Thermosonic-Adhesive Flip Chip Assembly for Advanced Microelectronic Packaging

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Outline

- Background to project; aims & objectives
- Work to date
- Future plans
- Conclusions
Flip chip technologies

Solder-based
- Controlled gap
- No gap control

Adhesive-based
- Non-conductive adhesive
- Anisotropic conductive adhesive
- Isotropic conductive adhesive

Metal-metal bond
- Direct thermo-compression
- Thermosonic compression

Mechanical contact
- Spring force; no intermediate layer
ACA packaging

**Advantages**
- Low cost
- Low cure temperature
- High density assembly
- High flexibility

**Disadvantages**
- Large joint resistances
- Reliability failures

Source: Sony Chemical
Thermosonic flip chip

Thermosonic bonding – basic principle

- Metal-metal bond formed by combination of heat, pressure and ultrasonic energy
- Ultrasound allows bonding at lower temp and/or pressure than with thermo-compression
- Various materials systems e.g. Au-Au, Au-Al, Cu-Al

History

- Used for wire bonding since mid 1960s – serial process
- First applied to flip chip in late 1990s (gold stud bumps on chip pads)

Previous work at Imperial College:

Advantages

- Direct metal to metal bonding
- No additional bonding materials
- Low bond temp
- High density assembly

Disadvantage

- Limited chip size


http://www.sound-gear.info
IeMRC project

Project aim

• To introduce a thermosonic bonding step into ACA/NCA assembly in order to replace the mechanical contacts by metal-metal thermosonic bonds

Objectives

• Demonstrate feasibility of TA assembly, both for NCA and ACA
• Optimize processes once established
• Examine electrical performance & reliability, and compare with traditional adhesive flip-chip processes
• Investigate feasibility of using low-cost ACA particles e.g. Cu, Al
• Apply the new technology to a demonstrator that can be functionally tested
Project tasks

- Design & construction of TA flip chip bonder
- Thermo-sonic (TS) bonding of conductive particles in adhesive
- Direct metal bump to metal pad TS bonding in adhesive
- Alternative TA bonding materials
- Demonstrator
- Reliability tests
- Electrical measurements

Heating, Pressure and Ultrasonic Energy

Bump
Adhesive
Conductive particle

Flip chip
Bump
Pad
Adhesive
Substrate
Work to date

**TS bonder upgrade**
- Fast IR laser heating of flip-chip pick-up tool
- Vacuum substrate holder
- Other improvements to existing bonder

**Flip chips and substrates**
- Dummy flip chips with electrical test patterns
- Flex and glass substrates

**First trials with and without adhesive**
- Chip to glass substrate (COG)
- Chip to flex substrate (COF)

**TA bonding materials**
- Process for ACA with embedded gold cylinders
- First batch in fabrication
TS bonder developed in earlier EPSRC project

- 40 W 60 kHz ultrasonic transducer & horn
- Vacuum pick-up tool for chip
- Load cell for controlled bonding force
- Heated stage (up to 250 °C)
- Substrate holding clamps
- Through-substrate alignment microscope
- Optical parallelism adjustment (± 1.5 μm for 3×3 mm² die)

Additional facilities required for TA bonding

- Rapid heating & cooling – to allow control over adhesive flow & curing
- Substrate chuck capable of handling rigid and flex substrates
IR laser heating of pick-up tool

Rationale

• Would like non-contact heating to avoid disturbance of ultrasonic path to tool
• Fibre-coupled IR lasers can provide highly localised heating

Verification

• FEA carried out to establish laser power requirements and effect on transducer temp

Temp profile at tool tip for 10 W point heat source

Thanks to Dr Lu and Dr Yin of Greenwich University for assistance with FEA
Final solution

- Symmetrical heating by two 30 W, 970 nm fibre coupled laser diodes (DPSS pump lasers)
- Compressed air cooling
- Heating rate up to \( \sim 35 \, ^\circ\text{C}/\text{sec} \); cooling to -10 \( ^\circ\text{C} \)/sec
- Fully interlocked, Class I enclosure (WIP!)
Vacuum substrate holder

Requirement

• Method for clamping substrates adequately for TS bonding
• Must be compatible with existing (through-substrate) alignment and co-planarity optics

Solution

• Glass window with machined vacuum channels – works well with both substrate types
Dummy flip chips

**Processing**
- Chip fabrication (ECS Partners Ltd)
  - Al metallisation over oxide
  - Passivation SiO₂/ Si₃N₄ (0.25/1 µm)
  - Dicing
- Bumping (in-house)
  - Electrolytic Ni plating (4 µm)
  - Electrolytic Au plating (1 µm)

**Chip size and structure**
- 3×3 mm² chip with 88 I/Os, 100 µm pitch
  - Bumps: Al/Ni/Au (1/4/1 µm)
- 4.5×4.5 mm² chip with 144 I/Os
  - Bumps: Al/Ni/Au (1/4/1 µm)
Test substrates

Substrate designs (both chip sizes)

- Flex substrates - PI/Cu/Ni/Au = 38/8/5/0.8 µm
- Glass substrates - Silica/Ni/Au = 500/5/1.0 µm

Manufacturers

- Flex: Compass Technology Com. Ltd.
- Glass: in-house

One electrical test group matched to the chip pattern
Initial assembly trials

Materials

• NCF (Sony MA101-40) or no adhesive
• Glass and flex substrates
• 3×3 mm² chip size

Conditions

• Film lamination: 0.2 MPa @ 80°C
• Final bonding force: 3.75 kg (43 gf/bump)
• Ultrasonic power/time: 16 W/300 ms
Results of initial trials

Initial inspection

• First assemblies show some co-planarity errors – needs optimization
• Also an alignment issue when using adhesive

Electrical tests

• Four-wire measurement using test groups
• ~6 mΩ joint resistance achieved in TA bonding
• Joint resistance: TA<TS<ACA?
  • TA may be lowest due to direct Au to Au welding & adhesive shrinkage?
• Graph shows selected individual tests
Results of initial trials (2)

Inspection following disassembly

- Chip separated from substrate following dissolution of adhesive with acetone
- Some Au bump residue seen on substrate pad; torn from bump during disassembly – suggests metal-metal weld
- Encouraging result but early days
Manufacture of TA bonding materials

1. **Seed layer and PR coating**
   - PR developed
   - Au stud electroplated
   - PR removal
   - Au seed layer dry etched

2. **NCF placement**
   - UV laser ablation
   - Laser transfer

3. **Sony NCF**

4. **Laser transfer onto Sony NCF**

5. **TA bonding**

6. **Au studs on fused silica wafer**
Au stud fabrication

Stud design

- Size: Ø10, 2.5µm high
- Pitch: 25 or 30µm; 6-9 studs/bump

Trial fabrication

- Au seed layer on fused silica wafer: 200 nm
- Au stud electroplated at 3 mA/cm²

Seed layer etching

- Sputter etching - 20 mins @ 200 W
- Etch rate ~10nm/min
Next steps

Further assembly trials with Sony NCF/ACF materials
- Explore process parameters
- Optimise using joint resistance as key performance indicator

TA bonding materials
- Complete and evaluate custom ACA (solid gold particles in NCF)

Reliability tests (with GE Aviation Systems)
- Thermal and humidity tests
- Temperature cycling / thermal shock if time allows
- Joint resistance as main criterion
Conclusions

- Aiming to improve the performance of adhesive-based flip chip assembly by incorporation of thermosonic bonds
- If successful, proposed processes will expand the range of applications for adhesive assembly
- Work to date has focused on putting facilities and materials in place. Work on TA bonder has produced a highly versatile bond tool
- Now need to optimise processes and evaluate through performance and reliability testing