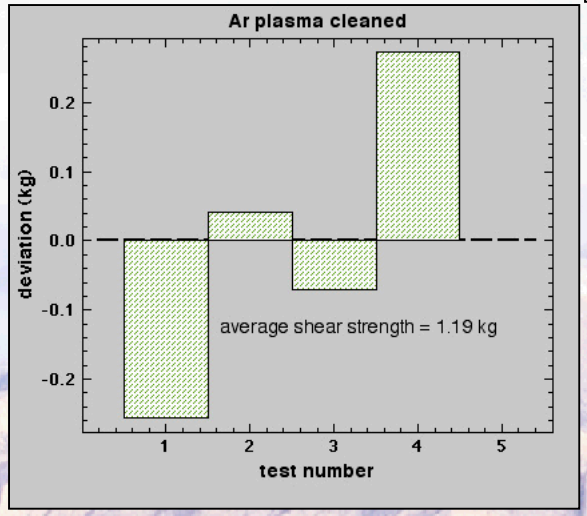
- Three surface treatments (dilute piranha clean, argon plasma clean, and dodecanethiol SAM coating) were used for the gold stud bump bonding experiments.
- The bonding was done immediately after the surface treatment.
- The 25μm thick gold stud bumps formed strong bonds at 150°C -155°C,
- The bonds were formed in 30-45 seconds under moderate force (18N-20N).
- Shear strengths were independent of the surface treatment. The average shear strength was ~1.2kg.
- The bonding temperatures are comparable to those reported in previous studies of argon plasma cleaned gold bumps.

Shear strengths as a function of surface treatment

•**SAM-coated bumps:**

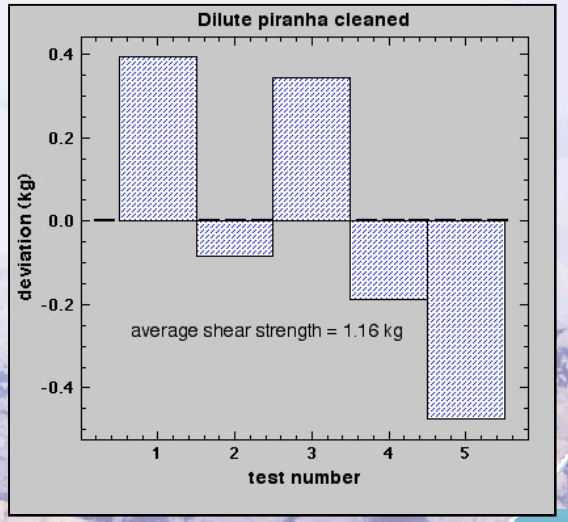
Shear strength independent of time till bonding; small deviation from the average.





•**Uncoated bumps:**

Shear strength depends on time till bonding; greater deviation from the average.



SAM Treated ENIG / ENEPIG Arrays Bonding

- Bonding experiments conducted with ENIG/ENEPIG bump arrays having 100nm thick immersion Au on the pad surfaces to 1μm thick blanket gold films with 100nm titanium on Si substrates.
- The arrays and substrates were coated with dodecanethiol SAMs.
- The lighter force was not sufficient to form strong bonds that meet the Mil-Std 883 die shear strength requirement of 1kg.
- Strong bonds were formed when the arrays were bonded under 200N at 180°C for 20 minutes.

180°C, 20 min.	25 N	200N
ENIG	0.13 - 0.22 kg die shear	3.31 – 4.23 kg die shear
ENEPIG	0.24 - 0.70 kg die shear	3.00 – 4.65 kg die shear

Plasma Treated ENIG / ENEPIG Arrays Bonding

- Bonding experiments conducted with ENIG/ENEPIG bump arrays having 100nm thick immersion Au on the pad surfaces to 1μm thick blanket gold films with 100 Ti on Si substrates.
- The arrays and substrates were Argon plasma treated (100W, 1 minute).
  - Bonded at 180°C .
  - 25N, 50N, 200N of force.
  - 1, 5, 10, 20 minutes.
- ENIG bonded at 180°C, 5 minutes, 25N.
- ENENIG bonded at 180°C, 1 minutes, 25N.
- Strong bonds were formed when the arrays were bonded under 200N at 180°C for 1 minute for both ENIG and ENENIG (50N at 180°C for 1 minute).
- The lighter force was not sufficient to form strong bonds that meet the Mil-Std 883 die shear strength requirement of 1kg.

Plasma Treated ENIG / ENEPIG Arrays Bonding

180°C, 1 min.	25N	50N	200N
ENIG	0.00 - 0.38 kg die shear	0.08 - 0.29 kg die shear	1.84 - 3.36 kg die shear
ENEPIG	0.47 - 0.83 kg die shear	1.54 – 1.62 kg die shear	2.09 - 2.47 kg die shear

180°C, 5 min.	25N	50N
ENIG	0.00 - 0.00 kg die shear	0.15 - 0.77 kg die shear
ENEPIG	0.00 - 0.00 kg die shear	0.83 – 1.04 kg die shear

180°C, 20 min.	25N	50N
ENIG	0.05 - 0.18 kg die shear	0.25 - 0.26 kg die shear
ENEPIG	0.79 - 0.64 kg die shear	0.76 – 1.49 kg die shear

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Conclusions

- Gold stud bump arrays formed strong bonds at 150°C to 155°C regardless of the surface treatment used (dodecanethiol SAM coated, argon plasma cleaned, or dilute piranha cleaned).
- An advantage of SAM coating the gold surfaces is that the hold time or storage time prior to bonding can be extended, compared to that of argon plasma cleaned gold surfaces.
- Shows the feasibility of ENIG and ENEPIG bumps for solderless flip chip bonding.
- The ENIG/ENEPIG pad arrays with 100 nm thick immersion gold films bonded to 1μm thick gold films at 180°C with dodecanethiol self-assembled monolayers or plasma treated.
- We are presently testing daisy chain electrical test structures with ENIG to ENIG, ENIG to ENENIG, and ENEPIG to ENEPIG .

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