Bonding technology for rough environments
Seminar at HiVe (Vestfold University College)

3 December 2010, Auditorium “Tønsberg”

Schedule
12.30 Welcome (Knut Aasmundtveit, HiVe)
   High Temperature Power Electronics Packaging –
   Presentation of KMB project HTPEP (Andreas Larsson, SINTEF)
   High Temperature SiC Power Transistors (Anders Lindgren, TranSiC)
   PhD in HTPEP (Torleif Seip, SINTEF/ HiVe)
   Discussion
14:00 Fine Pitch Interconnect of Microelectronics and Microsystems for use in
   Rough Environments (ReMi) –
   Presentation of KMB project (Maaike V Taklo, SINTEF)
   Metal coated polymer spheres, novel interconnection technology
   (Helge Kristiansen, ConPart)
   PhD in ReMi (Hoang-Vu Nguyen, HiVe)
   Discussion
15:00 Concluding remarks
High Temperature Power Electronics Packaging

HTPEP

HiVe 03.12.2010
Funding and partners

• Norwegian research project
  – PETROMAKS program
    • 2009 – 2012
    • 6.4 MNOK

• Partners
  • 1.6 MNOK
Project keywords

- Packaging
- High power
- Harsh environment
  - High temperature
  - High pressure
  - Vibrations
- Reliability
  - Downhole operation
- Silicon carbide (SiC) bipolar transistors (BJT)
  - Power module design for electric motor
Packaging

Die attach technology

- SiC BJT from TranSiC
- AuSn SLID bonding
- Nano foil bonding
- Standard high temperature soldering

BitSiC BT1206AA/P1

Nano foil
Wang J. et al. 2004

AuSn SLID
Knut Aasmundtveit et al. 2009
Packaging

Substrate technology

- Silicon nitride, $\text{Si}_3\text{N}_4$
- Aluminum nitride, AlN
- Advanced materials
  - SiC particle–reinforced Al (AlSiC)
  - Diamond particle–reinforced SiC (DR–SiC)
Packaging

Simulation aided design

• COMSOL Multiphysics

Warpage

Thermal performance

Hot spots
(Stress concentrations)

Plastic strain & fatigue

Au layer

Cu layer
Top side interconnect

- Au ribbon bonding
  - Large cross-sectional area
- Au stud bumps possible for sandwich solution

Luu T. T. et al. 2010
Case study

Concept development
Case study

Concept development
Case study

Concept development

- Version 1.1
  - Thermal distribution
    (Heat transfer coefficients used for convective flow)

Still

\[ T_j \approx 315^\circ C \]

Forced convection

\[ T_j \approx 265^\circ C \]

NB! Different scales on the plots, hence the dissimilar color distribution
Thanks for your attention!

HTPEP

Andreas Larsson
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Power Transistors in Silicon Carbide
TranSiC was founded in 2005
Spin-off from the Royal Institute of Technology, Stockholm
Products available since 2009
R&D, Production, Testing and Sales
Adding foundry production
Current investors:
  – Volvo Technology Transfer AB
  – Industrifonden
  – Midroc New Technology
Silicon Carbide characteristics

Key Features SiC:

- Wide Band Gap (3 times)
- High Breakdown Field (10 times)
- High Thermal Conductivity (3 times)

SiC compared to Si in Power Transistors:

- High operational temperature
- High radiation tolerance
- Increased efficiency
- Smaller devices
- Faster Switching Capability
- Robust and reliable
Why Bipolar Junction Transistors?

- Low Vcesat
- More efficient
- Better utilization of material
- Higher current density
- Faster switching
- Easy paralleling
- No active Si-oxide
- Low leakage at high temperatures
Available products 2010

- High Efficiency discreets
  - 1200V 6A and 20A
  - TO-247
  - Low Vce(sat)
  - Fast switching
  - Tolerant to natural radiation

- High Temp / Hi-Rel discreets
  - 1200V 6A and 20A
  - TO-258
  - Operational temp up to Tj 250°C
  - Radiation Hard
  - Low Vce(sat)
  - Fast switching
High temp packages

- Based on mil TO-258
- Isolated design
- Added SiN substrate
- High temp substrate attach
- High temp die attach
- Polyimide coating
Static I-V Characteristics

150°C

$U_{CE} = 0.75V$ Gain = 35

250°C

$U_{CE} = 1V$ Gain = 28
Vce(sat) Characteristics

Vce(sat) vs. Collector current

Vce(sat) vs. temperature
Gain Characteristics

Gain vs. Collector current

Gain vs. temperature

Gain Characteristics

Gain vs. Collector current

Gain vs. temperature

2010-12-13

www.transic.com
Leakage Characteristics

- Very low leakage
- Low thermal generation rate of charge carriers due to the wide band gap

Leakage current @ 1200V
Switching Temperature Dependence

**Turn on**

**Turn off**
SPICE Model Agreement

I-V Characteristics

Base-Collector Cap

Measured
Simulated

$I_B = 200 \text{ mA } @ 25 ^\circ \text{C}$

$I_B = 250 \text{ mA } @ 150 ^\circ \text{C}$

$I_B = 300 \text{ mA } @ 250 ^\circ \text{C}$

$C_{BC}$ (pF)

$V_{BC}$ (V)
High efficiency applications

- PV Inverters
- Industrial Drives
- Wind Power
- Electrical Hybrid Vehicles
High temp / Rad hard applications

- Oil and Gas
- Geothermal
- Aerospace
- Space
- Defense
TranSiC Projects Q4 2010

Key Projects October 2010:

- Geothermal / Drilling 8 US + Norway
- PV Inverter 6 Eu + US
- HEV 3 US + Sweden
- Space 2 US
Contact

Thank you for your attention!

www.transic.com
anders.lindgren@transic.com
Fine Pitch Interconnect of Microelectronics and Microsystems for use in Rough Environments

ReMi

HiVe 03.12.2010
Funding and partners

• Norwegian research project
  – BIA program
    • 2008 – 2012
    • 6.8 MNOK

• Partners
  • 1.7 MNOK

Norwegian research project
– BIA program
• 2008 – 2012
• 6.8 MNOK

Partners
• 1.7 MNOK
Project keywords

• Packaging
• Fine pitch
• Harsh environment
  – Thermal cycling
  – Temperature storage
  – Vibrations
• Reliability
  – Ammunition, consumer application, geophysical survey
• Interconnects based on
  – Metal coated polymer spheres (MPS)
Project structure

Conpart

SINTEF ICT

Westfold University College

IDEX

Nammo

WesternGeco

OSI

Optoelectronics

R&D Material technology

R&D Packaging processes

Product implementation

Volume production
Project tasks

• Case I: Fuse
  – FFI and Nammo

• Case II: Fingerprint sensor
  – Idex

• Case III: Ceramic package
  – WesternGeco

• PhD study: Hoang Vu Nguyen
• Interconnect challenge: MEMS onto PCB

• Isotropic conductive adhesive (ICA)
  – 4-30 µm particle sizes in Epotek 353
  – Stensil printing
  – Amount of MPS above percolation limit

• 2008-2009
  – Design of MEMS and dummies
  – Design of PCB test cards
  – Mounting of chips (process development)
  – Thermal cycling until short

• 2009-2010
  – Design of card for shooting tests
  – Mounting of chips
  – Limited thermal cycling
  – Shooting tests

• Characterization by electrical measurements and cross sections

• Conclusions
  – ICA with MPS is applicable for the application
  – Stencil printing must be optimised for the finest pitch when using the largest spheres
Case II: Fingerprint sensor

- Interconnect challenge: MEMS onto ASIC
  - Anisotropic conductive film (ACF)
    - Film from subcontractor (using MPS from Conpart)
    - Lamination
    - Amount of MPS below percolation limit
- 2008-2010
  - Literature review
  - Assembly (VUC/Tampere)
    - Lamination (below Tg)
    - Bonding (above Tg)
  - Cross-section & surface analysis
  - Thermal analysis (Tg)
    - TGA/DSC
  - Testing
    - “Reflow”
    - TSC
    - Humidity
- 2011: Publication planned

Assembly at Tampere University of Technology (pressure needed)
Pads for daisy chains
IR for inspection
Case III: Ceramic package

- Interconnect challenge: Ceramics onto PCB
  - MPS with solder as BGA
    - Spheres from Sekisui and Conpart
    - References: SnPb and SnAgCu BGAs
    - Solder onto LTCC
    - Mounting onto PCB

- 2008-2010
  - Review
  - Chip design
  - Board design
  - Mounting of balls on chip
  - Mounting of chip on board

- 2011
  - Thermal cycling, shock, vibrations
  - Publication?
Thanks for your attention!

ReMi

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www.conpart.no
Polymer-particles for Electrical interconnects
The challenge

- Electrical contacts are exposed to severe cyclic strains as well as potential mechanical shocks during its life-time.
- Combining electrical conductivity of metal with the mechanical elasticity and toughness of a polymer
Conpart solution

- Develop materials where the mechanical and electrical properties are de-coupled
- Use of metal plated polymer balls
  - Combining the mechanical properties of polymers with the conductivity of metals
- Tailor-making mechanical properties of the polymer
- Unique manufacturing process for unsurpassed size distribution and homogeneity of material
Numerous applications

BGA / CSP technology

Anisotropic Conductive Adhesive

Isotropic Conductive Adhesive

mandag 20. desember 2010
Unique particle technology

- Extremely narrow size distribution
- Predefined size
- No need for size classification
- Tailor made properties
Mechanical testing

- Deformation during uniaxial load
  - Deformation as a function of load
  - Measure deformation as a function of applied load
Disperse particles on a suitable substrate

Locate “individual” particles without any close neighbour

Position indenter tip onto chosen particle
Mechanical properties
Metallised

Graph showing the relationship between Force (mum) and Deformation (nm) for different gold samples (Gold A, Gold B, Gold C, Gold D) and a specific value of 38.0002.
Metallised II

Different stages of compression

mandag 20. desember 2010
BGA: Electrical resistance

- Whalley used 2D FEA and analytical models
- Predicted an increase of around $4 \times$ compared with solid solder ball e.g. 0.15mΩ to 0.54mΩ
- Is this significant? Unlikely!
- $R$ of 100µm 1oz Cu track is $\approx 4.5$mΩ/mm
BGA: Reliability estimations

- Several computational modelling studies also presented
- Most modelling studies confirm reduced stress levels, but do not use non-linear cyclic analysis to predict life
- Guillén Marin et al. (2008) used cyclic models to estimate cyclic life and to explore some design variables

<table>
<thead>
<tr>
<th></th>
<th>$\Delta \epsilon$</th>
<th>$N_f$</th>
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</thead>
<tbody>
<tr>
<td>Conventional (SMD)</td>
<td>0.635</td>
<td>34</td>
</tr>
<tr>
<td>Conventional (NSMD)</td>
<td>0.387</td>
<td>56</td>
</tr>
<tr>
<td>Polymer core BGA</td>
<td>0.053</td>
<td>413</td>
</tr>
</tbody>
</table>
BGA: Thermo-mechanical fatigue

Polymer core BGA
Conventional (NSMD)
Conventional (SMD)
175µm thick stencil
150µm thick stencil
125µm thick stencil
100µm thick stencil
75µm thick stencil
50µm thick stencil
0.22mm pad radius
0.21mm pad radius
0.19mm pad radius
0.18mm pad radius
20° wetting angle
10° wetting angle
0° wetting angle

Number of cycles to failure

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Anisotropic Conductive Adhesive

- The adhesive film is applied uniformly
- Pressure is applied during curing, giving conduction only between pads
- Thermoplastic or thermosetting
- Film (tape) or paste
Silicon on Flex

Si chip

Adhesive

Au plated Ni layer

Copper on flex
Magnetic ordering of particles

Particles trapped under a Flip Chip bump (Holloway, Interpack’99).

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ICA: Percolation

• Continuous electrical network
  – Particle to particle

• Strongly dependent on “characteristic length”
  \[ \zeta = \frac{L}{d} \]

• Dependent on “orientation” of particles (non-spherical)
ICA: Interesting electrical and mechanical properties

Electrical and Mechanical properties as a function of Volume fraction (% weight)
Seminar on Bonding Technology for Rough Environments

Metal Coated Polymer Spheres for Fine Pitch Interconnects
Reliability and Failure Mechanisms

Ph.D. Candidate: Hoang-Vu Nguyen

Principal supervisor: Asc. Prof. Knut Aasmundtveit
Subsidiary supervisor 1: Dr. Rolf Johannessen
Subsidiary supervisor 2: Prof. Yngvar Berg

3rd Dec., 2010
Interconnection technologies based on Metal coated Polymer Spheres (MPS)

- Increase the flexibility for interconnects
- Reduce stress induced on interconnects
- Potentially improve mechanical properties and reliability of systems
- MPS could be versatilely employed
Anisotropic Conductive Adhesive Film (ACF)

- Alternative to solder interconnects
- **Fine pitch**
- Improve mechanical properties
- Improve reliability in rough environments
- Low cost
- Environmental friendliness


M. J. Yim et al., International Journal of Adhesion & Adhesives 27 (2007), pp 77–84
Anisotropic Conductive Adhesive Film

- **Electrical properties:**
  - Insignificant differences between samples with interconnect pitch from 110 µm to 200 µm
  - High bond yield
  - No short circuit between adjacent joints of the two daisy chains

- **High mechanical shear strength**
  - above 500 N for 3.1 x 3.1 mm² die

- **Thermal shock cycling test (-40 - +125 °C)**
  - 750 thermal cycles have been tested
  - Contact resistance slightly decreased
  - No open circuit or short circuit between the two daisy chains

Interconnect pitch: 110, 125, 150 and 200 µm

Silicon chips and substrates were fabricated by MiNaLab, SINTEF ICT, Norway
Isotropic Conductive Adhesive (ICA)

- Conventional ICA (Ag epoxy)
- Adhesive matrix
- Conductive particles

- Novel ICA filled with MPS

- Critically increase the viscosity of the system?
  - limit the processing capabilities of the novel ICA

- Reduce adhesion strength?
  - reduce volumetric fraction of the adhesive matrix

J. Morris, Lecture at Vestfold University College, Borre, Norway, 2008
Feasibility study – Adhesive filled with non-metalized polymer particles

Rheological properties

Well fitness of both semi-empirical models to the measured data

Negligible long range interactions between particles in our system

Mechanical shear strength

Summary

- Anisotropic conductive adhesive film
  - Insufficient differences between samples with interconnect pitch from 110 µm to 200 µm
  - No open circuit or short circuit between adjacent joints after 750 thermal shock cycles (-40 - +125 °C)

- Isotropic conductive adhesive
  - ICA filled with MPS is very promising
  - Further study for mechanical, electrical properties and reliability
Thank you for your attention!

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