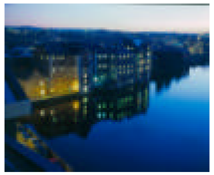
Evaluation of Adhesive Materials for High-Reliability Flip-Chip Assembly

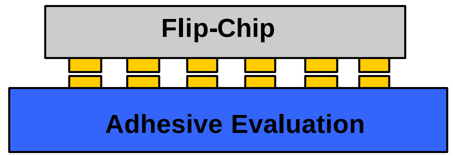
Finbarr Waldron

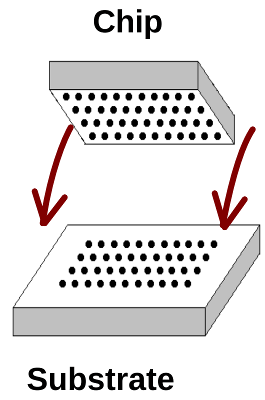


**Tyndall National Institute,
Lee Maltings, Prospect Row,
Cork, Ireland.**

Presentation Outline

- **Objectives & Technology Overview**
- Flip-Chip Adhesives Evaluation Programme
  - *Materials Selection & Property Evaluation*
  - *Flip-Chip Test Chip*
  - *VFL Substrate*
  - *Test Vehicle Assembly / Assembly Verification*
  - *Reliability Evaluation*
- Conclusions & Acknowledgements





Introdution - Aims & Objectives

- Evaluate reliability of commercially-available flip-chip adhesives for use in space applications.
- Study a representative range of materials.
- Determine thermomechanical properties & behaviour.
- Assess quality of assembly achievable.
- Measure thermal performance.
- Investigate ability to withstand harsh environmental stresses.

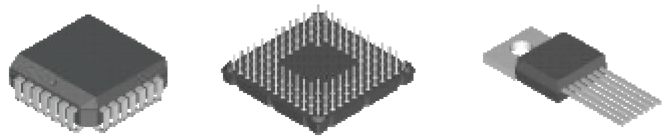
Work Undertaken by:

- Tyndall National Institute, Cork, Ireland (Prime Contractor)
- ASTRIUM, Velizy, France (VFL substrates)

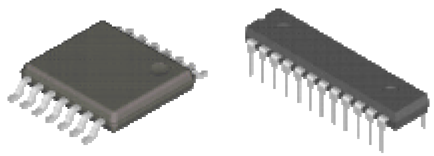
Micropackaging Technology

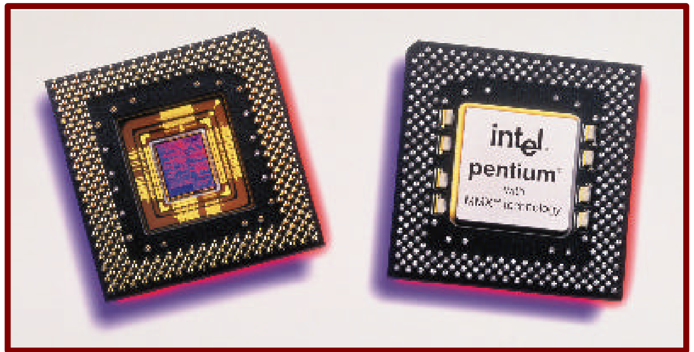
Traditional Packaging Technologies:

- **Advantages:**
  - Well proven technologies
  - Robust & Reliable (especially ceramic & metal-can)
  - Good thermal performance (ceramic / metal)
  - Cost-effective (plastic)



- **Drawbacks:**
  - More complex than necessary
  - Electrical performance
  - Limited density
  - Size & weight

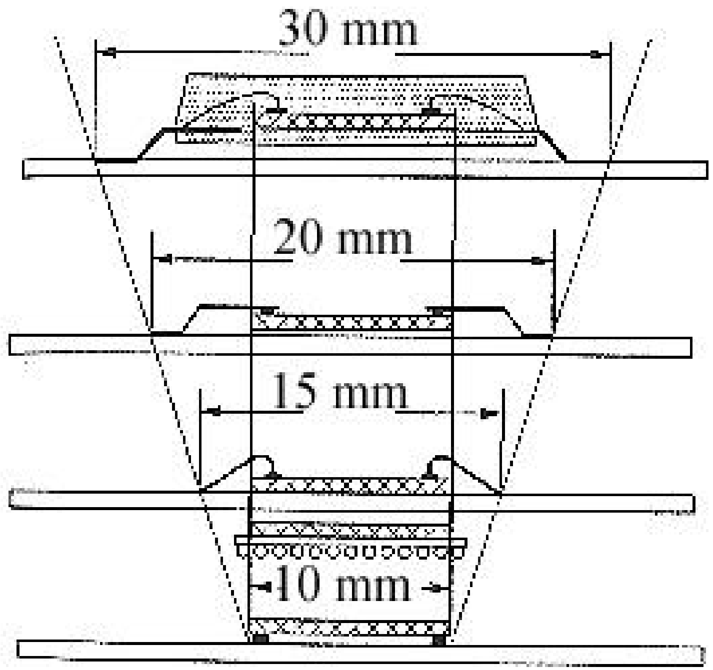




Micropackaging Technology

Comparison of Alternative Packaging Options:

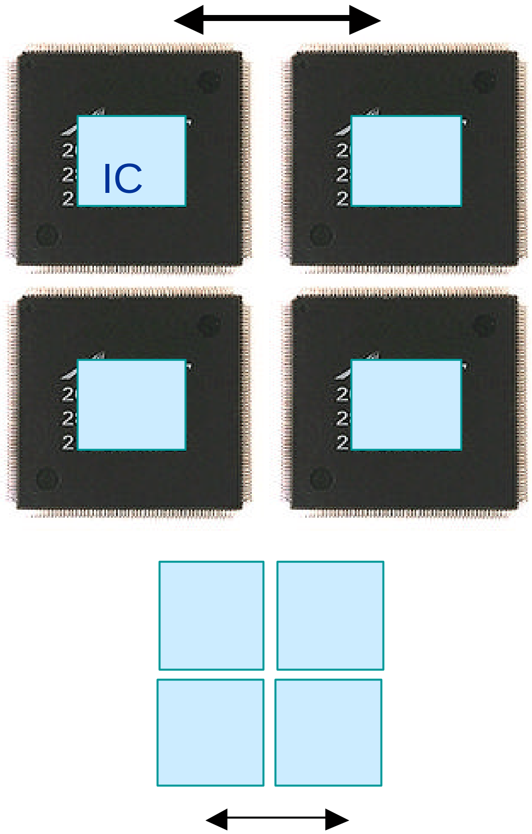
Type	Footprint Area
QFP:	900 mm² - 100%
TAB:	400 mm² - 44%
COB:	225 mm² - 25%
CSP:	115 mm² - 13%
Flip-Chip:	100 mm² - 11%



(Source: Hewlett Packard)

Flip-Chip Technology

IC edge to edge distance using plastic packages



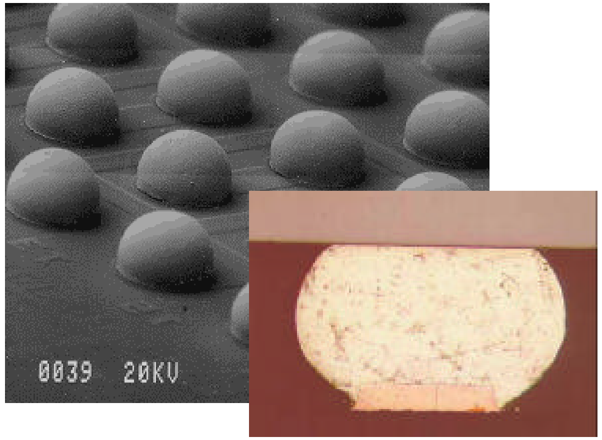
IC edge to edge distance using flip-chip

Flip-Chip Packaging:

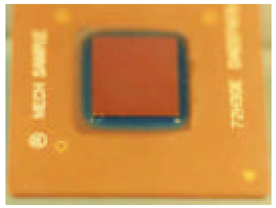
- **What?**
  - ***Direct attachment of the IC to a substrate***
- **Why?**
  - ***Almost zero interconnection parasitics between chip and package***
  - ***Possible to put chips almost edge to edge***
  - ***High packing density of ICs***
    - *Standard PCB: 10% of area occupied by silicon (“packing density”)*
    - *Flip-chip PCB: 75% packing density*
  - ***Very short interconnect – high speed***

Flip-Chip Technology

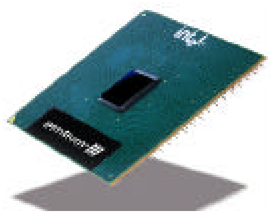
Solder-based Flip-Chip Assembly:



- **Controlled Collapse Chip Connection (C4)**
- **Originally developed by IBM in 1960's.**
  - **Form solder bumps on chip pads**
    - ***Mask & deposit***
    - ***Plated bumps***
  - **Place chip on substrate & align accurately**
  - **Reflow (high temp.)**
  - **Underfill (increases bond area – reduces stress)**



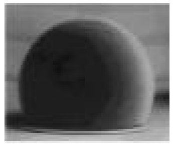
Adhesive-based Assembly:



- **Chip bumps not always required**
- **Typical bump metalisation Ni/Au (Electroless deposition)**
  - **Adhesive applied to substrate (blanket or selective deposition)**
  - **Place & align chip**
  - **Cure adhesive (usually low temp. process).**

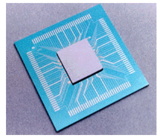
Flip-Chip Assembly Technologies

Solder Flip-Chip:



- Advantages:
  - Very robust joints.
  - Solder wetting forces aid alignment.
  - Good thermal performance
    - heat transfer through joints.
  - Good electrical performance.
  - High density, small size & weight.
- Disadvantages:
  - Thermo-mechanical stresses high
    - joints unyielding.
  - Requires very well controlled process.
  - High temperature process.
  - Cost – need high density to justify.

Adhesive Flip-Chip:



- Advantages:
  - Compliant nature - low stresses.
  - Fine pitch capability.
  - Easy assembly process
    - low temp & no fluxes.
  - Reasonable cost.
- Disadvantages:
  - Poorer electrical performance
  - Reduced thermal performance
  - Long term reliability questionable
    - harsh environments ??
  - Best suited to small-area die.

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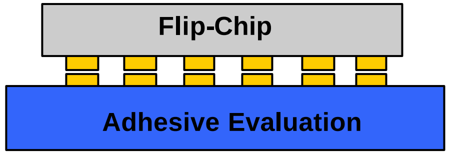
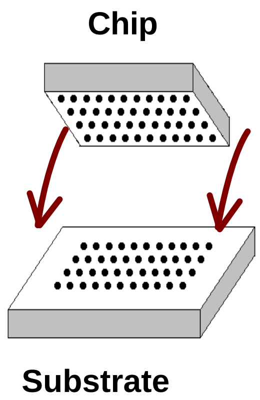
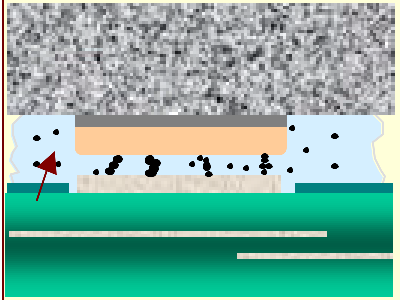




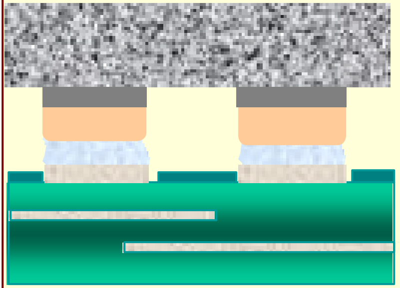
Adhesive Flip-Chip Technology



ACA:

- *Need not be selectively deposited*
- *Low filler particle loading*
- *Particles form connections when adhesive is compressed*
- *Z-axis conduction only*

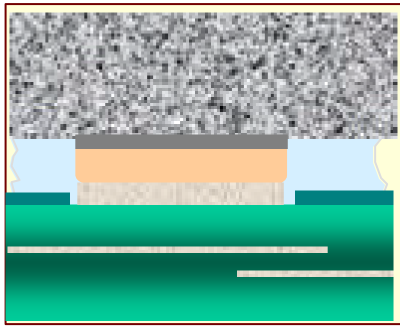
- *Filler types:*
  - Au-coated polymer spheres
  - Solid metal spheres (plated)
  - LMP Solders (Sn-Bi)



ICA:

- *High filler particle loading (typically Ag flake)*
- *Conductive in all directions*

- *Must be selectively deposited:*
  - Screen / stencil printing with very accurate alignment
  - Transfer by contact with thin film



NCA:

- *Deposited on entire placement area*
- *Non-conductive – no filler particles*
- *Connection formed by pressure*
- *Connection maintained by high shrinkage forces after cure*

- *Connection quality enhanced by surface asperities*
- *Can be used with fusible solder coatings on contact surfaces*
  - Reflow after high-temp cure
  - Robust connection.

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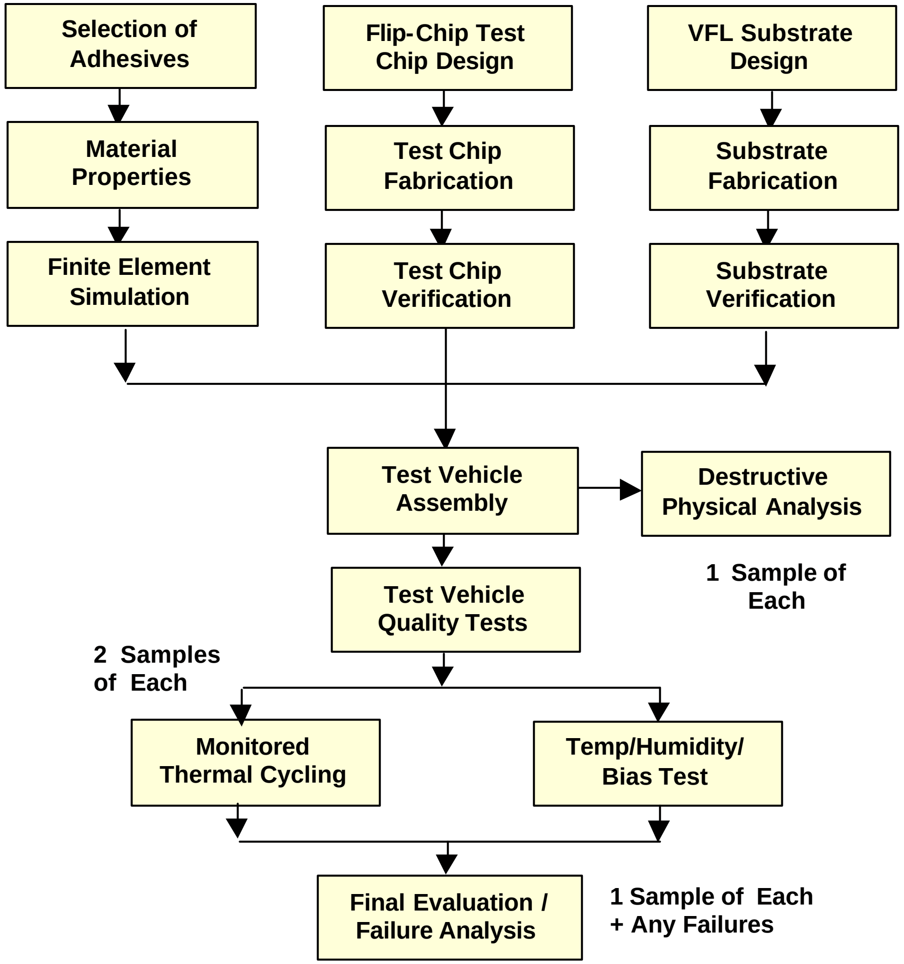
Evaluation Programme



Phase 1:

Materials & Technology Selection

WP1: - Selection of Adhesives.

- Physics-of-Failure Investigation.

WP2: - Test Chips Design & Fabrication.

WP3: - VFL Substrate Design & Manufacture.

Phase 2:

Manufacturing & Reliability Evaluation

WP4: - Assembly of Test Structures.

- Non-Destructive Evaluation.

WP5: - Reliability Performance Testing.

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Summary of Selected Materials

Anisotropic Conductive Adhesives (ACA)

ACA 1: **Loctite 3441 - Anisotropic Conductive Adhesive, Gold-coated polymer filler.**

ACA 2: **Loctite 3446 - Anisotropic Conducive Adhesive, Fusible Bismuth Spheres filler.**

ACA 3: **Bondline 2909 - Anisotropic Conductive Adhesive, Gold-coated polymer filler.**

ACA 4: **Creative Materials Inc. - CMI 121-23, Anisotropic Conductive Adhesive, Silver flake filler.**

ACA 5: **Dexter TG 9001 R1 - Anisotropic Conductive Adhesive, Gold particle filler.**

Isotropic Conductive Adhesives (ICA)

ICA 1: **Loctite 3880 - Isotropic Conductive Adhesive - Silver flake filler.**

ICA 2: **Delo ICABOND IC182 -Isotropic Conductive Adhesive - Silver flake filler (75% wt.)**

ICA 3: **Bondline 2920 - Isotropic Conductive Adhesive - Silver Flake filler.**

ICA 4: **Creative Materials Inc. - CMI 118-06-SD -Isotropic Conductive Adhesive - Silver (74% wt.).**

Non-Conductive Adhesives (NCA)

NCA 1: **Loctite 3565 - Non-Conductive Underfill Adhesive**

NCA 2: **Hysol QMI 536 Non-Conductive Adhesive, PTFE-filled.**

NCA 3: **Creative Materials Inc. - CMI-122-24 Non-Conductive Low-Stress Underfill - Nitride filler.**

NCA 4: **Bondline 6900 - Low Viscosity Non-Conductive Underfill Adhesive**

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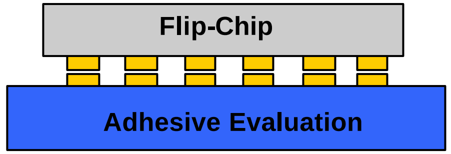

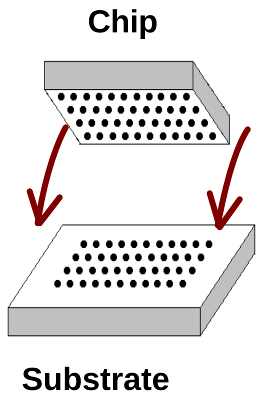

WP1: Materials Property Evaluation

Material Properties Studied:

- Coefficient of Thermal expansion (CTE) – Thermo-mechanical Analyser (TMA)
- Glass Transition temperature (T_g) – Differential Scanning Calorimeter
- Young's Modulus (e) – DMTA / Instron Tester
- Lap Shear Strength – Instron Tensile Tester

Adhesive	Type	Measured Tg (°C)	Datasheet T_g (°C)
Loctite 3441	ACA	146.3	150
Loctite 3446	ACA	151.7	156
Bondline 2909	ACA	117.8	121
CMI-121-23	ACA	107.3	105
Dex TG9001-R1	ACA	109.3	110
Loctite 3880	ICA	95.3	64
Delo AC-182	ICA	86.7	90
Bondline 2920	ICA	110.6	113
CMI-118-06	ICA	98.1	100
Loctite 3565	NCA	145.3	155
Hysol QMI 536	NCA	N/a	-31
CMI 122-24	NCA	95.3	127
Bondline 6900	NCA	125.4	Not Quoted

Measured Glass Transition Temp. (T_g) v Datasheet Values.

Tyndall DSC System

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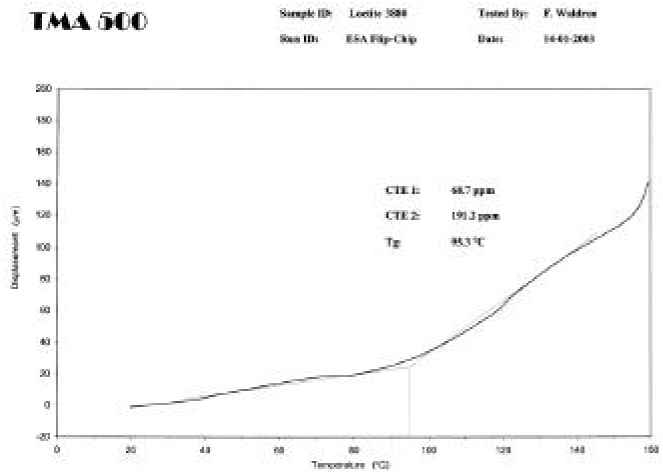
WP1: Materials Property Evaluation

Adhesive	Measured Values CTE below Tg (ppm)	Measured Values CTE above T_g (ppm)	Datasheet Values CTE below T_g (ppm)	CTE above T_g (ppm)
Loctite 3441	57.3	151.2	55	140
Loctite 3446	54.0	147.8	55	140
Bondline 2909	36.3	104.1	35	100
CMI-121-23	58.7	160.2	Not Quoted	Not Quoted
Dex TG9001-R1	70.1	154.2	67	Not Quoted
Loctite 3880	68.7	191.2	110	188
Delo AC-182	88.3	197.2	Not Quoted	Not Quoted
Bondline 2920	76.7	173.2	79	189
CMI-118-06	28.7	148.2	17	147
Loctite 3565	28.7	92.4	25	80
Hysol QMI 536	N/a	190.9	93	174
CMI 122-24	38.2	160.2	55	168
Bondline 6900	60.5	120.1	31	31

Measured CTE Values v Datasheet Values.



TMA Scan – Loctite 3880

Results:

- **CTE, Tg & Bond Strength show reasonable agreement with manufacturer's values (where quoted).**
- **For CMI-122-24, Measured T_g = 95.3° (Manufacturer's T_g = 127°C).**
- **In many cases Tg < 125°C**
- **Modulus values not quoted in many cases.**
- **Bond strengths generally high, but Loctite 3565 has quoted bond strength of 4.9 MPa.**

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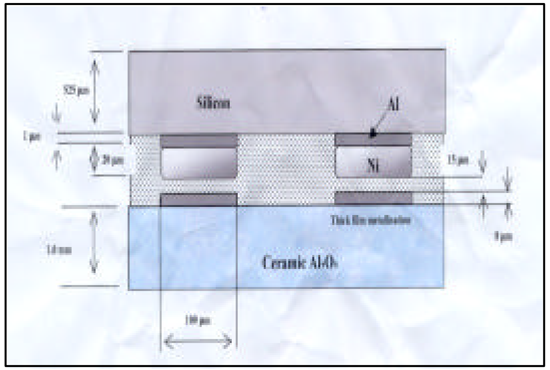
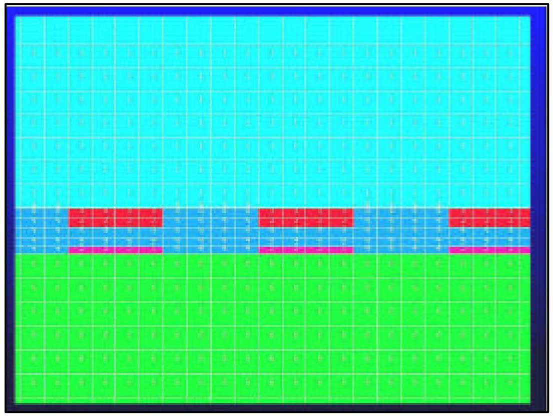
WP1: Materials Property Evaluation

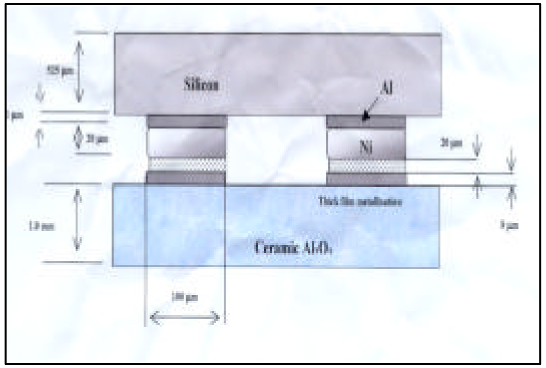
ACA:

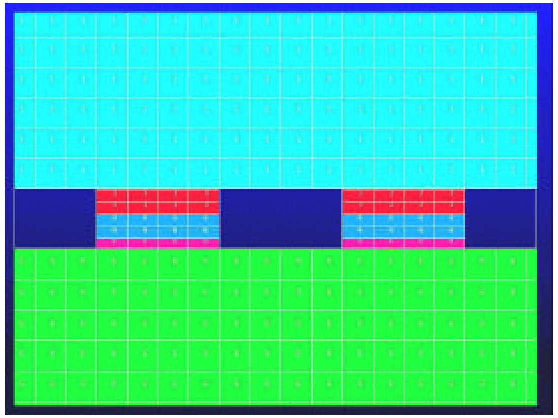




Blanket deposited ACA with thickness = 8.0 μm

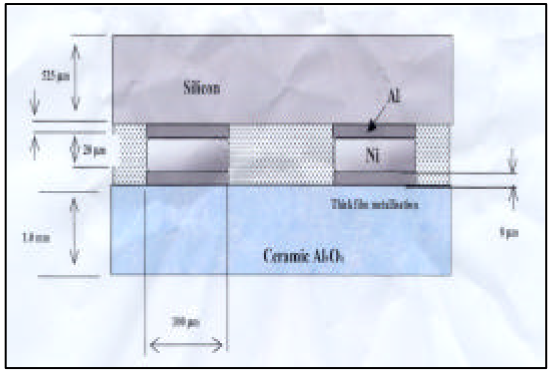
ICA:

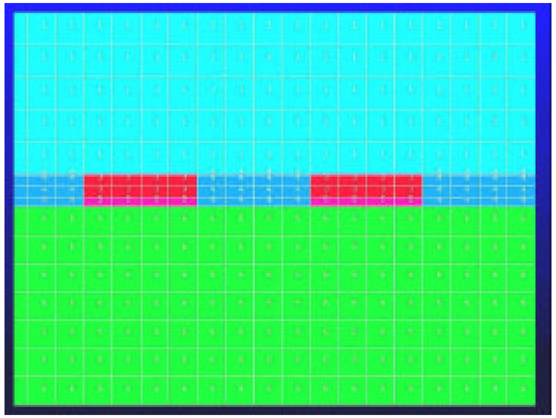




Selectively-deposited ICA with thickness = 8.0 μm

NCA:

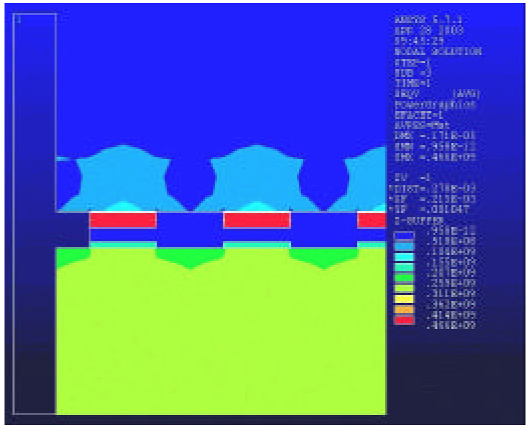




Blanket-deposited NCA No adhesive assumed in joints

WP1: Materials Property Evaluation

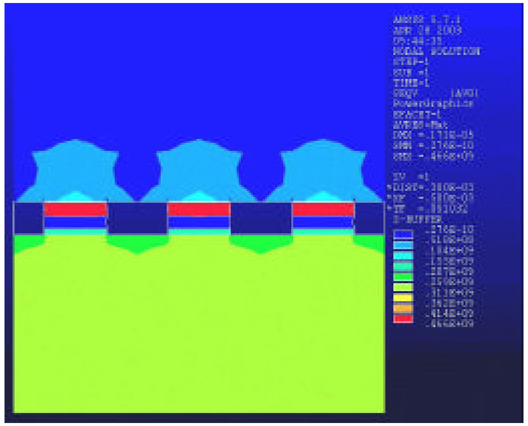
ACA Results:



Finite Element Model at +125°C showing worst case stress condition for ACA materials.

- Acts as own underfill – large bond.
- Compliant & relieves stress.
- Stress negligible at each temp (-55°C and +125°C).
- Unlikely to fail due to stress
- Conduction may be disrupted by movement – 3 mm possible.

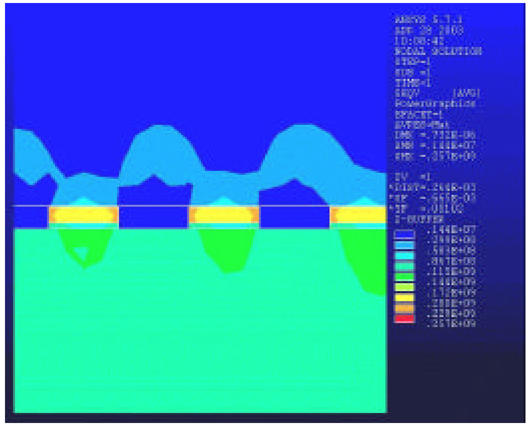
ICA Results:



Finite Element Model at +125°C showing worst case stress condition for ICA materials.

- Smaller bond area.
- Also compliant.
- Stresses higher than ACA, but still low overall.
- Unlikely to fail due to stress
- High filler density – less Affected by movement.

NCA Results:



Finite Element Model at -55°C showing worst case stress condition for NCA materials.

- No adhesive in joint area.
- Compliant.
- Slightly higher stresses than ACA.
- One material could fail due to stress > bond strength (Loctite 3565).

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WP1: Materials Property Evaluation

Conclusions – Materials Property Evaluation:

- Greatest choice of adhesives for flip-chip assembly were in the ACA category.
- Measurement of CTE for all of the selected materials showed good agreement with manufacturers values (where quoted).
- Measurements of T_g for the adhesives also agreed closely with the manufacturers figures (except one NCA - CMI-122-24 where T_g = 95.3° (CMI T_g = 127°C).
- T_g in many cases is lower than the target 125°C upper operating temperature.
- Modulus information not quoted for many adhesives.
- Expected stresses in all materials are low due to their compliant / soft nature.
- ACA may be prone to movement of up to 3.0 μm leading to a risk of open circuits.
- ICA also prone to risk of movement, but open circuits less likely due to filler density.
- Highest risk of stress failure is with NCA material (L 3565) at 125°C where model predicts Von Mises stress of 3.9 MPa. Loctite 3565 has quoted bond strength of 4.9 MPa.

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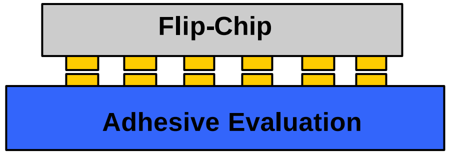
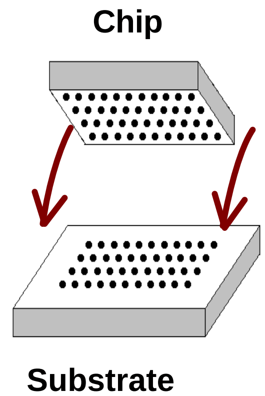
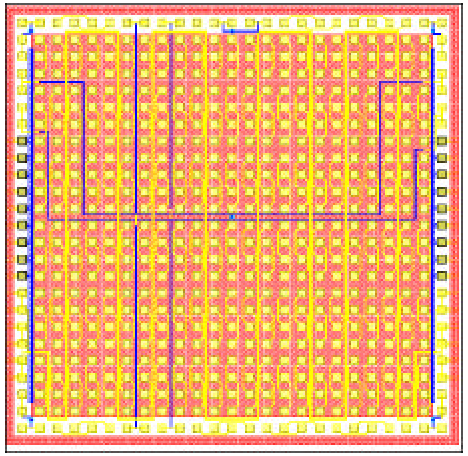




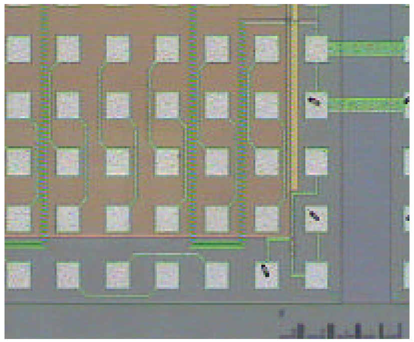
WP2: Flip-Chip Test Chip

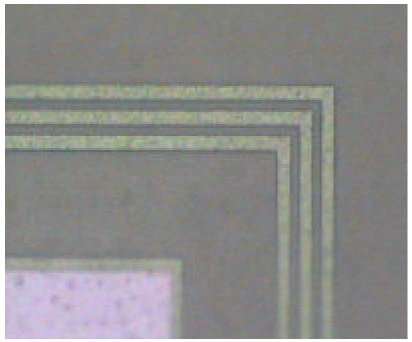
Test Chip Details:

- 1 Polysilicon Heater Resistor.
- 6 Temp-Sensing Diodes.
- 1 Triple-track Corrosion Monitor.
- 14 Peripheral Daisy Chains.
- 1 Pad Array (23 X 23).
- Basic unit size = 5 mm X 5mm.
- Designed to allowed multi-unit die.
  - *10 mm X 10 mm.*
  - *15 mm X 15 mm.*

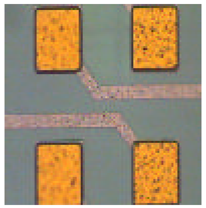


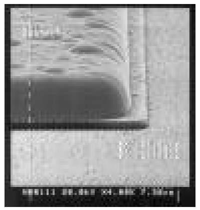
Flip-Chip Test Chip (5 mm X 5 mm)





FCTC Test Structures



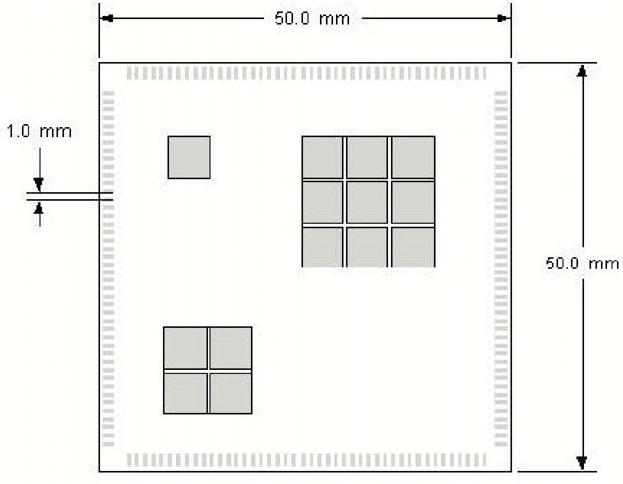


Flip-Chip Test Chip with Ni/Au bumps

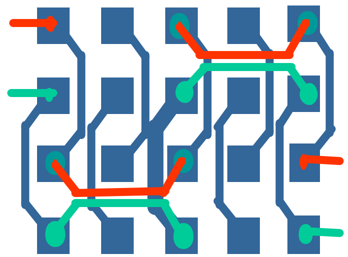
WP3: VFL Substrate

Substrate Details:

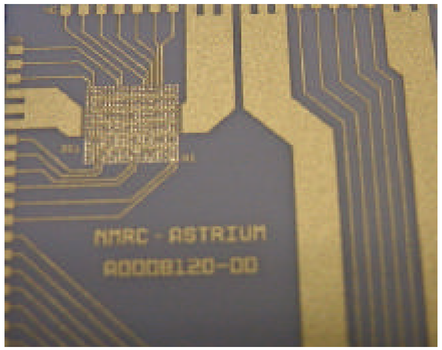
- Very Fine Line (VFL).
- High-reliability substrate.
- Ceramic material.
- Thick film technology.
- Single interconnect layer.
- 3 chip sizes per substrate.
    - *5 mm X 5 mm.*
    - *10 mm X 10 mm.*
    - *15 mm X 15 mm.*
- 50.0 mm X 50.0 mm.
- 50 mm track & gap.
- Edge connector.
- 180 i/o pads.

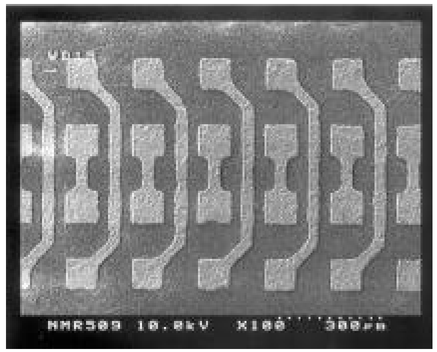


180 I/O substrate



VFL substrate layout designed for FCTC to allow daisy chains of Joints to be formed.



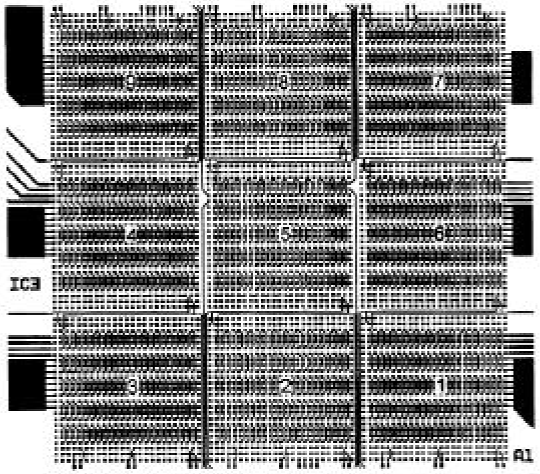


Detail Views – Astrium VFL substrate.

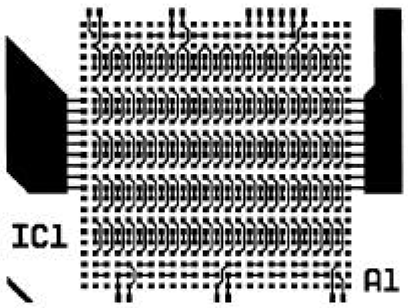
WP3: VFL Substrate

Substrate Verification:

- Electrical continuity
  - *Flying probe tester (Astrium)*
- Optical & SEM Inspection (NMRC)
  - *Dimensions & pitch etc. correct*
  - *Metalisation quality / composition*
- Metal tape adhesion test
- 80 manufactured / 60 required



IC3 View side pad



IC1 View side pad

Single Chip Site

- *2 daisy chains per chip*
- *Continuity & isolation measurements.*
- *2 inputs, 2 outputs & 2 intermediate.*
- *1 set of heater & diode connections*

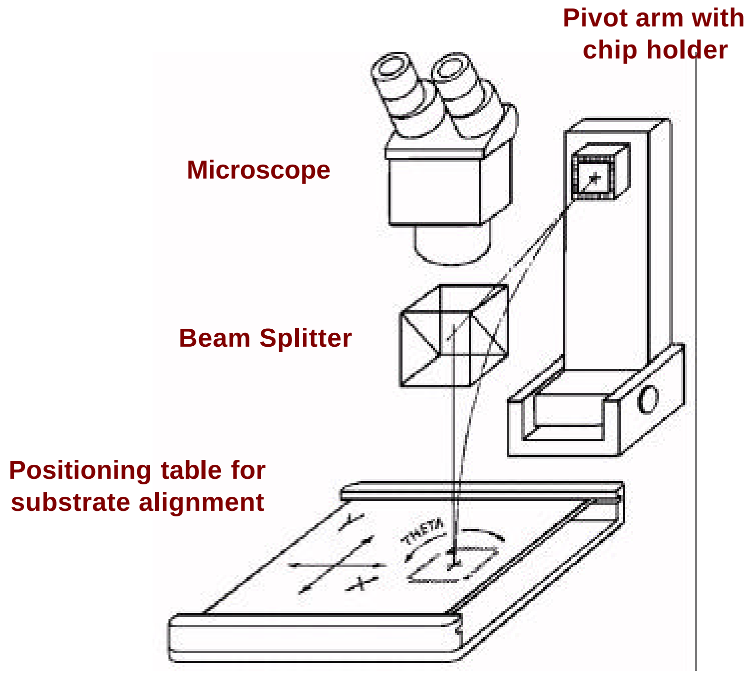
3 X 3 Chip Site (15 mm X 15 mm)

- *2 daisy chains per single chip.*
- *Continuity & isolation measurements across full area of 15 mm X 15 mm chip.*
- *2 inputs, 2 outputs & 11 intermediate connections in total.*
- *Only 2 intermediate connections for dice 4,5,6.*
- *6 sets of heater & diode connections*

WP4: Test Vehicle Assembly

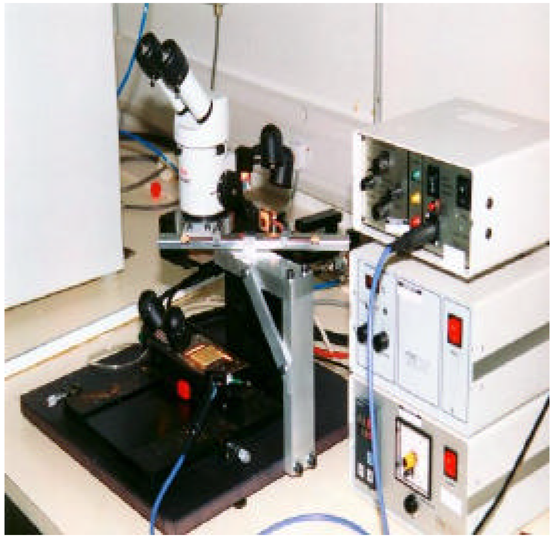
Process Flow:

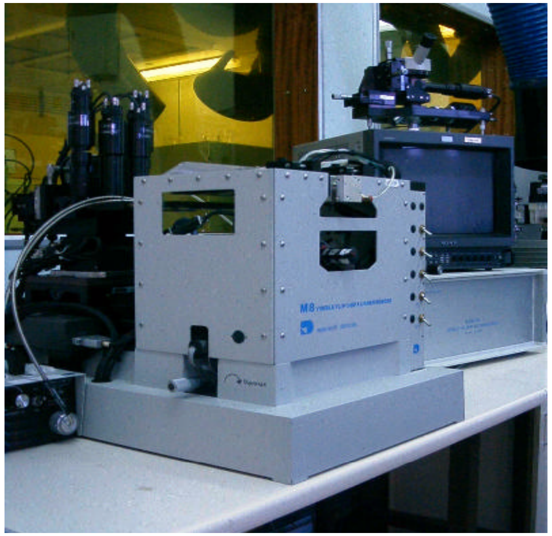
Process step	Parameters
Dispense Adhesive on Substrate	➢ *Dispense pressure* ➢ *Volume / thickness*
Align Chip and Substrate	➢ *X, Y, q*
Place in Contact	➢ *Light Pressure*
Apply Pressure	➢ *Load per bond*
Cure at elevated Temperature	➢ *Temperature* ➢ *Curing time / profile*



Flip-Chip Aligner / Bonder Diagram
(FINETECH Electronic GmbH)

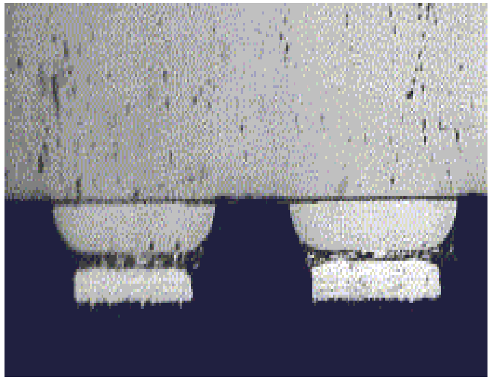
WP4: Test Vehicle Assembly

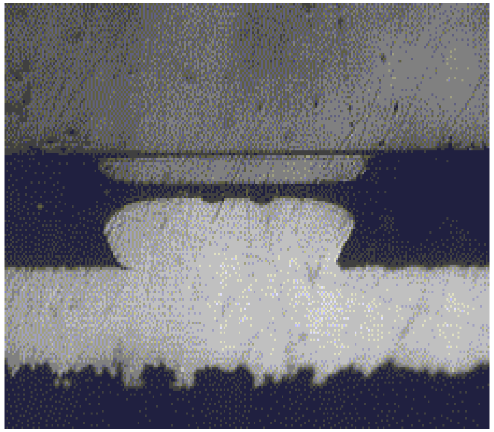




- Tyndall Fineplacer 145 PICO Flip-Chip Bonder.
- Manual Alignment.
- Small Volume Lab System.

- Tyndall Research Devices M3 Flip-Chip Bonder.
- Semi-automatic.
- Prototyping Quantities.





ACA Flip-Chip Bonds

WP4: Test Vehicle Assembly

Optimised Process Conditions:

Bondline 2909 ACA:

- **Recommended cure:** 175°C, 30 sec, 35 MPa.
- **Optimised cure:** 140°C, 30 sec,
  160°C, 5 sec
  Load = 40 Mpa.

  → Thickness = 7.0 μm. (approx)
- **Bond Strength:** > 5 Kg shear for 5x5 die (non destructive test)
- **Joint Resistance:** 4.0 to 9.0 Ω (mean).

Loctite 3565 NCA:

- **Recommended cure:** 150°C, > 60 min
- **Optimised cure:** 150°C, 60 min
  Load = 50 MPa

  → Thickness ~ 28.0 μm (between joint areas)
- **Bond Strength:** > 5 Kg shear for 5X5 die (non destructive test)
- **Joint Resistance:** 10.0 Ω

WP4: Test Vehicle Assembly

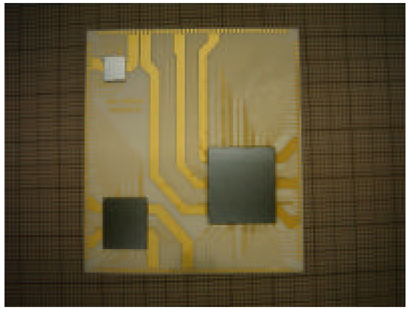
Verification Procedure:

- High Mag. Inspection.
- X-Ray Inspection.
- SAM Inspection.
- Electrical Check.
- Bond Test (5Kg Shear).
- Thermal Resistance.
- Bond Shear Test (Destructive).
- Microsection (Destructive).

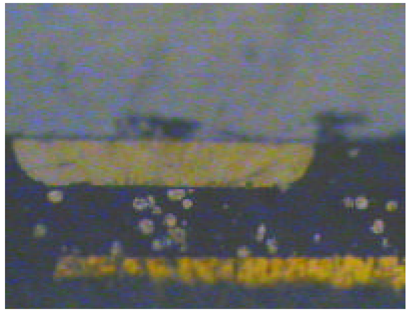
Main Problems / Issues:

- Misalignment.
- Excess Adhesive.
- Inadequate Pressure.
- Substrate Flatness.

} Open Circuits

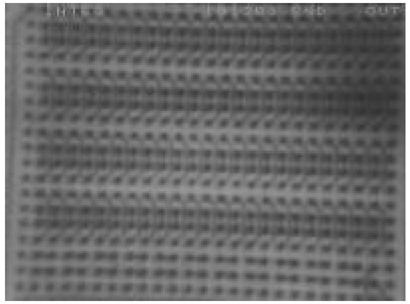


Complete Assembly

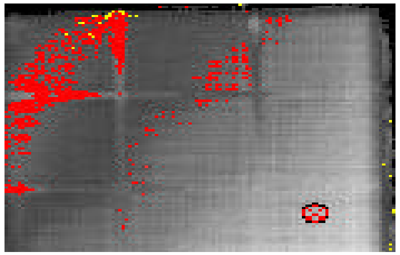


Poor ACA Joint

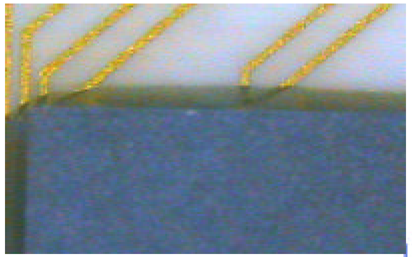
Misalingment



X-ray Alignment Check



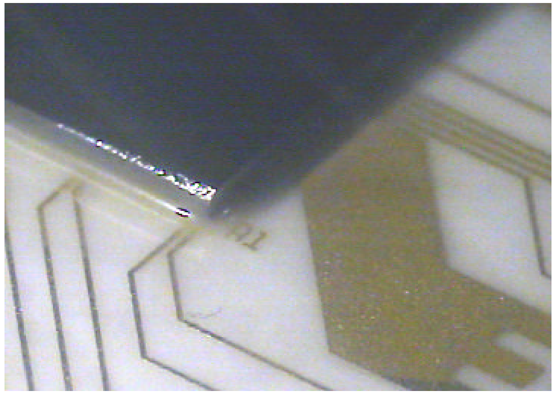
SAM Image - Tilt



Excess Adhesive

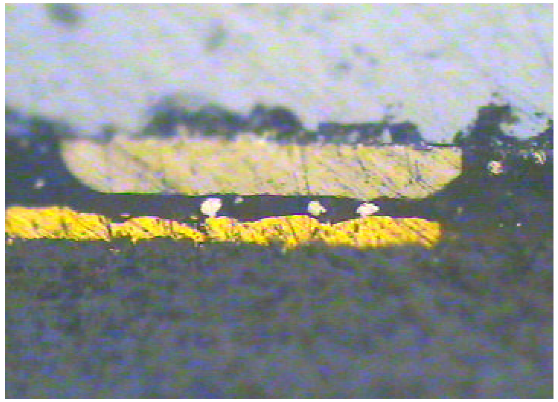
WP4: Test Vehicle Assembly

Assembly Verification:



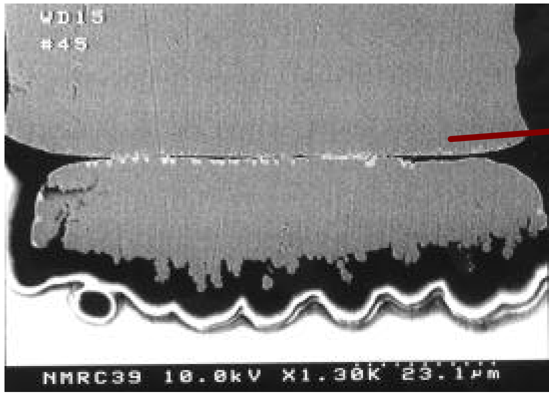
Good Edge Fillet - ACA

Good ACA Joint

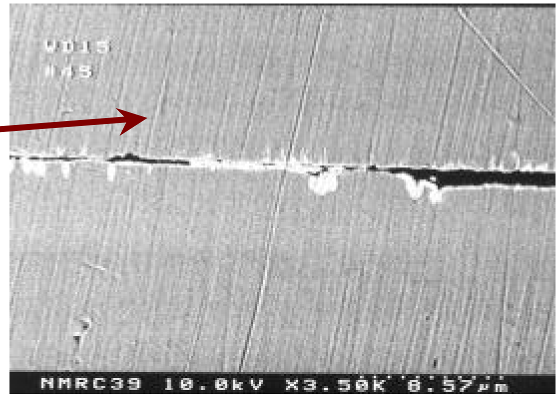


Good ACA Joint

NCA – Well Aligned



Good NCA Joint



Good NCA Joint

WP4: Test Vehicle Assembly

Summary of Thermal Evaluation:

ICA Materials:

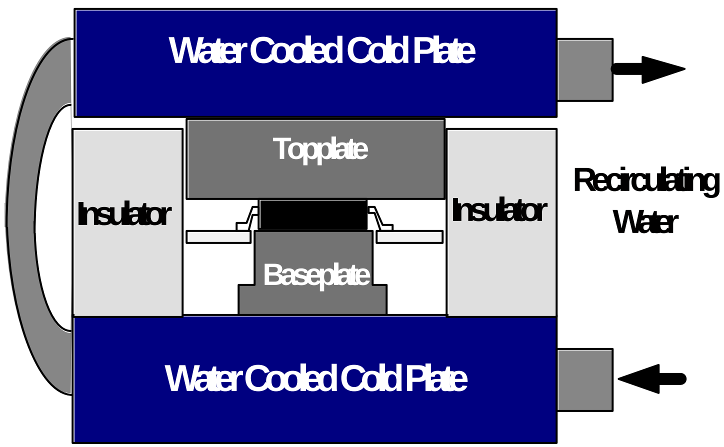
Quoted: 2.00 – 3.20 W/m°K
Measured (Av.): 2.57 W/m°K
******High Ag Content but selective deposition*

ACA Materials:

Quoted: 0.70 - 1.20 W/m°K
Measured (Av.): 1.05 W/m°K
******Blanket deposition helps conductivity result*

NCA Materials:

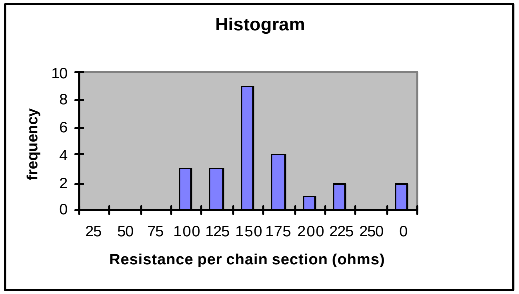
Quoted: 0.02 - 0.03 W/m°K
Measured (Av.): 0.92 W/m°K (good)
Measured (Av.): 0.22 W/m°K (poor)
******Good bump-to-substrate contact helps result*



Dual Cold Plate System

WP4: Test Vehicle Assembly

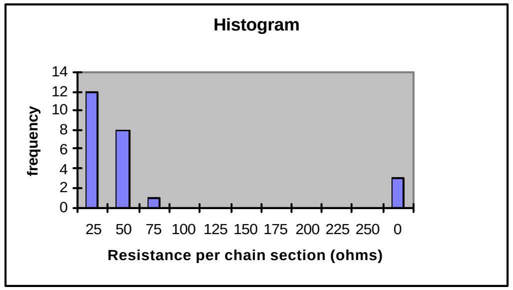
Electrical Evaluation:



ACA – Loctite 3446:

- Mean Chain Resistance = 127.58 O
- Standard Devation = 51.54 O
- No of Opens Chains = 2 / 22

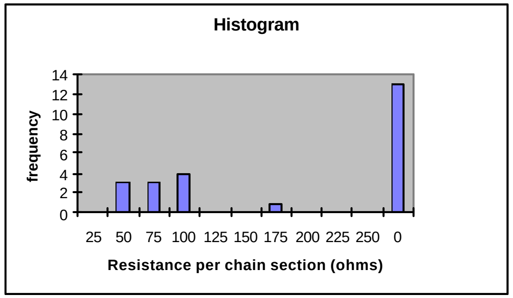
- Smallest no. of opens.
- High resistance chains.



ICA – CMI-118-06:

- Mean Chain Resistance = 22.92 O
- Standard Devation = 13.66 O
- No of Opens Chains = 3 / 22

- Best overall results.
- Small no. of opens.
- Low resistance joints.



NCA – Bondline 6900:

- Mean Chain Resistance = 31.04 O
- Standard Devation = 42.13 O
- No of Opens Chains = 13 / 22

- Worst overall results.
- Large no. of opens.

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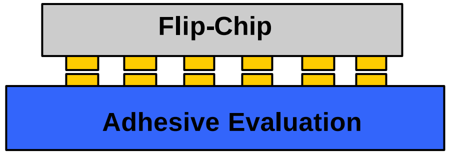
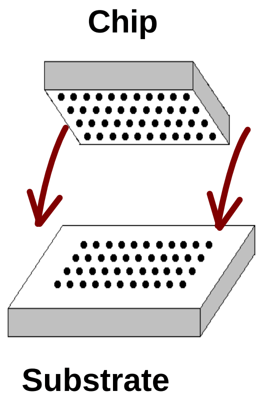
Presentation Outline

- Objectives & Technology Overview
- Flip-Chip Adhesives Evaluation Programme
  - *Materials Selection & Property Evaluation*
  - *Flip-Chip Test Chip*
  - *VFL Substrate*
  - *Test Vehicle Assembly / Assembly Verification*
  - ***Reliability Evaluation***
- Conclusions & Acknowledgements





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WP5: Reliability Evaluation

Test Sample Assembly
(5 Samples - Each Material)

Initial Characterisation
- Visual Inspection
- Electrical test
- Thermal Resistance
- Radiographic Inspection
- SAM Inspection

Control Samples
1 per material

Monitored Thermal Cycling
(5 X 100 cycles – 55°C /+125°C)

Assessment Tests
- External Visual (each 100c)
- Thermal Res. (200 & 500)
- X-ray (200 & 500 cycles)
- SAM (200 & 500 cycles)

THB Test
(1,000 hrs / 85°C / 85% RH)

Assessment (168, 500, 1,000 h)
- Electrical Test
- External Visual
- Thermal Resistance
- X-ray & SAM

Analysis of Failures (WP5)
DPA of 1 sample of each
DPA of any failures

esa ESTEC

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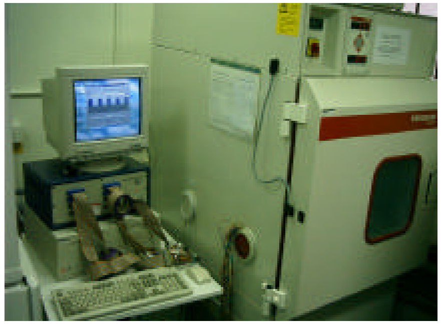
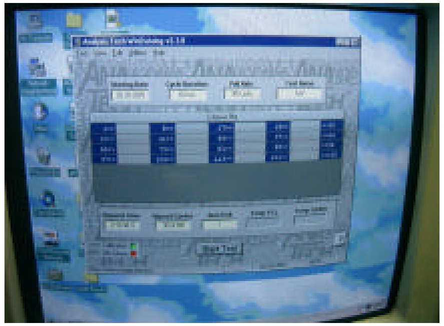
WP5: Reliability Evaluation

Monitored Thermal Cycling Test:

- Mil-Std-883E, Method 1010.7
- Upper Temp: +125° C
- Lower Temp: -55°C
- Dwell: 15 Min
- No. of Cycles: 500
- Tests at 100, 200 & 500 cycles.

Monitored Thermal Cycling Test

Temp / Humidity / Bias Test:

- JESD A-101 B
- Temperature: +85° C
- Humidity: 85% RH
- Bias: -10V / Gnd /+10V
- Duration: 1,000 hours
- Interim Tests at 168, 500 & 1,000 hrs.

Humidity Test

Interim Test Sequence:

- Electrical Check
- Visual Inspection
- X-ray Inspection
- SAM Inspection
- Thermal Resistance

WP5: Reliability Evaluation

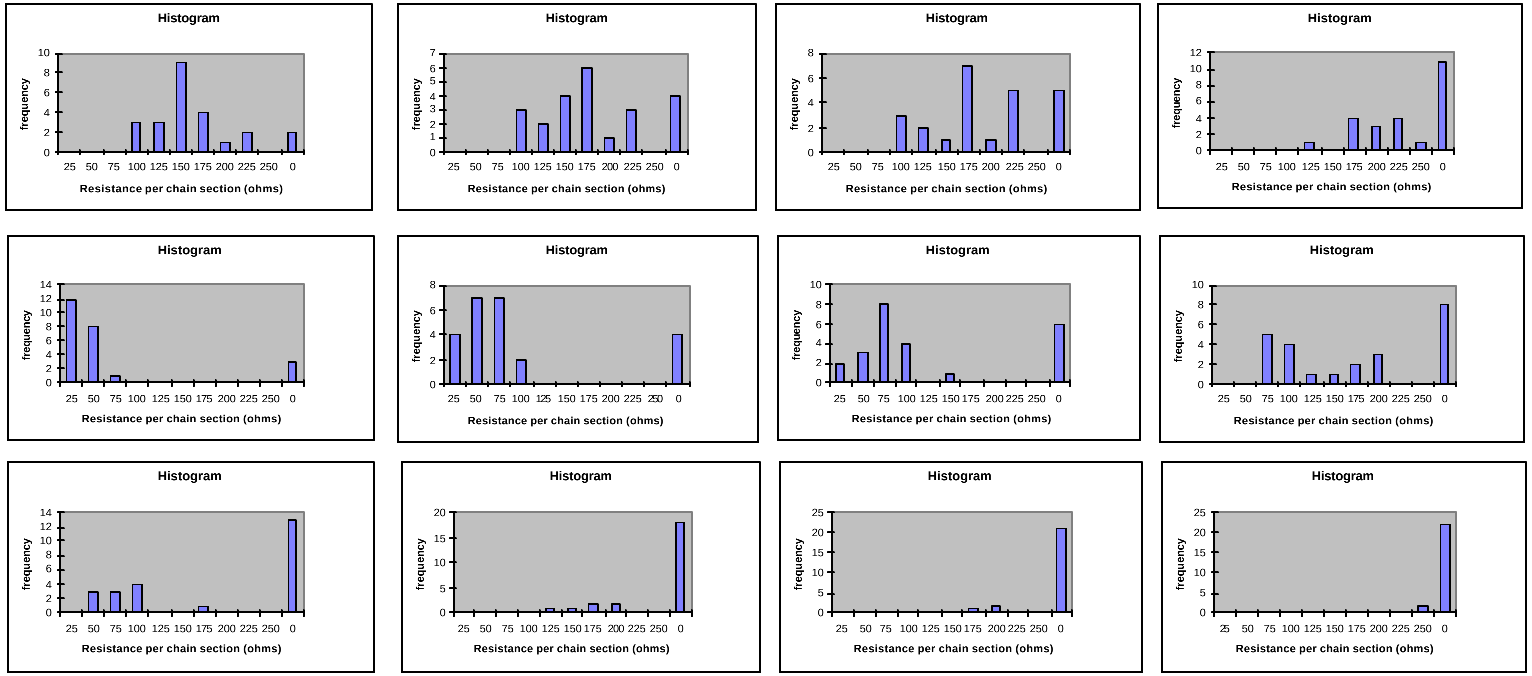
Monitored Thermal Cycling Test (Daisy Chain Resistance):

Start **100 Cycles** **200 Cycles** **500 Cycles**

ACA

ICA

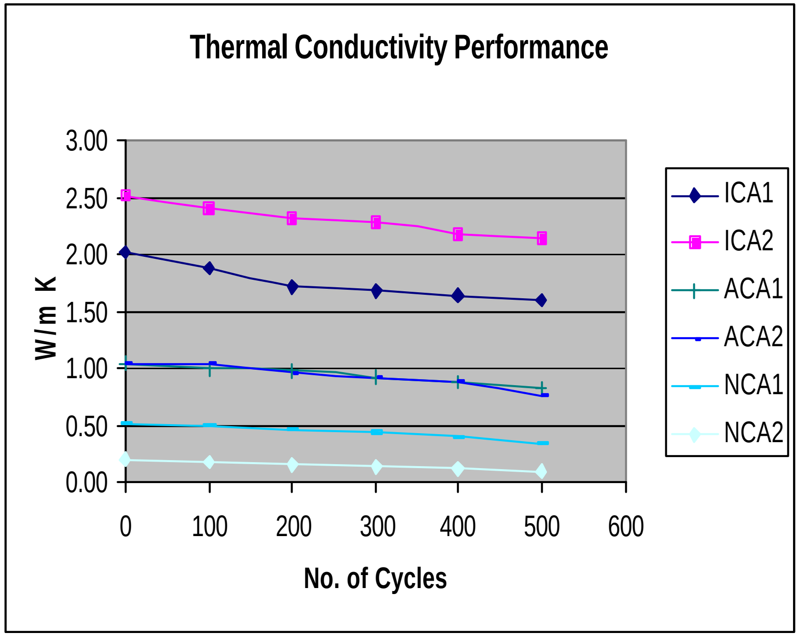
NCA



WP5: Reliability Evaluation

Monitored Thermal Cycling Test:

- Significant Electrical Failure Rate from all three adhesive families.
- Significant early failure trend with ACAs.
- More gradual trend with ICA materials.
- Dramatic early failure rate with NCAs.
- Thermal performance also deteriorates.
- Failures due mainly to thermo-mechanical expansion, movement, delamination & softening (Tg).



Thermal Conductivity Change Thermal Cycling Test

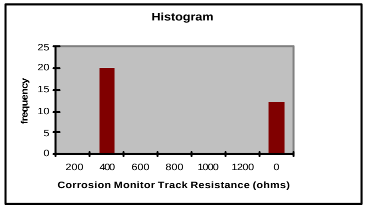
Tyndall National Institute

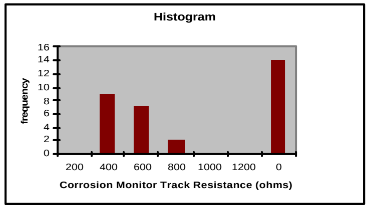
WP5: Reliability Evaluation

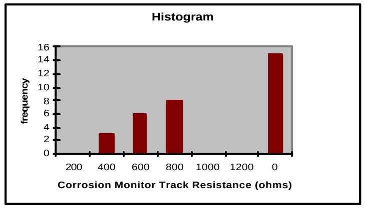
Temperature / Humidity / Bias Test (Corrosion Track Resistance):

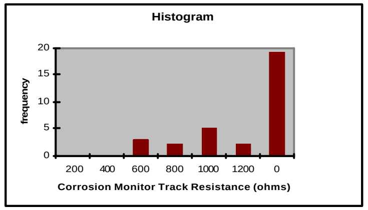
Start | **168 hours** | **500 hours** | **1,000 hours**

ACA

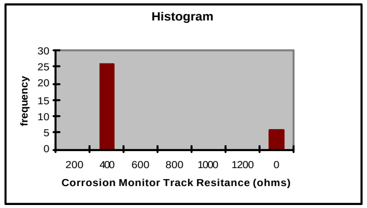


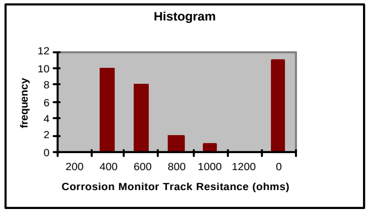


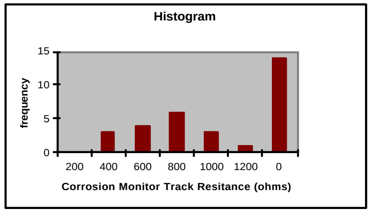


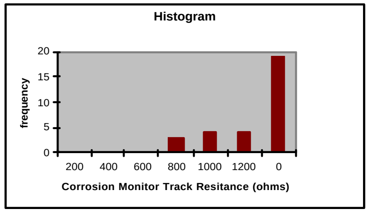


ICA

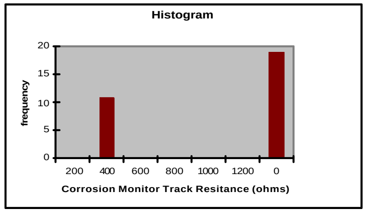


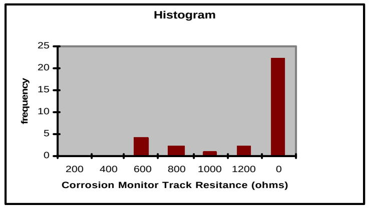


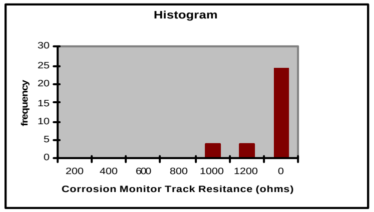


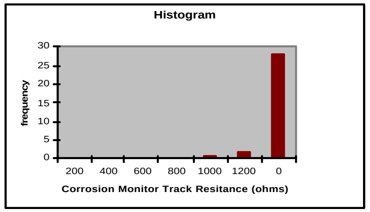


NCA





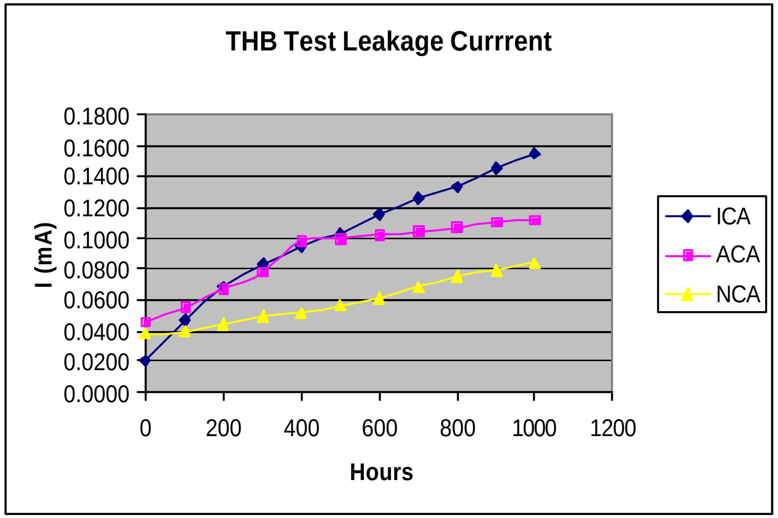




WP5: Reliability Evaluation

Temperature / Humidty / Bias Test:

- Significant Electrical Failure Rate from all three adhesive families.
- Least no. open circuits from ICAs.
- Worst open circuit performance from NCAs.
- Highest leakage current in ICA case (Ag).
- Lowest leakage current in NCA case (no filler).
- Open circuit failures due mainly to corrosion.
- High leakage currents due to dendrites, & ionic content of materials.



Leakage Current during THB Test

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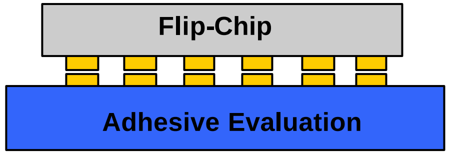

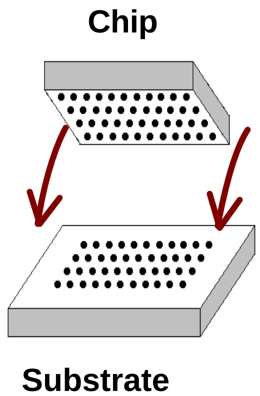

Conclusions 1

- **Adhesive do not meet demands of harsh-environment stress tests.**
- **Tg is much lower than + 125°C in many cases:**
  - ***Poor thermomechanical behaviour.***
  - ***Materials soften at elevated temperatures.***
  - ***Movements & open circuits occur.***
- **Adhesive flip-chip best suited to small-area dice:**
  - ***More difficult tocontrol deposition quality over a large area***
  - ***Substrate roughness an issue***
- **Selectively-Deposited ICA materials probably best overall:**
  - ***Best electrical & thermal properties.***
  - ***Selective deposition – lower risk of shorts***
  - ***Did show higher leakage currents in THB tests (migration / dendrite growth).***

Conclusions 2

- **Performance in Temperature Cycling Test Poor**
  - ***Large no. of open circuts caused.***
  - ***Thermomechanical movement.***
- **Corrosion failures occured in THB test:**
  - ***Adhesives absorb moisture.***
  - ***Non-hermetic protection.***
  - ***Adhesives contain ionic elements.***
  - ***High leakage currents, especially with ICAs.***
- **Adhesives best suited to small are die used in benign environments.**
- **Not suited to the demands of the space environment !!**

Acknowledgements

- **ESA / ESTEC – Funding for Project**
  - ***Alberto Boetti – Technical Supervision & Guidance.***
- **Astrium, Velizy, France**
  - ***Jean-Claude Tual – Substrate Layout.***
  - ***Brigitte Braux – Astrium Project Manager.***
- **Tyndall**
  - ***Gary Relihan – Materials Properties.***
  - ***Denis O' Mahoney – FE Modelling.***
  - ***Adrian Mulcahy – Assembly & Analysis Work.***
  - ***Eoin Sheehan – Chip and Substrate Test.***
  - ***Tony Compagno – Reliability Tests.***