Adhesives in Microelectronics and MEMS Applications

Helge Kristiansen

Helge Kristiansen

Conpart AS

Gåsevikvn. 4, Kjeller

P.O. Box 144, N-2027 Kjeller

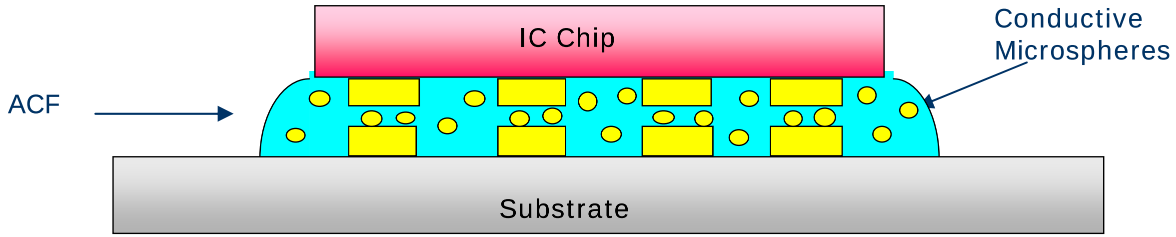
NORWAY

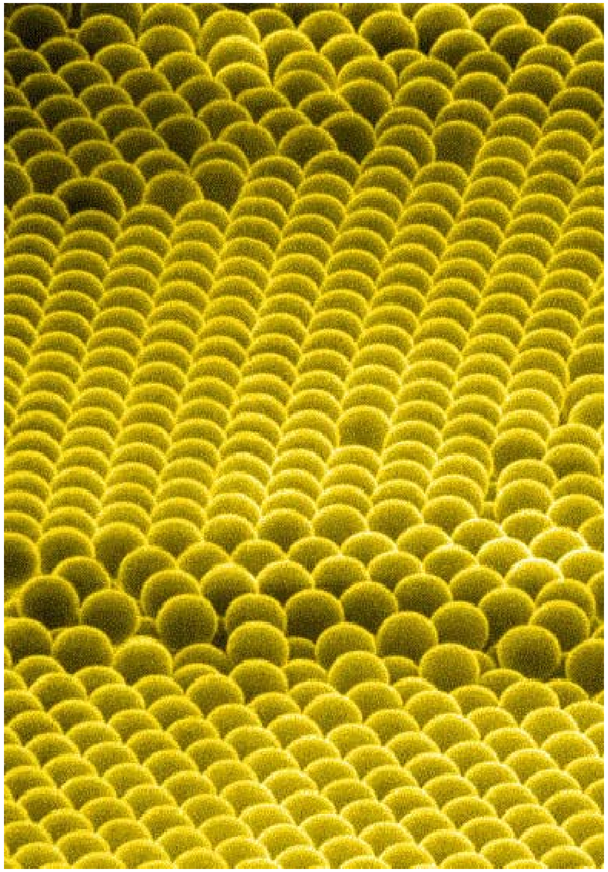
Phone +47 64 84 43 00

Mobile +47 930 36 073

E-mail: helge@conpart.no

www.conpart.no

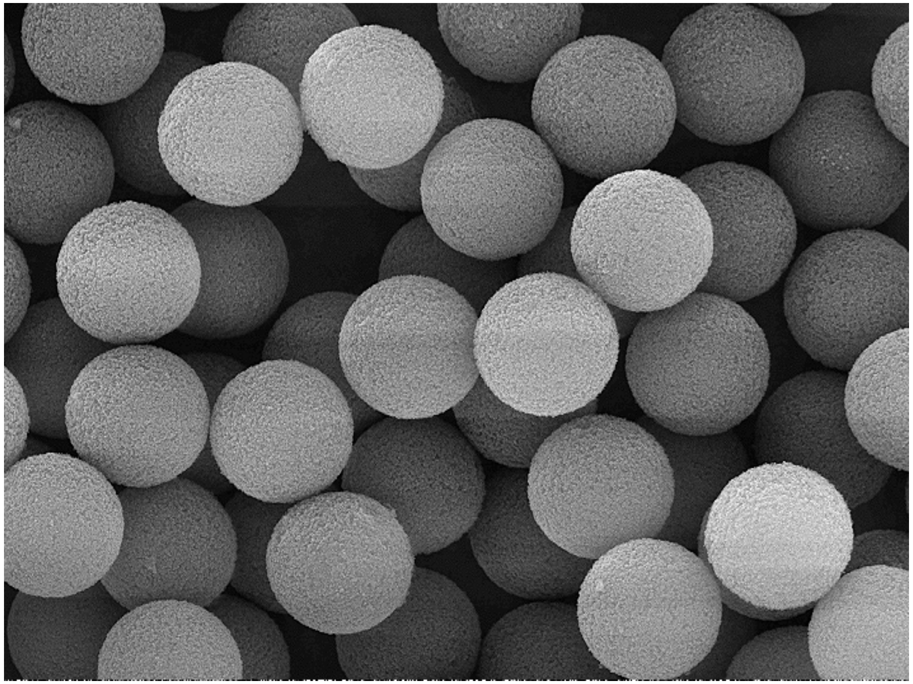


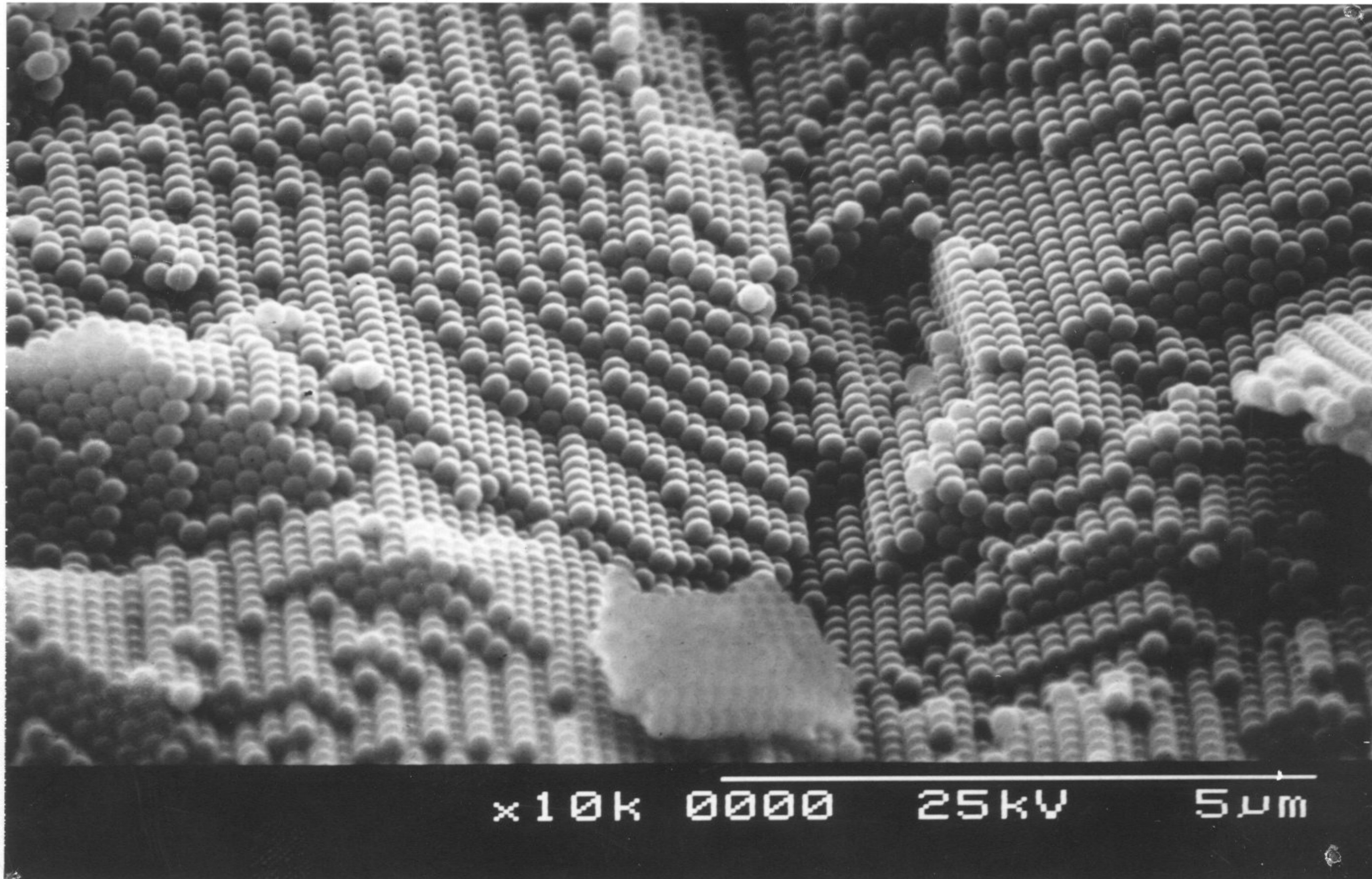


Monosized polymer particles

Polymer particles with exceptional properties

- Mono sized particles
- Size 1 – 200 μm
- Polymer composition
- Surface chemistry
- Functional groups
- Porosity
- Magnetic
- Metal plated
- Core & shell

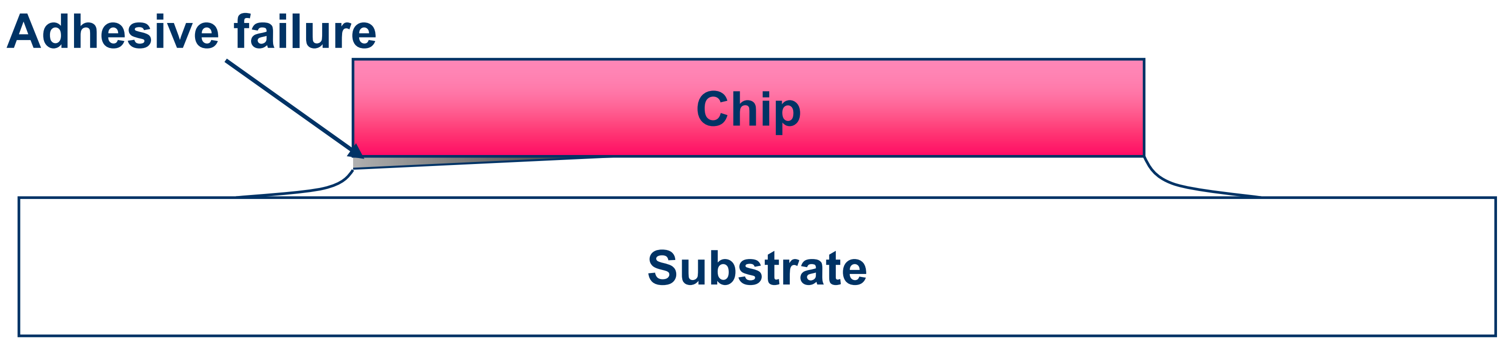


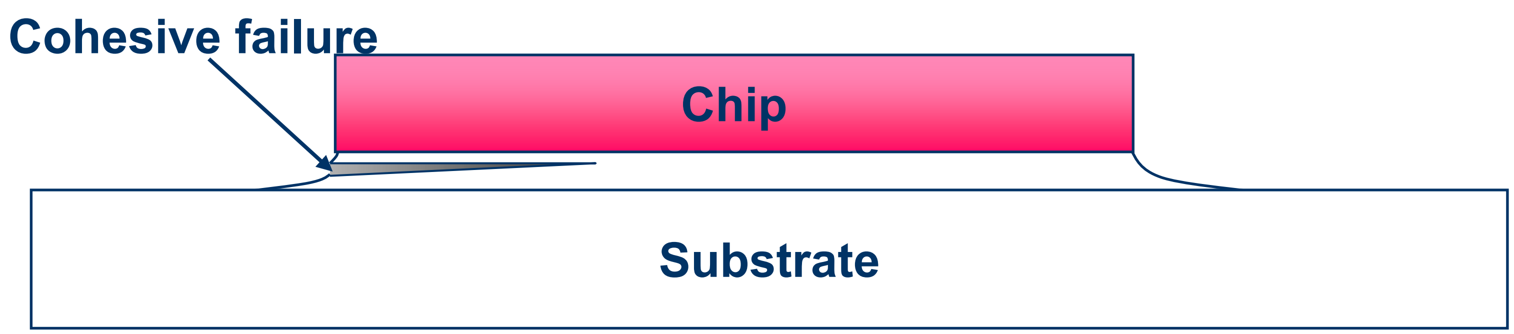

x10k 0000 25kV 5µm

Adhesion

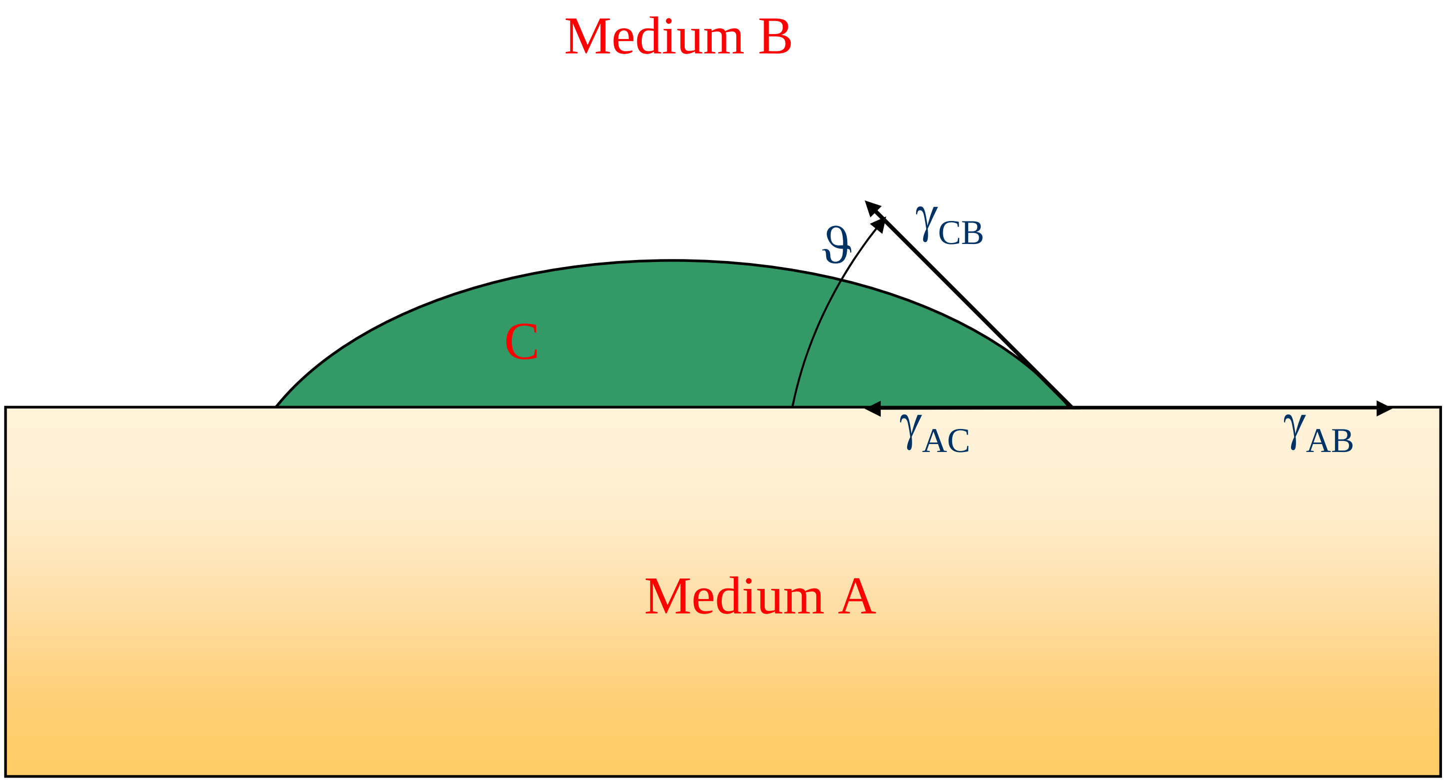
- Adhesion relates to the interface between adherent and adhesive
- The most important mechanism for adhesion is inter-molecular and surface forces
  - Van-der Waal (dispersion forces)
  - Hydrogen bonds
  - Very short range (sub nm)
- Generally no chemical bonds
- Other factors like mechanical “interlocking” have very little importance in typical electronic systems
- Cohesion: Internal “strength” of the adhesive (often chemical bonds)

Adhesive / cohesive





Contact angle



Criteria for wetting

- Force balance (along interface)

$$\gamma_{AB} = \gamma_{AC} + \gamma_{CB} \cdot \cos \vartheta$$

  - $\gamma_{A(B)}$: Surface energy solid (-air) [N/m], [J/m^2]
  - $\gamma_{C(B)}$: Surface energy adhesive (-air)
  - γ_{AC}: Surface energy solid-adhesive

- For a good wetting

$$\gamma_A > \gamma_B$$

Polymer properties

- Low weight (0.9 - 1.5 g/cm^3)
- High thermal expansion
- Hygroscopic
  - Affects mechanical and electrical properties
- Glass transition
  - Introduces new degrees of freedom in the material
  - Increases thermal expansion
  - Reduced mechanical strength

Polymer

- Long chains of monomers
- Linear or branched
- Thermoset
  - Best chemical and mechanical stability
  - Epoxies, polyurethane, silicone
- Thermoplastic
  - Simplifies rework
  - Teflon, polyesters

Thermoplastics

- Reversible melting ↔ solidifying
  - Heating provides thermal energy for polymer chains to move “freely”
  - Cooling reduces the molecular motion
- Linear molecular chains
  - Entanglement
  - Inter-molecular forces
  - No chemical cross bonding
- Mechanical anisotropy
  - Preferential orientation of molecules
- Polyesters, acrylics

Properties of thermoplastics

Fillers	Tg	Bond Temp	Rework	Die Shear	Thermal	Modulus
	°C	°C	min. °C	MPa	W/m°C	GPa
None	-40	100 - 150	110	11	0.20	0,4
Ag, AIN, None	25	150 - 200	160	14	0.3-3.0	0,4
Ag, AIN, None	45	160 - 220	170	17	0.3-3.0	3,2
Ag, AIN, None	85	160 - 250	170	19	0.3-3.0	2,5
None	145	200 - 230	210	24	0.22	1
Ag, Au, AIN, None	180	325 - 400	350	25	0.3-3.0	2,2
None	280	350 - 450	400	31	0.25	2,3

Thermoset

- Do not melt upon heating
- Forms links or chemical bonds between adjacent chains, during curing (intra-molecular bonds)
- Three dimensional rigid network
- Properties depend on the molecular units, and the length and the density of the cross-links
- Thermosetting resins are usually isotropic
- Epoxies, silicones, urethanes

Glass temperature

- Second order phase transformation
- Discontinuous volume expansion, heat capacity and mechanical properties
- Thermal energy sufficient to allow rotation about chemical bonds
  - Depends on bond (Carbon or silicone)
  - Adjacent molecular groups (dipoles, bulkiness and symmetry)

Different classes of organic adhesives

- **Solvent-based adhesives:** The adhesive is solved in a suitable solvent or dispersed in water. The adhesive solidifies during drying (not curing)
- **Thermoplastic adhesives:** Based on thermoplastic materials, that is solid to liquid is a reversible phase change. Typically polyimide- and polyester (easily oxidized)
- **Thermosetting adhesives:** Improved mechanical properties, high temperature and chemical resistance

Structural adhesive

- Good load-carrying capability
- Long-term durability
- Resistance to heat, solvent, and fatigue
- 6 main types:
  - Urethanes
  - Acrylics
  - Epoxies
  - Silicones
  - Anaerobic adhesives
  - Cyanoacrylates

Structural adhesives

- Cyanoacrylate
  - Cyanoacrylates adhesive bonds quickly to plastic and rubber but have limited temperature and moisture resistance.
  - Cured by humidity present on surfaces
- Acrylics
  - Acrylics, a versatile adhesive family that bonds to oily parts, cures quickly, and has good overall properties.
  - Cure at room temperature when used with activators.
    - The adhesive and activator can be applied separately to the bonding surfaces. Often a low viscosity activator
    - The adhesive and activator premixed in a static mixer prior to application. Anaerobic
- Anaerobics, or surface-activated acrylics
  - Bonding threaded metal parts etc.

Silicones

- Solvent born resins
  - Evaporation of solvent
  - Curing at elevated temperature
- Room Temperature Vulcanisation RTV
  - One part RTV systems generally cured by moisture
    - Give of by-products during cure
  - Two part RTV generally cured by a platinum complex
- UV cured
- Very wide temperature range
  - -50 – 200 ^{0}C

Silicones (II)

- Soft, low modulus material
  - Very low Tg (typically -65 ^{0}C)
- Very high CTE (Typically 350 ppm/ ^{0}C)
- Very low dielectric constant
  - Low dielectric loss
- Easily modified to provide a range of physical and mechanical properties, cure system, and application techniques.
- Very low surface tension (24 mN/m)
- Very mobile, vapor attaches to all surfaces
  - Wire bonding problems

Silicones (III)

- Good water and moisture resistance
  - However, very high water permeability If adhesion is good, a continuous water film is <u>not</u> obtained at the interface
  - NB! Oxygen bridge bonding to die surface prevents Al corrosion)
  - Relatively low equilibrium moisture content
  - Very low levels of mobile ions
- Good sealing properties
  - Very durable for glass sealing
- Weather well out-of-doors
- Low surface tension expels liquid water

(Poly)urethanes

- One or two component systems
- Often solvent based
- Low stress materials
  - Good flexibility and elasticity
  - High thermal shock resistance
  - Good peeling characteristics
- Moisture curing system (~ 50%RH)
- Good adhesion to many organic materials

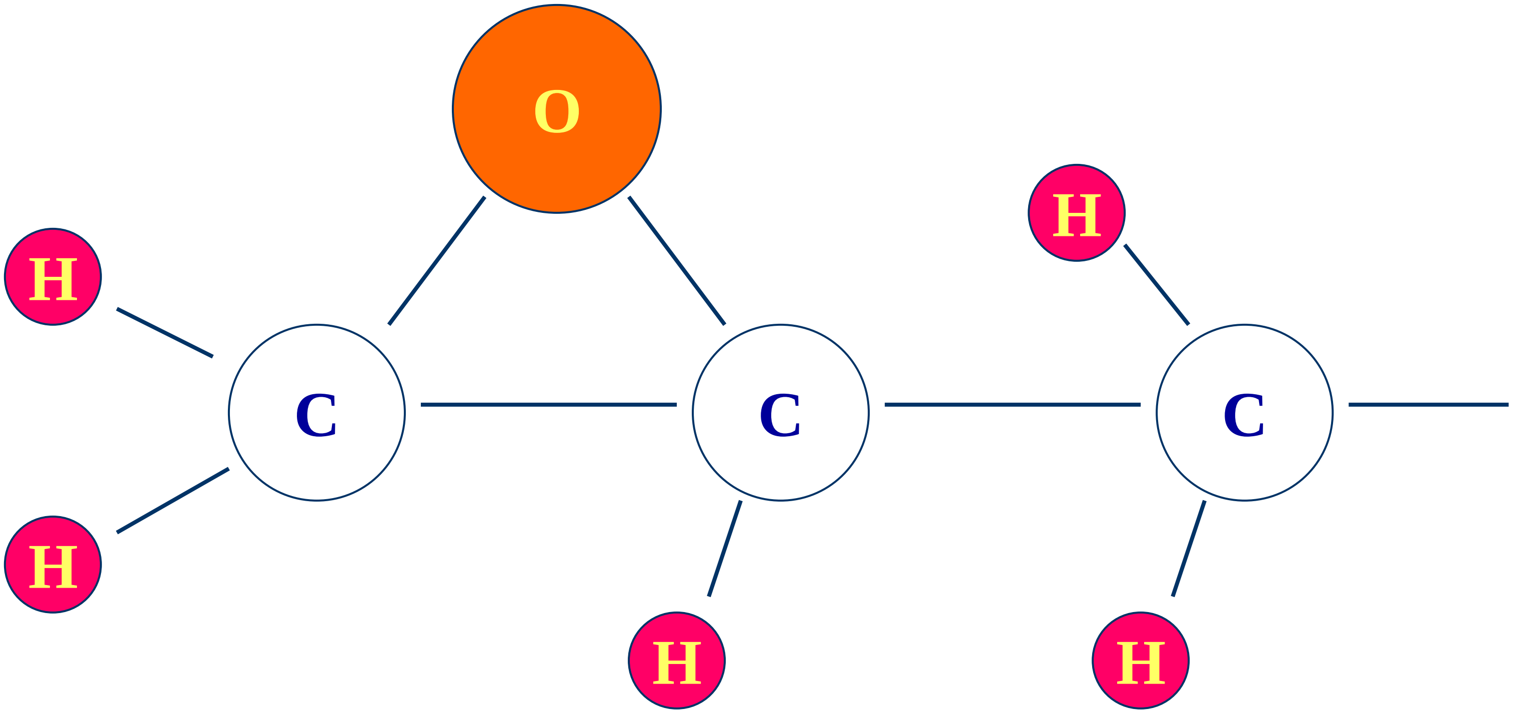
Epoxies

- Thermoset
- Thermal cure (UV or light cure optional)
- Relatively high E-modulus
  - Brittle
- Generally good adhesion
  - Hydrogen bonding (NB! Except gold, due to lack of oxygen at the surface))
  - Mechanical interlocking
- Typical shrinkage upon curing is in the order of 1 to 2 percent
- Relatively low moisture permeability

Curing

- The selection of a curing agent is as important as the choice of the resin
  - Rate of reactivity
  - Degree of exothermal
  - Gel time
  - Curing time
  - Mechanical properties of the cured adhesive.
- The number of epoxide groups in the molecule determines the “functionality” of the resin
  - Increasing glass transition temperature
  - Decreasing Thermal Coefficient of Expansion (TCE)

Epoxide group



Modification of properties

- Choice of resin system
- Choice of hardener
- “Fillers”
  - Electrical (dielectric) properties
  - Mechanical properties
  - Possible ionic contamination

Fillers

- Plasticizers, flexibilizers or elastomers
  - Plasticizers (an additive that is physically blended into the resin (do not become part of the polymer). Plasticizers in epoxies are typically rubber or thermoplastic particles. They have to be > 1 micron to be efficient
  - Flexibilizers are chemically reacted into the epoxy system (often thermoplastic polymers)
    - Reduces solvent and moisture resistance and lowers Tg
  - Elastomers remains as a distinct second phase (two separate cross-linked networks)

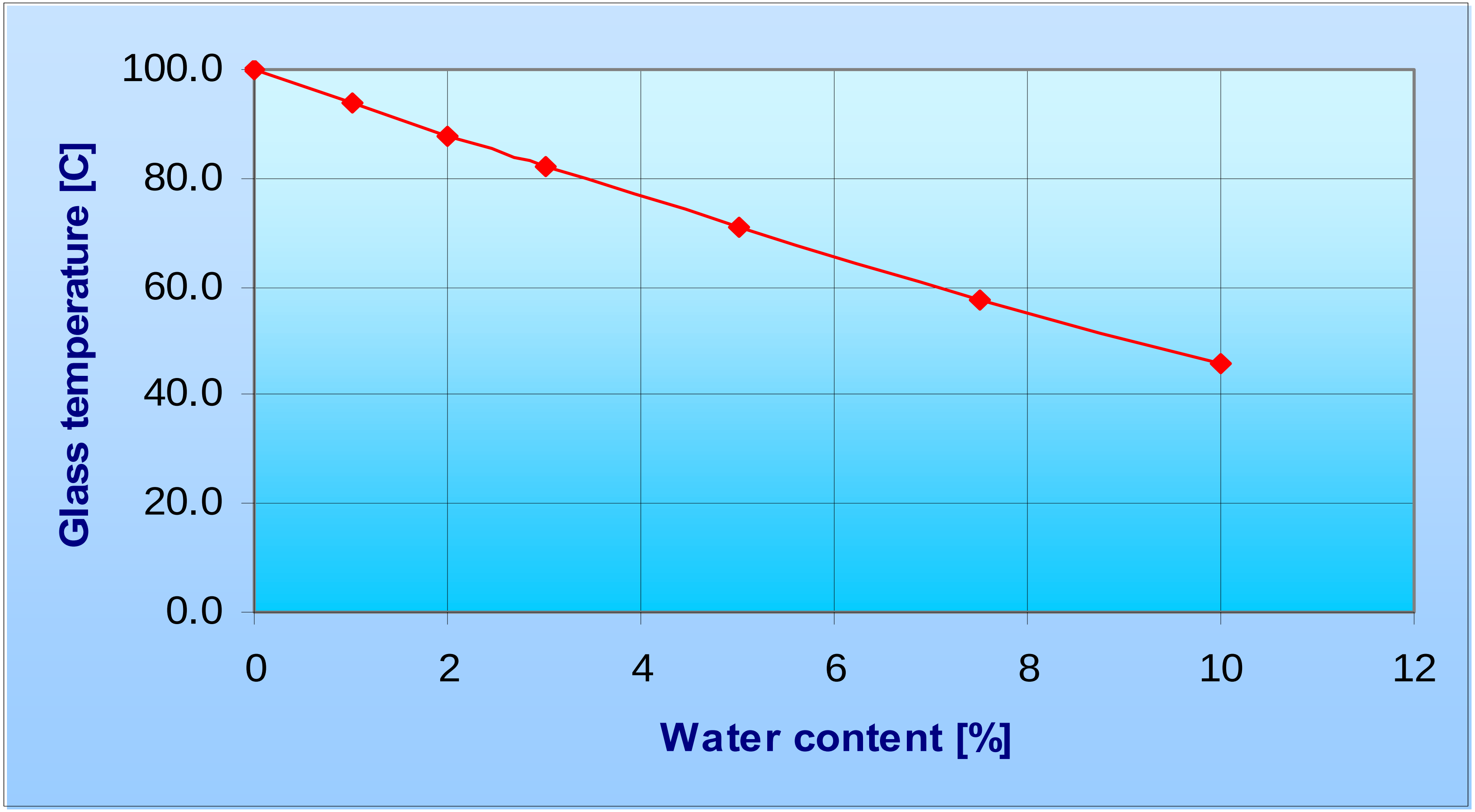
Plasticisers

- Absorbed liquids (soft solids), decrease the glass temperature
- Increased “free volume”
  - Reduces the internal viscous friction

$$\frac{1}{T_{g(PF)}} = \frac{w_p}{T_{g(P)}} + \frac{w_L}{T_{g(L)}}$$

  - Ex. Glass temperature of water : approx. –135 ^{0}C.

Influence of water

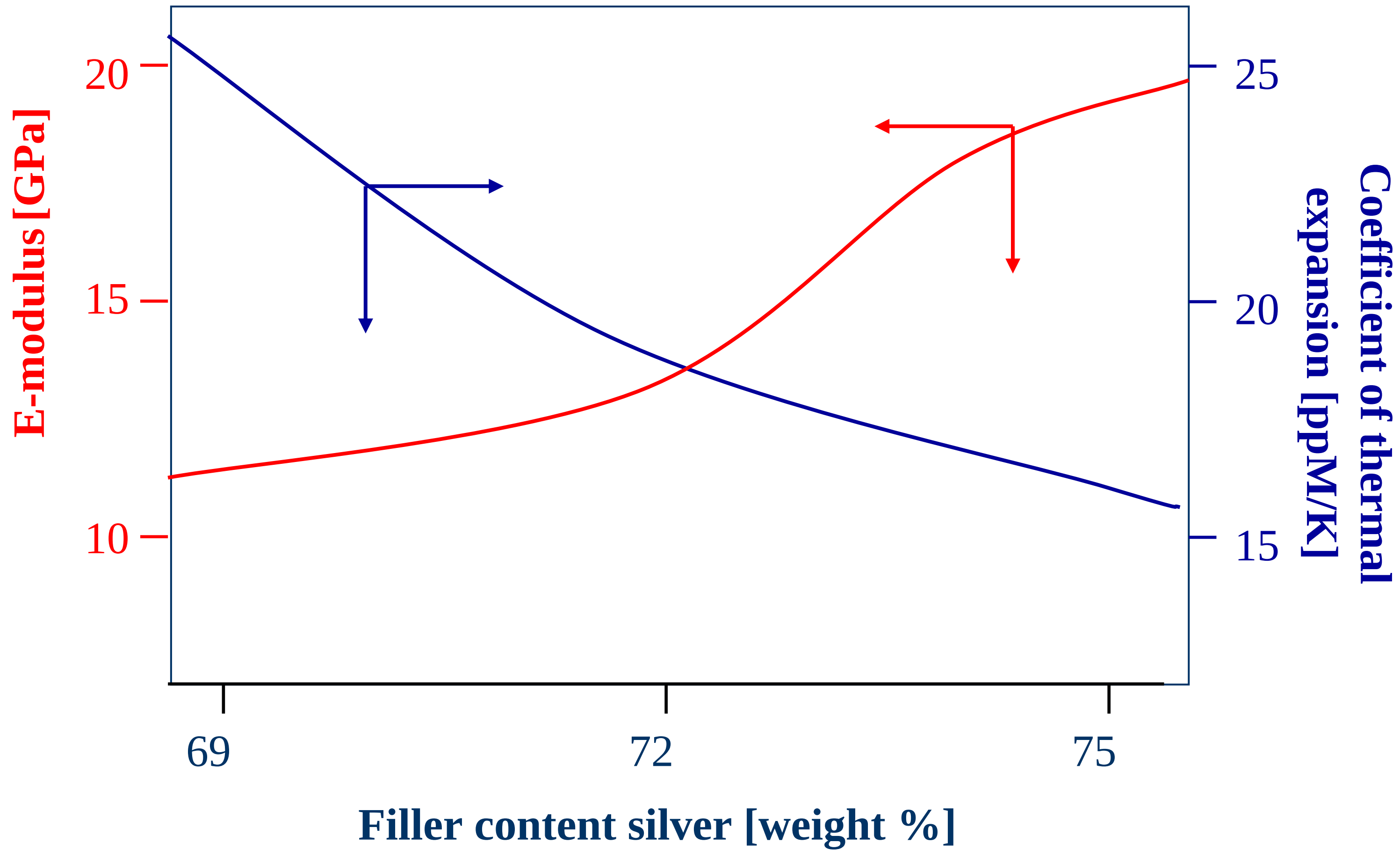


conpart

Silver epoxies

- Low impact strength
  - High loading of silver particles
- Solutions
  - Reducing filler rate by use of porous silver particles (Fraunhofer)
  - Randomise particle orientation, by making conductive composite particles (Georgia Tech)
  - Introduce plastizisers, to increase the ability to absorb mechanical energy (Ablestik)
  - Polymer spheres with silver coating

Mechanical properties



conpart

Criteria for adhesive selection

- Means of “dispensing” of adhesive
  - Screening, film, dispensing, stamping etc…
    - Viscosity / rheology:
    - Unwanted flow (capillary driven), leaching
- Good adhesion to parts:
  - What is the main components to be bonded (surface!!)
  - Surface cleaning
- Demands for mechanical properties
  - Strength - flexibility
    - E-module / Elongation before break
  - Sensitivity to mechanical stress
  - Requirements for temperature cycling

Criteria for adhesive selection

- Processing temperature
- Thermal expansion adhesive:
  - High CTE will often increase stress in adhesive joint due to the increased miss-match with the components to be bonded
  - High thermal expansion is likely to increase diffusion of humidity etc..
- Low ionic contamination
- Thermal (and electrical) conductivity
- Void free bond line
  - Local stress concentration (crack initiation)
  - Poor local thermal contact

Requirements from application (I)

- **Glass transition temperature** relative to operational (and storage) temperature of the device.
  - Radical change of mechanical properties
    - Reduced “E-modulus”
    - Increased thermal expansion
  - Increased diffusivity above Tg.
- **Water absorption**:
  - Changes mechanical properties (plasticizer)
    - Reduced T_G
  - Changes dielectric properties

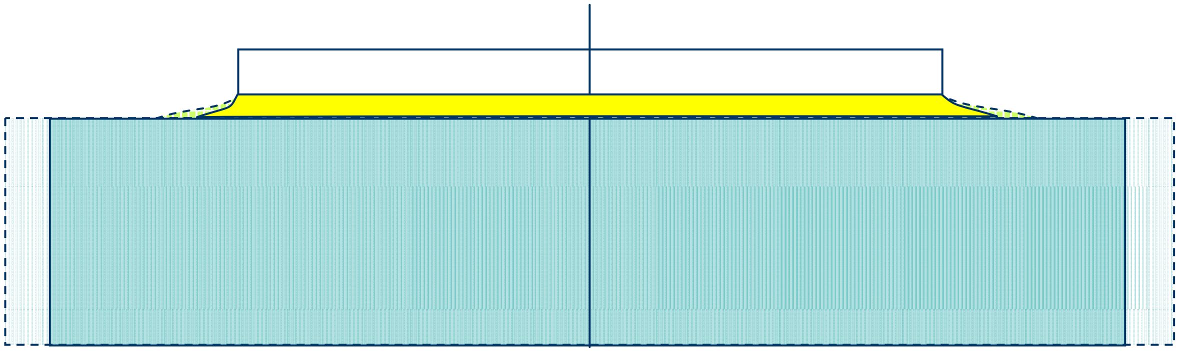
Resin bleed

- Resin bleed is the unwanted capillary action of low viscous parts of the adhesive
- Contamination of bond pads
  - Destroy the ability to perform wire bonding
- Relatively low molecular weight thermoset
  - During initial heating
  - Ultra clean surfaces (high surface tension)
  - Rough surfaces (large surface area)

E-modulus of different die attach adhesives

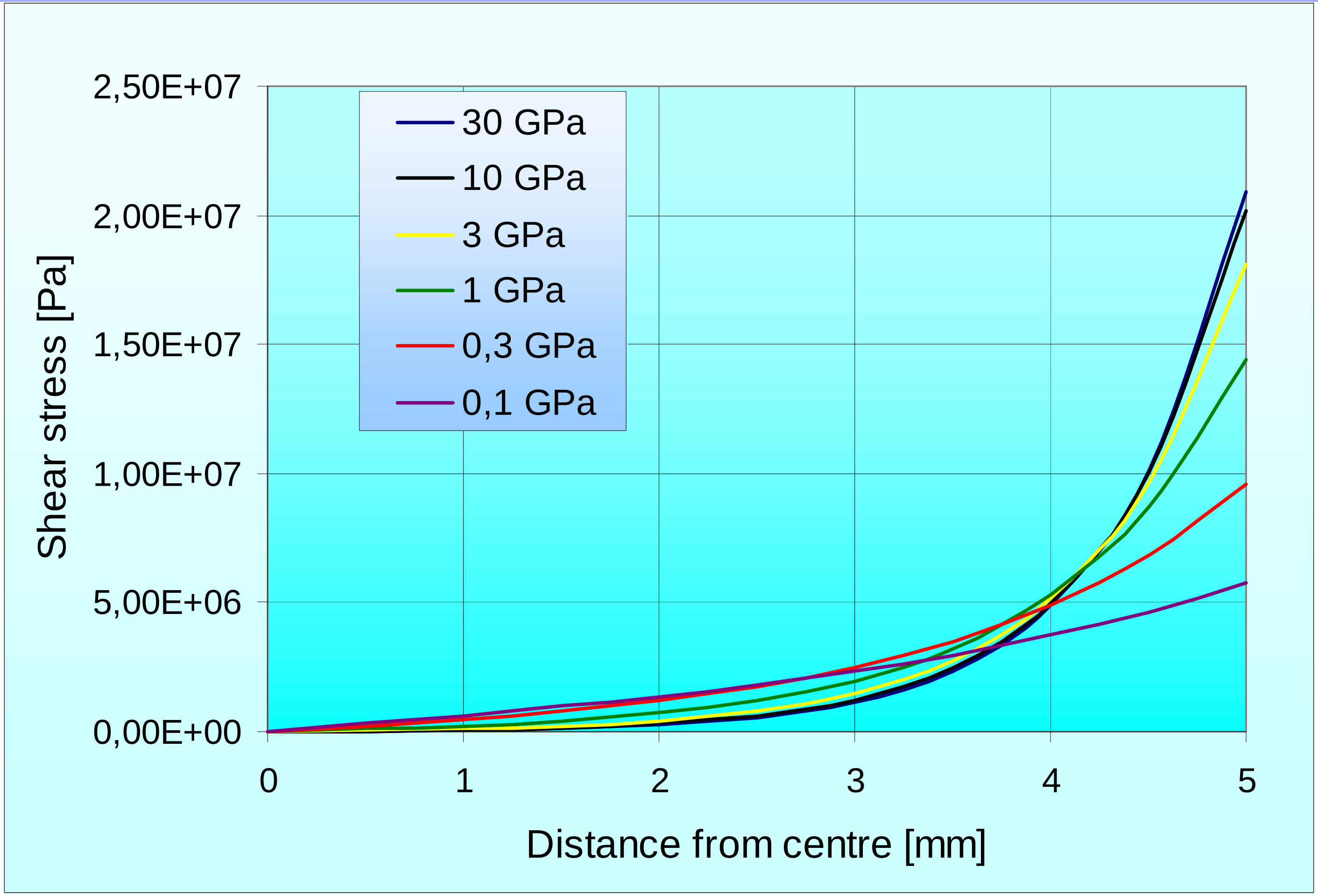
Adhesive		T_g [C]	E-modulus (dynamic) [GPa]			
			@ -65	@ 25	@ 150	@ 250
A	Epoxy	53	2,68	2,30	0,21	0,17
B	Epoxy	30	1,81	1,63	0,01	
C	Epoxy	88	5,78	4,98	0,36	0,27
D	Epoxy	40	5,40	2,87	0,12	0,05
E	Epoxy	67	6,27	5,30	1,18	0,45
F	Thermoplastic	98		2,40		
G	Cyanate Ester	245		6,90		

Stress in “Die attach”



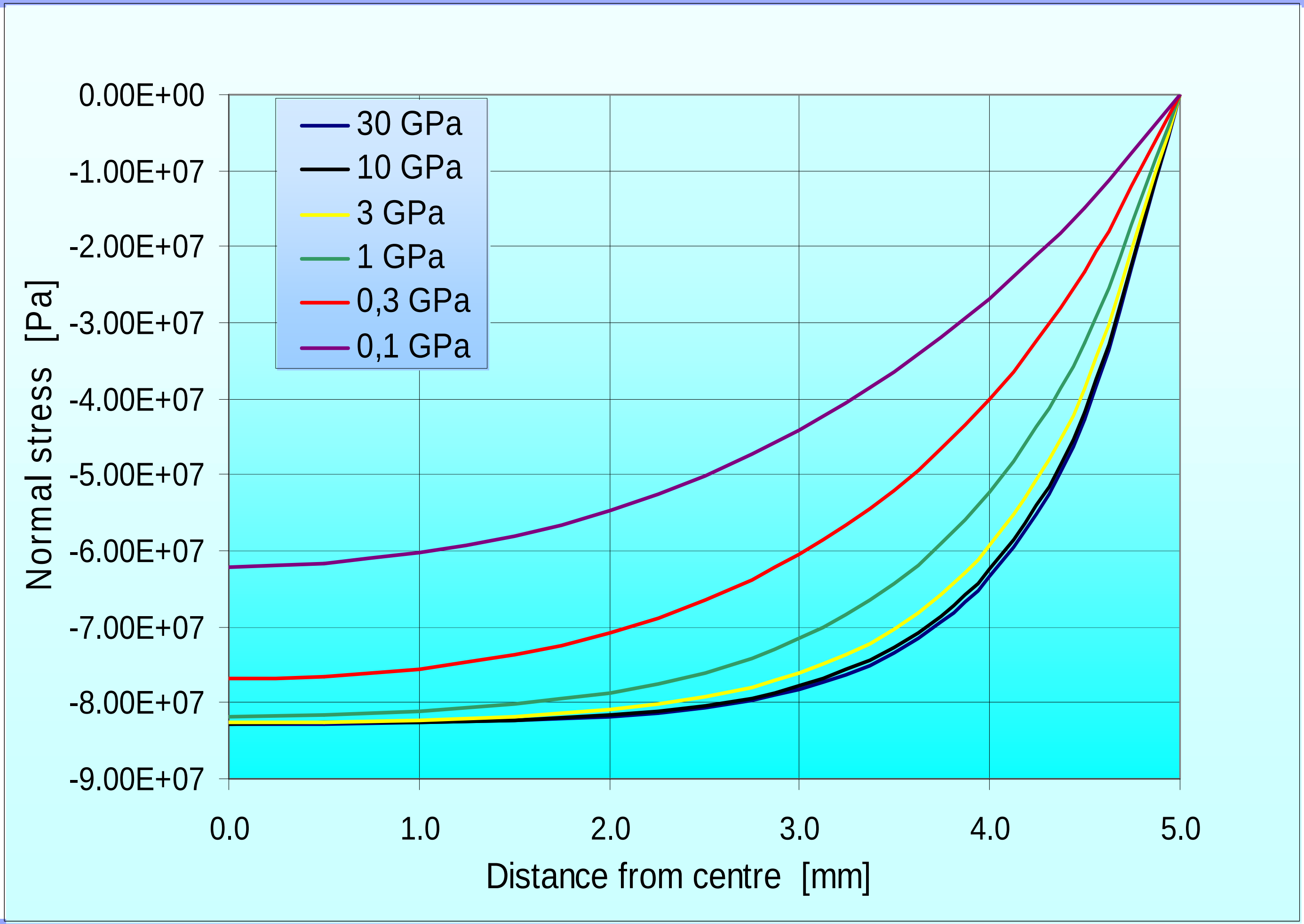
	Chip	Substrate	Adhesive
E-modulus	190 GPa	20 GPa	-
CTE	2,6 ppM/K	18 ppM/K	50 ppM/K
Thickness	0,4 mm	2,0 mm	0,03 mm
Poisson ratio	0,25	0,4	0,45

Shear stress in adhesive

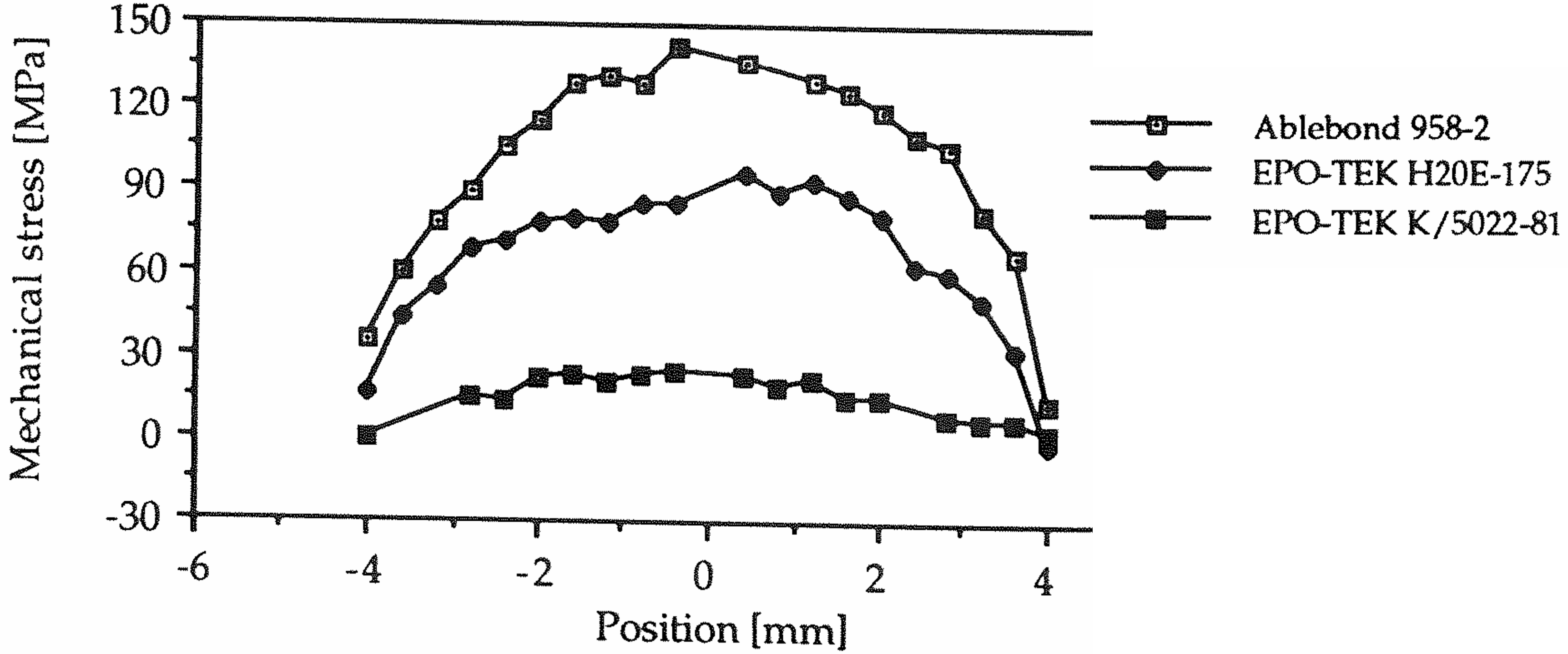


conpart

Normal stress in die

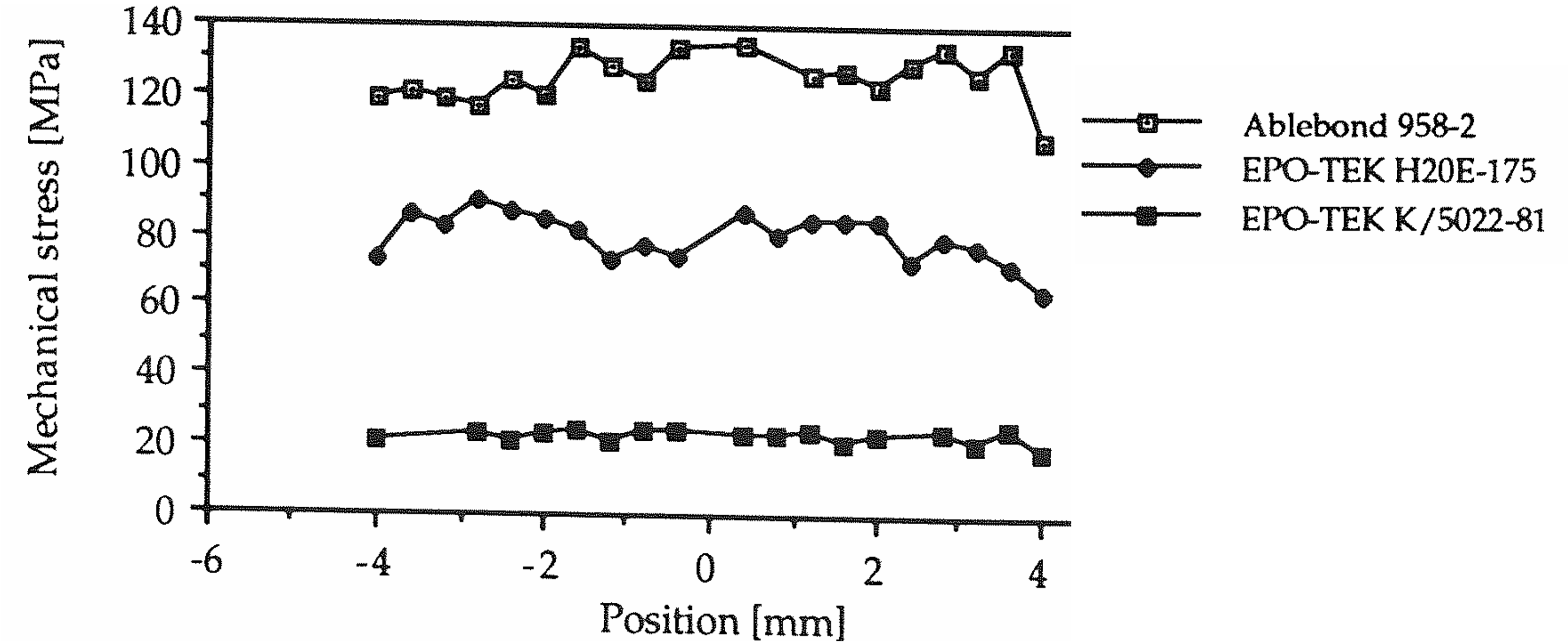


Measured stress in silicon die



- Silicon chip onto copper substrate
- Compressive stress along the centre-line
- Measured with Piezo-resistors

Measured stress in silicon die (II)



- Compressive stress normal to the centre-line
- Measured with Piezo-resistors

Measured and calculated stress

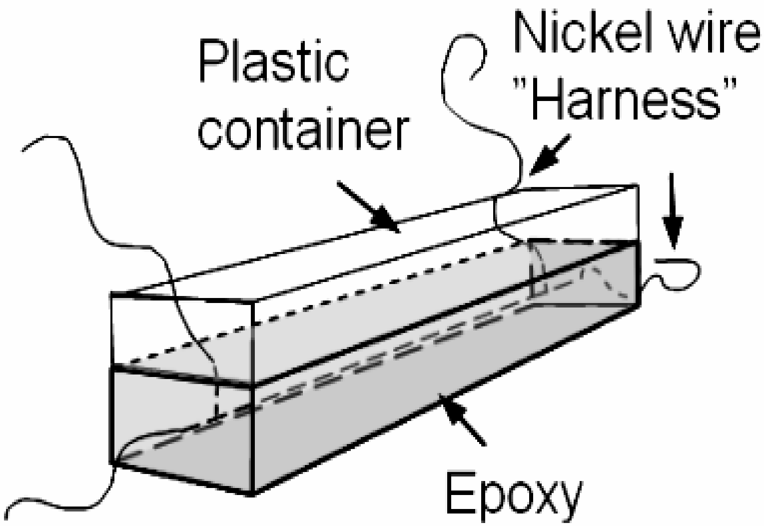
Adhesive	Cure temp	Strain calc.	Strain meas.
958-2	150°C	$1740 \cdot 10^{-6}$	$543 \cdot 10^{-6}$
H20E-175	160°C	$1880 \cdot 10^{-6}$	$343 \cdot 10^{-6}$
K/5022-81	210°C	$2570 \cdot 10^{-6}$	$105 \cdot 10^{-6}$

Adhesive	Stress calc.	Stress meas.
958-2	429 MPa	132 MPa
H20E-175	457 MPa	84 MPa
K/5022-81	629 MPa	26 MPa

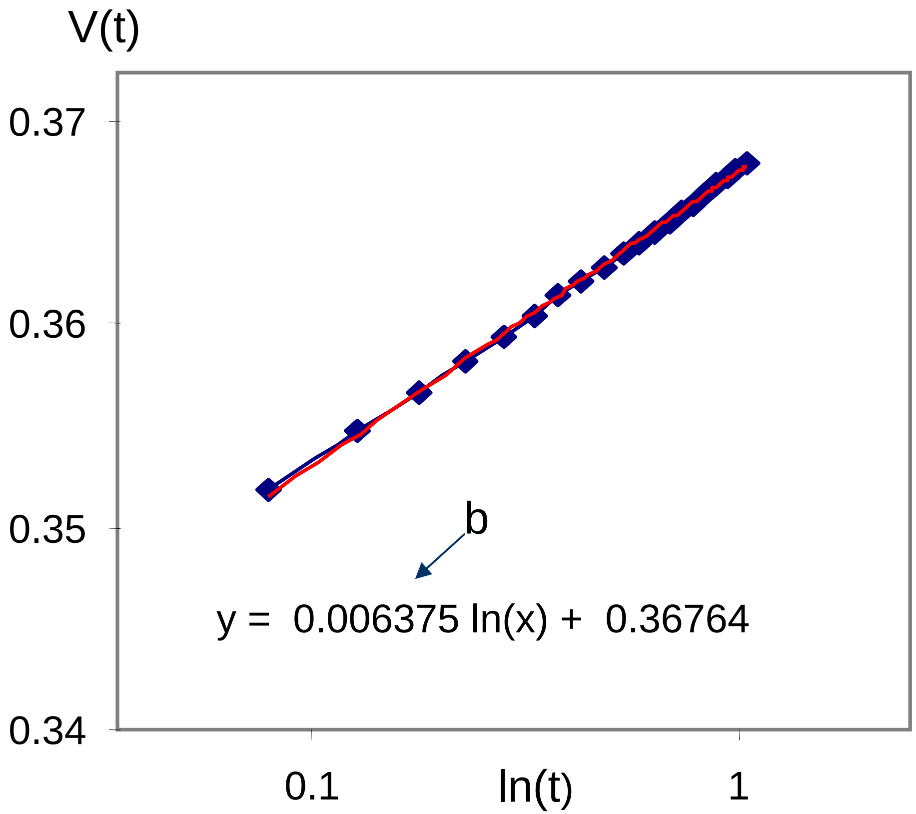
Comments: Measured stress

- Observed strain (stress) much lower than calculated!
- K/5022-81 (polyimide based): problems with the curing of the adhesive
- What is the effective ”Zero-stress” temperature?
- Plastic deformation?

Transient Hot Wire



$$\lambda = \frac{\alpha \cdot R^2 \cdot I^3}{4\pi \cdot h \cdot b}$$



Results

- λ increase with increased amount of conductive filler

- For Nano scale particles λ increase more than theory suggest;

  0% 0.20W/mK

  10% 0.35 W/mK

  20% 0.56 W/mK

- Surface treated alumina better:

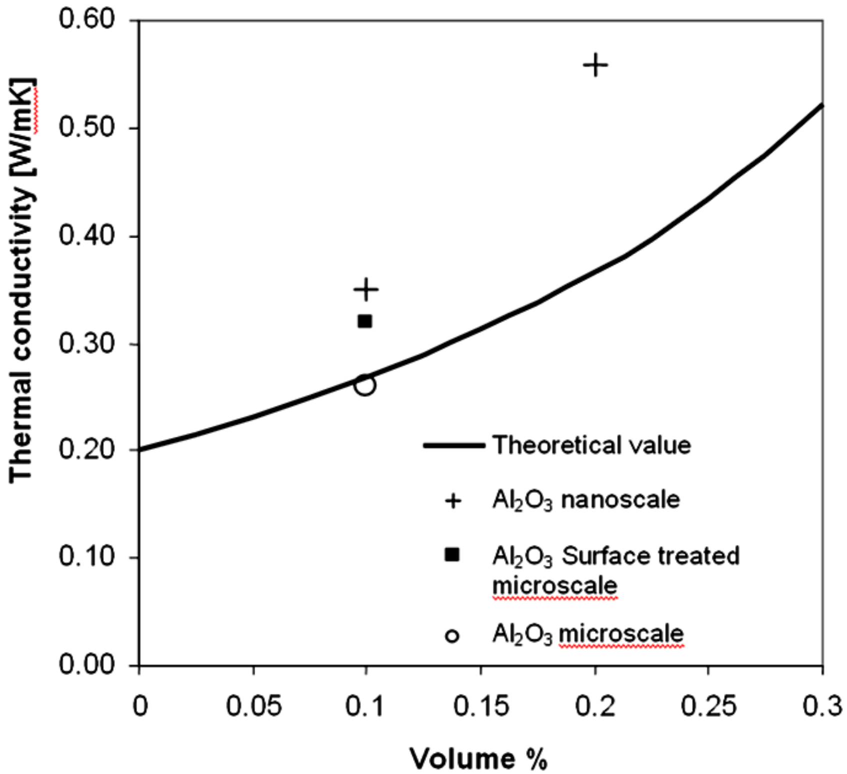
  Untreated: 0.26W/mK (10%)

  Treated: 0.32W/mK

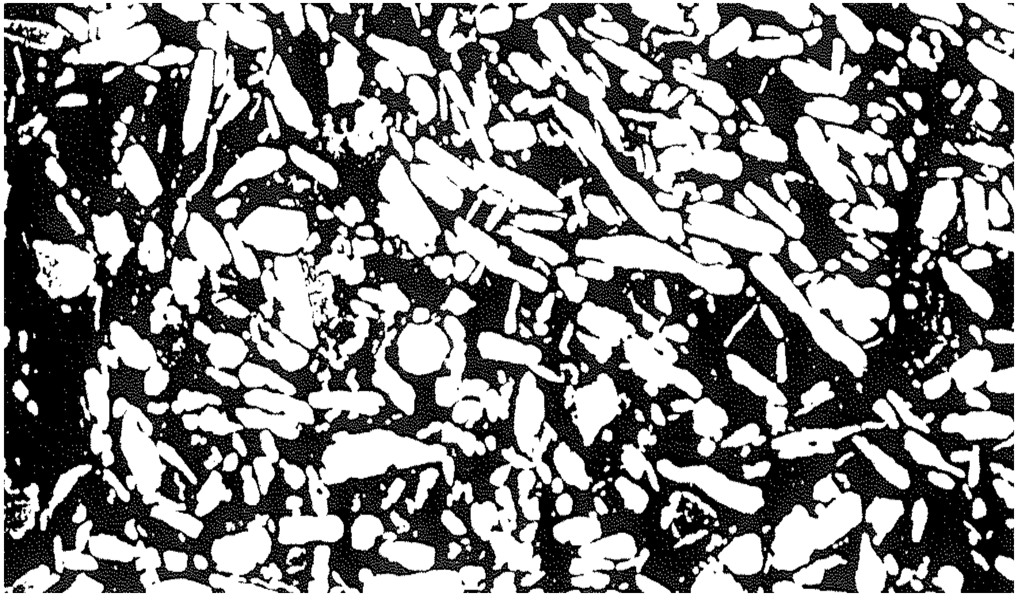
- Nanoscale particles better than micro scale particles:

  Micro: 0.26 W/mK

  Nano : 0.35 W/mK (10%)

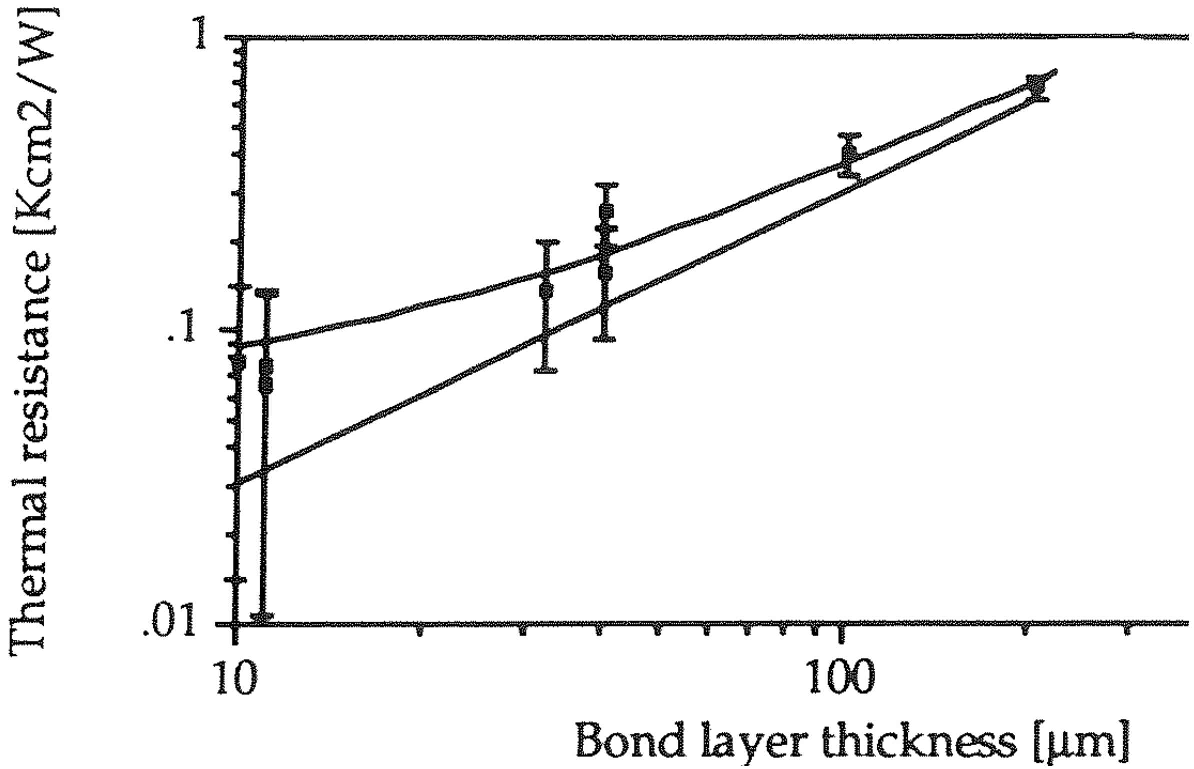


Silver epoxy



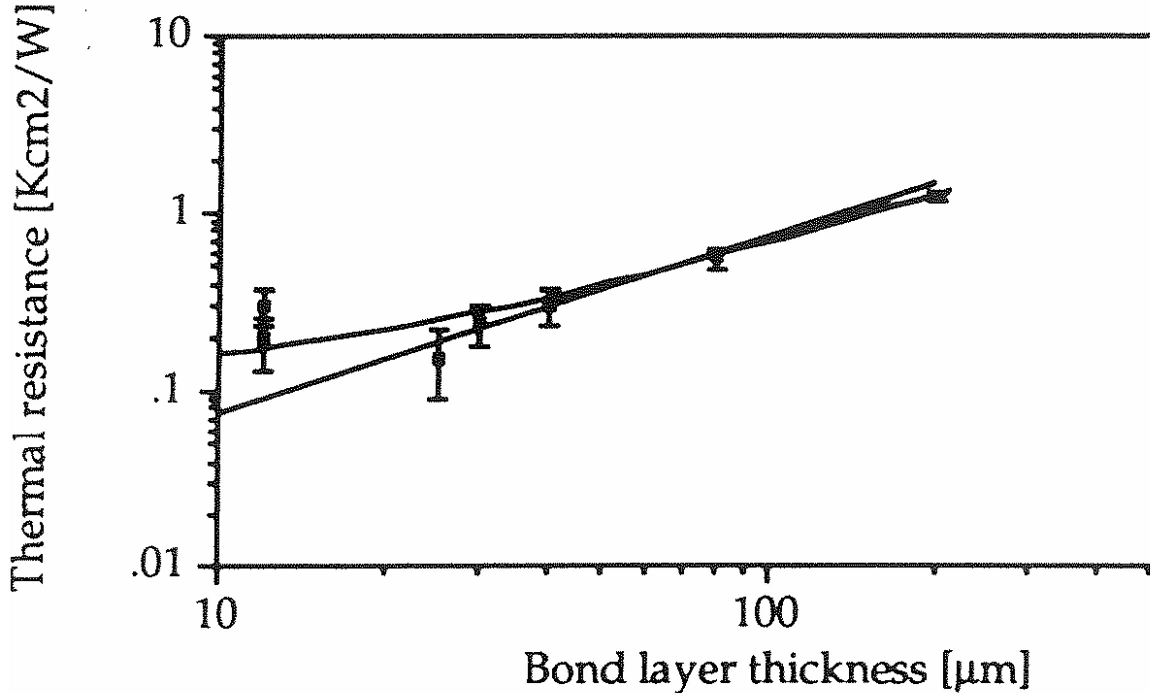
- Silver flake distribution in Ablebond 952-8
- Elongated particles

Thermal interface resistance



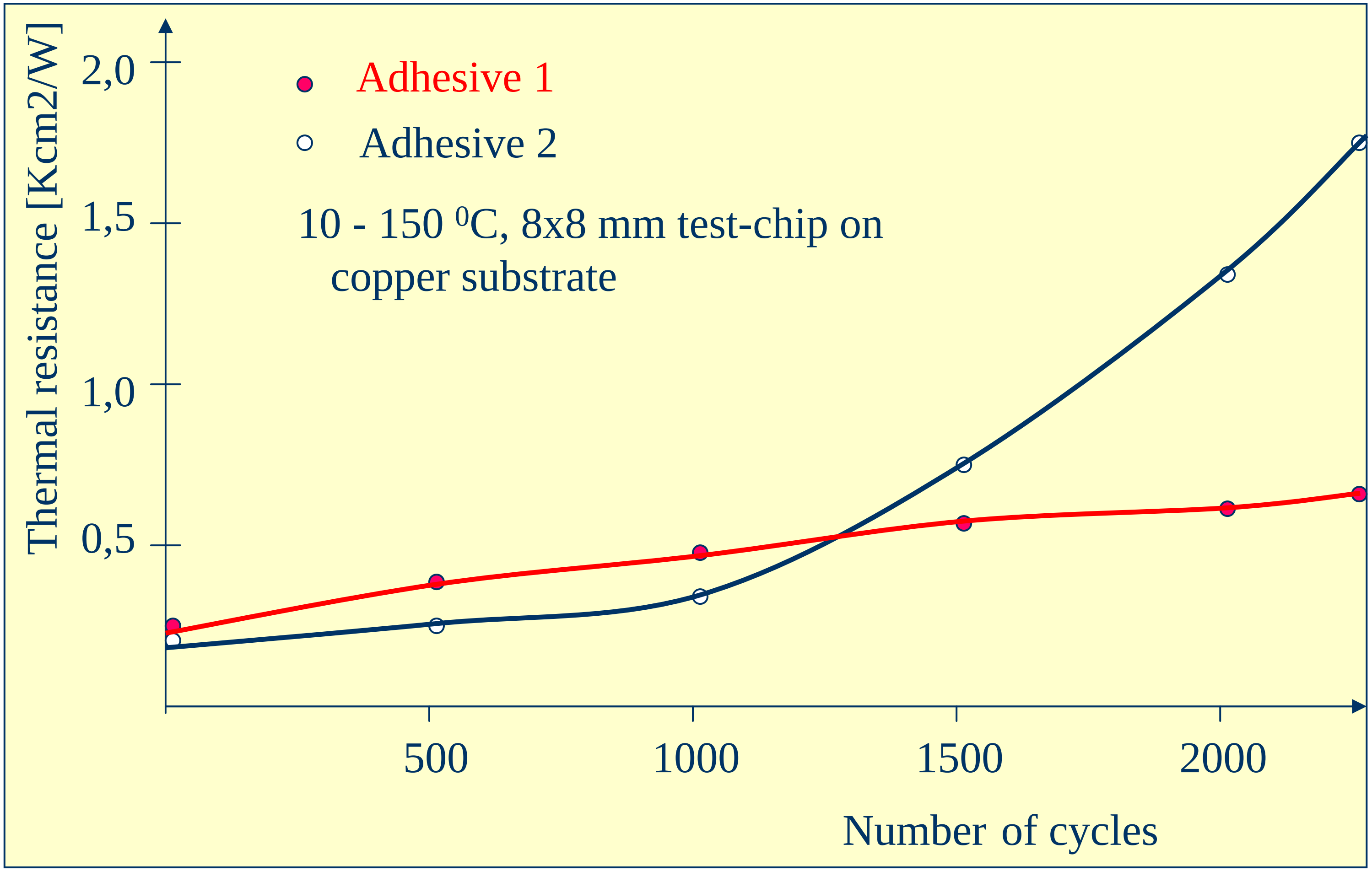
- Ablebond 958-2
- Silicon chip onto molybdenum substrate

Thermal interface resistance (II)



- Epo-Tek H20E-175
- Silicon chip onto copper substrate!

Temperature cycling of die attach

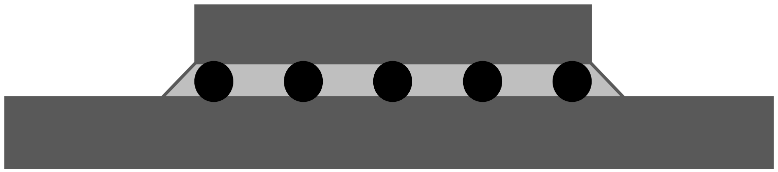


conpart

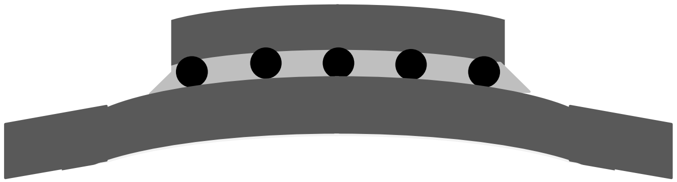
Adhesive as underfill

- Bump lifetime under thermal cycling decreases with induced strain
- Bumps without underfill:
  - CTE mismatch => cyclic shear strain
  - Crack growth
- Bumps with underfill
  - Strain reduction
  - Lifetime increase 10X

Si chip (CTE=2.6 ppm /K)

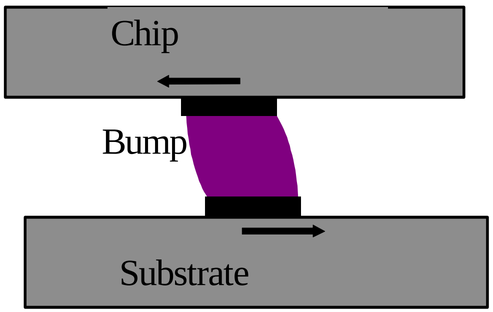


FR4 (CTE= 18 ppm /K)

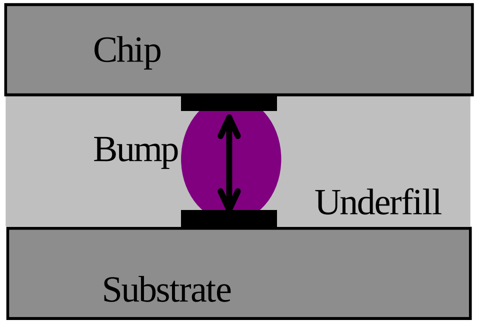


Effect of Underfill

- Mechanical coupling chip/substrate
  - Reduces bump shear strain
  - Strain highest at chip edge
  - Strain depends on shear modulus of underfill
- Introduces axial strain
  - CTE mismatch solder/underfill
  - Depends on underfill CTE
  - Affects all bumps equally
- Impact on lifetime?



Shear mode



Tensile mode

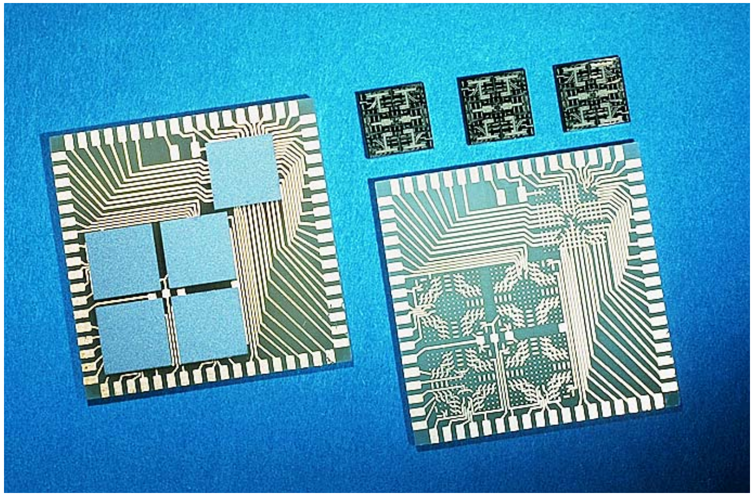
conpart

Measurement of bump lifetime - Aims

- Measure number of thermal cycles to failure
- Two underfill materials (different CTE)
- Measurements as function of distance to chip centre
  - No variation: Axial strain dominates
  - Lifetime decreases with distance: Shear strain
- Establish simple analytical model for bump lifetime
- Compare experimental lifetimes with model

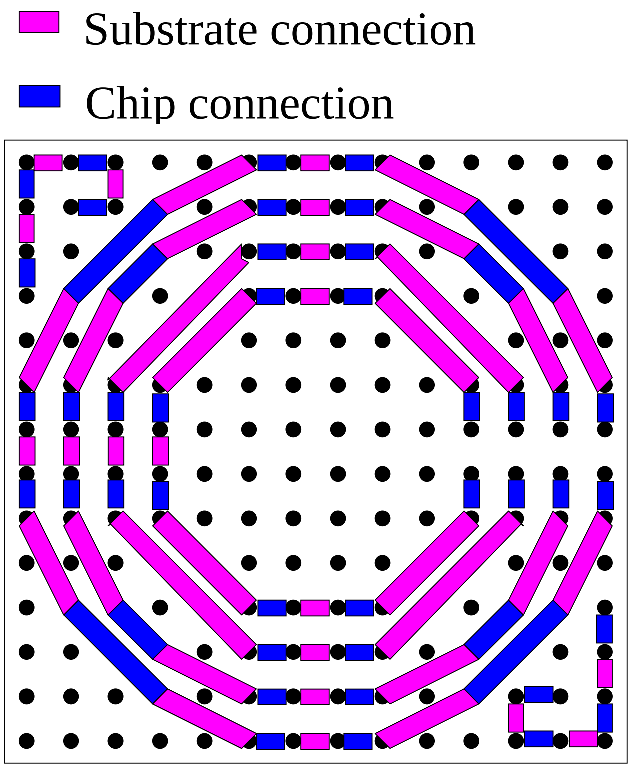
Experimental method

- Test sample:
  - Silicon test chip with eutectic solder bumps
  - Reflowed to FR4 substrate
  - Underfill applied and cured
- Thermal cycling
  - -55 - 145 ^{o}C
  - 2 cycles per hour



Lifetime measurements

- Daisy chain connections on chip/substrate
  - Grouped in “rings” with similar distance to centre
  - Continuity of each ring monitored
    - In situ
    - For each 50 cycles (at RT)
  - Resistance increase = failure



Underfill characteristics

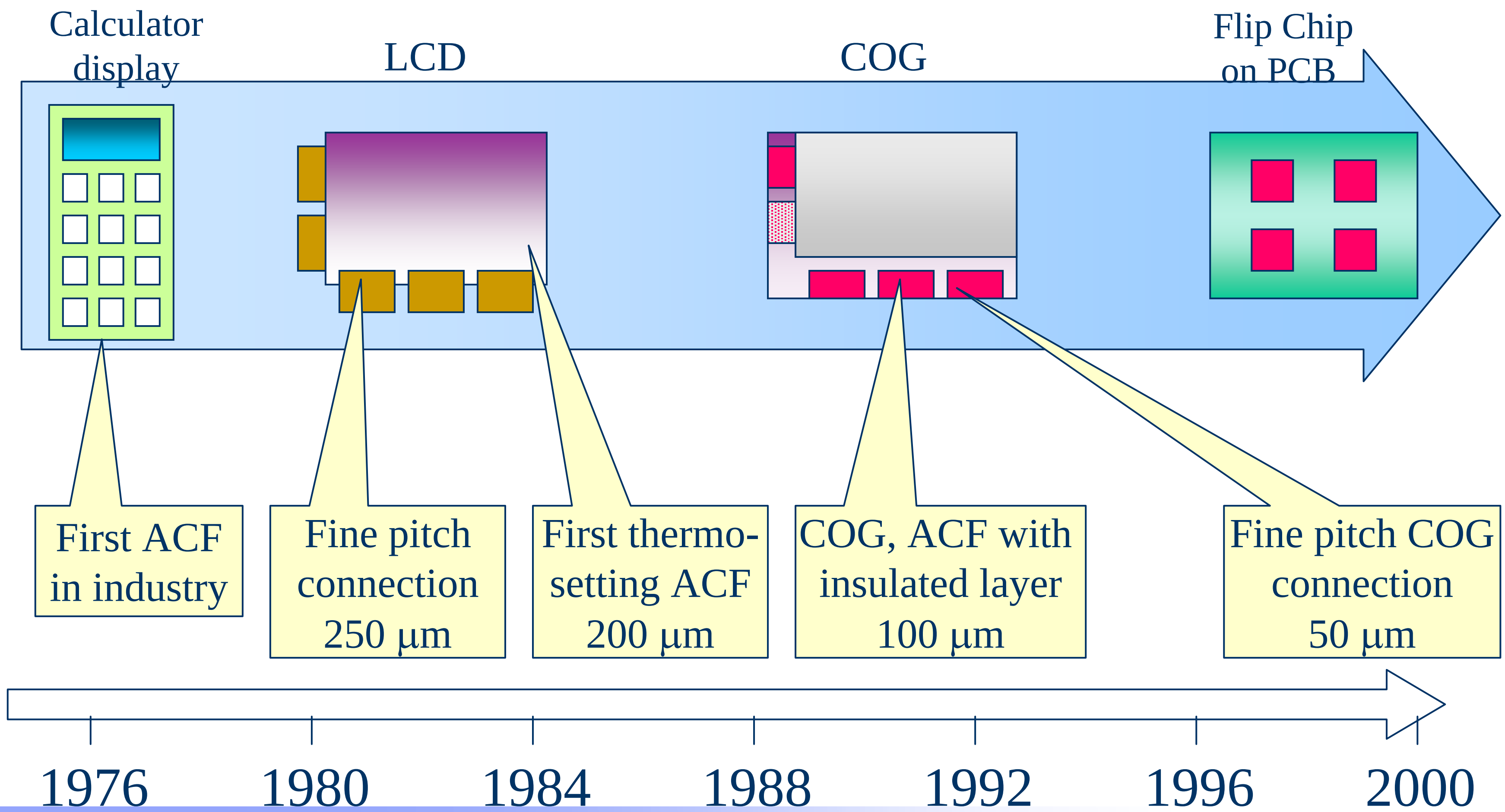
- Two different types used:
  - Filled: CTE = 28 ppm/K
  - Unfilled: CTE = 58 ppm/K
  - Tg: 120 ^{o}C
  - CTE and Tg measured by DMA
- Curing: 150 ^{o}C
- Maximum cycling temperature (145 ^{o}C) exceeds Tg!

ACA technology

Overview

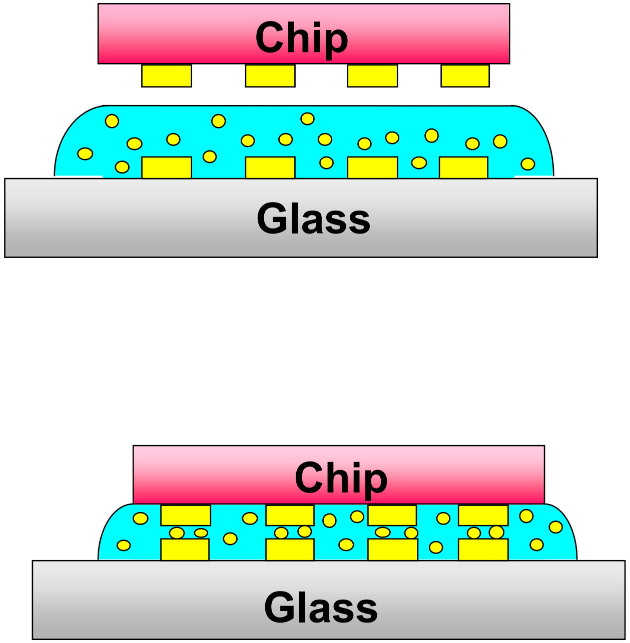
- Introduction
- Anisotropic conductive adhesive
  - Z-axis conductive film
- Typical products
- Joint quality
- Reliability
- Different FlipChip techniques
- Conclusions

ACF History


Calculator display
LCD
COG
Flip Chip on PCB
First ACF in industry
Fine pitch connection 250 µm
First thermo-setting ACF 200 µm
COG, ACF with insulated layer 100 µm
Fine pitch COG connection 50 µm
1976
1980
1984
1988
1992
1996
2000

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



Particle compressed between bump and pad

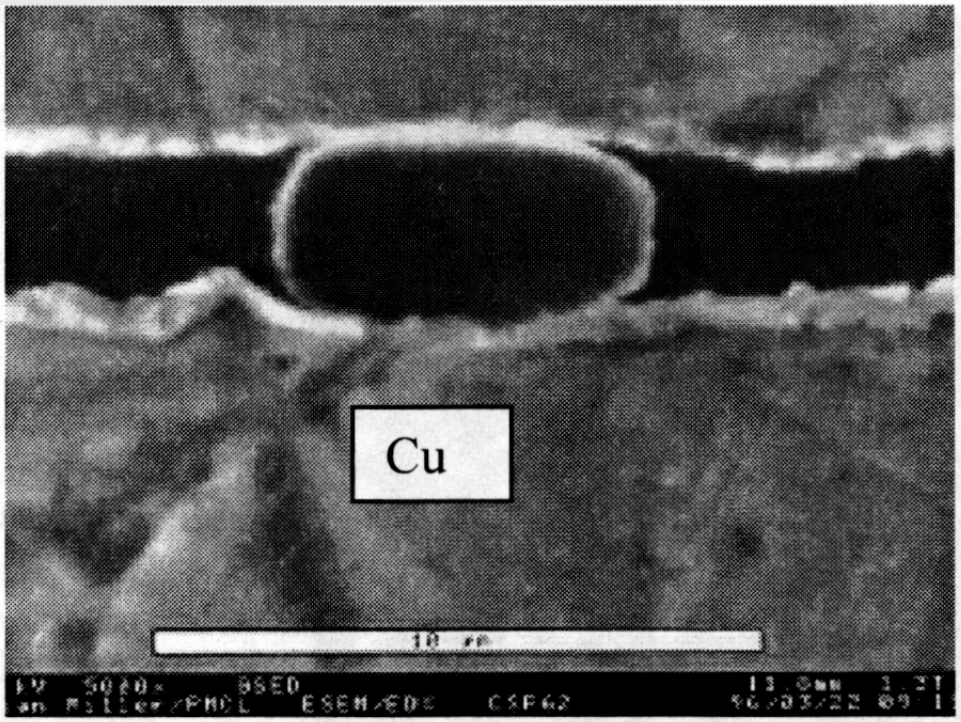


Figure 11: Close-up view of a deformed Au coated DVB-PS polymer particle in ACF film after bonding.

Driving force

- Possibly higher reliability
  - Right choice of adhesive and bonding surface
- Fewer process steps
  - No fluxing or cleaning
- Finer pitch
  - Anisotropic Conductive Adhesive
  - Non-conductive Adhesive
- Environmental friendly
  - No lead

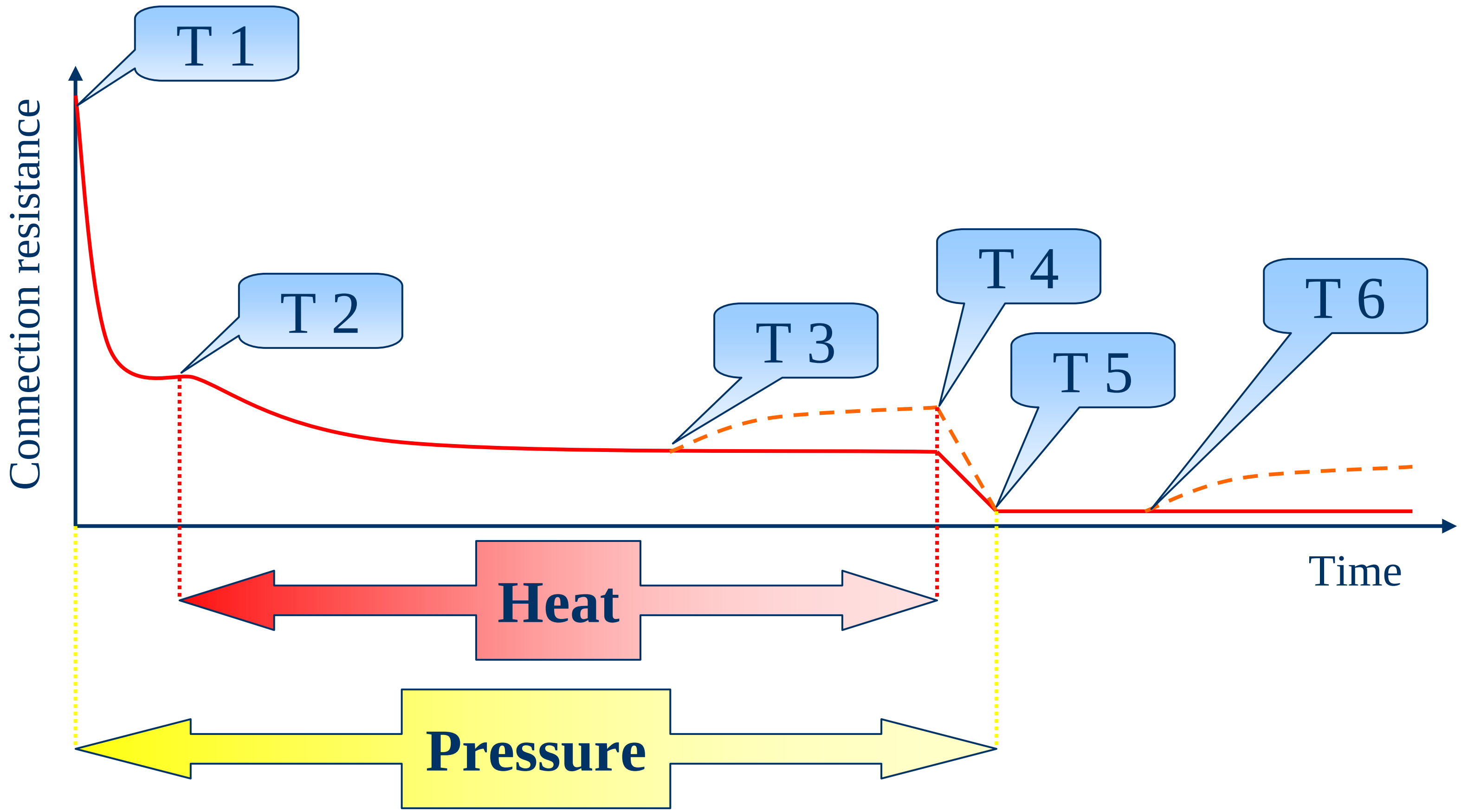
Introduction

- Lower temperature processing
  - Lower thermal stress
- New materials in packaging
  - Polyester based flex circuits
  - Low cost plastics
- Non solderable surfaces
  - ITO conductors (LCD's)

Optimising process conditions

- Large number of particles on pad
- Low particle density between neighbouring pads
- Fast process time
- Reliable and uniform connection resistance

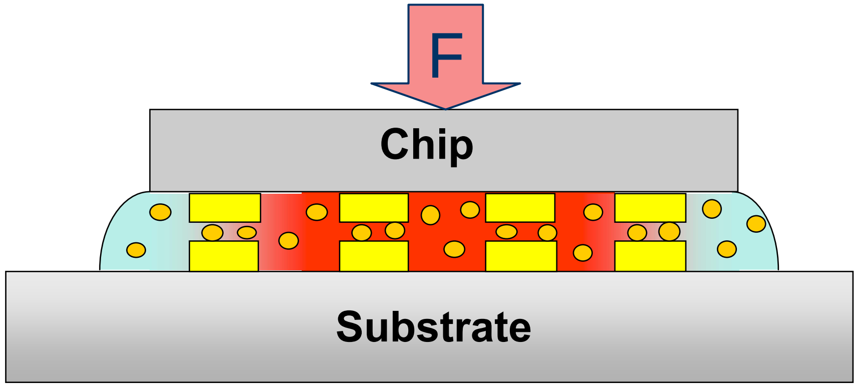
Curing cycle

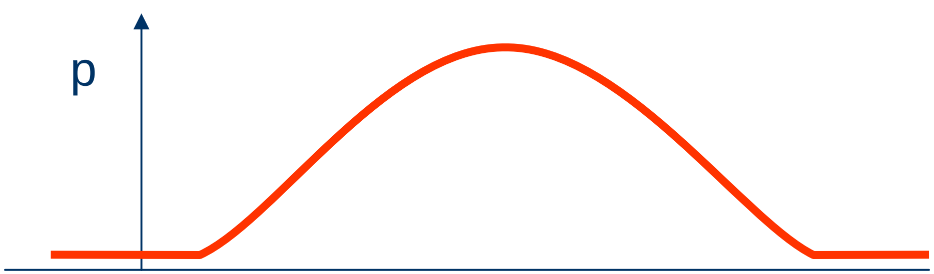


Curing cycle (II)

- T 1: Start of pressurisation
- T 2: Start of heating
- T 3: The resistance increase depending on electrode material
- T 4: End of heating
- T 5:
- T 6: End of pressure
  - If curing is insufficient, the resistance may start to increase

Bonding force



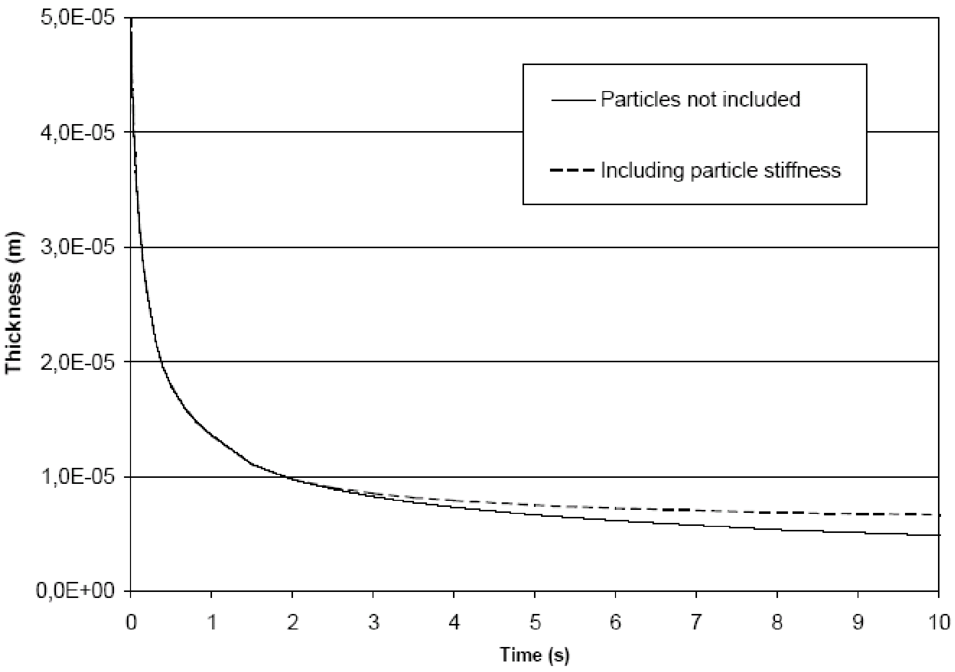


- The applied bonding force is counter balanced by
  - Squeezing of the adhesive film
  - Compression of particles
- Squeeze film pressure
  - Film thickness
  - Chip dimension
  - Viscosity of adhesive
  - Rate of squeezing

$$F = \int_{A_{Chip}} p\,dA + \sum_i \kappa_p \varepsilon$$

Squeezing of adhesive film

- Flat silicon surfaces
- 1st stage: squeeze of adhesive only
- 2nd stage: compression of particles

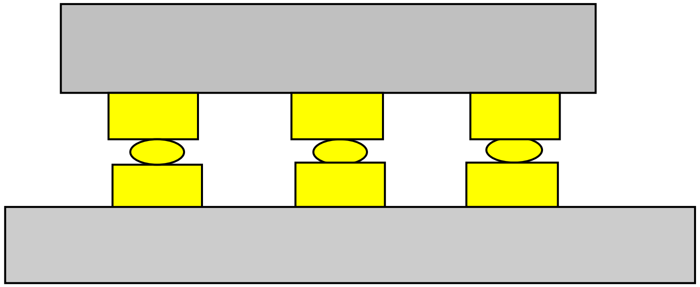


Factors influencing on joint quality

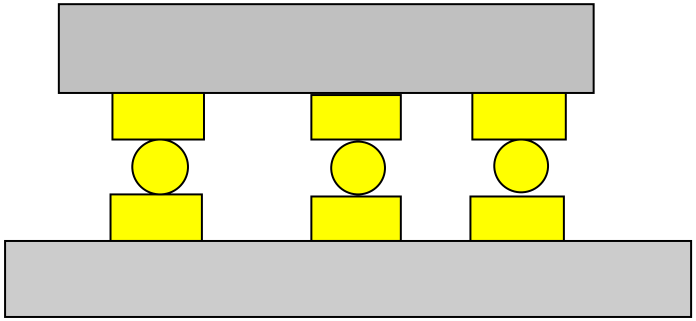
- Coplanarity.
- Bump height and uniformity
- Pressure and pressure distribution.
- Particle distribution
- Cure temperature and cure time
- Temperature ramp rate
- Alignment accuracy

Contact stability (I)

- Stable contact
  - Uniformly deformed particles
  - Adequate pressure

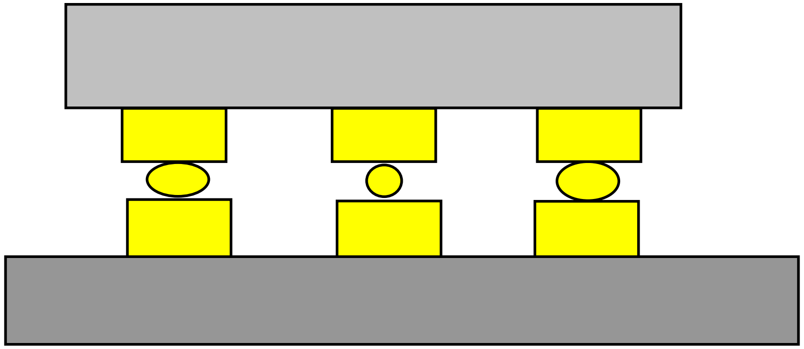


- Unstable contact
  - Too low pressure during connection

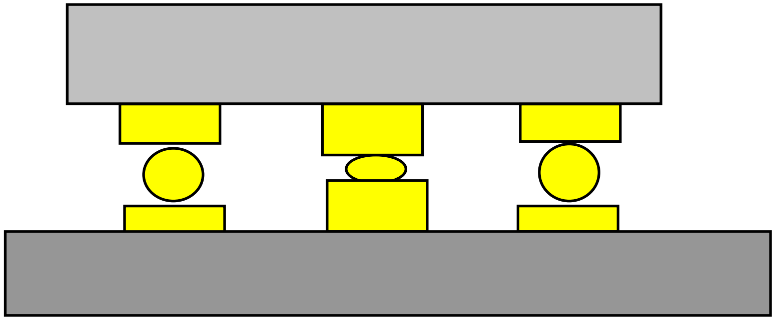


Contact stability (II)

- Uneven particle size
  - Not uniformly deformed particles



- Uneven bump-height
  - Not uniformly deformed particles



Degradation mechanisms

- Oxidation and hydration of conductors
- Polymer degradation by moisture or UV-light
- Adhesive failure due to humidity adsorption
- Crack formation
- Thermal and mechanical fatigue

Failure mechanisms I

- Adhesive
  - Thermal and mechanical fatigue
  - Humidity
  - UV light
- Cohesive
  - Humidity
  - Thermal and mechanical fatigue

Failure mechanisms II

- Oxidation of metal surfaces
  - Humidity
  - Corrosive gases
- Expansion / swelling
  - Thermal and mechanical fatigue
  - Humidity

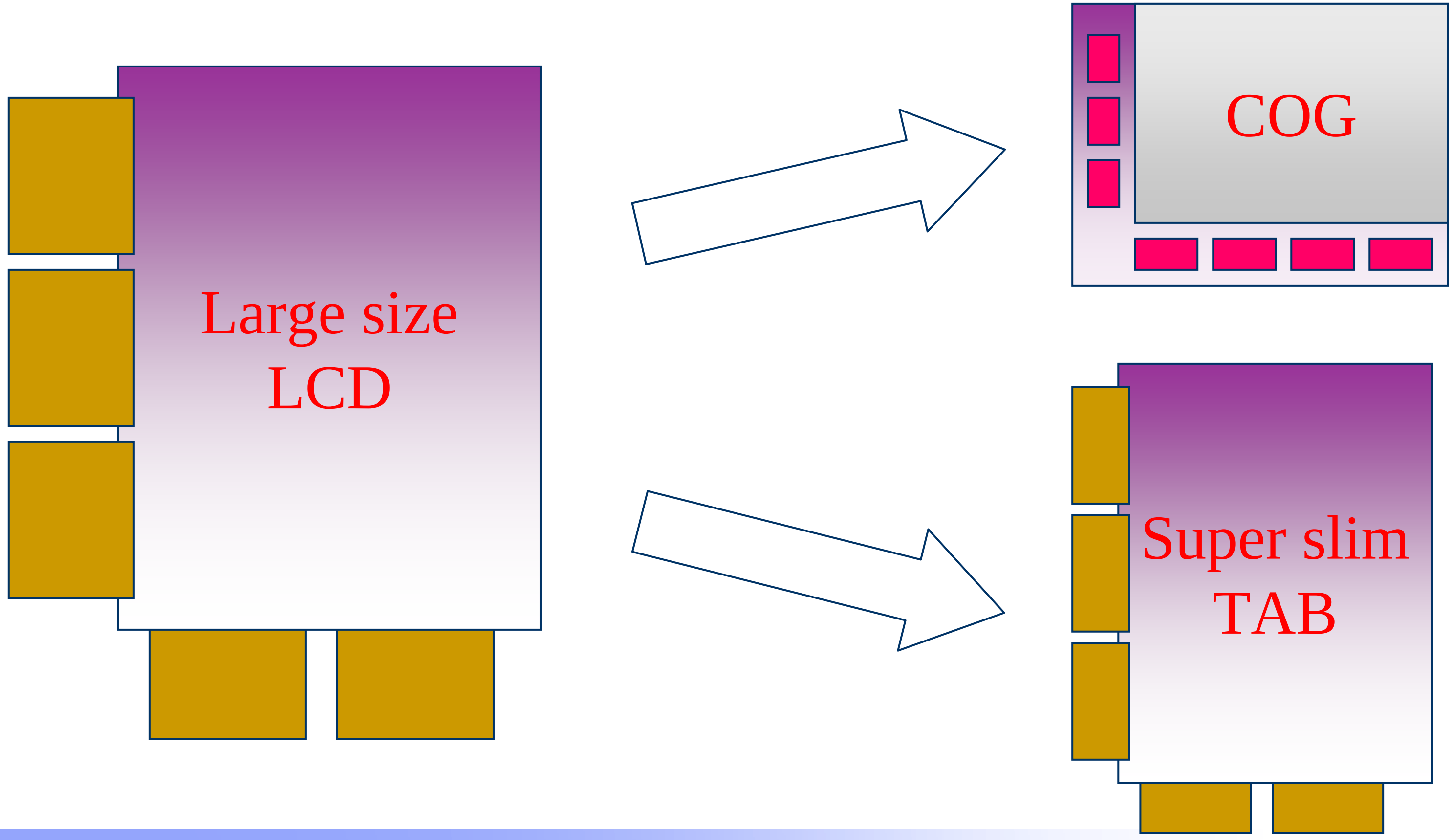
Typical reliability tests

- Temperature cycling from -40 to +125 ^{0}C
- Constant humidity test: 85 ^{0}C, 85%RH
- High temperature ageing at 125 ^{0}C
- Temperature cycling from -40 to +125 ^{0}C
- NB!: Tests are typically adopted from solder
  - Different failure mechanisms

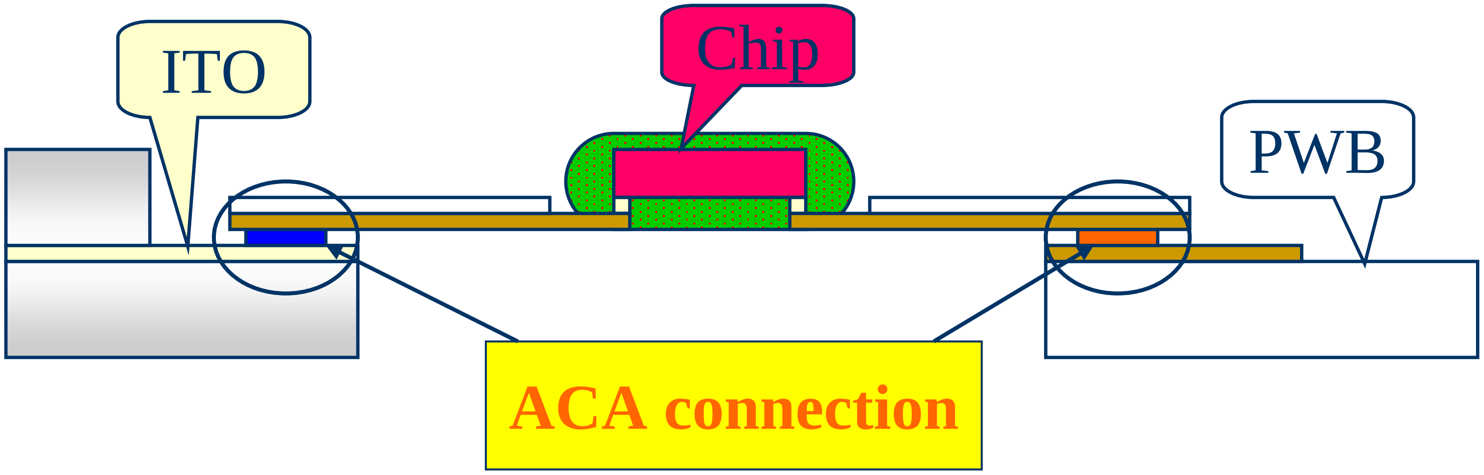
The use of ACA Technology

- Typical applications:
  - Flat panel displays
  - Smart cards
  - Single or multi-chip modules
  - Piezo electric components (printer heads etc.)
  - Micro mechanical and Micro optical components
- Low temperature bonding
  - Plastic, clothing

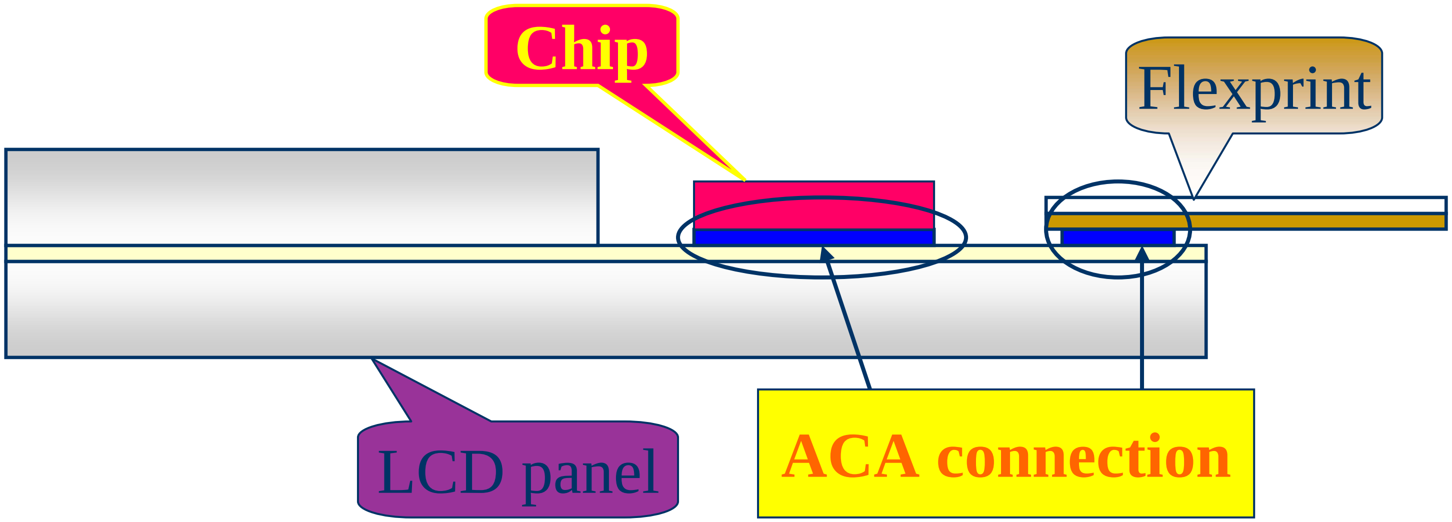
Mounting trends



TAB connection



Chip on Glass

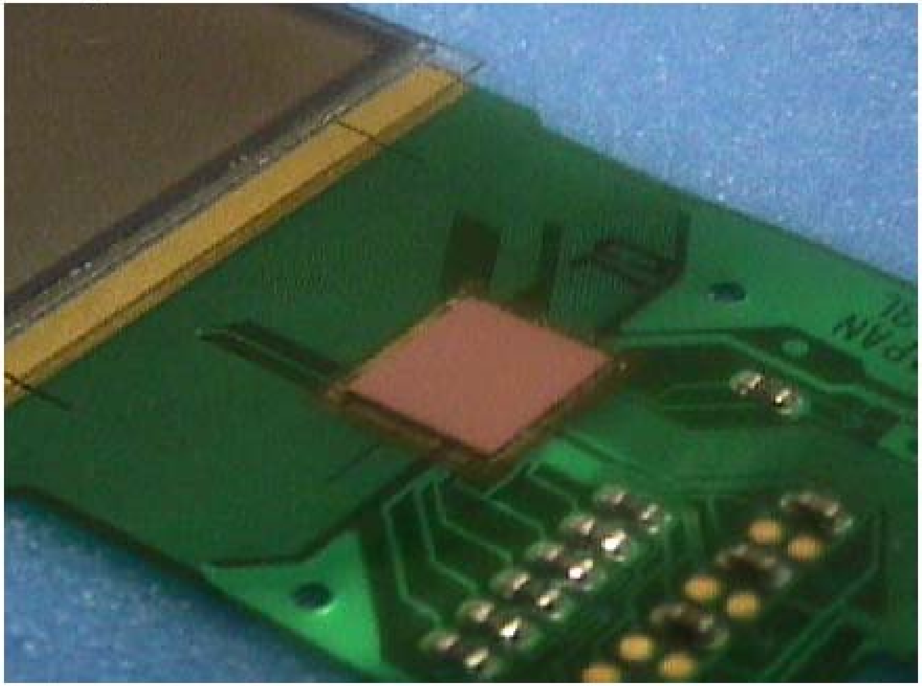


Chip on Glass; Sharp DVD player

conpart


小型ゲーム機
Portable Computer Game

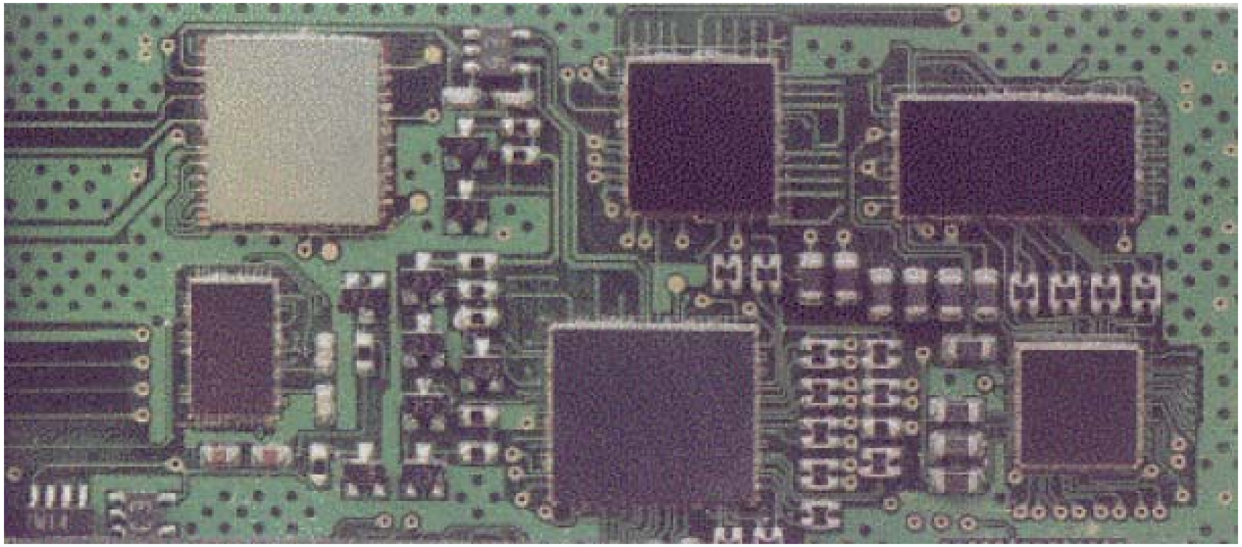
ACF applications



- Chip on Flex
- Flex on Glass

ACF Flip Chip on rigid board

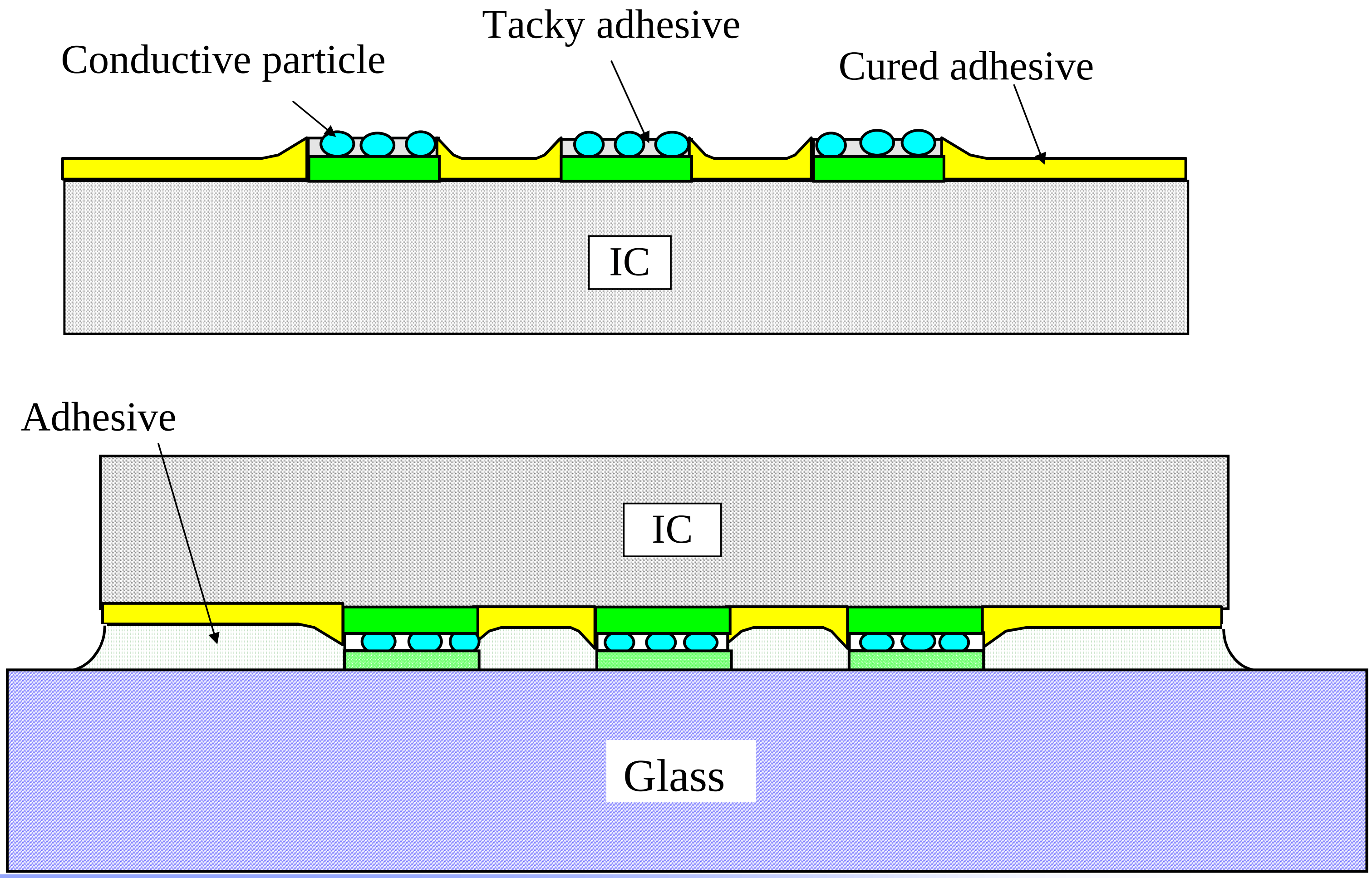
- Personal digital assistant (PDA) by Casio Computer
- Six IC´s (Microcontroller, Gate Array, Memory, decoder
- and amplifier) are mounted with flip-chip.
- Minimum pitch is 124 µm
- Sequential build-up substrate.



Key factors for Chip on Glass

- More than 5 particles per bump
- Ensure insulation
  - Insulated particles for low pitch?
- Development of more elastic binder material
- Higher T_g material
- Less moisture absorption

Sharp; "ELASTIC"

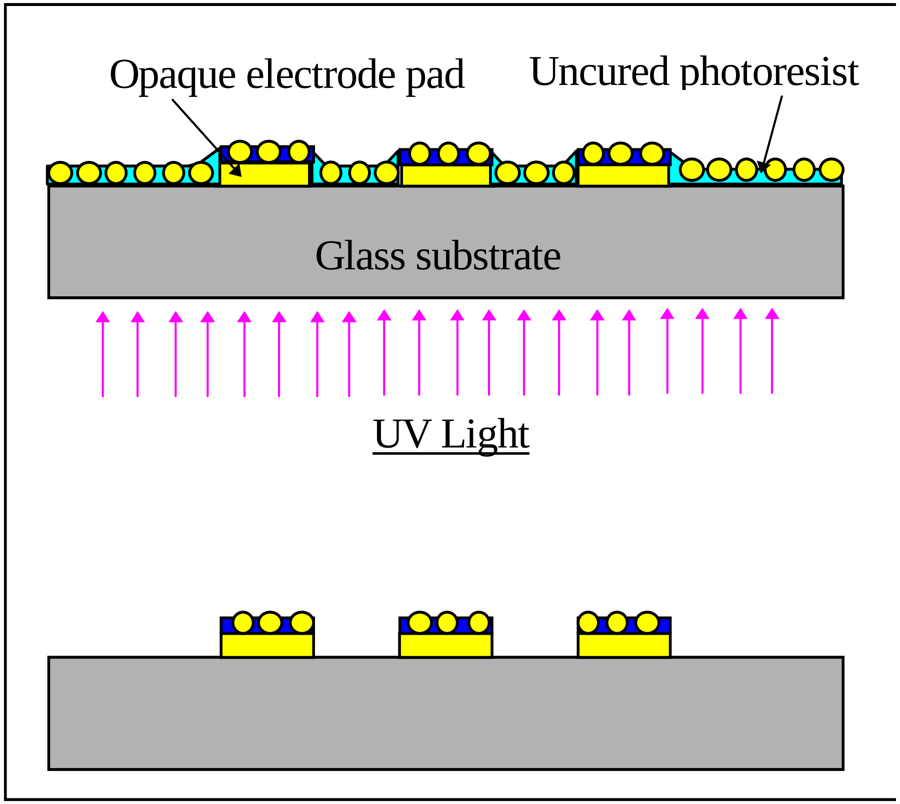


Sharp; “ELASTIC “

- ELASTIC: Electrical interconnection using light-setting adhesive
- Placing particles on tacky adhesive
  - Photo process
  - Gold plated plastic spheres
  - No need for bump plating
- 50 micron pitch demonstrated

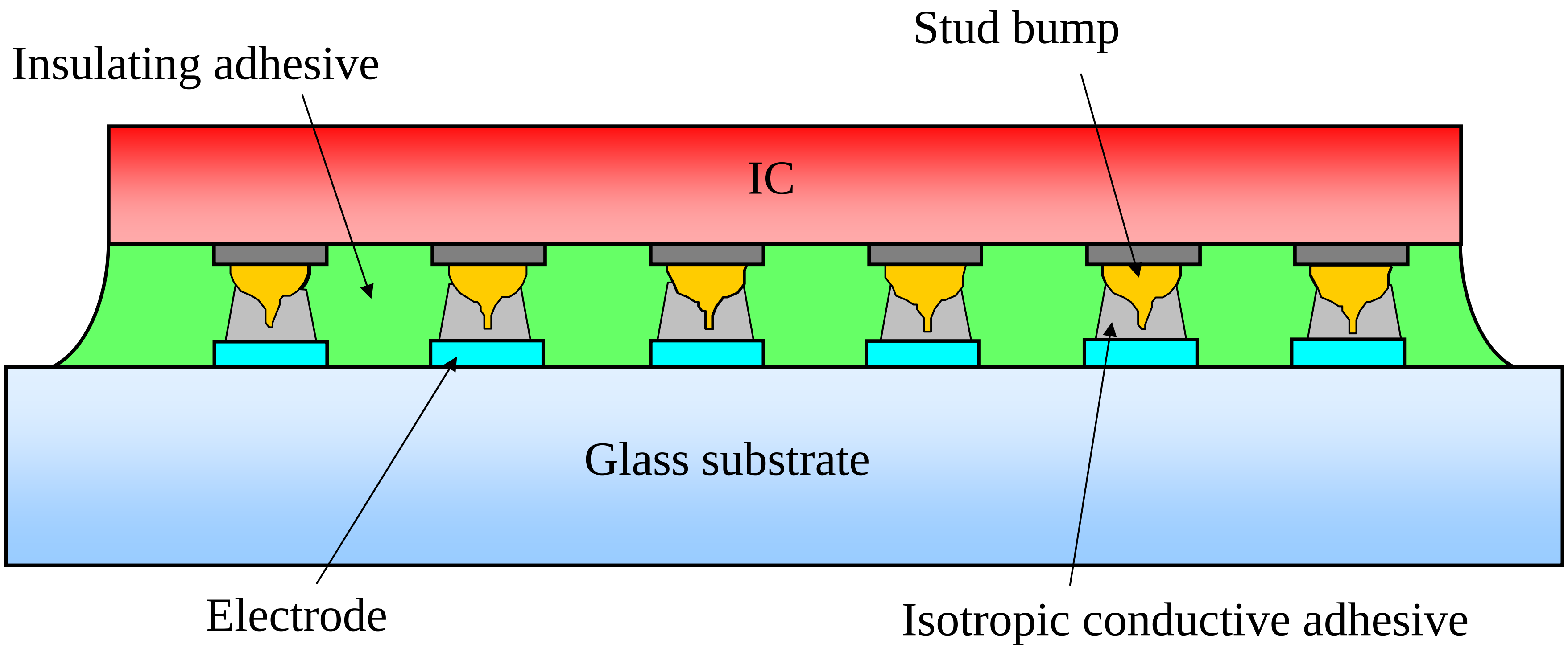
Mitsubishi

- Photo process with conductive particles
  - UV transparent substrate
  - Non transparent pads
- Waste of conductive particles?

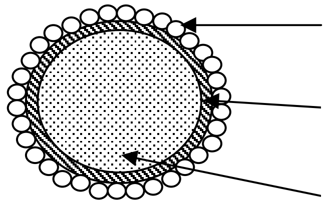


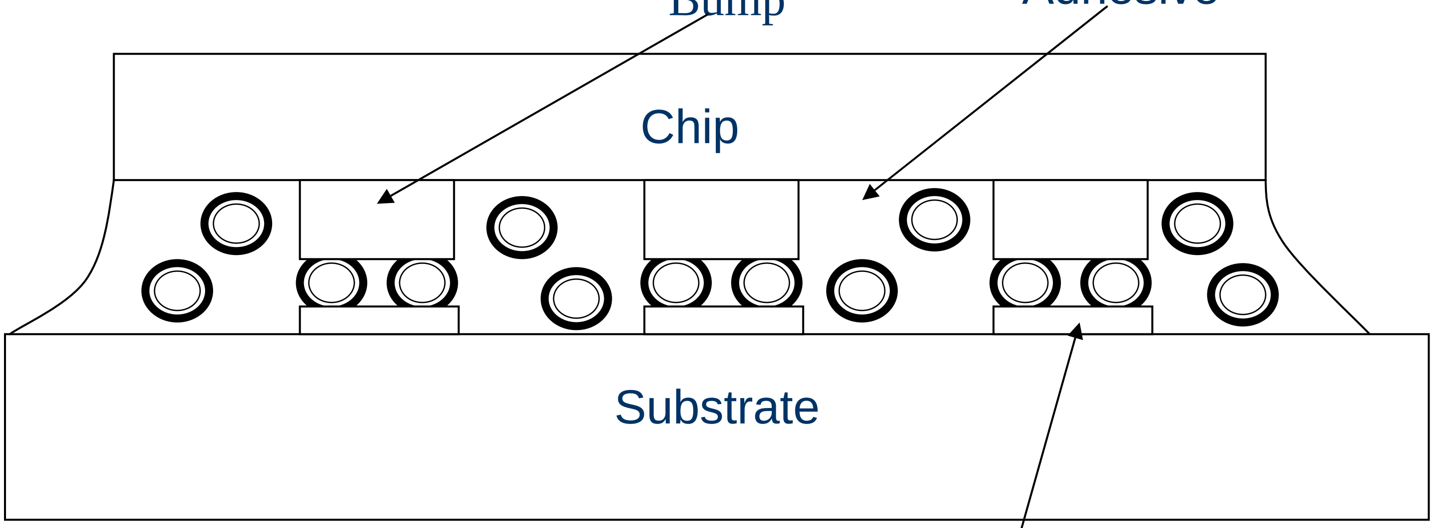
Matsushita; Stud “wire” bumps

“Isotropic Conductive Adhesive”

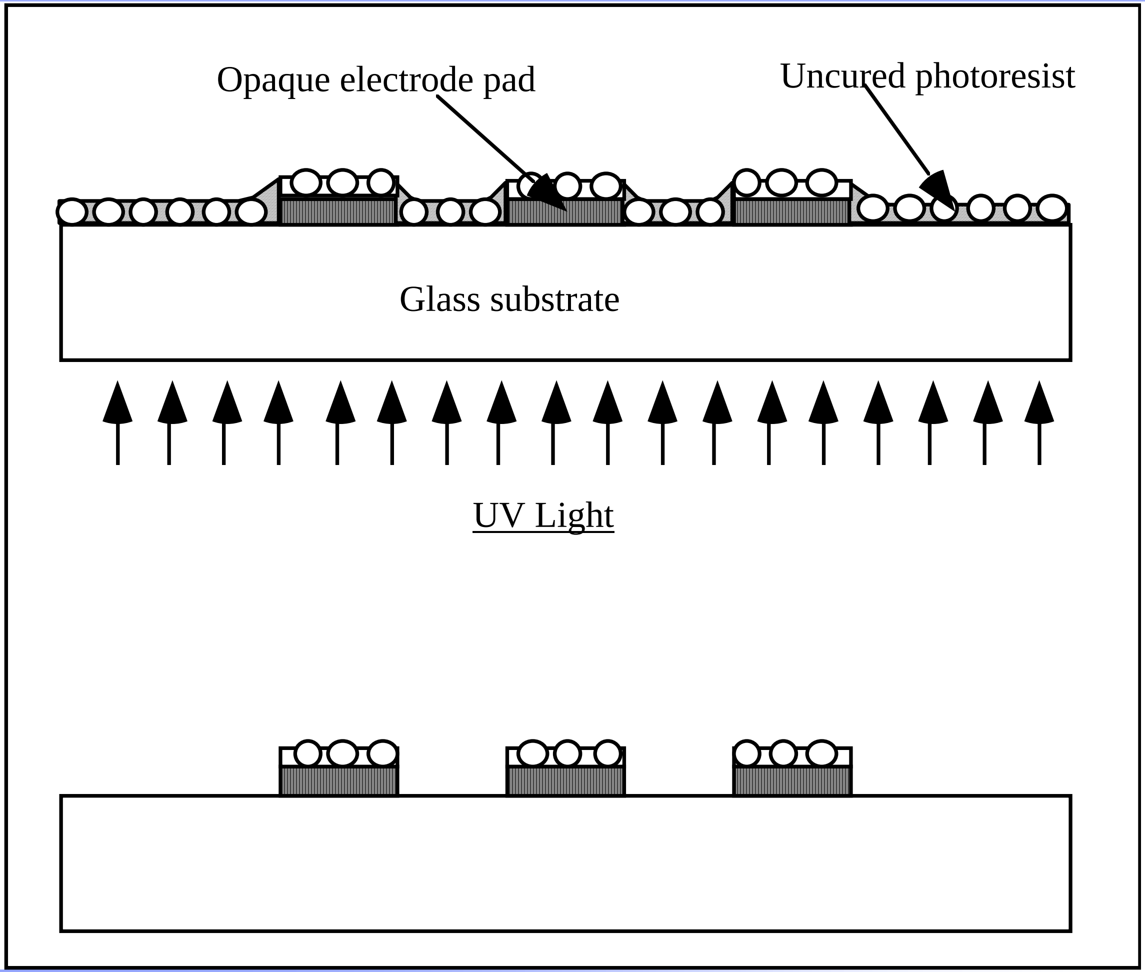


Casio; "Microconnector"

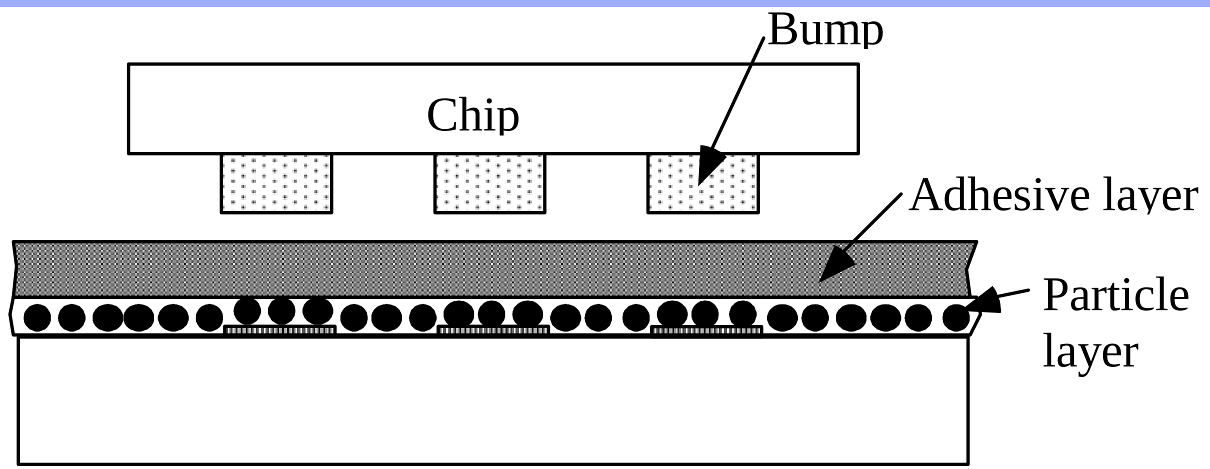


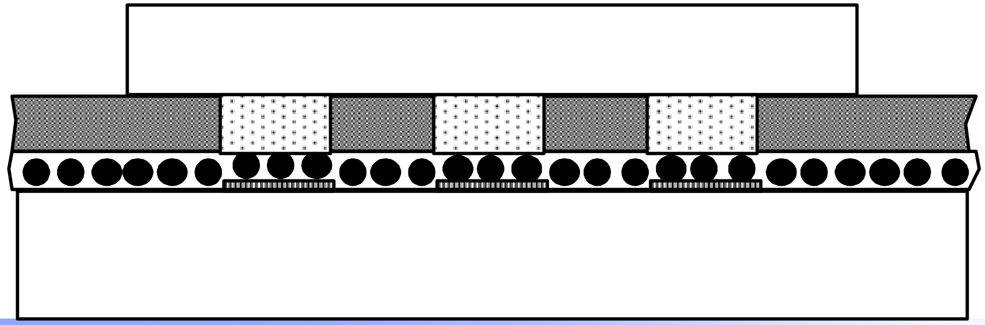


Mitsubishi


Opaque electrode pad
Uncured photoresist
Glass substrate
UV Light

Hitachi: Double layer ACA

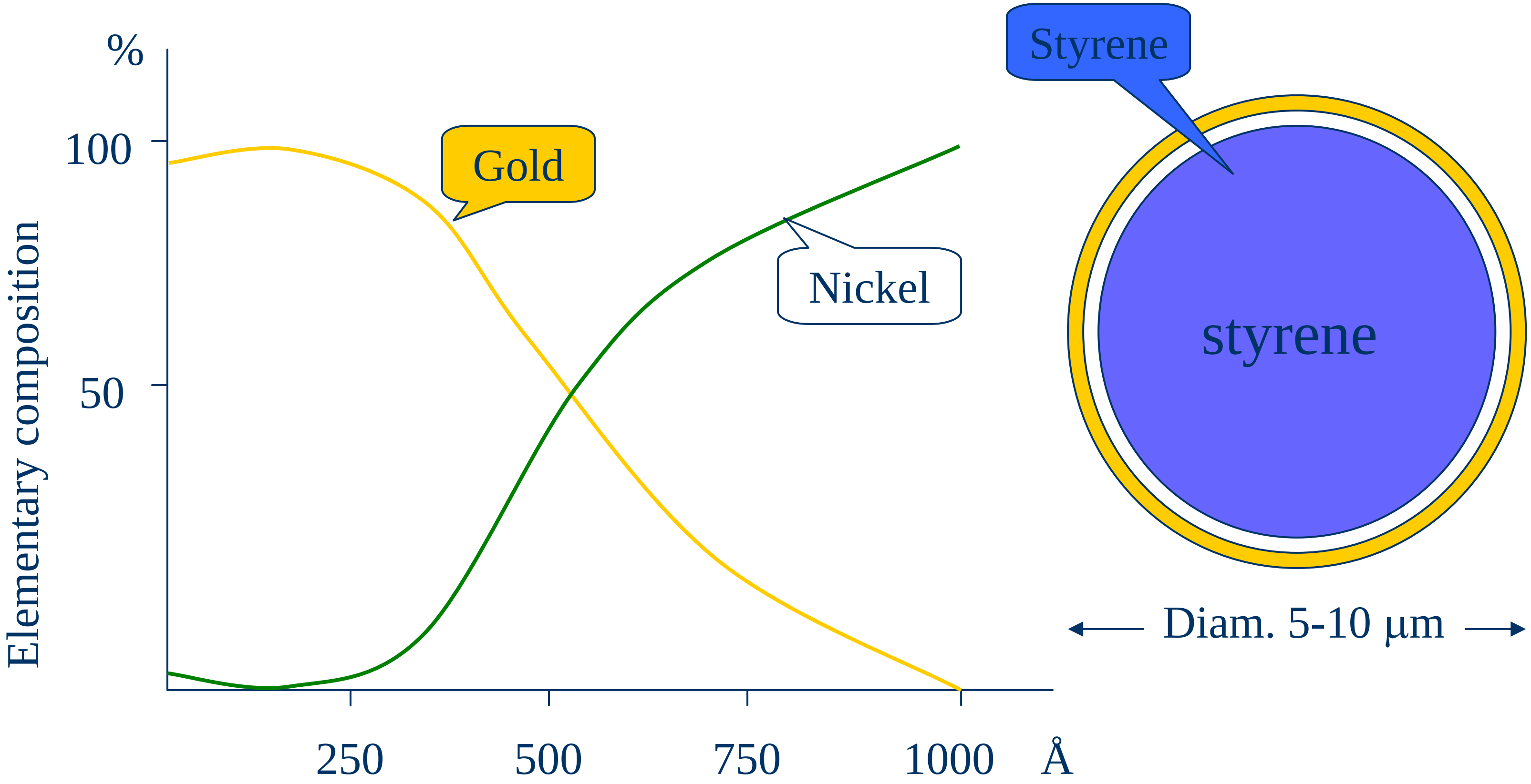




Conductive particles

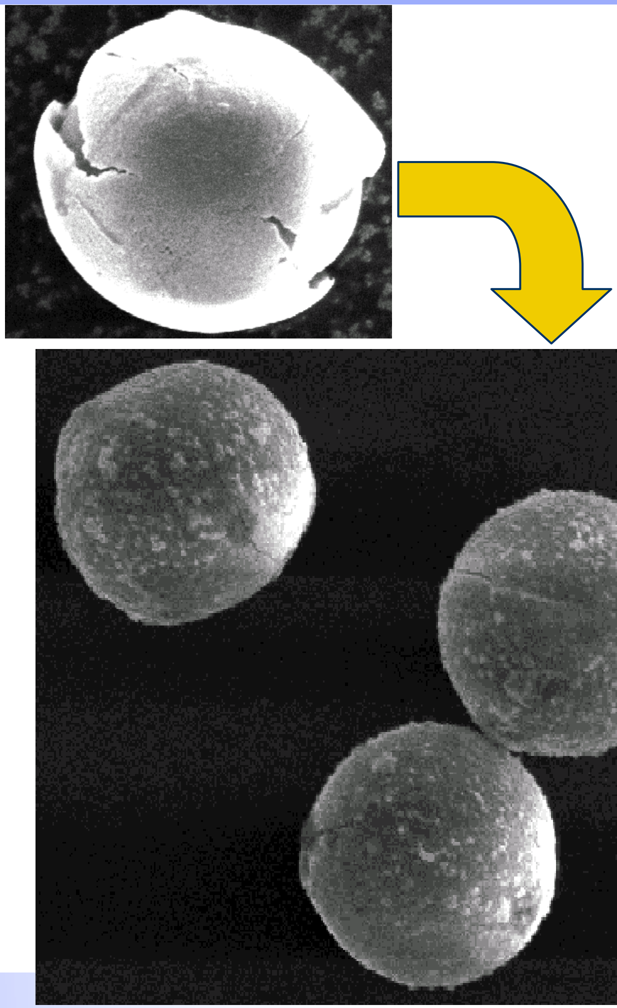
- Volume fraction 5 to 10 %
  - Responsible for the electrical contact
  - Pure metals such as gold, silver or nickel
  - Metal-coated particles with plastic or glass cores.
- Typically 3 to 10 micron in size,
- Treating particles separately from the adhesive.
  - Small volume fractions of particles in the ACA, gives minor changes in mechanical behaviour, at least in the case of metallised polymer particles.

Conductive particle

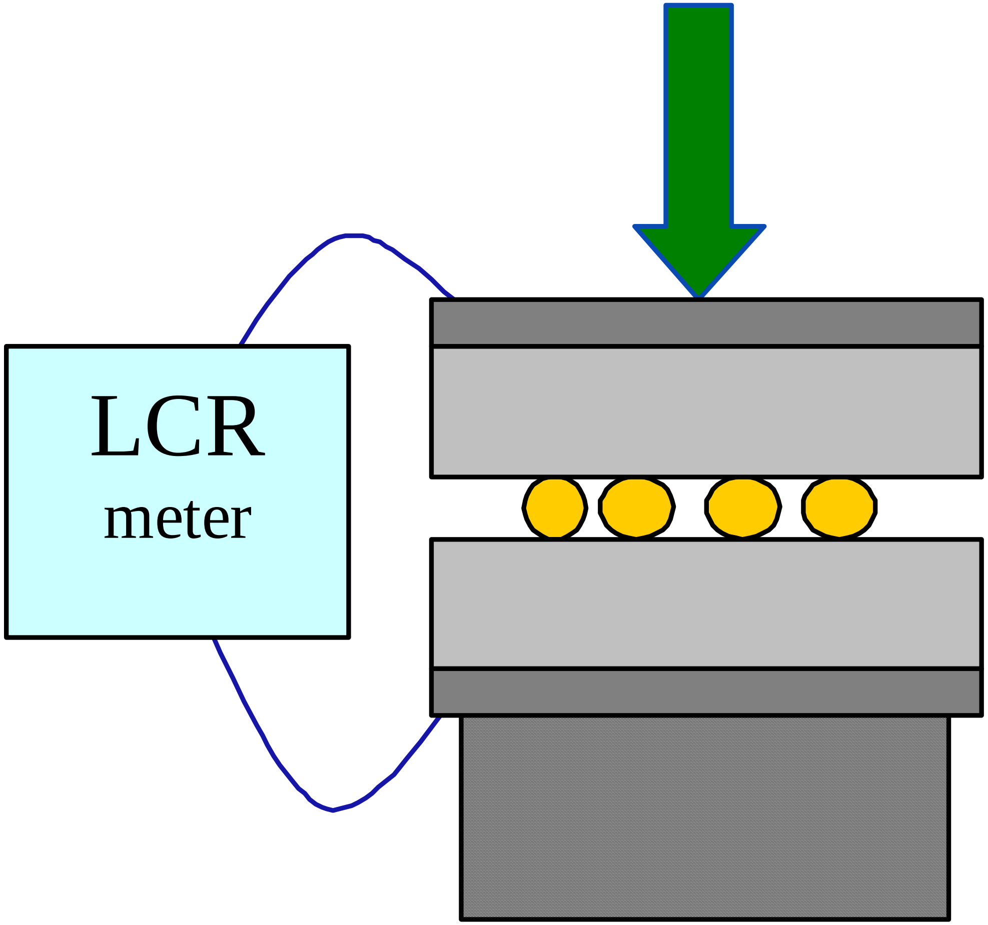


Particle development

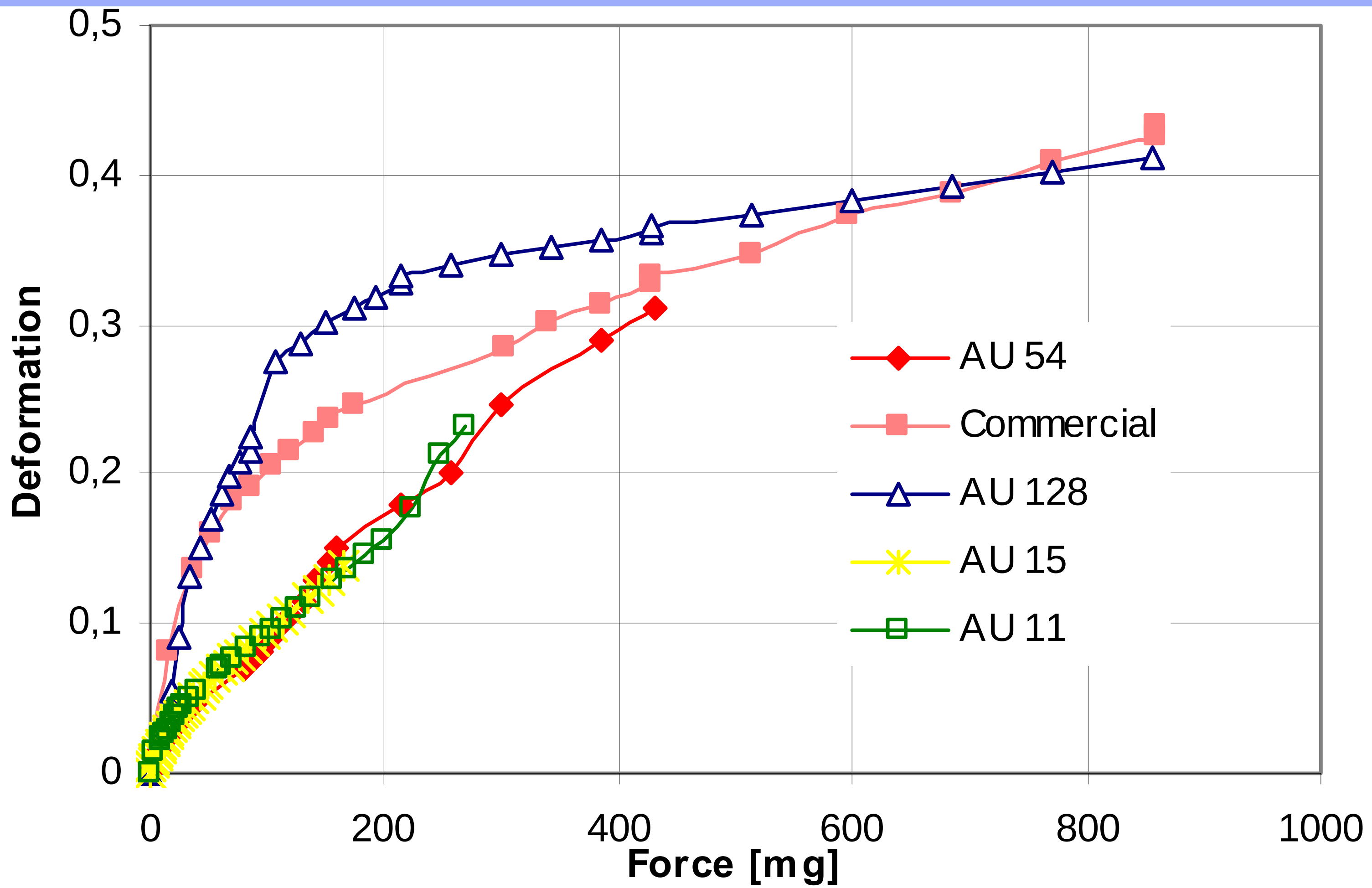
- 1st generation (Dyno Specialty Polymers), focus on
  - Different polymer compositions
  - Cross-linking densities
- 2nd generation, focus on
  - Adhesion between metal and polymer core
  - Added chemical groups for bonding to the metal



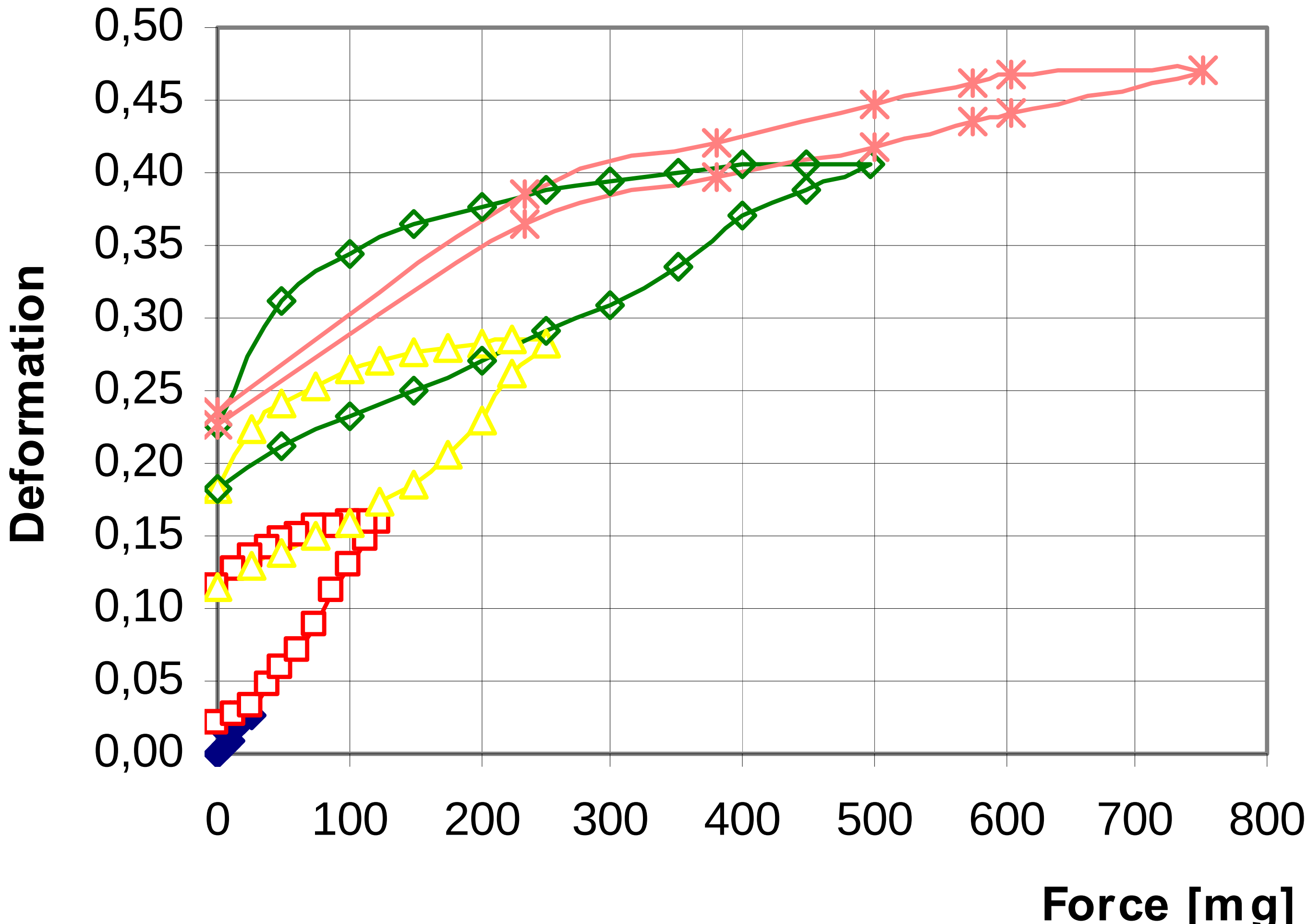
Testing of mechanical properties



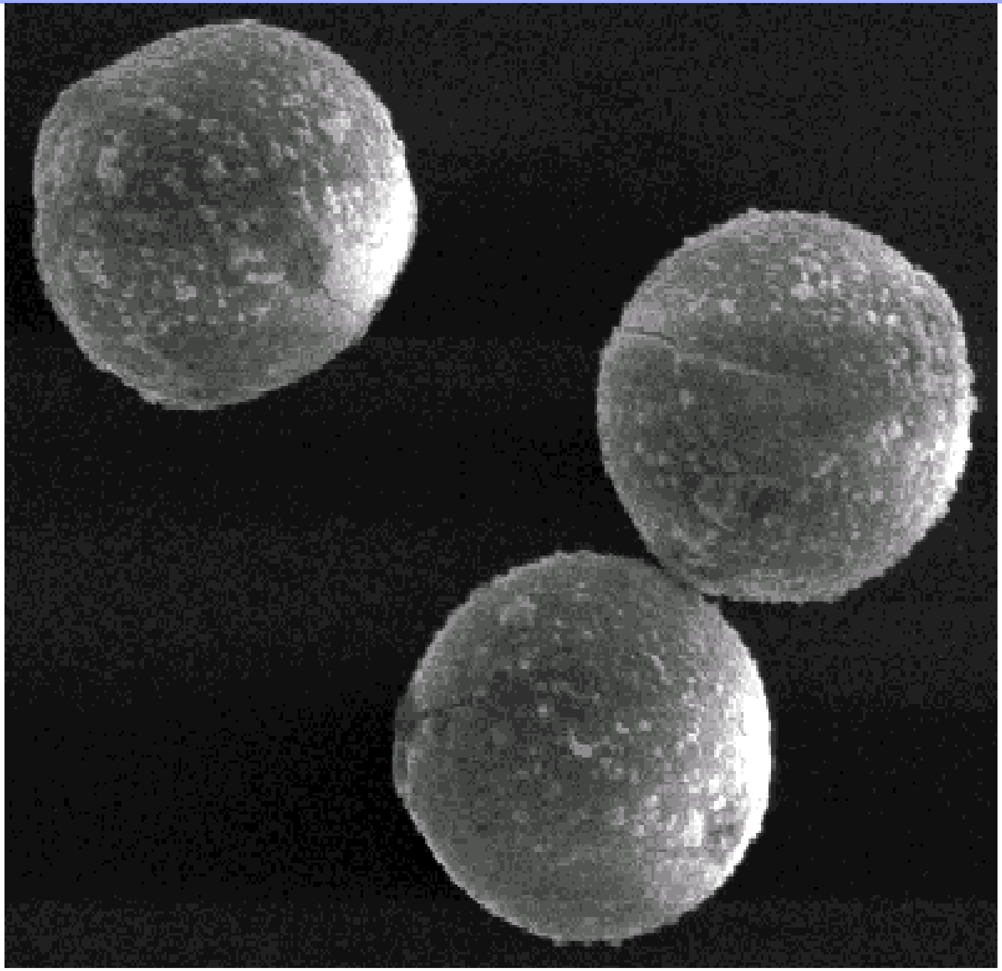
Results, mechanical testing (@RT)



2nd generation particle (@ 150 ⁰C)

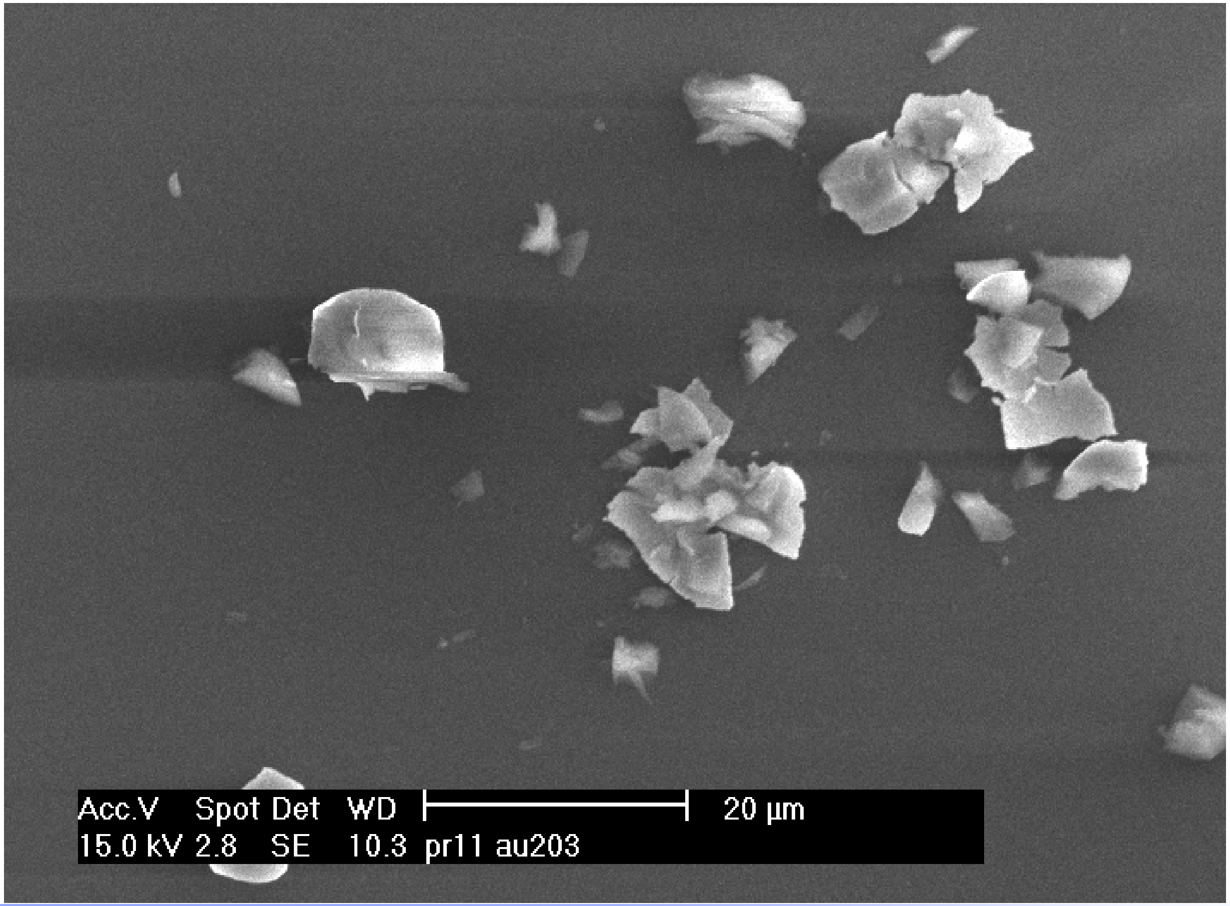


SEM picture of 2nd generation particle (tested at 150 ^{0}C)



- Very good adhesion between polymer and metal
  - Adhesion promoters included in polymerisation process
- Highly reliable contacts due to integrity of particles

Commercial particles (testing at 150 ^{0}C)

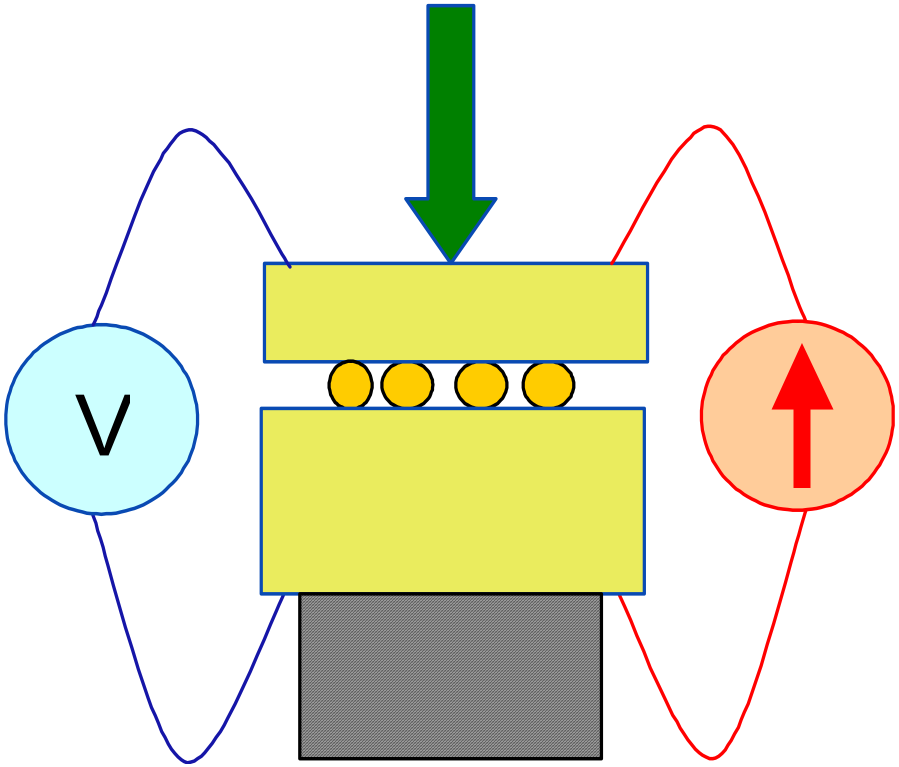


- Particles fully des-integrated
- Lack of adhesion between polymer and metal

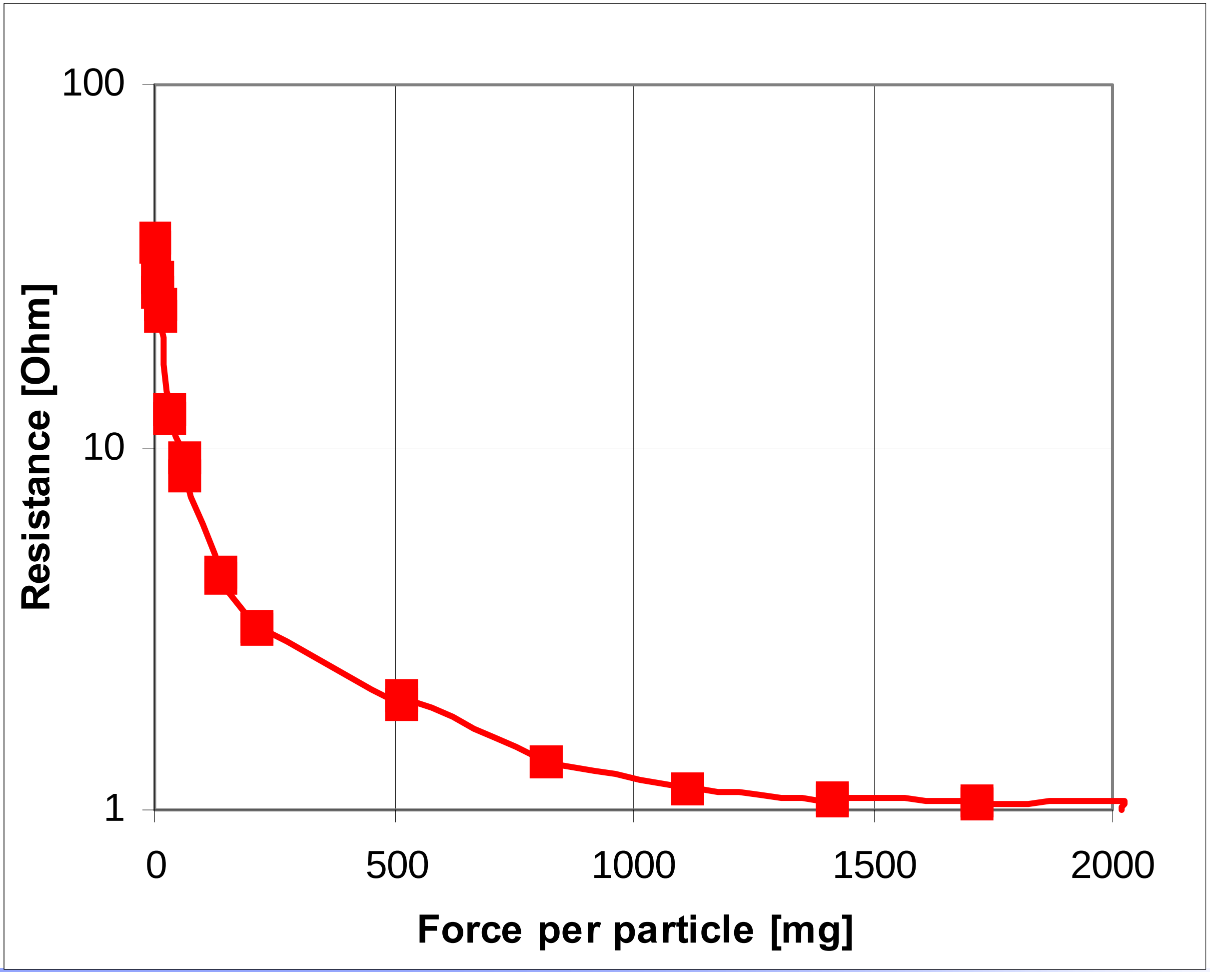
conpart

Measurement of contact resistance

- 4-wire measurement
- Ensemble of free particles
- Au-Pt electrodes



Electrical resistance AU-54



- Contact resistance versus "contact force"
- 4-point measurement
- "Free" particles
- Gold electrodes

Contact resistance versus cycling