Fraunhofer IZM

Electronic Materials

Non-Conductive Film (NCF) Underfill: Materials, Performance, and Evolution to Next Generation Devices

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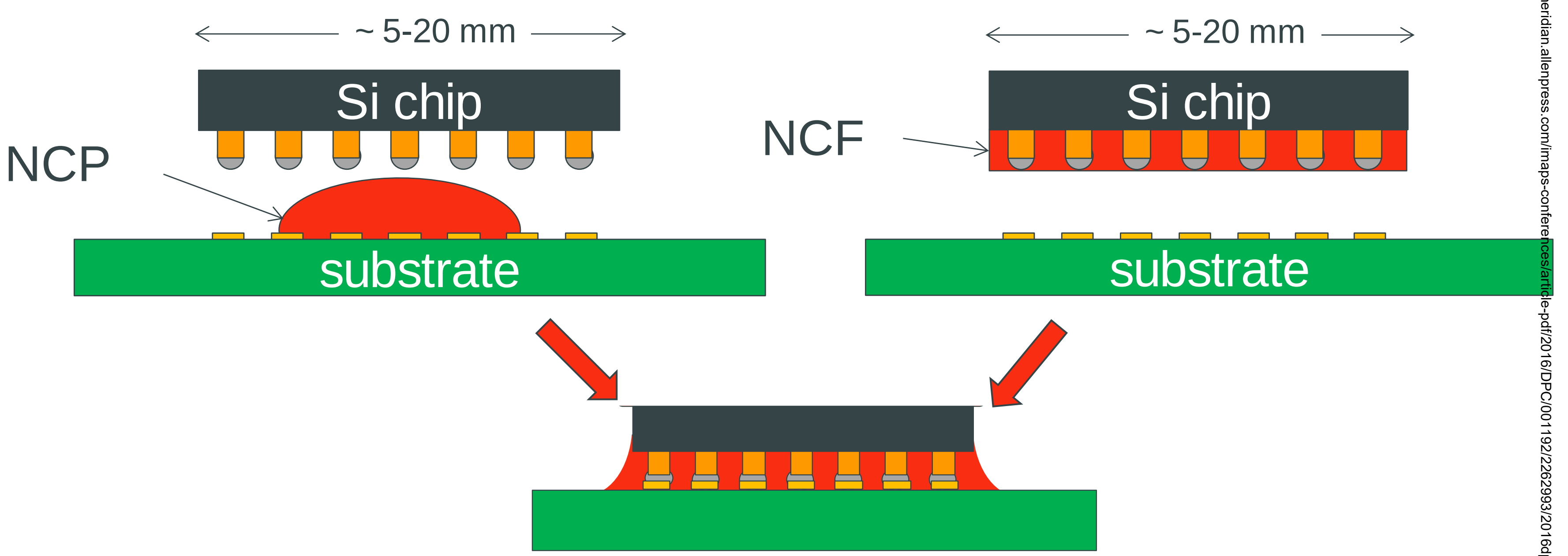
Outline

- Non Conductive Film (NCF) Application and Property Targets
- Current NCF Technology (GEN-1)
- Bonding in High I/O Devices (GEN-2)
- Exploration into Thermally Conductive NCF (GEN-3)
- Summary

Pre-applied Underfill Application
NCF Vs NCP Underfill



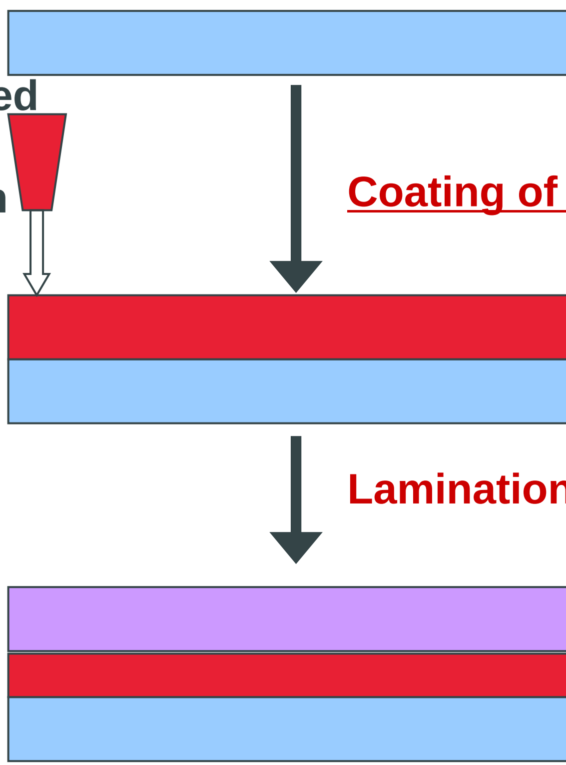
- NCF is applied to wafer or substrate prior to bonding; eliminates handling and dispensing from the assembly line
- NCF lamination provides precise, uniform placement – tight keep-out zones
- NCF is applied after back end of assembly – provides support to thinned die after back grinding

NCF Film Formation Process

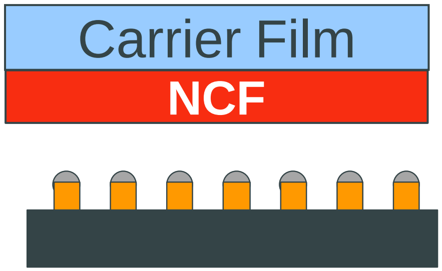
<u>NCF Dispersion</u>
- Resin
- Filler
- Curing Agent
- Solvent

Drying →

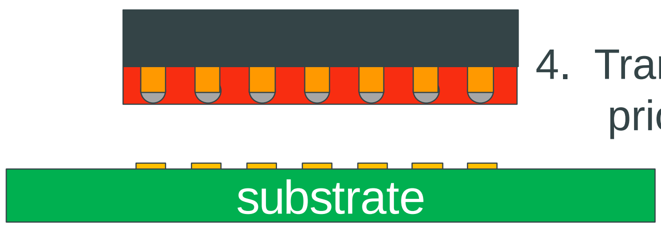
<u>NCF Coating</u>
- Resin
- Filler
- Curing Agent



Bonding Process and Key Parameters



1. Vacuum lamination (softens and adheres at moderate temperature)
2. Stability at ambient
3. Transparency for dicing



4. Transparency for alignment prior to TCB)

5. Thermo-compression bonding – low viscosity during solder reflow, self-fluxing, rapid curing post-reflow

6. Reliability- no filler entrapment in solder joints, correct balance of cured properties (Tg, modulus, CTE to reduce stress)

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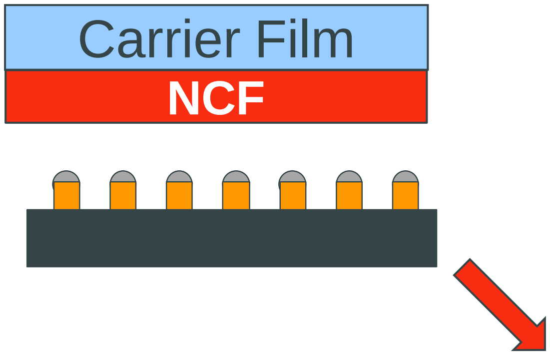

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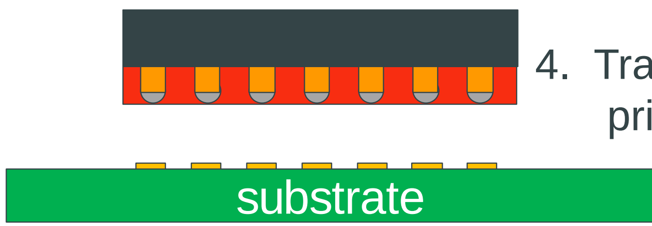

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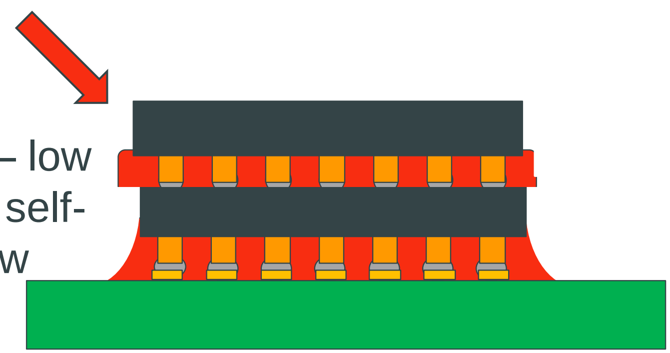

5. Thermo-compression bonding – low viscosity during solder reflow, self-fluxing, rapid curing post-reflow

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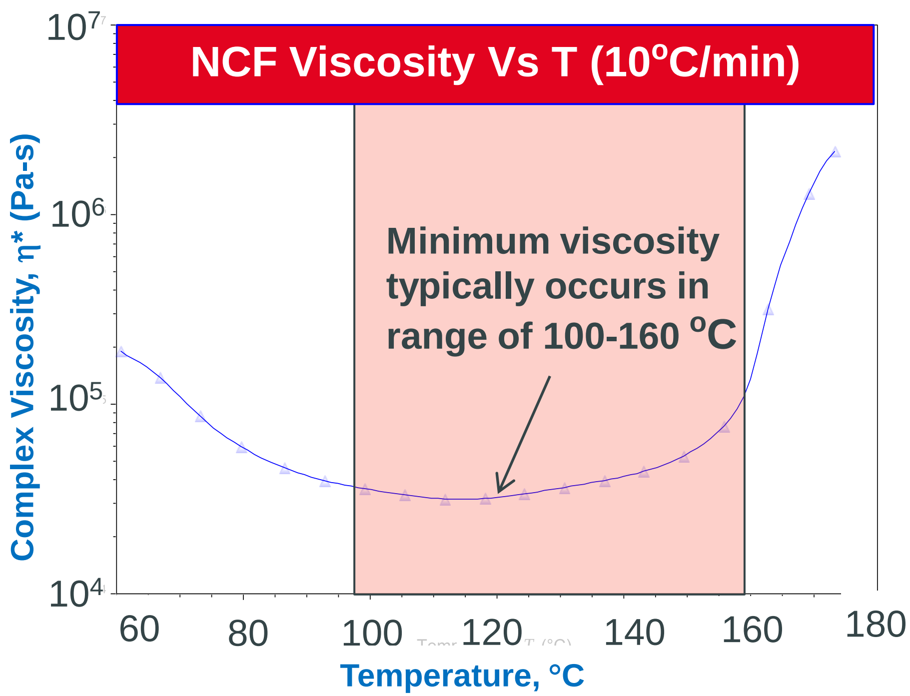
Current NCF Technology (GEN-1)

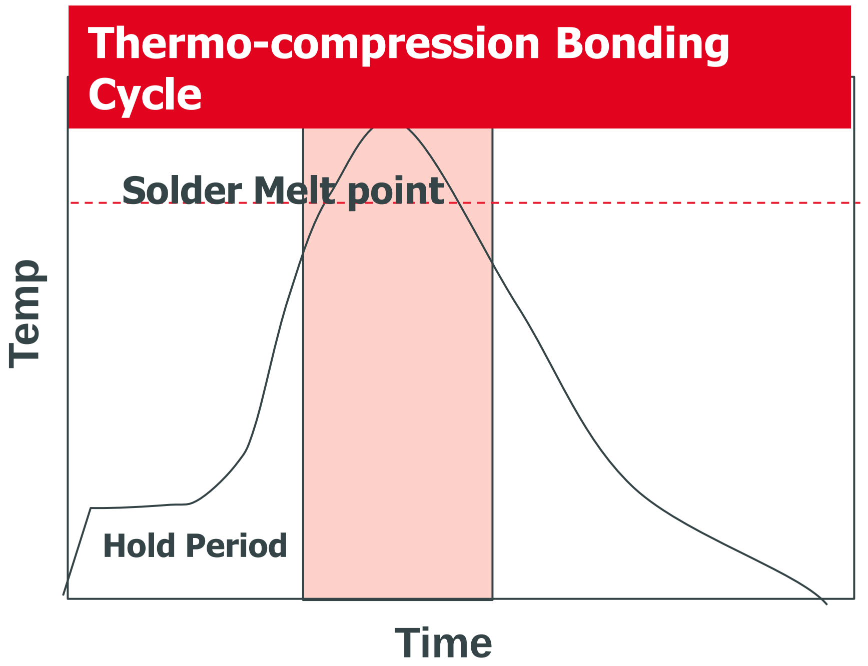
Properties of Current NCF

Property	GEN-1
Minimum viscosity, Pa-s	30,000 (130°C)
Cure onset temp (DSC, 10°C/min), °C	141
Peak cure temp (DSC, 10°C/min), °C	166
Tg (TMA), °C,	122
CTE, α_1, ppm/ °C	28
Modulus, GPa	5.8

- Higher viscosity provides resistance to voiding
- Cure latency maintains minimum viscosity during reflow
- Low CTE (<30 ppm/°C), High Tg (>120°C), intermediate modulus (5-8 GPa) maximize reliability in die to organic substrate design; CTE may be less critical for die-die assembly

Viscosity of GEN 1 and fit with Bonding Cycle



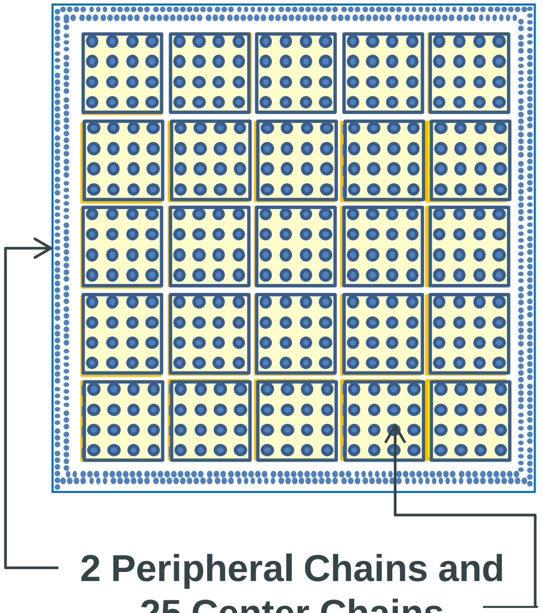


- Viscosity profile at 10°C/min shows minimum viscosity typically on the order of 10^3-10^4 Pa-s, with rapid curing above 160°C
- Thermo-compression bond cycle occurs over a range of ~10 s
- Hold period allows bump to penetrate NCF and contact bonding pad

Evaluation of GEN-1 NCF – Test Vehicle I

Test Vehicle I	
Silicon Die	
Die size, mm	7.3 x 7.3
Die thickness, µm	100
I/O count	1048 (mixed perimeter/area)
Cu pillar diameter, µm	50
Cu pillar height, µm	25
Solder cap	Sn/Ag
Solder height, µm	15
Bump pitch, µm	80 (perimeter), 300 (center)
Organic Substrate	
Substrate thickness, mm	0.356
Cu pad diameter, µm	50
Cu pad height, µm	12
Cu pad finish	OSP
Solder mask	Taiyo PSR 4000 AUS 703

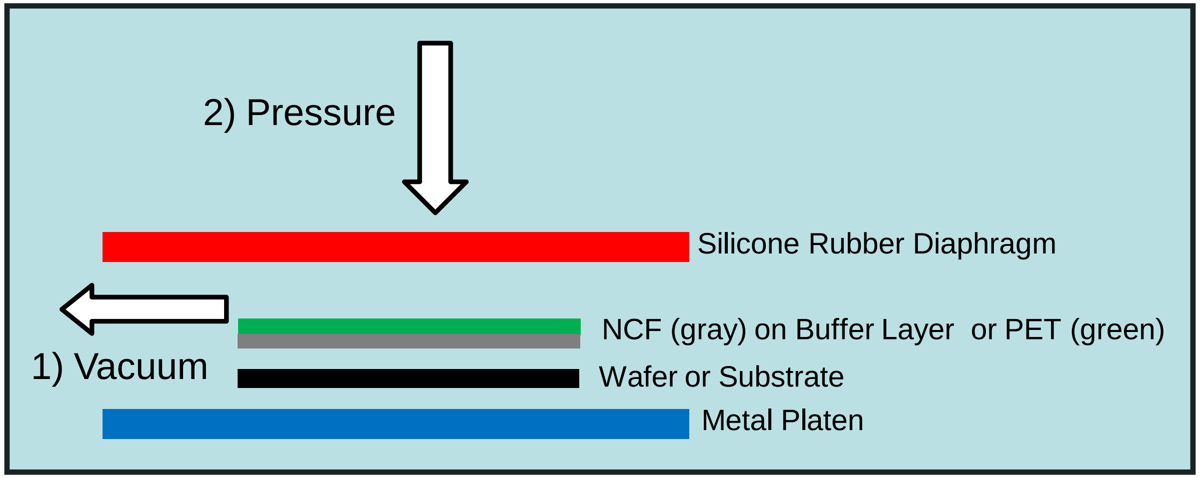
Bump Pattern



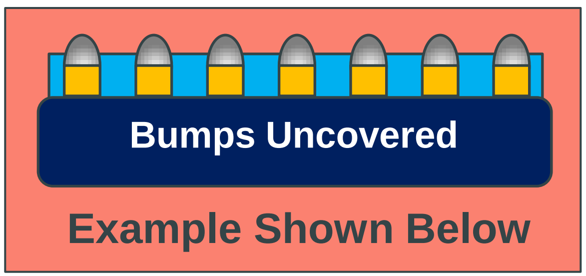
2 Peripheral Chains and 25 Center Chains

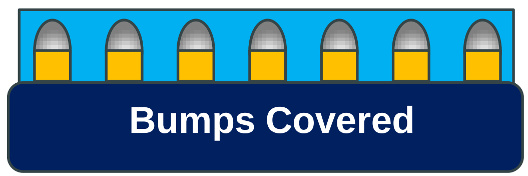
TV-I contains a 25 area arrays and 2 peripheral chains

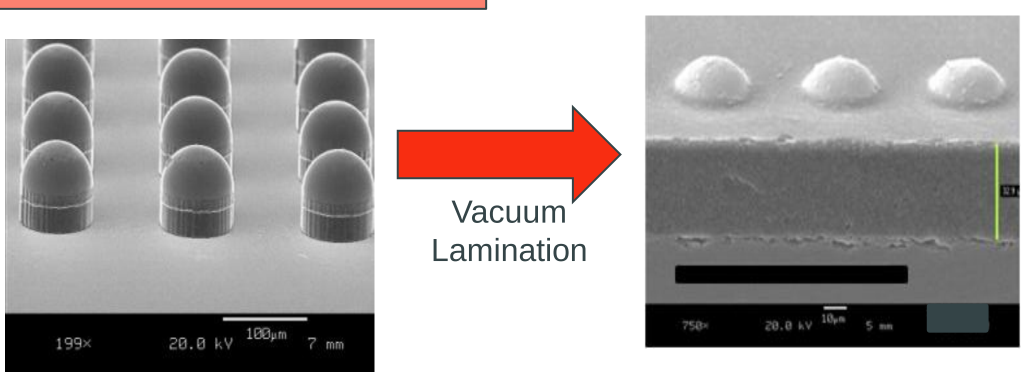
Vacuum Lamination

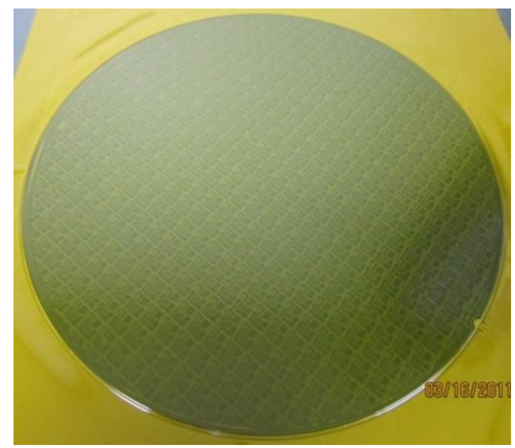


Parameter	Value
Diaphragm Position	top
Upper /Lower Temp (^oC)	80
Vacuum Time (sec)	30
Pressure Time (sec)	30
Pressure (MPa)	0.5



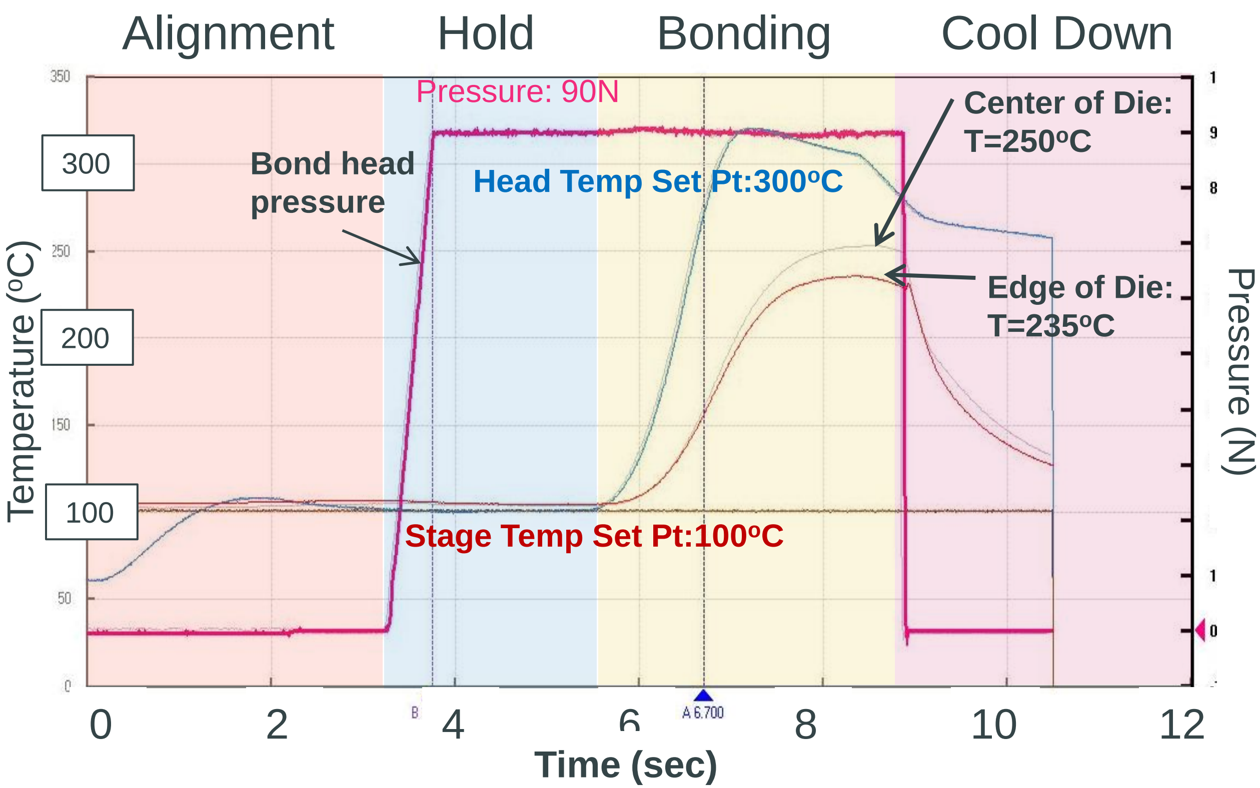






Laminated 300mm Wafer

Thermal Profile For Bonding TV-I

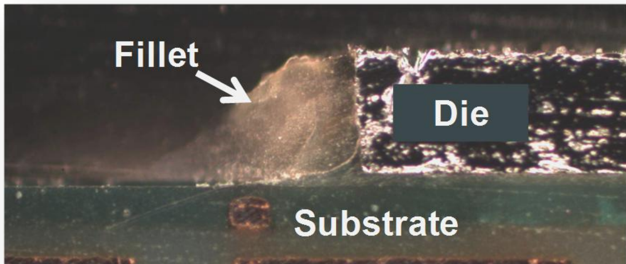


Process Step	Time (sec)
Alignment	1
Approach to Contact	3.2
Ramp up (80C/sec)	2.5
Hold @Peak	3.2
Cooldown	1.7 (var.)
Target	< 10 sec

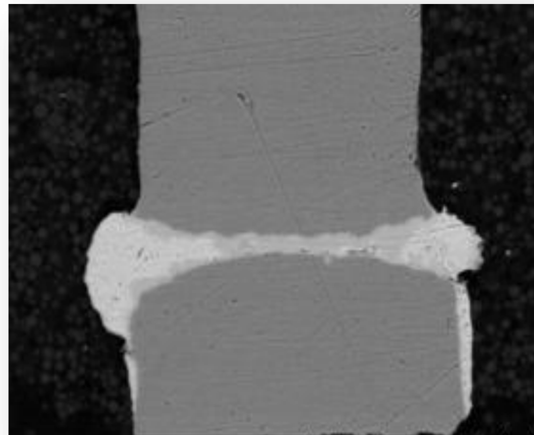
- ‘Hold’ stage is one parameter to be optimized to allow bumps to penetrate NCF and reach bond pad prior to reflow
- Solder reflow occurs under fixed bond head pressure.
- Temperature variation during bonding can be mapped to ensure all parts of the die exceed the reflow temperature

Bonding Results with TV-I

Fillet Formation



Interconnection



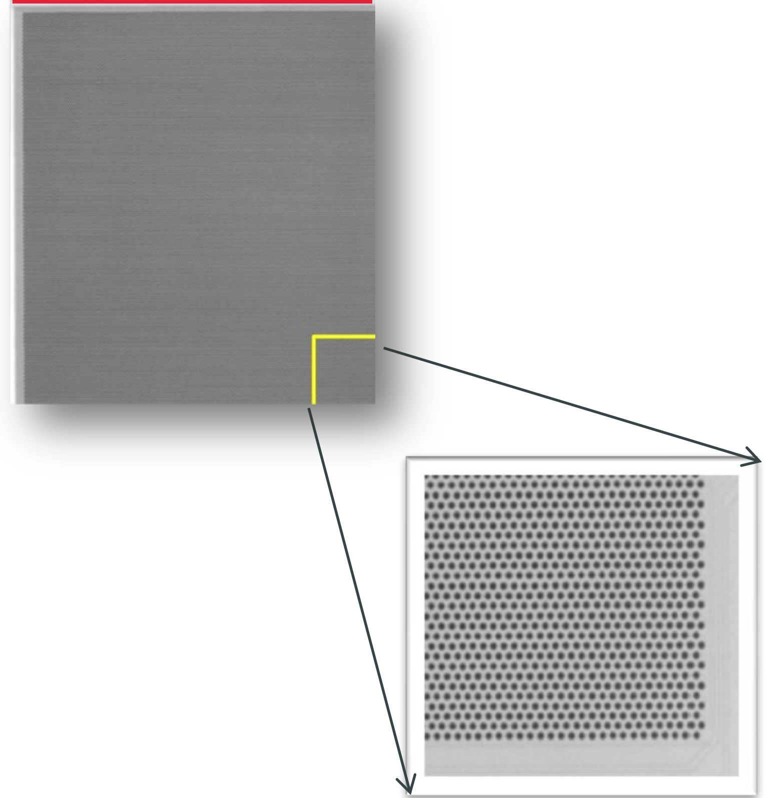
Flat Section

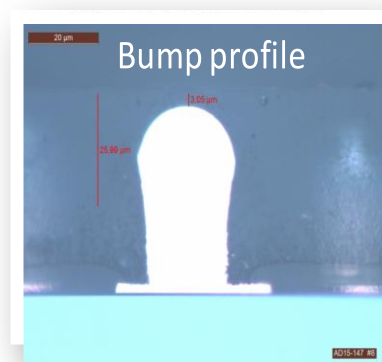
Test	Analysis	Result (Low N)
MSL3A (60C/60%RH/40hrs) - 3x 260ºC Reflow	Electrical resistance C-SAM inspection Cross-section	Stable electrical resistance No delamination, minimal voiding No solder or die cracks
TCT B (-55ºC to 125ºC) –2000 cycles		
Accelerated HTS (180ºC) –500 hrs		

Test Vehicle II

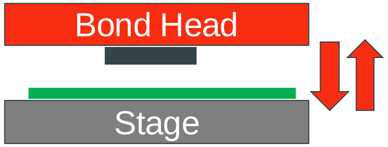
Test Vehicle II Parameters		
Silicon Die		
Die size, mm	10.2x10.2	
Die thickness, µm	500	
I/O count	36,000 (single daisy chain)	
Cu pillar diameter, µm	25	
Cu pillar height, µm	25	
Solder cap	Sn/Ag	
Solder height, µm	5	
Bump pitch, µm	55	
Silicon Substrates	**Pedestal Pad**	**Flat Pad**
Substrate thickness, µm	500	500
Cu Pad finish	Ni/Au	Ni/Au
Cu pad diameter, µm	30	25
Pad height, µm	25µm Cu/ 2µm Ni/ 0.5µm Au	1µm Cu/ 1µm Ni/ 0.5µm Au
Dielectric	Polymer	PE TEOS

Bump Pattern



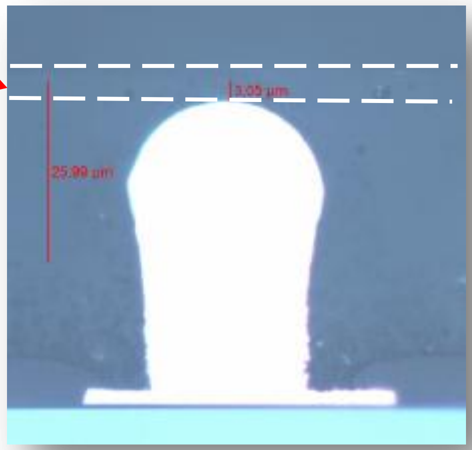


Lamination and Bonding Profile For TV-II

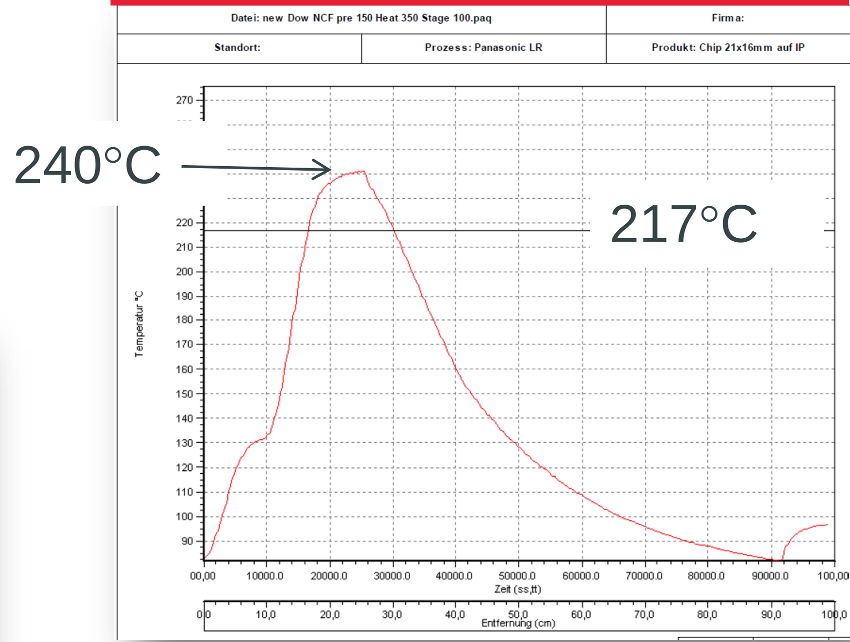


Lamination Parameter	Value
Film thickness	20 µm
Vacuum time	30 s
Pressure time	60 s
Pressure	0.5 MPa
Temperature	75 °C

NCF is 3-5 um above solder cap



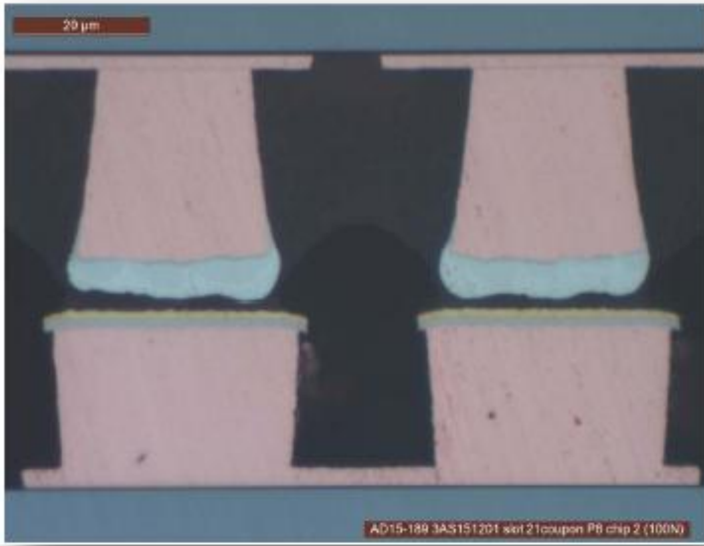
Bonding Profile for TV-II



Lamination conditions chosen to minimize NCF layer above solder cap
Varied bonding force (100N, 200N, 300N, 400N)

Bump Cross-section of GEN 1 NCF on TV-II

100 N Bonding Force



400 N Bonding Force

At 36,000 I/O, high viscosity of GEN-1 NCF prevents pillar – pad contact

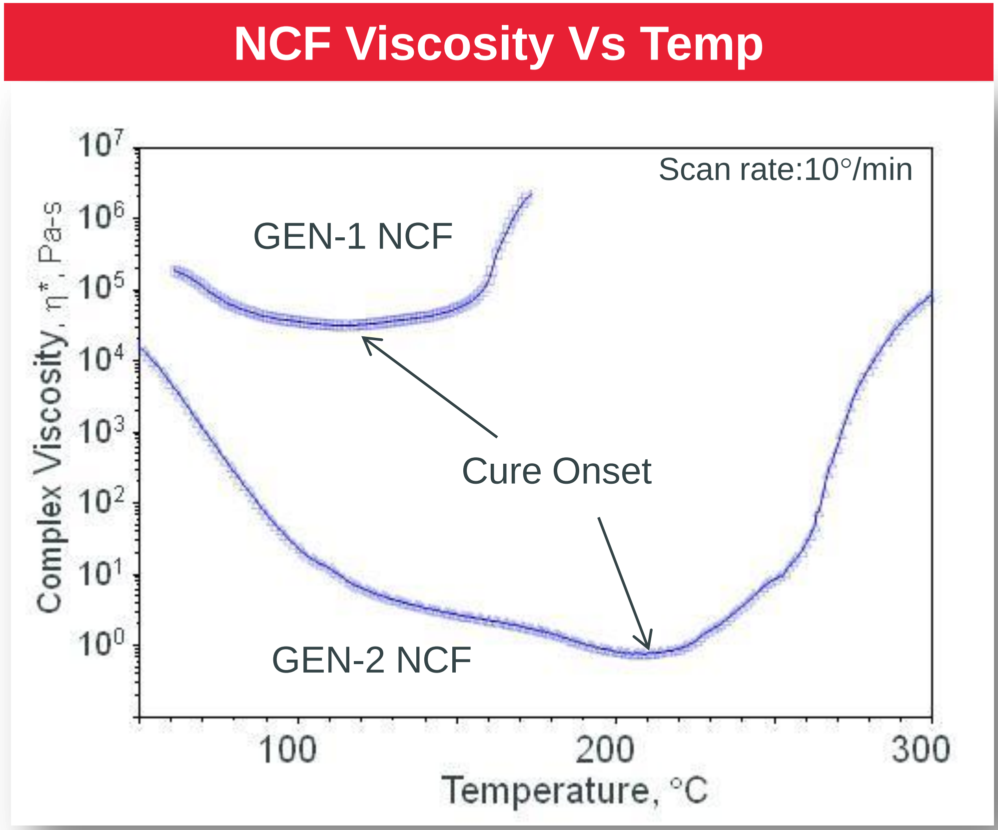
GEN-2 NCF Development for High I/O

GEN-2 NCF: Material Properties

	Units	GEN-1	GEN-2
Minimum Melt Viscosity	Pa-s	31,000	1
Cure Onset Temp (DSC)	°C	141	207
Peak Cure Temp	°C	166	250
CTE, α_1	ppm/°C	28	25
CTE, α2	ppm/°C	120	95
Tg,	°C	122	92
Modulus, DMA, GPa	°C	5.8	7.5

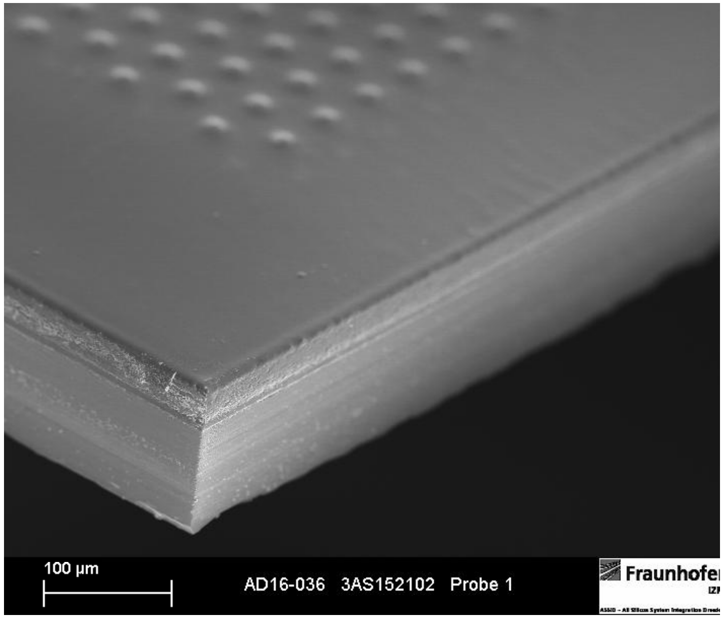
- Key changes (GEN-1 → GEN-2)
  - Lower viscosity to reduce resistance during bonding
  - Delayed cure to increase time for solder wetting

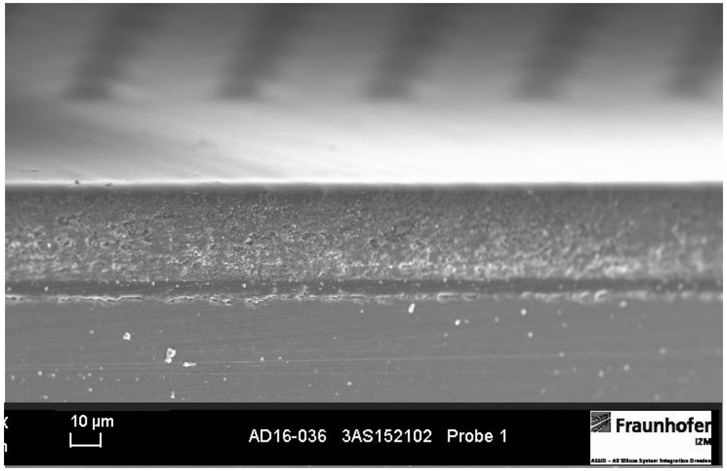
Viscosity Comparison – GEN-1 and GEN-2 NCF



- Viscosity of GEN-2 NCF is 4 orders of magnitude lower than GEN-1
- GEN-2 NCF has significantly delayed cure onset point

Lamination and Dicing GEN-2 NCF



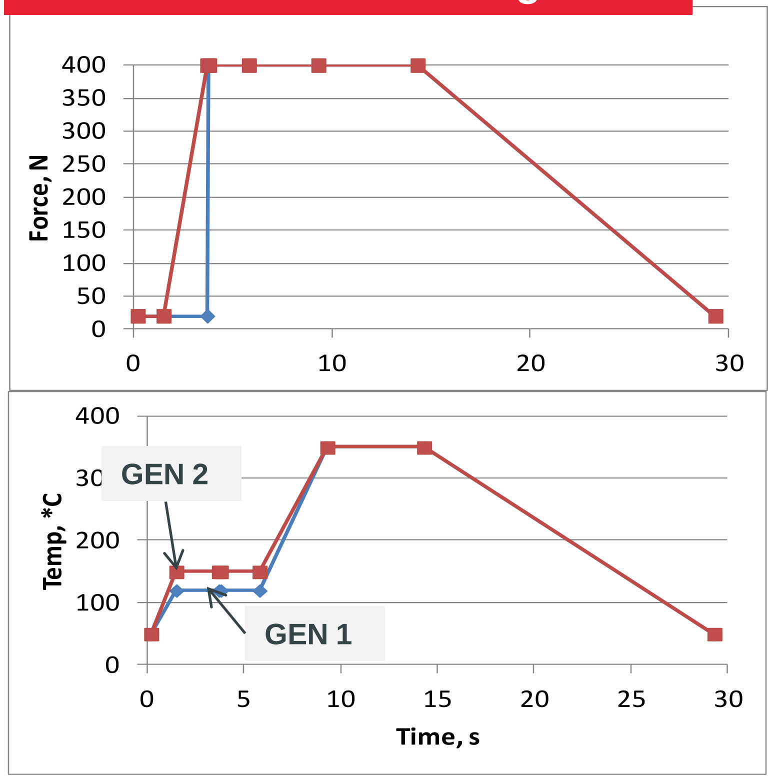


- NCF resists edge chips and cracks during mechanical blade dicing
- Important to smooth edge flow during bonding

Lamination Parameter	Value
Vacuum time	30 s
Pressure time	60 s
Pressure	0.2 MPa
Temperature	70 C

Bonding Profile for GEN-2

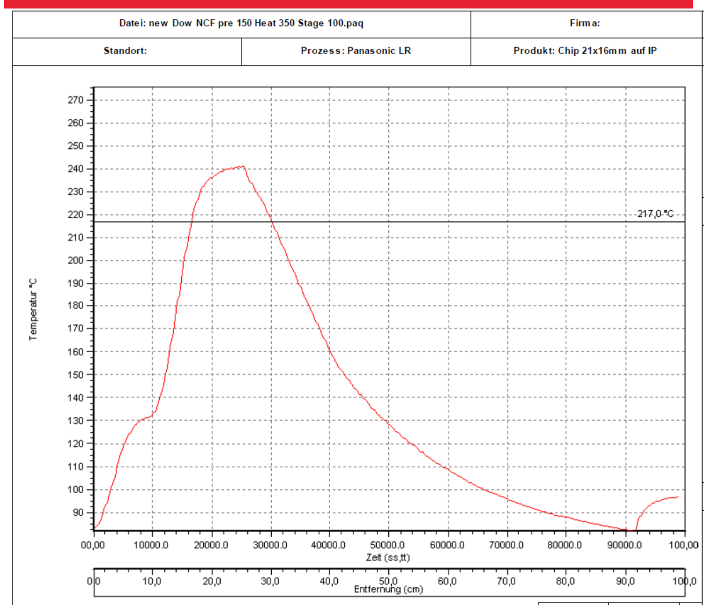
Bond Profile Settings



Pre-Heat Optimization – GEN2

Force, N	400	400	**400**	400
Head Temp, °C	**180**	**170**	**150**	**140**
Stage Temp, °C	100	100	**100**	100
Exposure time, s	5	5	**5**	5
Flow	+++	++	**OK**	-

Actual Bond Profile



- Higher temperature used in pre-heat stage
- Force ramp initiated slightly earlier

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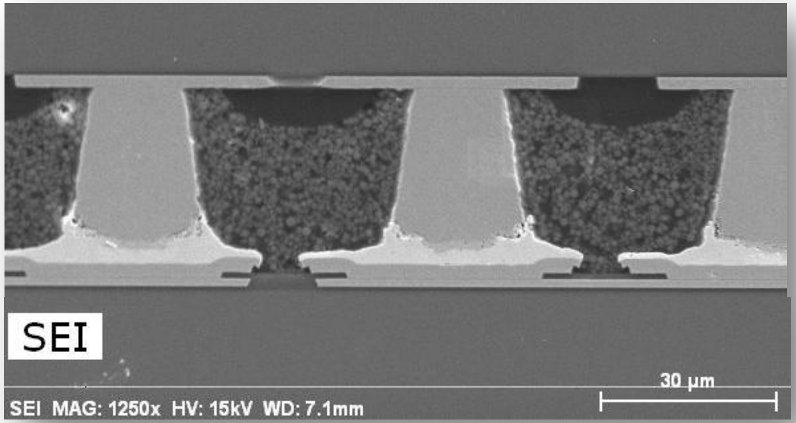
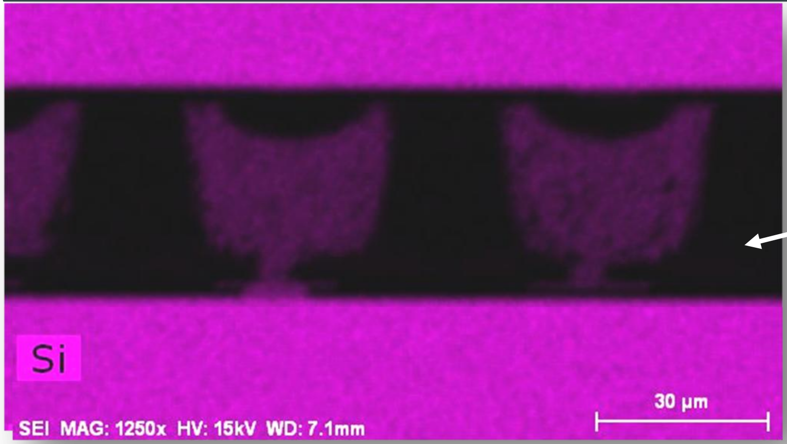
Bonding Results for GEN-2 NCF on TV-II

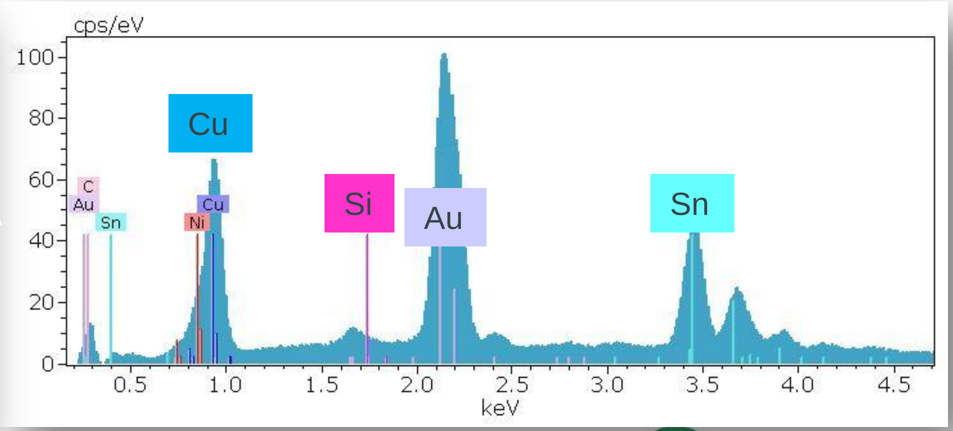
SEM Image of bonded Joint



- SEM shows good joint formation with uniform filler distribution
- EDS spectrum shows no silica entrapment
- Significantly increased voiding detected relative to GEN-1
  - Viscosity adjustment and use of optimized processing (including use of pressure curing) to be applied

Si EDS and Element Spectrum of bonded Joint





Initial e-test validation – GEN-2 NCF

Preconditioning
MSL 3A60°C/60% RH/40h
3x 260C reflow

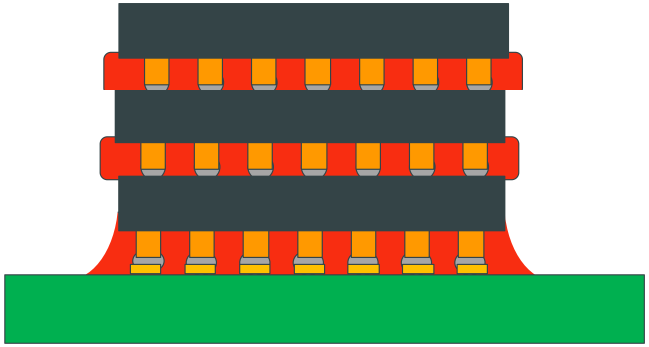
Die Number	Diced Initial, 0h	Diced 40h 60°C/60% RH	Diced 3x Reflow (260°C)
	R (Ohms)	R (Ohms)	R (Ohms)
1	8.11E+02	8.13E+02	8.13E+02
2	7.73E+02	7.49E+02	7.54E+02
3	7.94E_02	7.88E+02	7.82E+02
4	7.41E+02	7.49E+02	7.77E+02

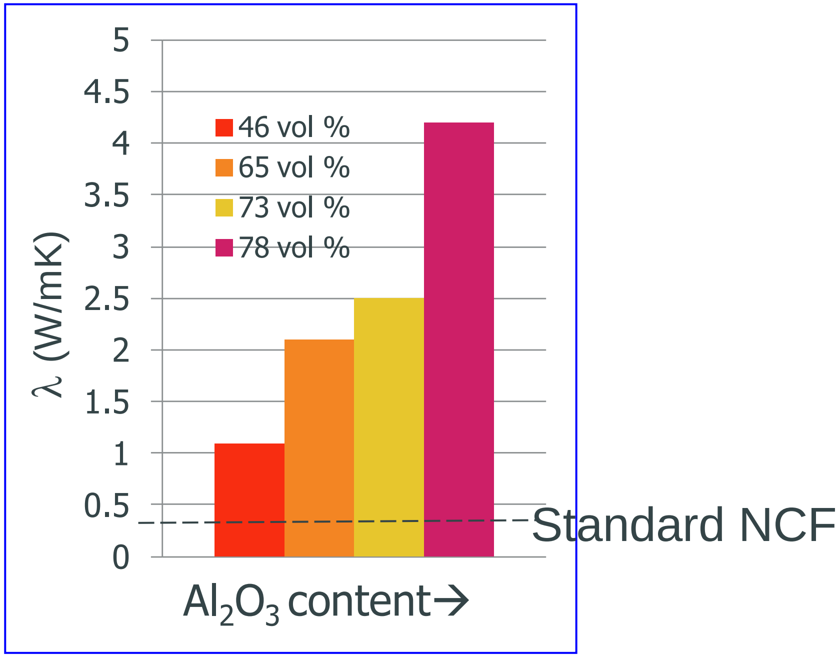
Target resistance for TV-II, 850 Ohms met for all die
→TCT test and analysis

NCF with Increased Thermal Conductivity (GEN-3)

Substituting Conductive Fillers for Silica

Thermal Conductivity

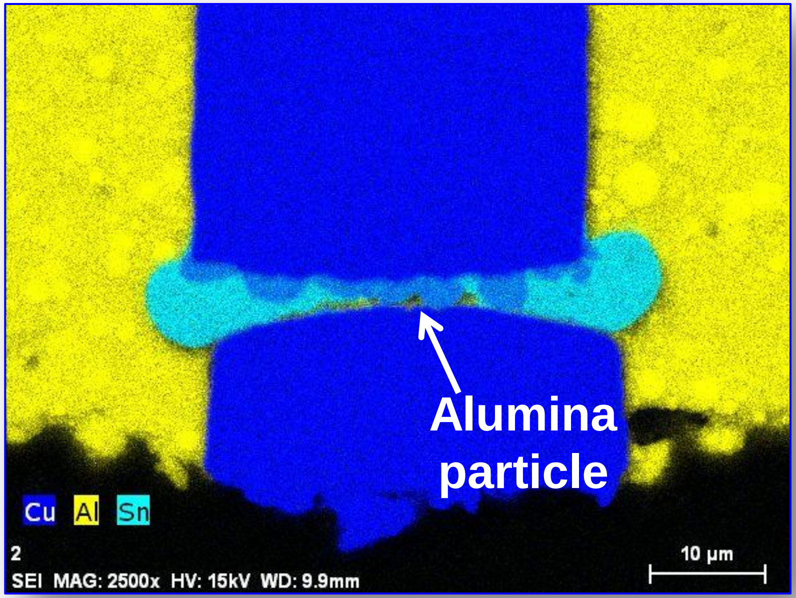




- Other ceramic fillers, like silica, can be readily dispersed in film composites
- Loading levels sufficient to achieve > 4 W/mK form films that can be laminated with conventional temperature and pressure
- Drawbacks are reduced transparency, bonding (filler entrapment), and possibly reliability (high modulus)

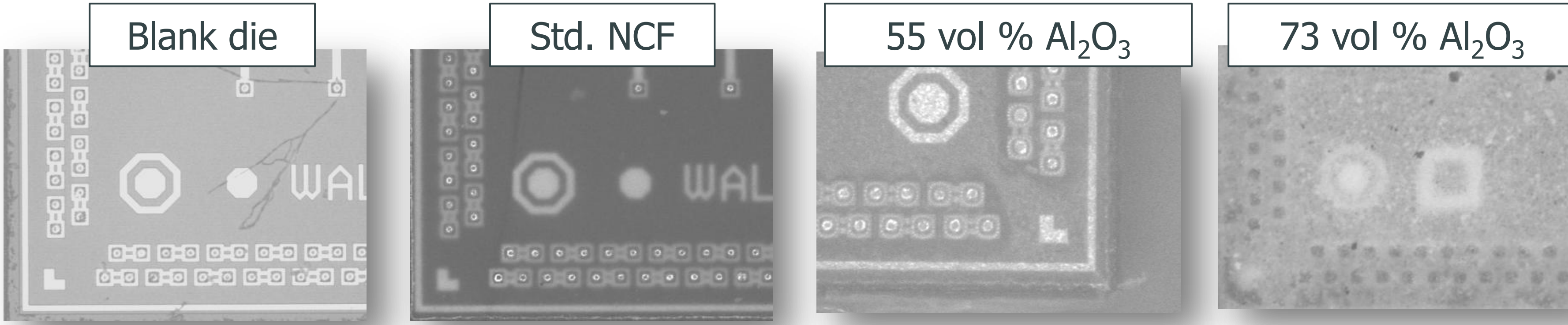
Joint Inspection of Bonded Copper Pillar

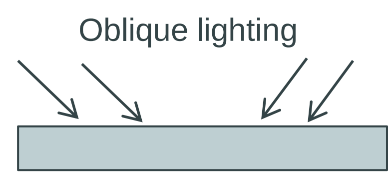
Element Map by EDS



- Test Vehicle I - Bonding Force 90 N creates solder-pad contact.
- Intermetallic region is irregular
- Alumina (73 vol %) visible in solder/pad interface

Issues with Ceramic-Filled NCF, cont'd –
Transparency





- Lamination T = 70-90 C
- High conductivity must be achieved with reduced filler content,
- Focus on resin matrix and interaction with filler interface

Summary

- NCF technology for area array die with fine pitch perimeter
    - Good joint formation
    - Minimal voiding with good fillet on 100 um die
    - Good reliability
- GEN-2 – High I/O
    - Good joint formation with no detection of filler entrapment
    - Final modifications underway
- GEN-3 High Thermal Conductivity
    - Films > 4 W/mK
    - Conventional lamination temperature (70-90C)
    - Material development aimed at maintaining TC with reduced filler content

Acknowledgements

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Thank You

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