Polymer Composites for Electronics Packaging Applications

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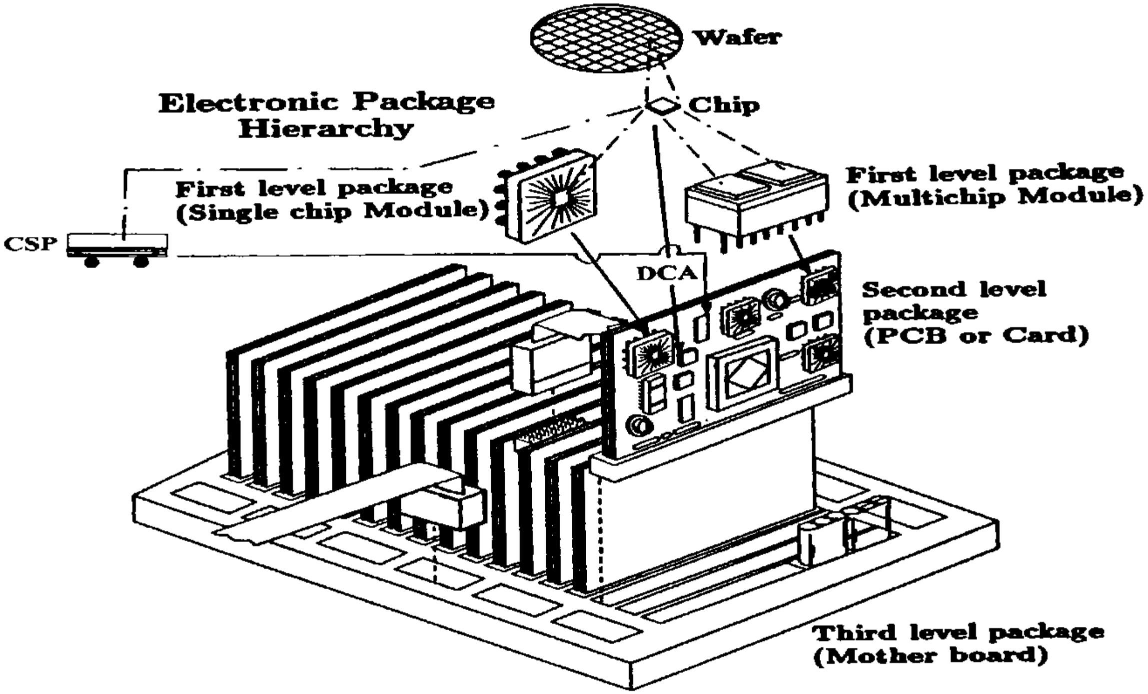
SIITME 2014 Bucharest

Supported in part by the IEEE CPMT Society Distinguished Lecturer program.



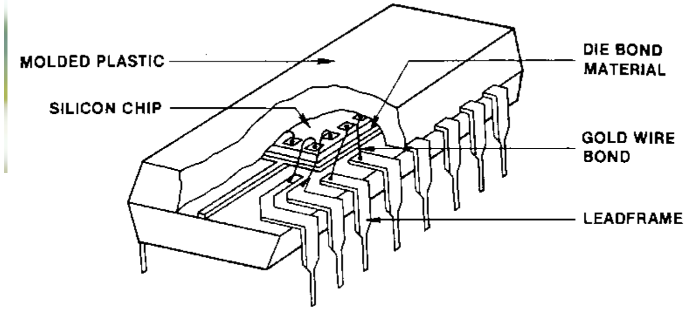


FIGURE 1-12. Cutaway view of a postmolded plastic package in the configuration of a dual-line package (DIP).

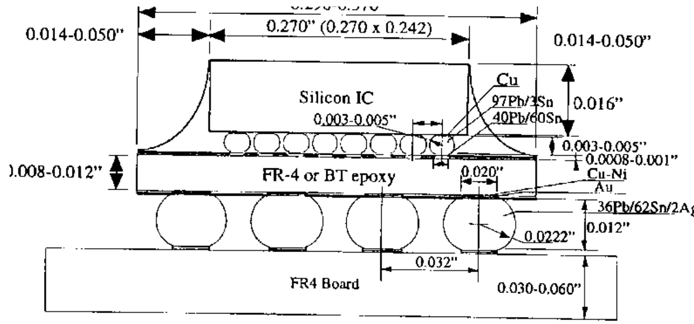
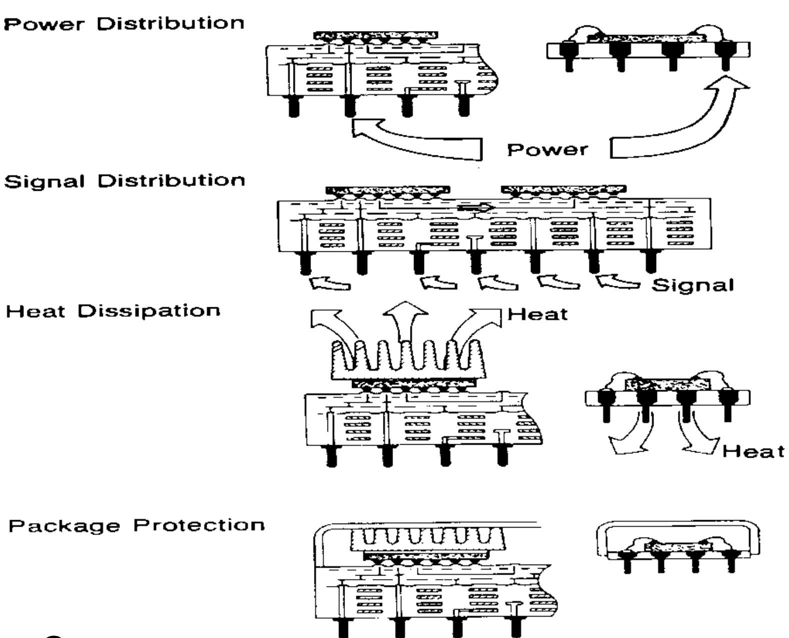


Figure 1: Schematic of a SLICC package.



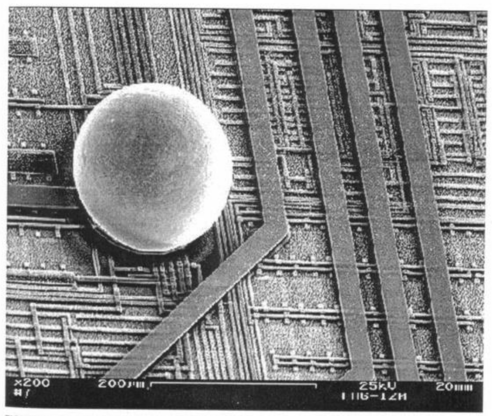


FIGURE 10.12 Comparison of typical WLP dimensions on a chip.

Packaging Issues

Thermal

3D Integration

Embedded Passives

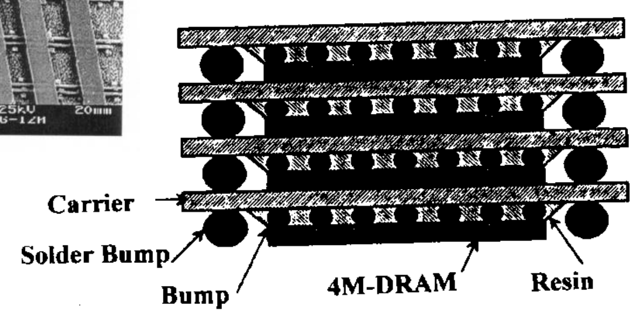


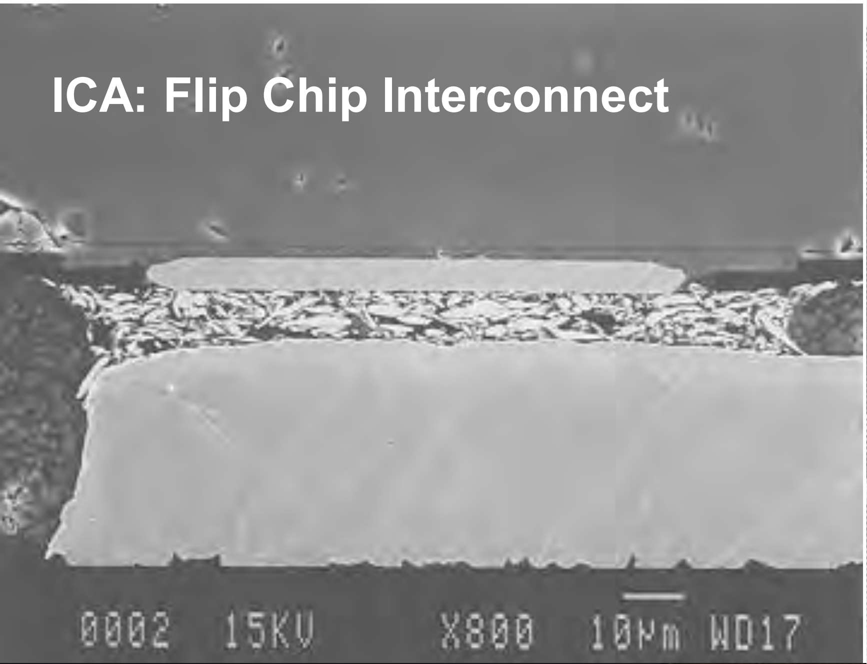
Figure 1.11 NEC's 3-D stack-up chip scale package (CSP) for memory devices.

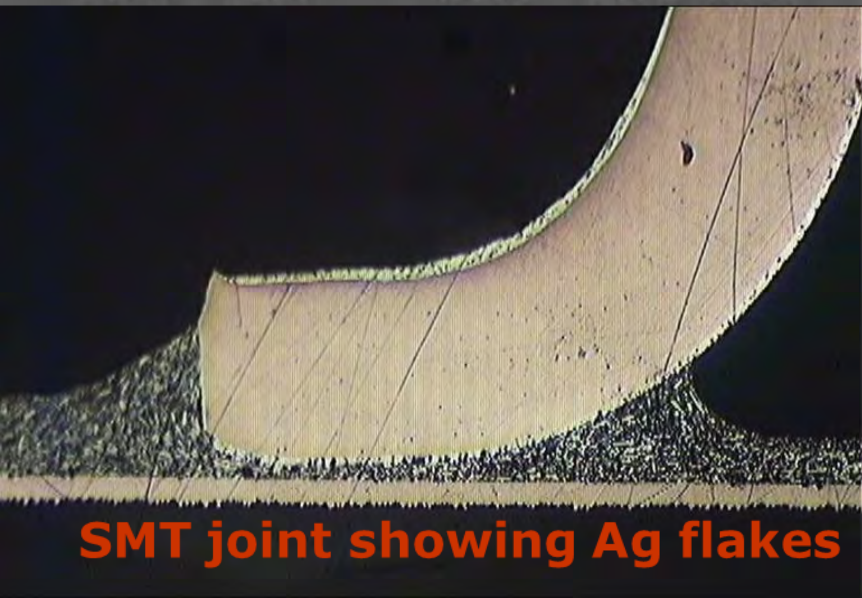
Figure 1-1. Four Major Functions of the Package & Mechanical Support

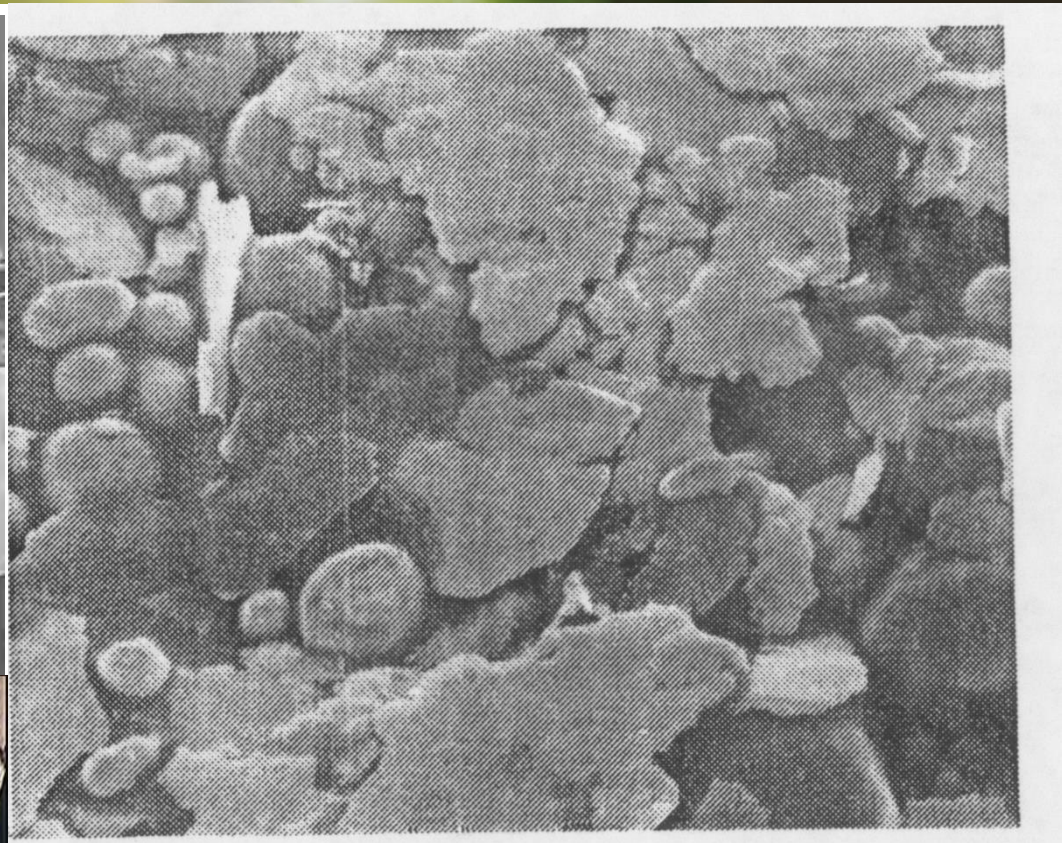
Roadmap

- Polymer/metal composite example: Isotropic Conductive Adhesive (ICA)
- Percolation
- Polymer cure
- Electrical properties
- Reliability:
  - Drop test
  - Galvanic corrosion
- Miscellaneous
  - Magnetic alignment
  - Flip chip underfill filler
- Nanoparticles
  - ICAs
  - Embedded components
- Carbon nanotubes (CNTs) & graphene
  - Electrical & thermal

ICA: Isotropic Conductive Adhesives







Bi-modal distribution

e.g.

10µm diameter flakes (<1µm thick)

plus

1-3µm diameter powder (spheres)

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Creep & Coffin-Manson Lifetimes: Comparisons with Solder (Rusanen)

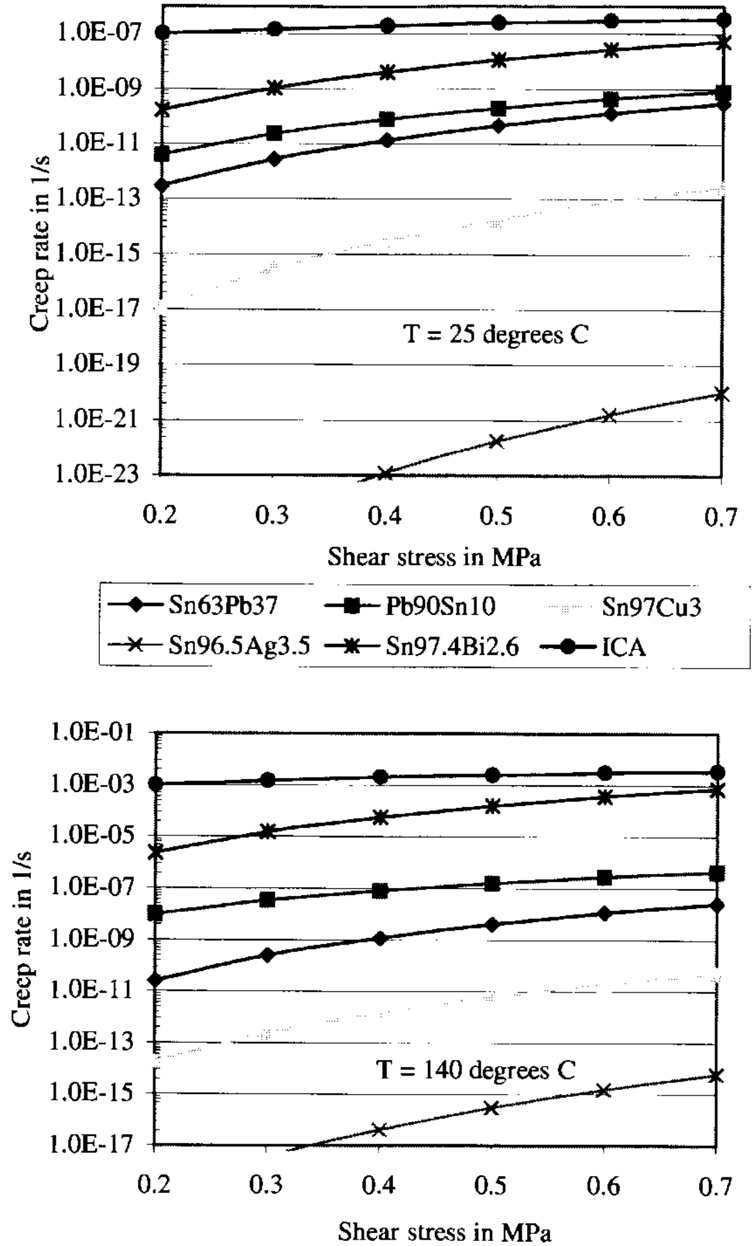
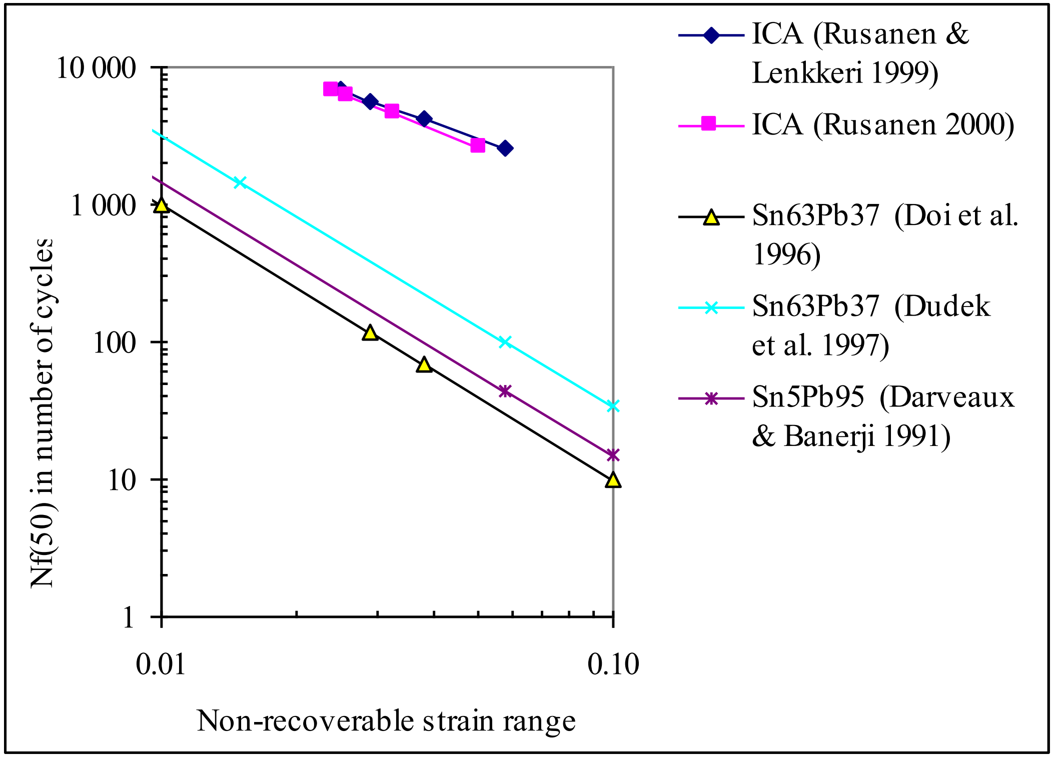


Figure 8. Creep rates of joining materials at temperatures of 25°C and 140°C.



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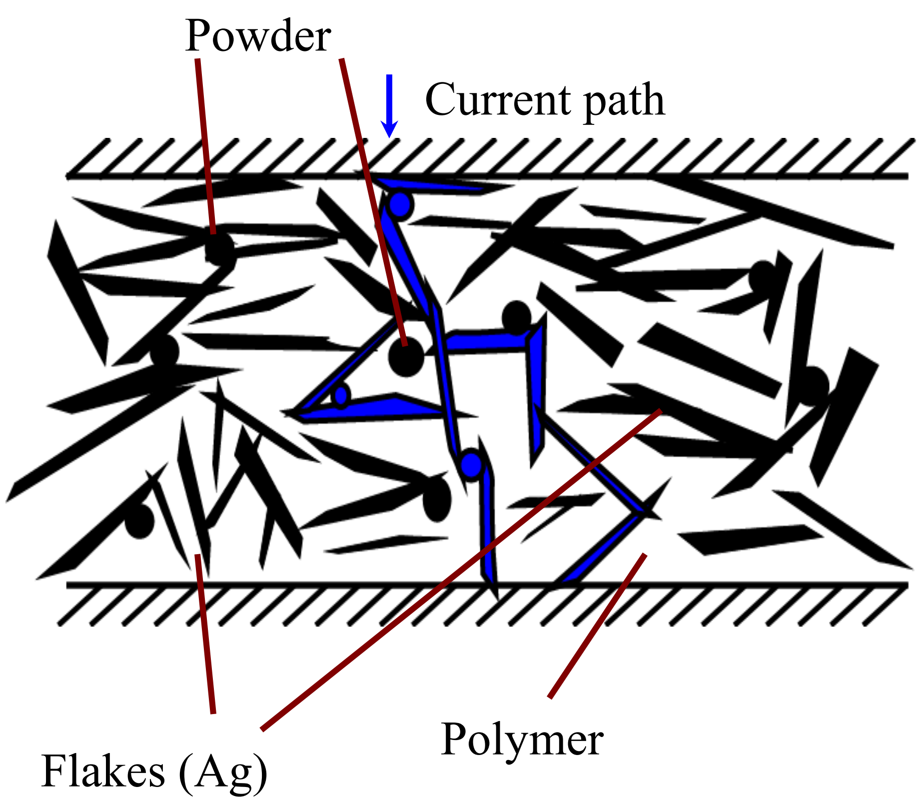
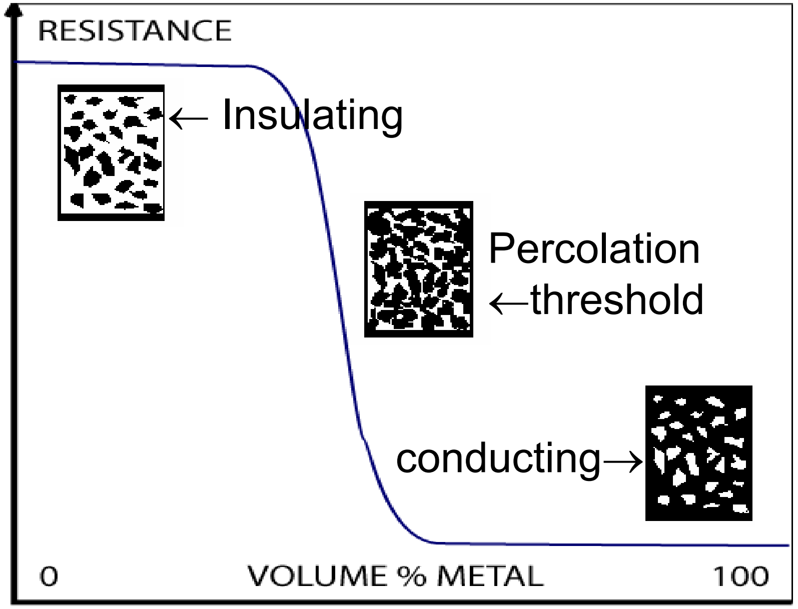
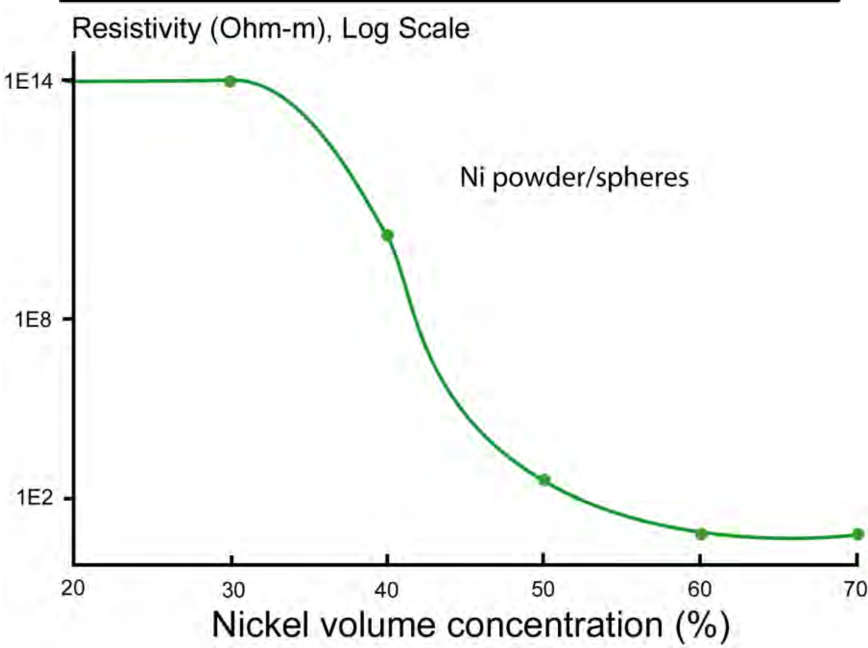
ICA: Conducts by percolation







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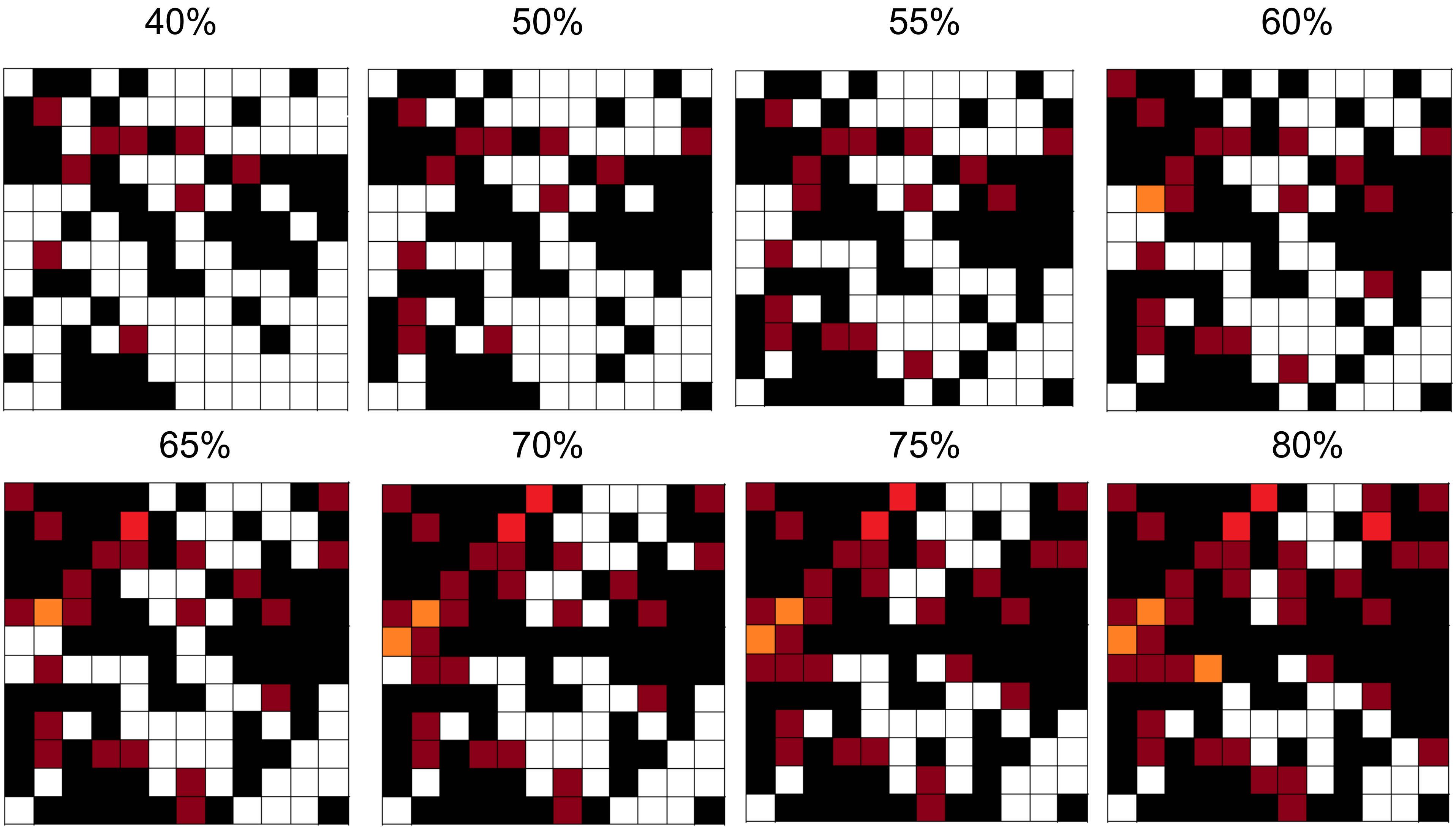
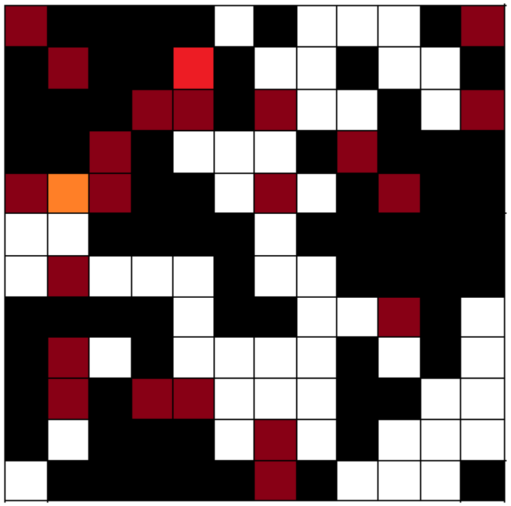
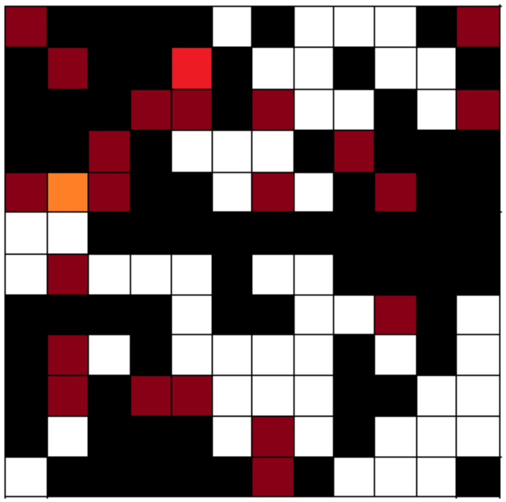
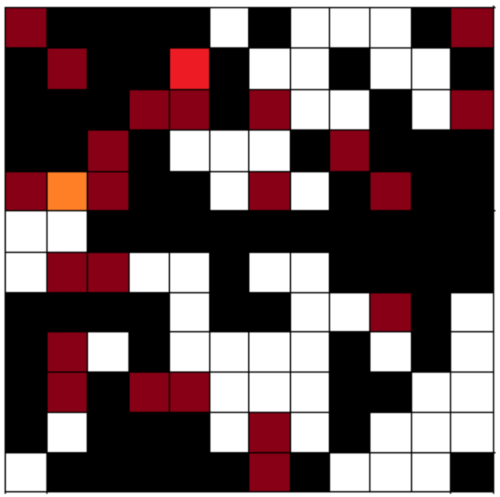
Site percolation modeling in a 12x12 array



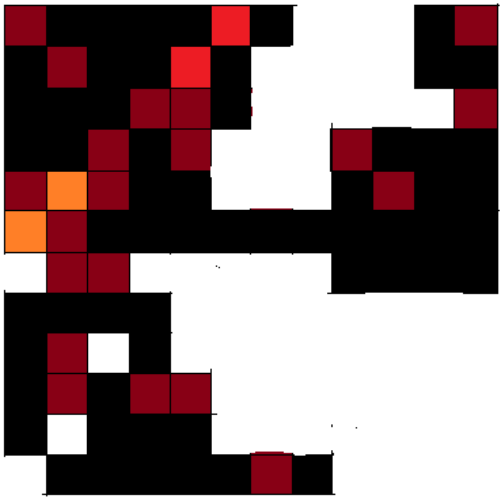
Critical percolation


65%


65%+1


65%+2

Percolating Cluster (70%)

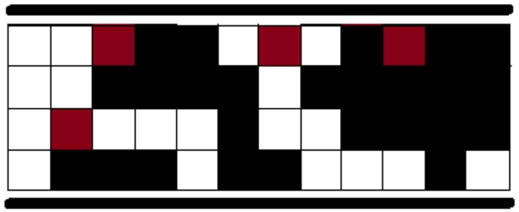


Size Effect

Middle 1/3 sections:

55%

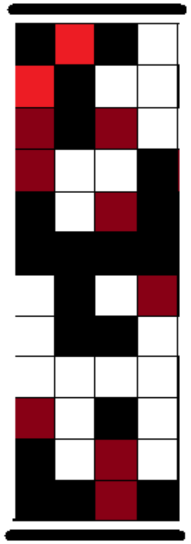
conducts



75%

no

conduction



Monte Carlo Percolation Models

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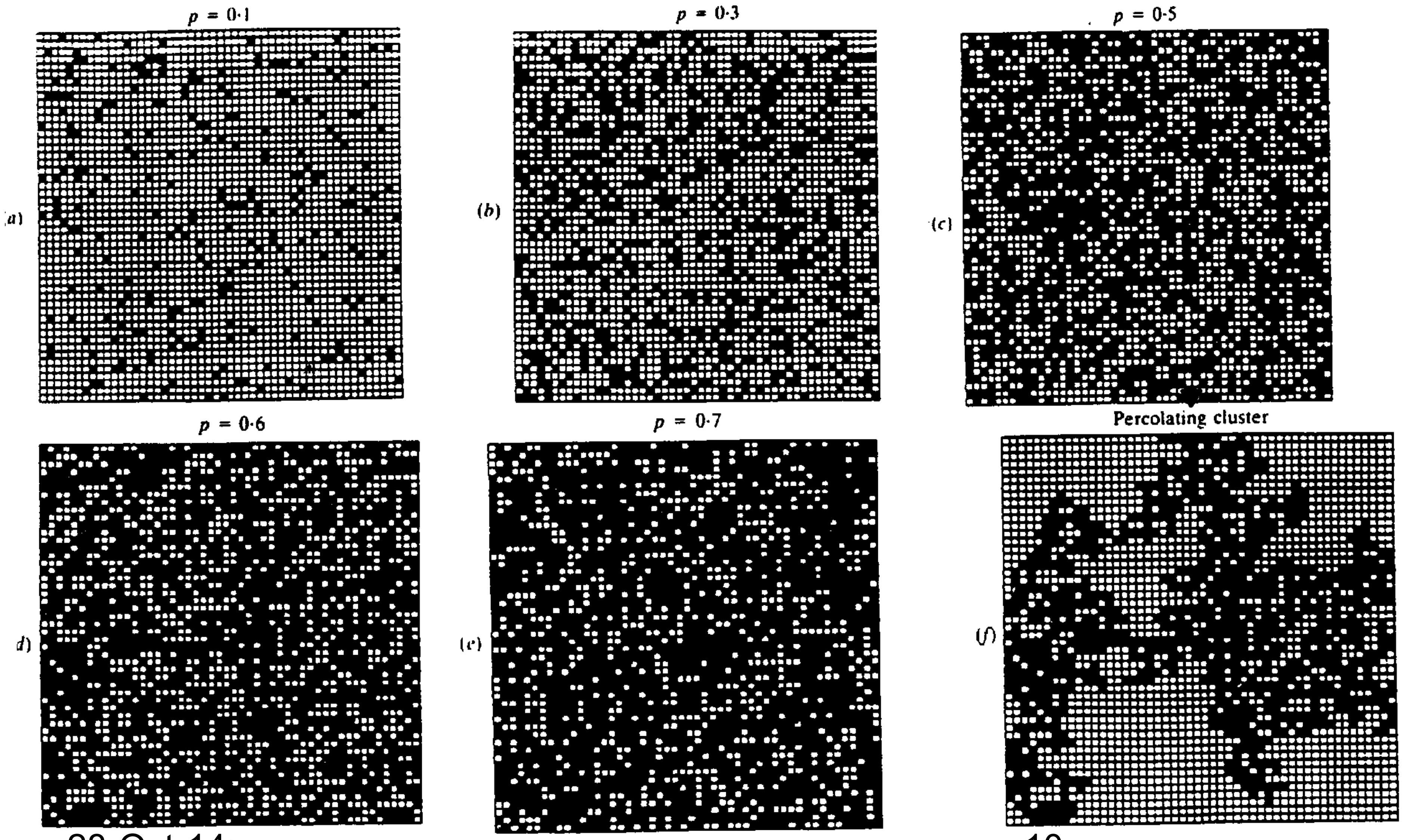
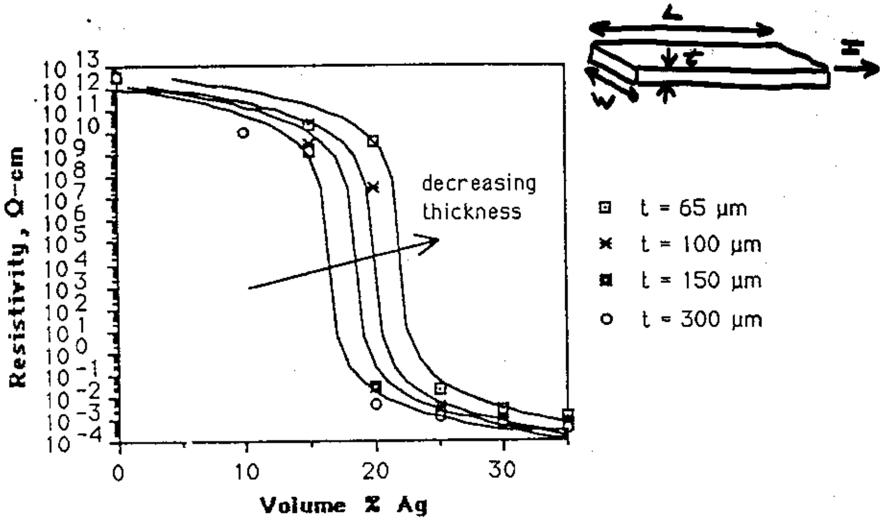
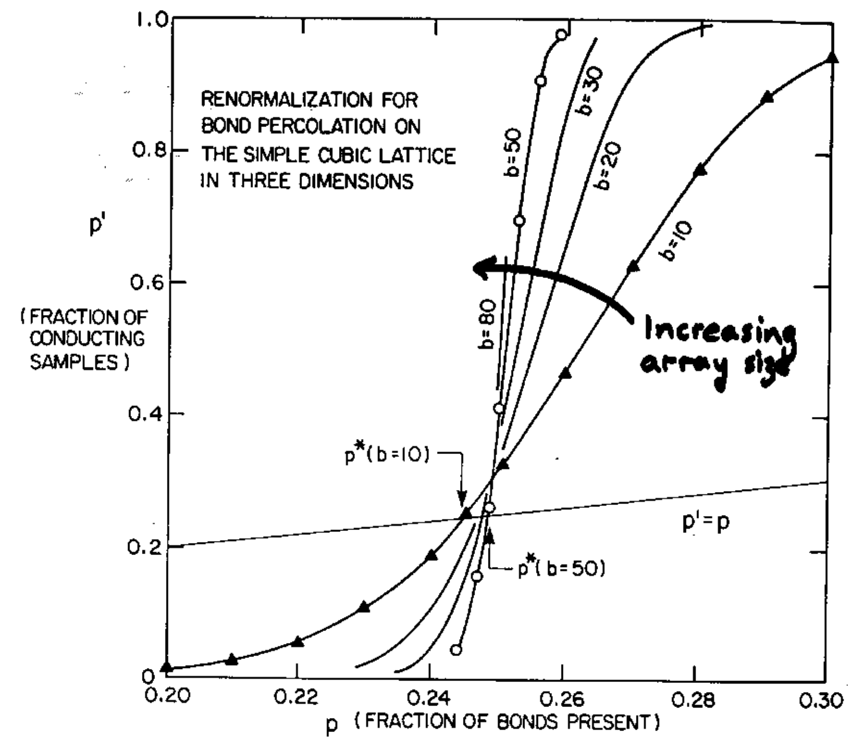


(Smilauer)

Percolation Threshold: Size Effects & Dispersion





- Averaged simulations

- Reproducibility
  - small sizes
  - incr tolerances
  - higher Ag

Constable et al (Adhesives'98)

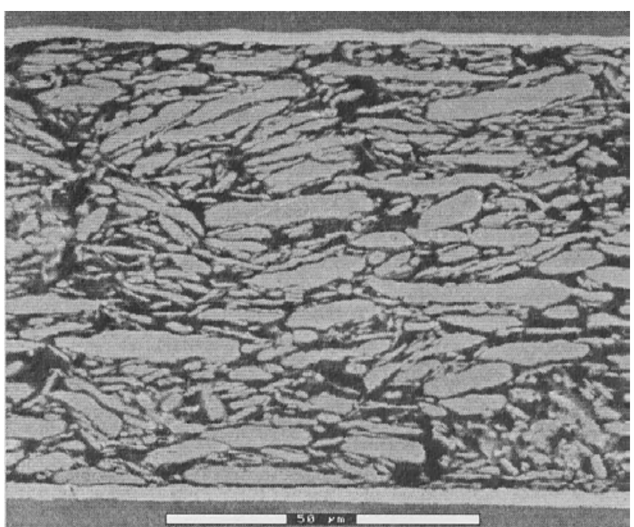


Fig. 3a Adhesive A, 900x magnification.

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Polymer Cure Process

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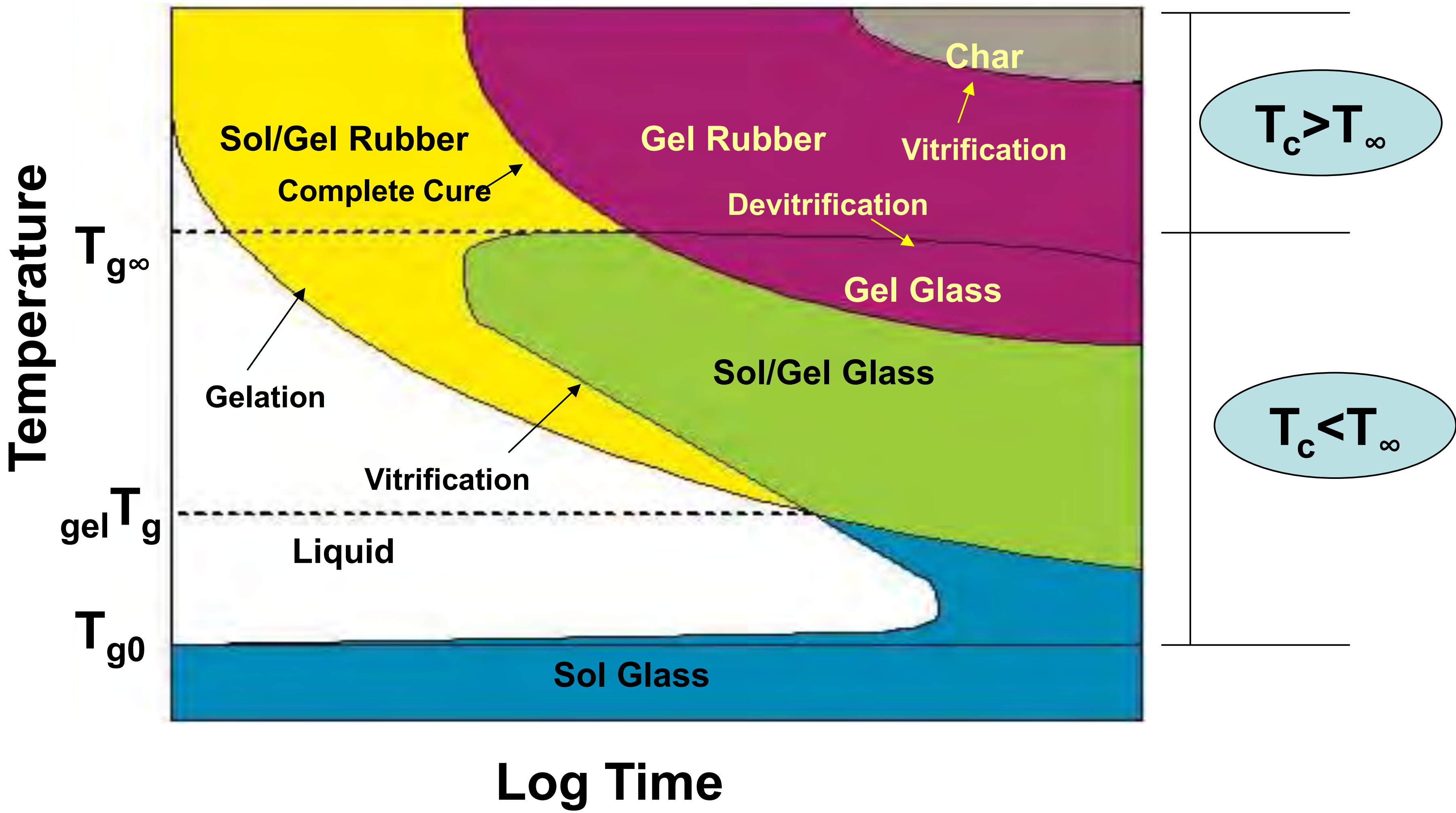


DSC: Differential Scanning Calorimetry

Directly determine degree of cure α & rate of cure dα/dt

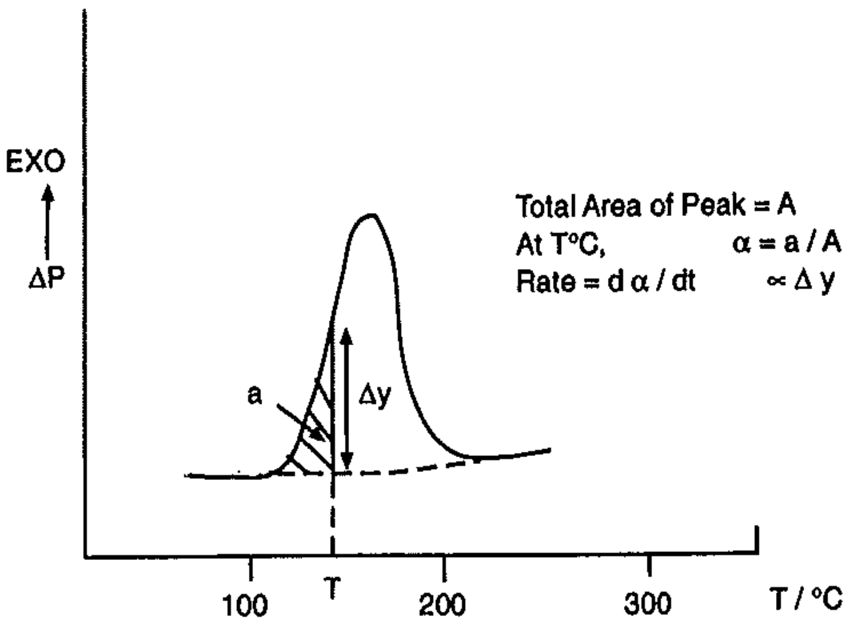
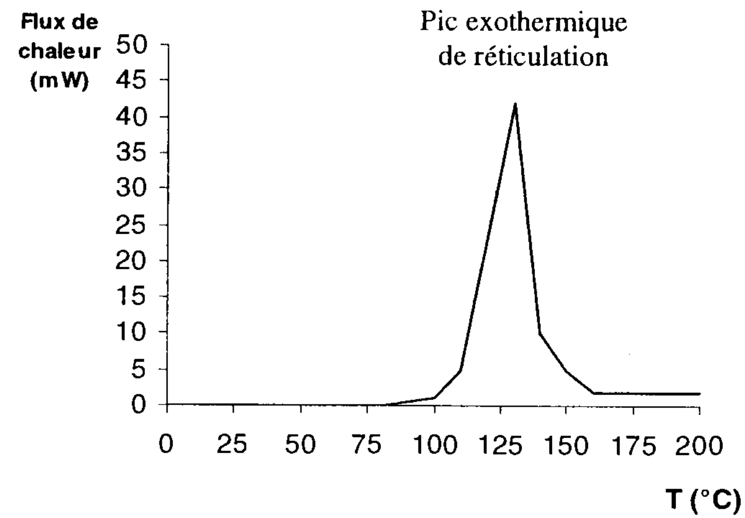
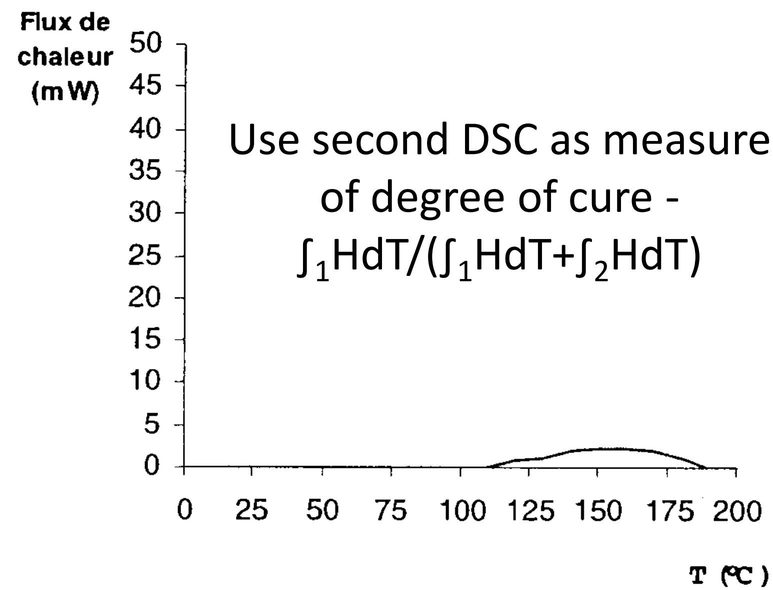


Figure 3.33 DSC curve for exothermic reaction showing measurement of partial and total areas.

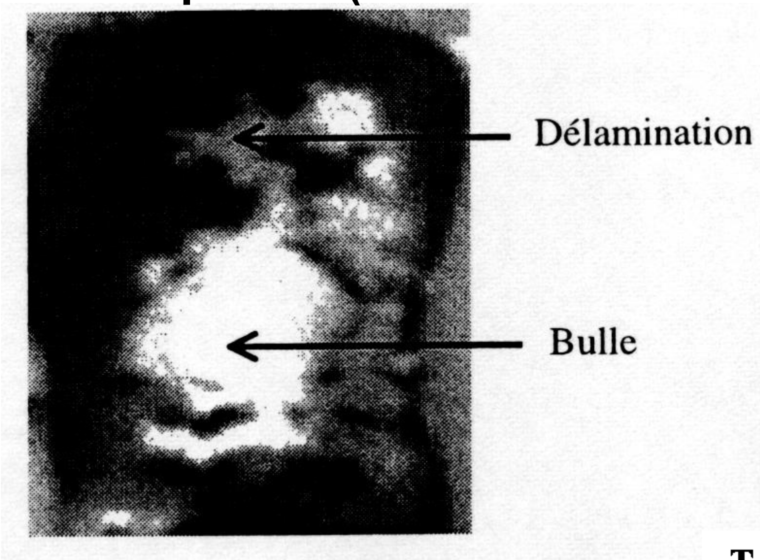


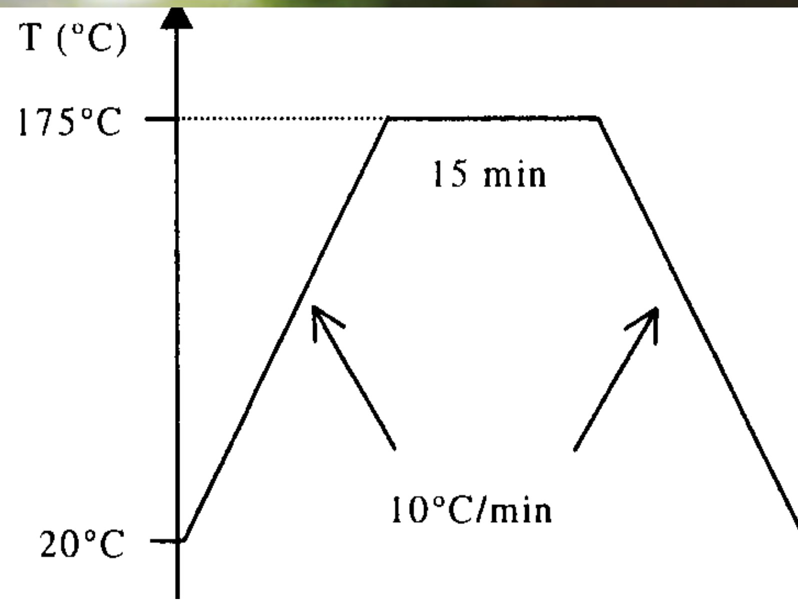


Use second DSC as measure of degree of cure - $\int_1 HdT/(\int_1 HdT+\int_2 HdT)$

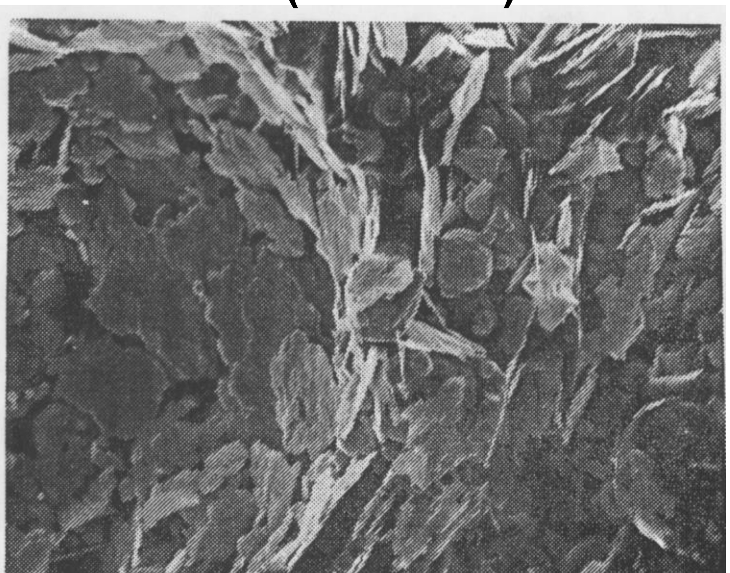
Delamination & Bubbles

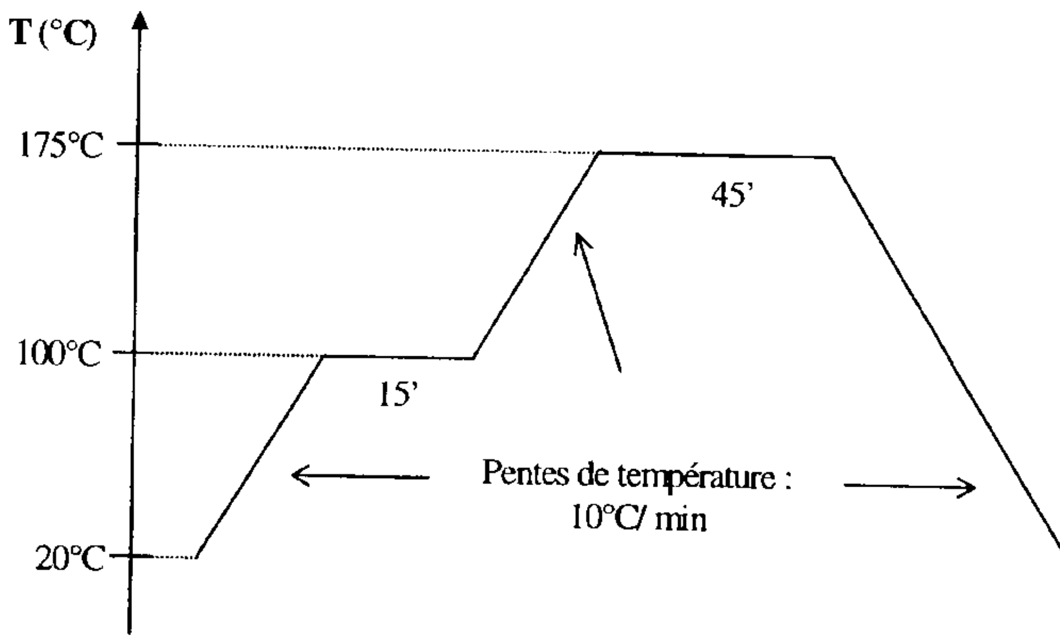
Thermoplastic (Perichaud/Fremont)





Thermoset (Morris/Li)





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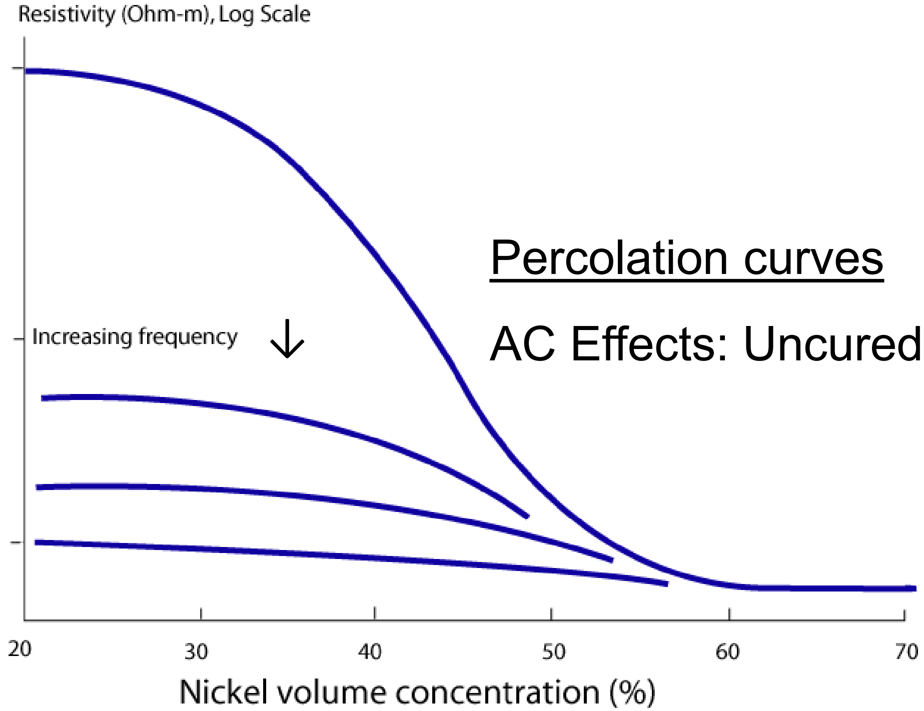
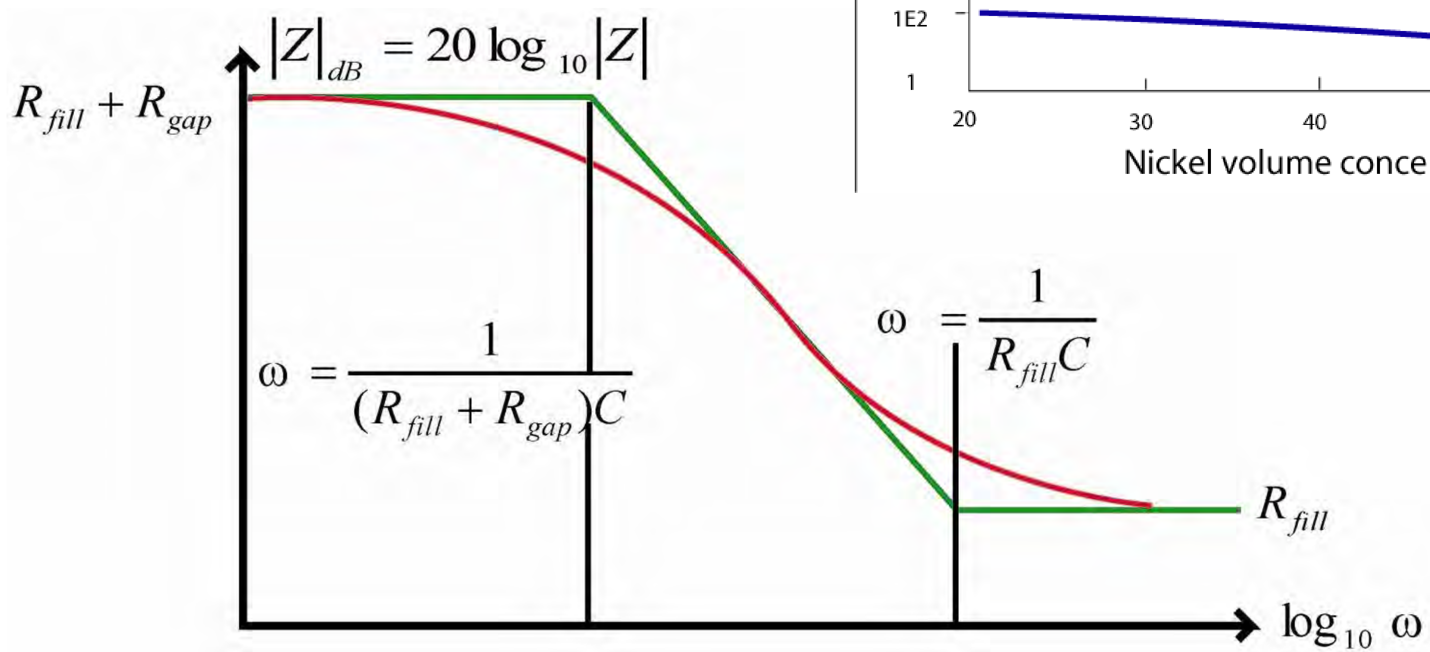
Frequency Effects:

Tunnel Gaps?



Percolation curves

AC Effects: Uncured



Experimental: TCR Results

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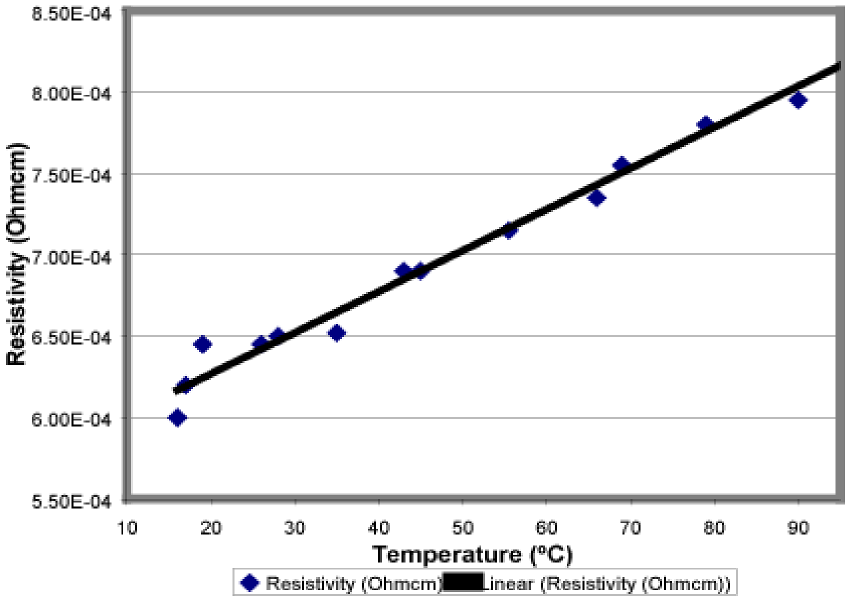
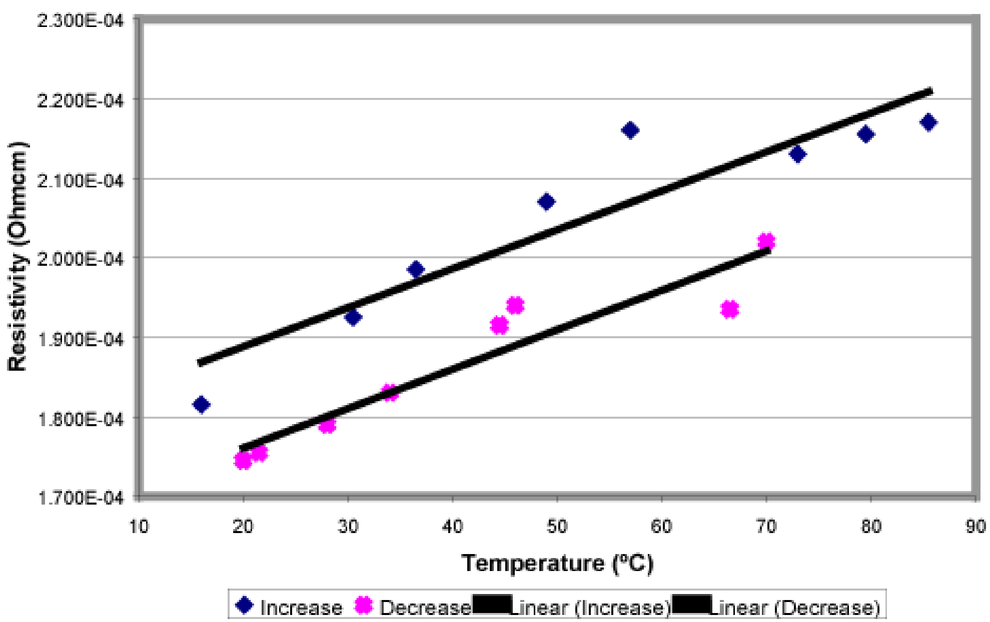




$TCR_{ICA} \approx TCR_{Ag}$

$\therefore\ R_{ICA} \approx R_{Ag}$

Contact R negligible

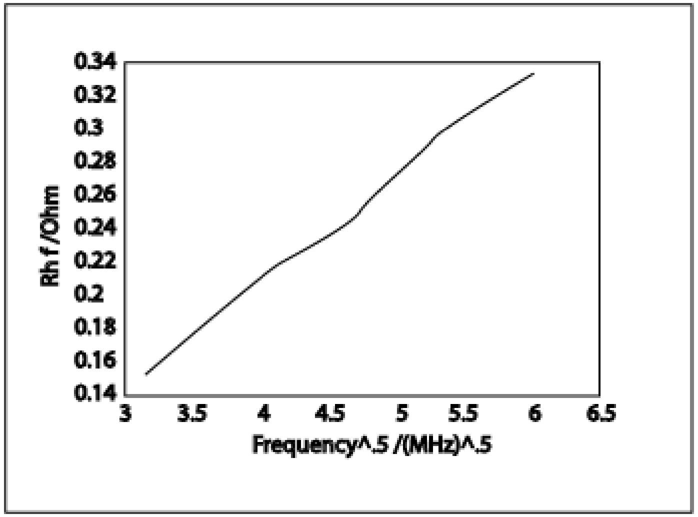
Resistivities for various temperatures.

(a) Brass stenciled CT-5047-02 thermoset sample (TCR-0.0039/ºC).

(b) (b) CSM-933-65-1 screen printed thermoplastic sample {TCR=0.0038/ºC}

Frequency Effects: Skin Effect

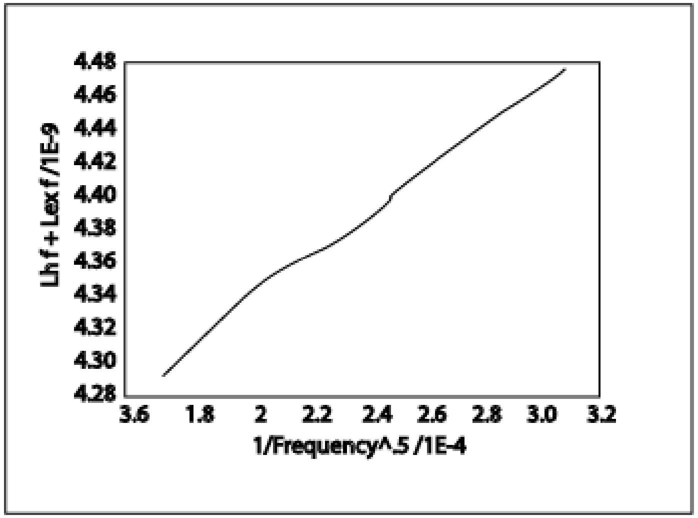
R



√f

This graph shows the linear relationship between the resistance at high frequencies and the square root of frequency

L



1/√f

This figure exhibits the linear relationship of the inductance at high frequencies with f^.5

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Impact Strength/Drop Test
(Tong)

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- Adhesion tests passed
- Devices fall off PWB if dropped
  - Large devices fail; small OK
- No correlation between drop test results and adhesion strength testing
- Complex shear modulus
  - Storage and loss moduli

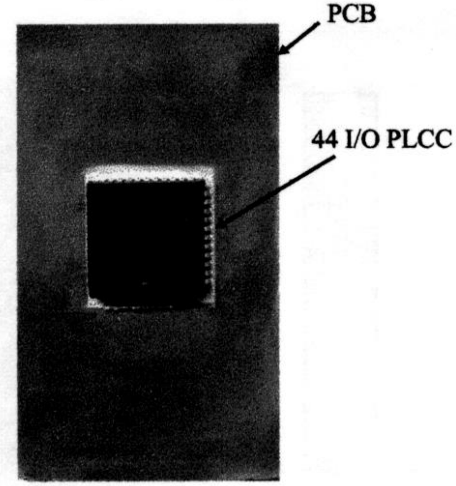


Figure 2. A Photograph of a Drop Test Sample

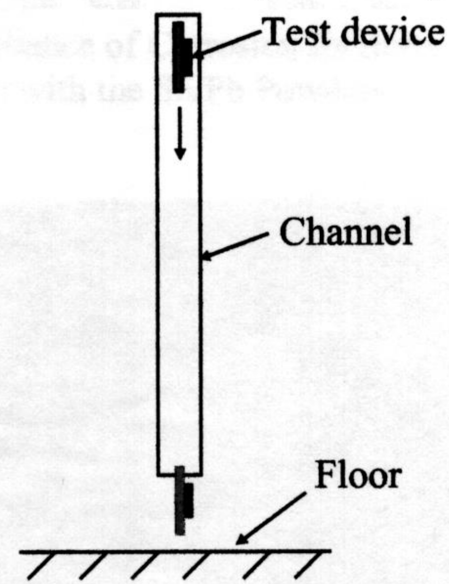
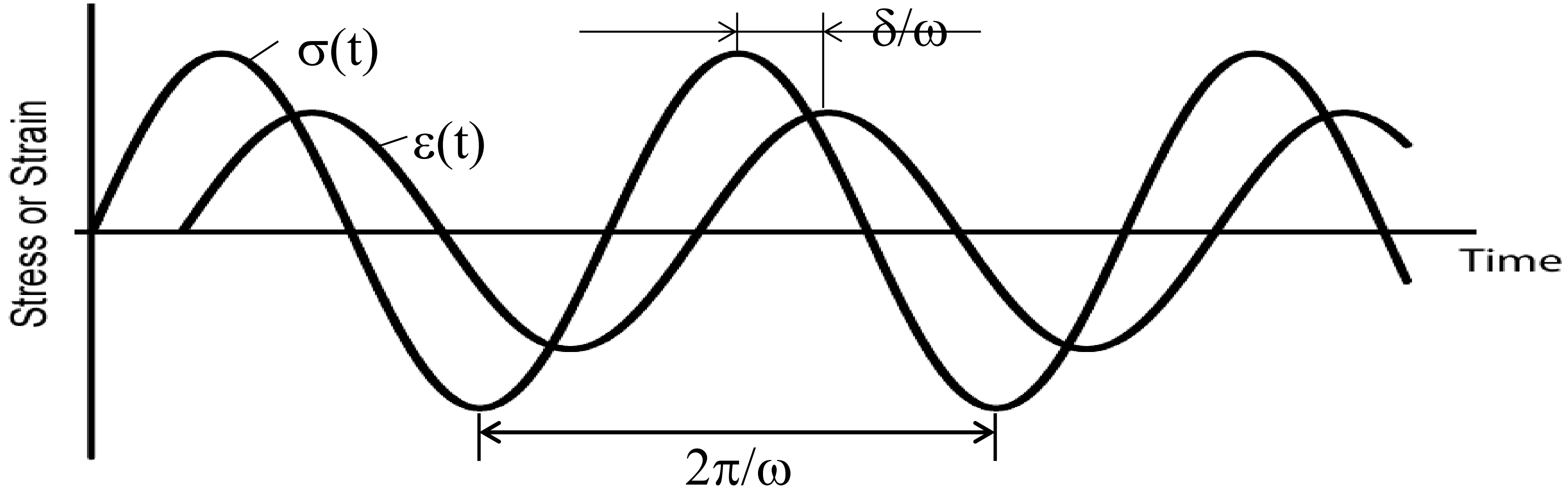


Figure 3. A Schematic of Drop Test Set-up

Shear Stress σ & Strain ε Complex Shear Modulus



Shear stress $\sigma = S/A$
Shear strain $\varepsilon = a/h$

$$\sigma = G\varepsilon$$

Elastic shear modulus

$$G = G' + iG''$$

Loss tangents:

$$\tan\delta = G''/G'$$

Charge density $\sigma = Q/A$
Electric field $E = V/d$

$$\sigma = \varepsilon E \quad [Q = (\varepsilon A/d)V]$$

Dielectric constant

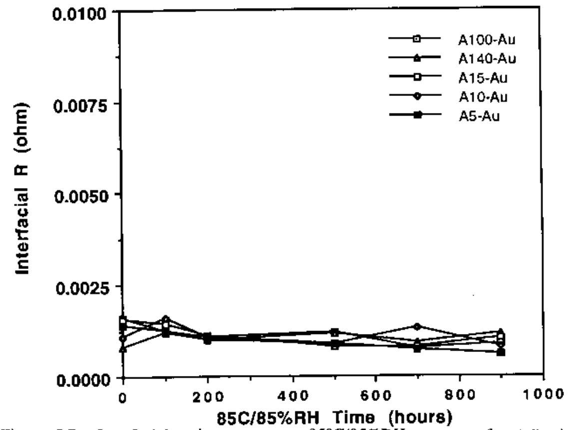
$$\varepsilon = \varepsilon' + i\varepsilon''$$

$$\tan\delta = \varepsilon'' / \varepsilon'$$

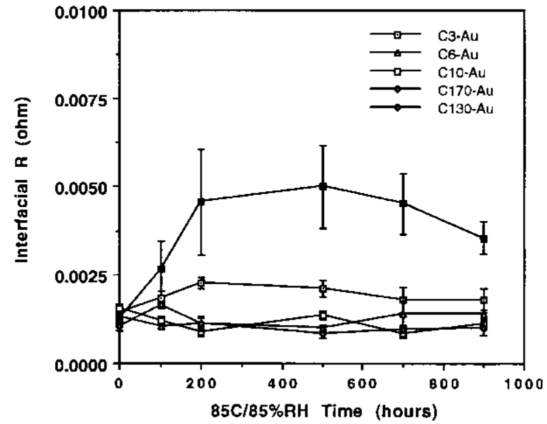
- **High tanδ by $T_{amb} > T_g$ → high CTE**

Contact R 85/85: Au & Cu contacts

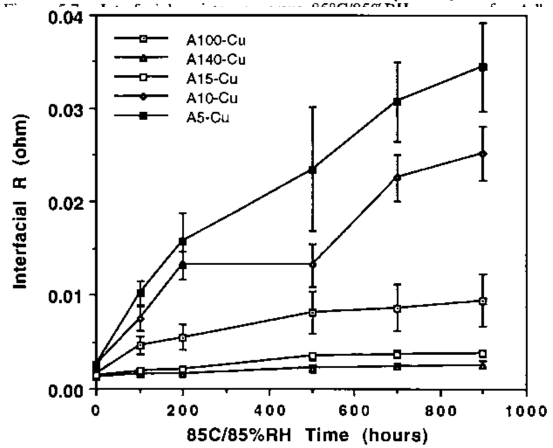
A on Au



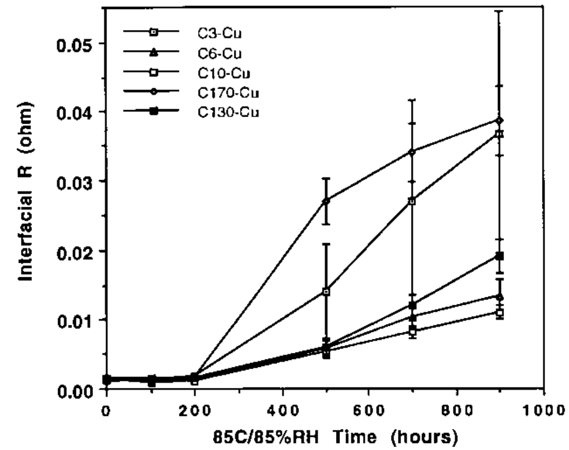
C on Au



A on Cu



C on Cu



(Li & Morris)

Galvanic Corrosion

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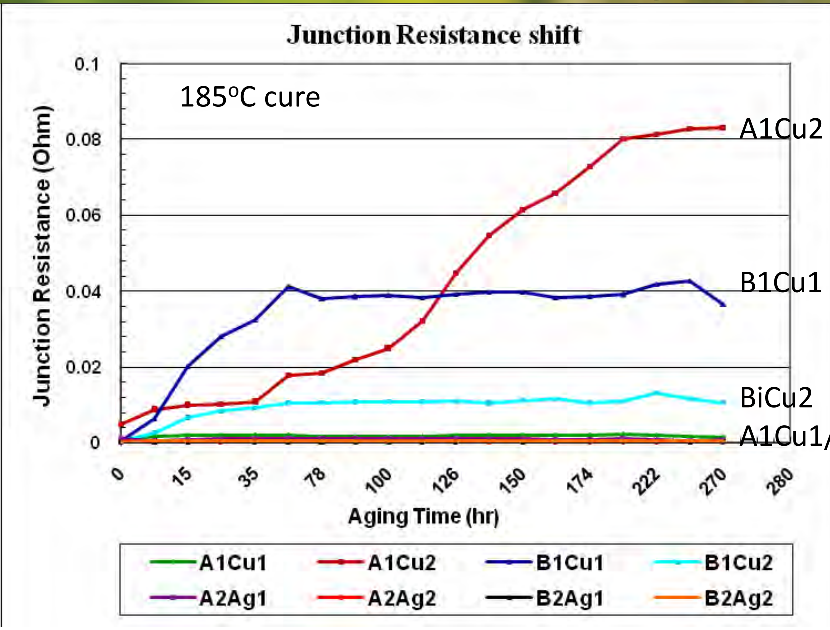
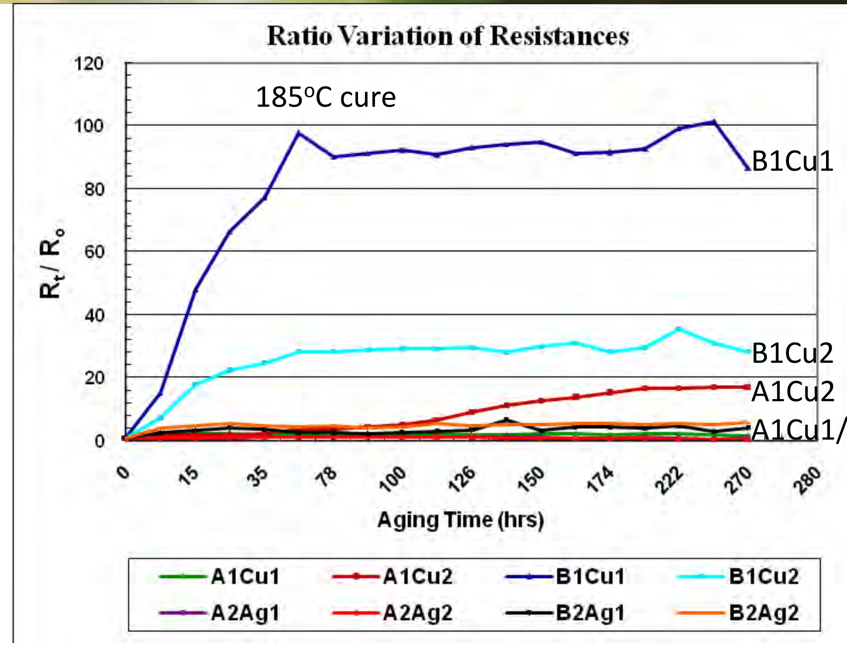
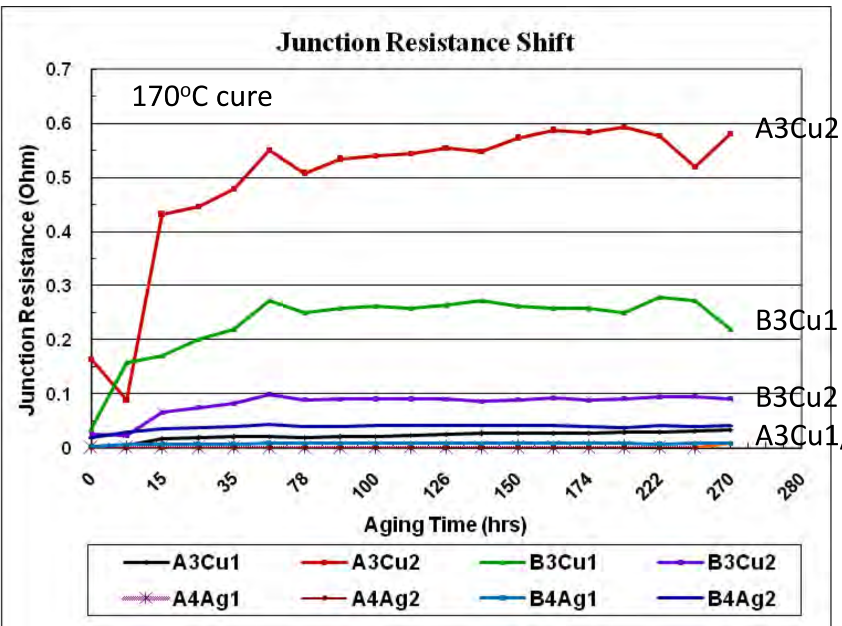
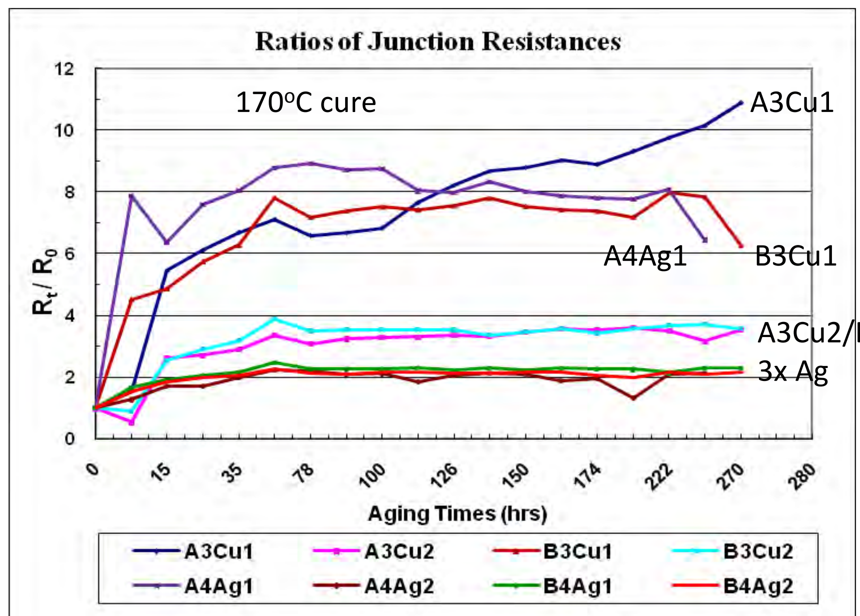
Electrode Reaction	Normal Potential
$Au - 3e^- = Au^{3+}$	1.50 v
$Pt - 2e^- = Pt^{2+}$	1.20 v
$Ag - e^- = Ag^+$	0.80 v
$Cu - e^- = Cu^+$	0.52 v
$H_2O + O_2 + 4e^- = 4OH^-$	0.40 v
$Cu - 2e^- = Cu^{2+}$	0.34 v
$Pb - 2e^- = Pb^{2+}$	- 0.13 v
$Sn - 2e^- = Sn^{2+}$	- 0.14 v
$Ni - 2e^- = Ni^{2+}$	- 0.25 v

ICA: Lee, Cho, & Morris, Proc. EMAP 2007
Ag-ICA performance comparison on Cu and immersion-Ag PWB contacts









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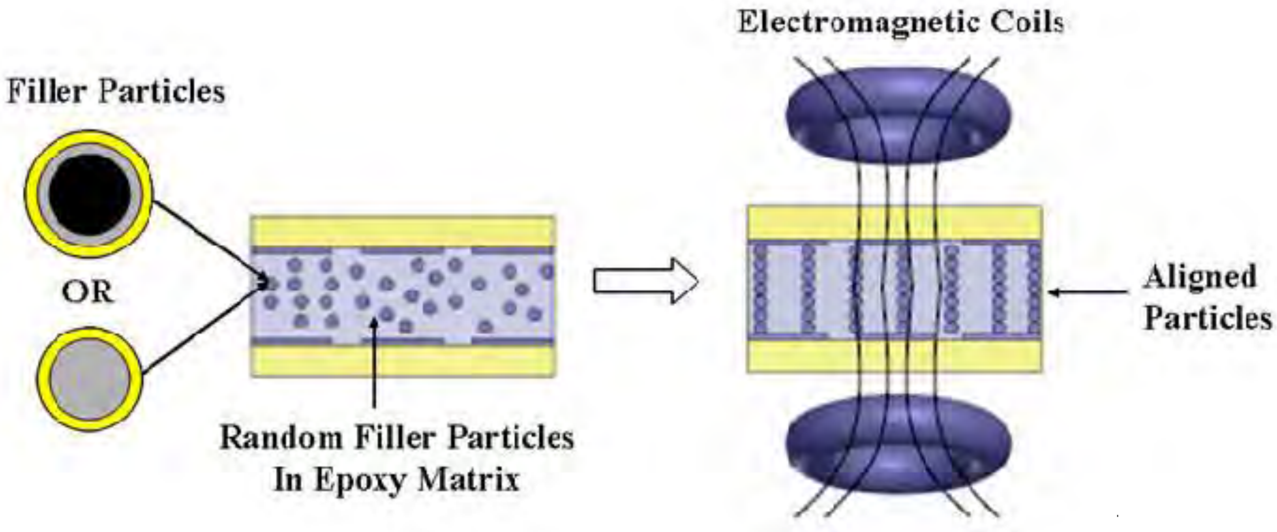
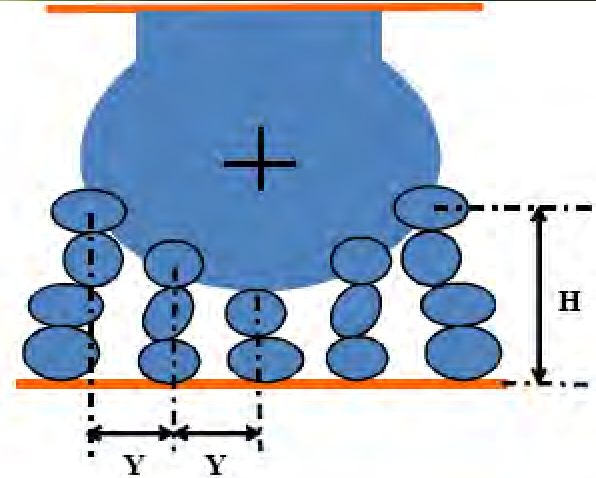
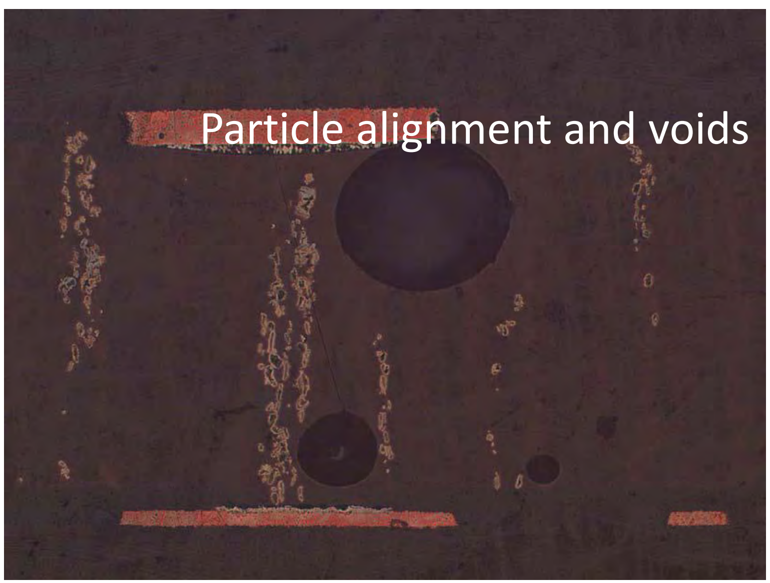
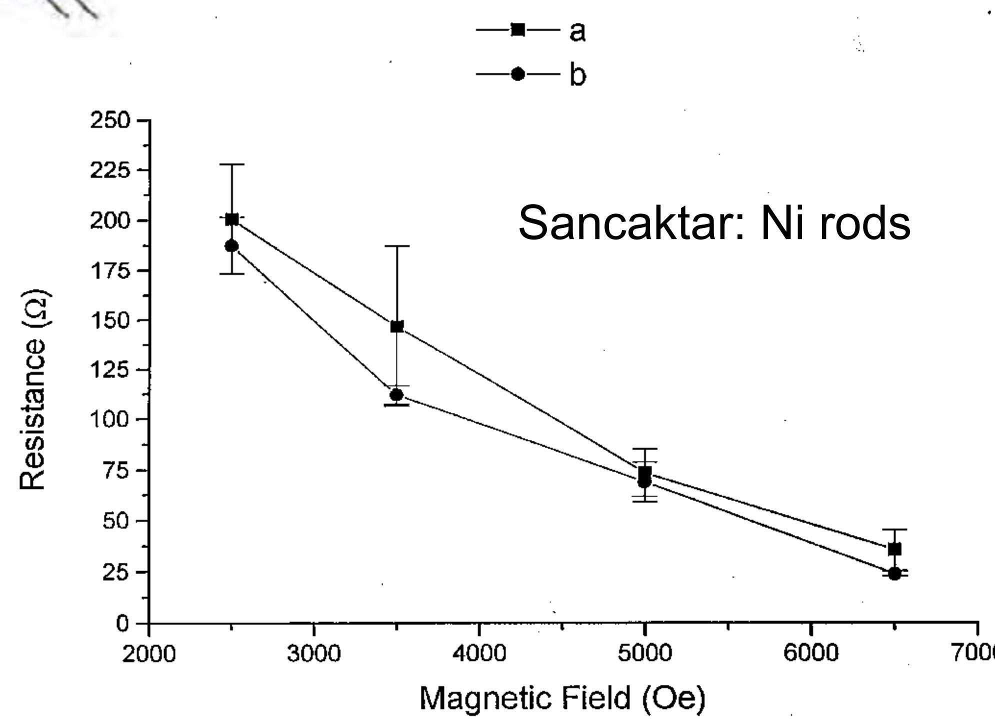
Ramkumar & Srihari, Proc. ECTC 2008, pp. 225-233
Magnetic field alignment of Ag-coated Ni particles









Nano-Silica Flip-Chip Underfill

Compare CTE mis-match:
- Si = 4-5 ppm/°C
- Ag = 20 ppm/°C
- Epoxy = 54 ppm/°C
- FR4 = 36 ppm/°C

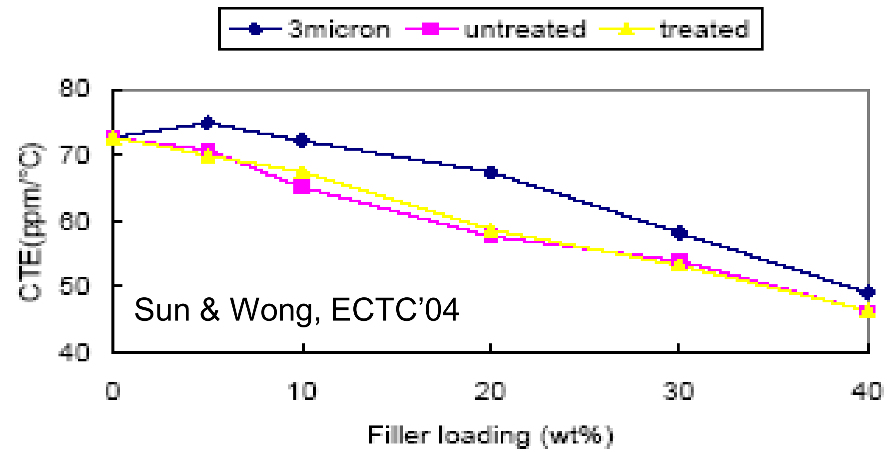


Figure 6 CTE of silica filled composite underfills

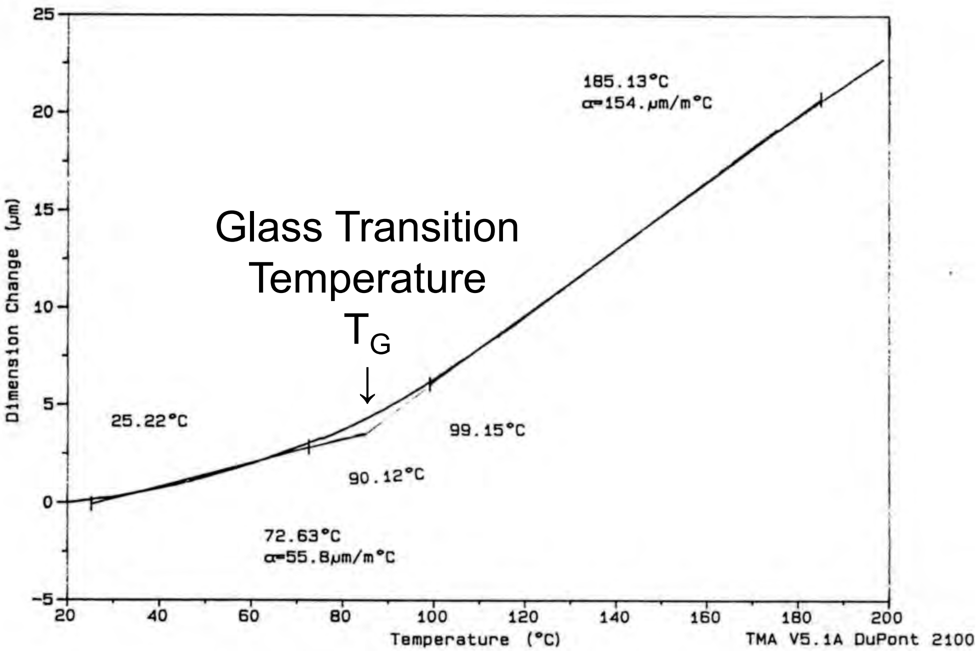


Figure 4.4: Typical TMA graphs for Adhesive A showing CTE above and below T_g.

CTE/modulus reduction with less settling

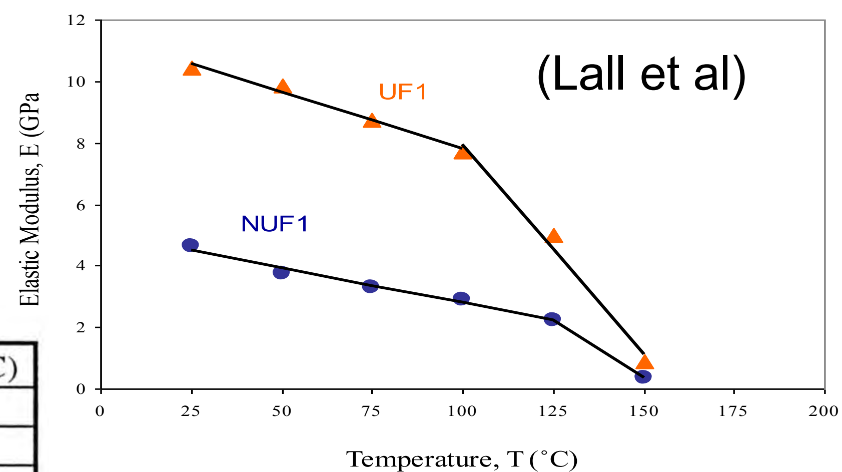


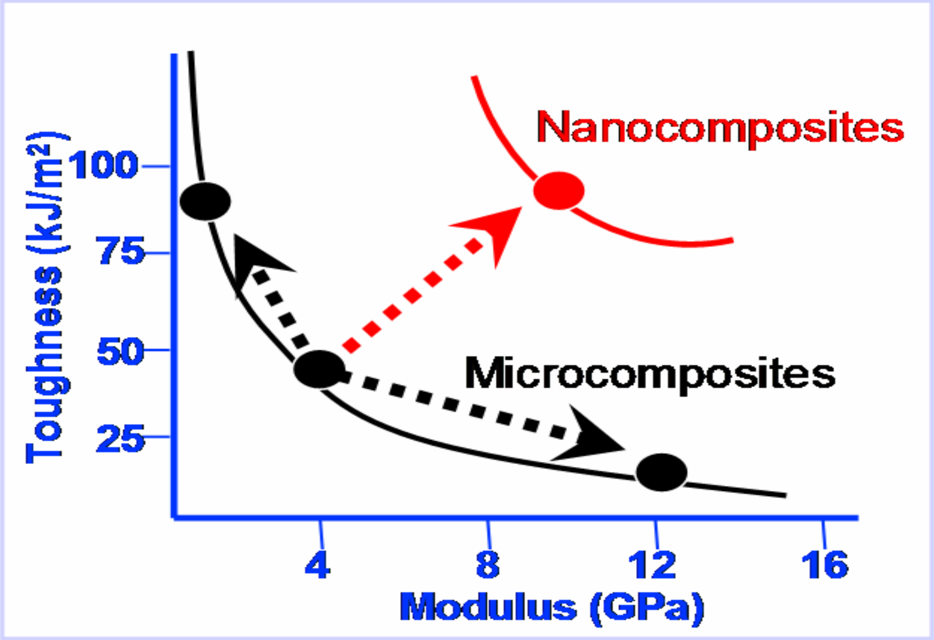
Table 4.3. TMA experimental results for cured block samples.

Materials	T_g (°C)	CTE (<T_g) (μm/m°C)	CTE (>T_g) (μm/m°C)
Adhesive A	90	56	155
Adhesive B	90	61	168
Adhesive C	90	78	218

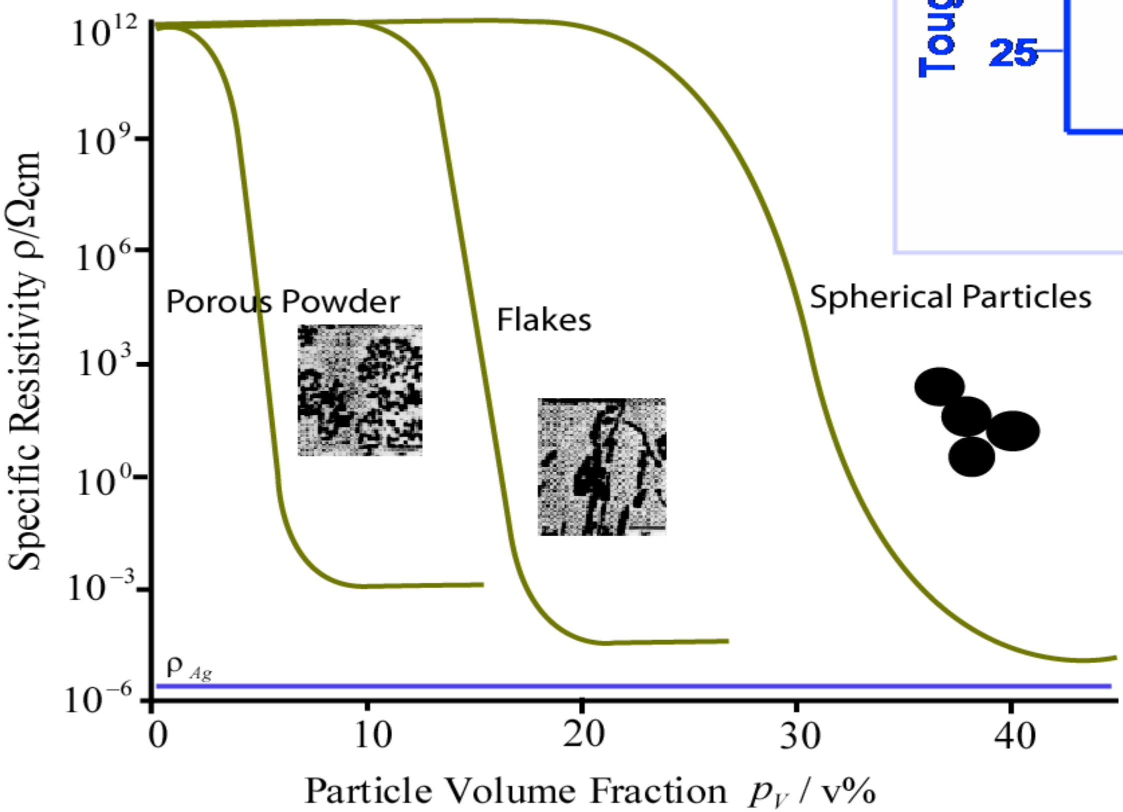
- Polymer/metal composite example:
  Isotropic Conductive Adhesive (ICA)
- Percolation
- Polymer cure
- Electrical properties
- Reliability:
  - Drop test
  - Galvanic corrosion
- Miscellaneous
  - Magnetic alignment
  - Flip chip underfill filler
- Nanoparticles
- Carbon nanotubes (CNTs) & graphene

Nanoparticle Composites

(High surface/volume ratio
→catalysts, etc)



Nanoparticles → single grain, no defects
(Mallik) Incr surface area → incr adhesion



Percolation limits of different ICA filler particles

Added Ag more effective on conductivity as flakes or powder than as nanoparticles

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Nanoparticle Sintering

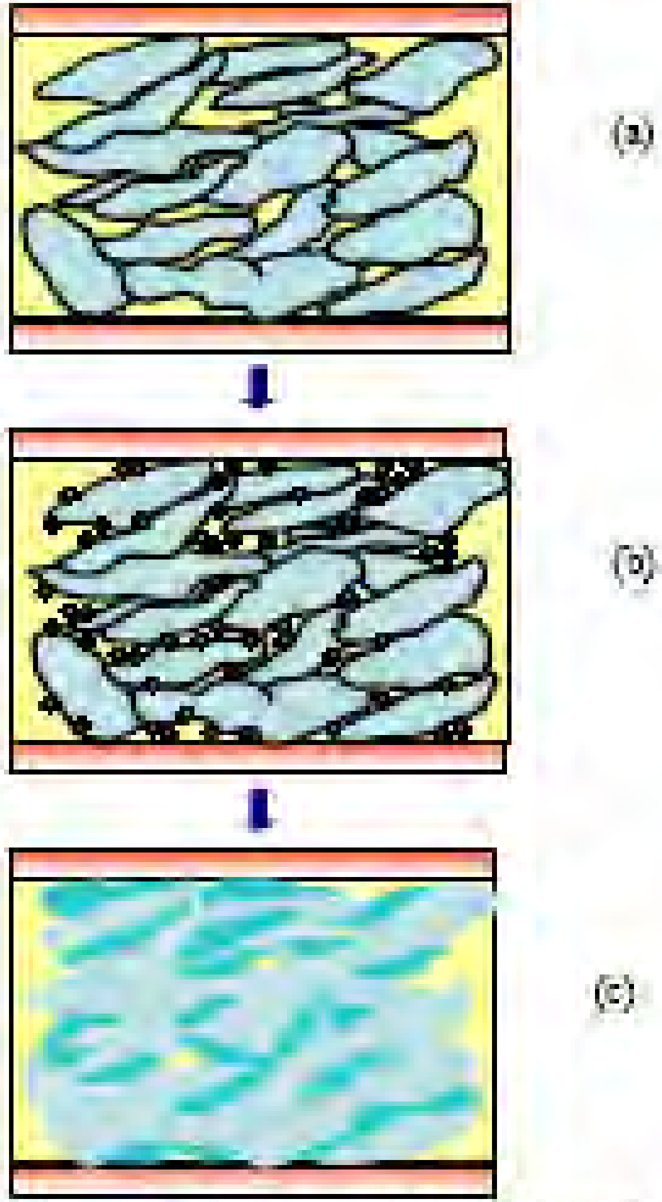
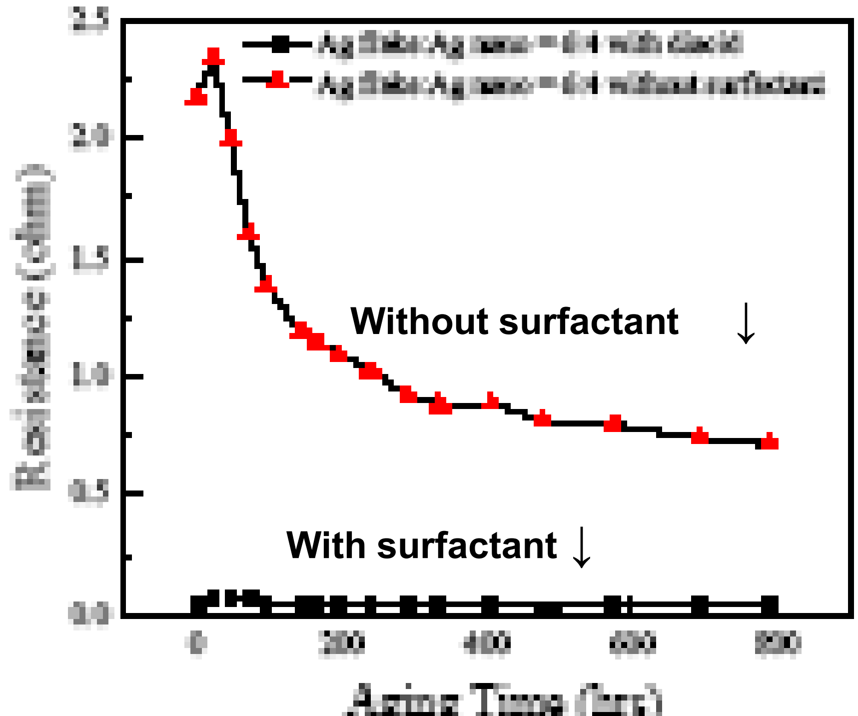


Figure 1. Schematic of particles and flakes between the metal and pads. (a) is conductive adhesives with silver flakes as fillers; (b) is conductive adhesives with both flakes and nanoparticles as fillers; (c) is conductive adhesives with sintered particles among flakes as fillers.

Surfactants: 5% diacids



[Wong et al, ECTC ’04 & ’06]

Nanoparticle Sintering

Portland State UNIVERSITY

- Sintering by surface self-diffusion, which is thermally activated, with net diffusion away from convex surfaces of high curvature.
- Particle interior retains crystallinity (not melting)

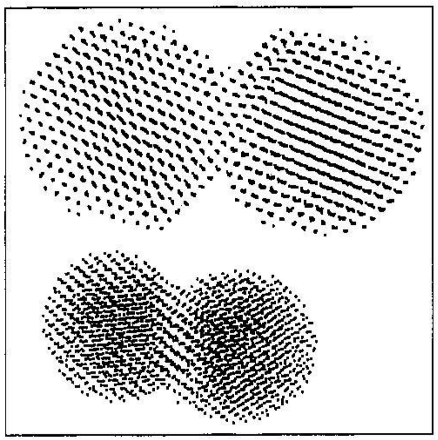
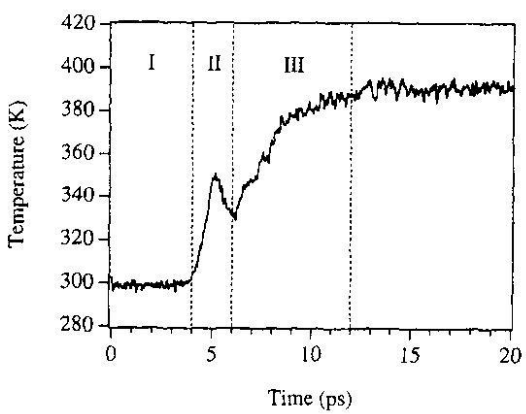


Figure 10. Side view of neck formation for particles of sizes 1014 and 2439 atoms.



gure 5. Variation of temperature of the system with time. This can be divid into three zones as explained in the text.

$$\frac{X^n}{R^m} = A(T).t \quad where$$

$$X = \text{neck radius} \ \& \ R = \text{sphere radius}$$

$$Bulk\ diffusion: n = 5\ m = 2$$

$$Surface\ diffusion: n = 7\ m = 3$$

Surface diffusion dominates (Ohring)

$$t \propto (X/R)^7 R^4$$

Raut, Bhagat, Fichthorn,
Nanostruct. Mater. 10(5) 1998, 837-851

Embedded Components

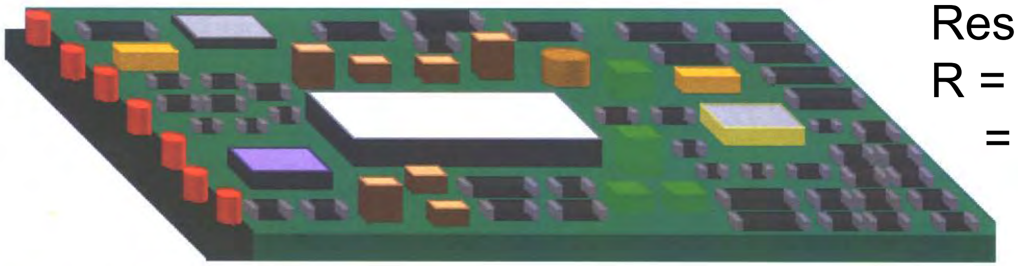


Figure 11: PWB vs SiP

Resistors (length L, width W, thickness t):
R = (L/W)(ρ/t)
= Number of squares x resistance/square
Decrease t → increase R
decrease power

Embedded capacitors:
C: Shrink area → shrink thickness for same C, i.e. μm scale → nm

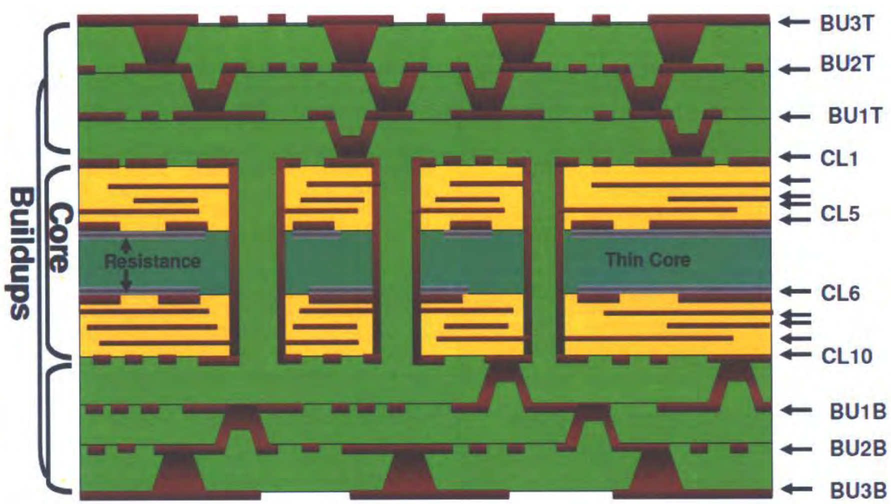


Figure 2: System in a Package (SiP): 3-10-3 cross section using resin coated copper capacitive (RC3) materials. Substrate cross section has resistance layers in the middle.

Das et al, ECTC 2009, 591-598

TCC control of nanocomposite capacitors:
High-k $BaTiO_3$- & low-k BCB

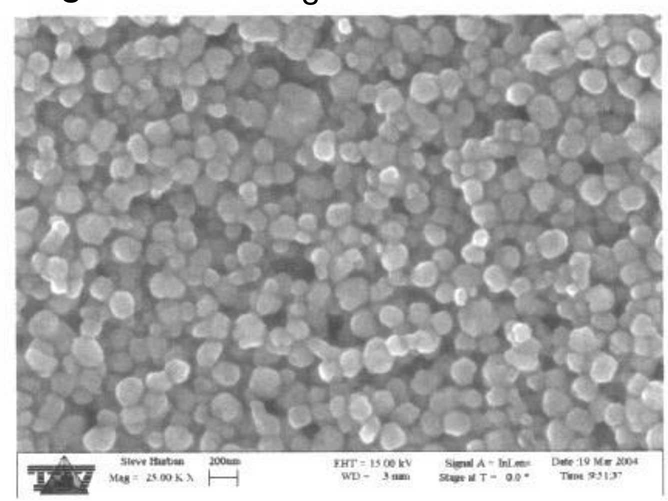


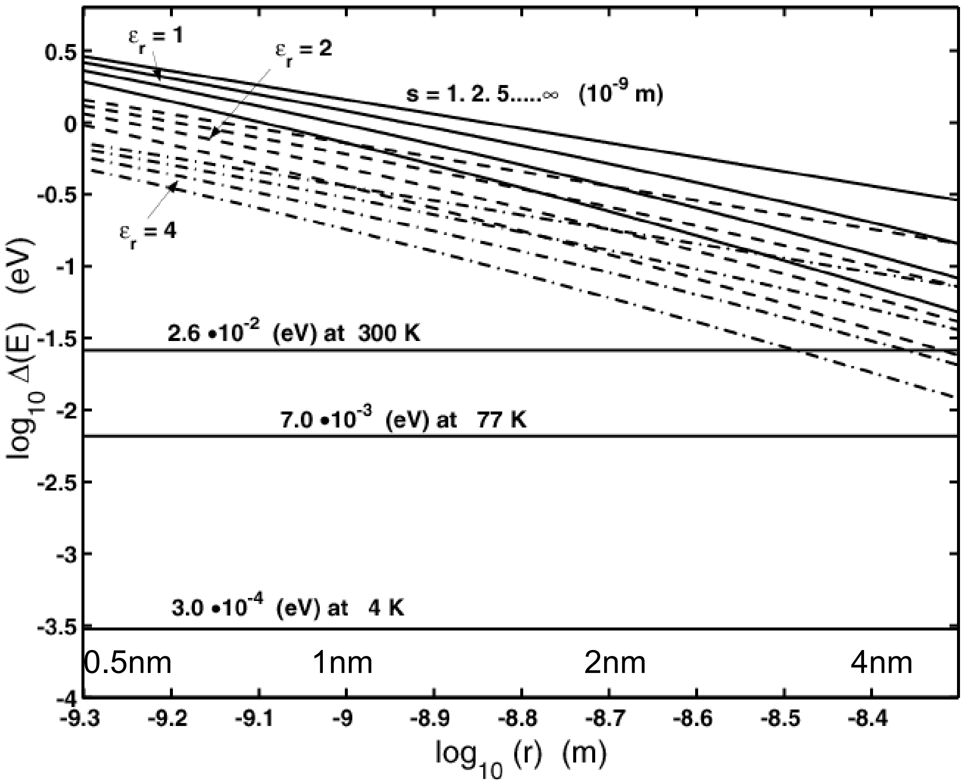
Figure 3: Larger area SEM images of RC3 nanocomposites.
[Abothu et al, ECTC'06]

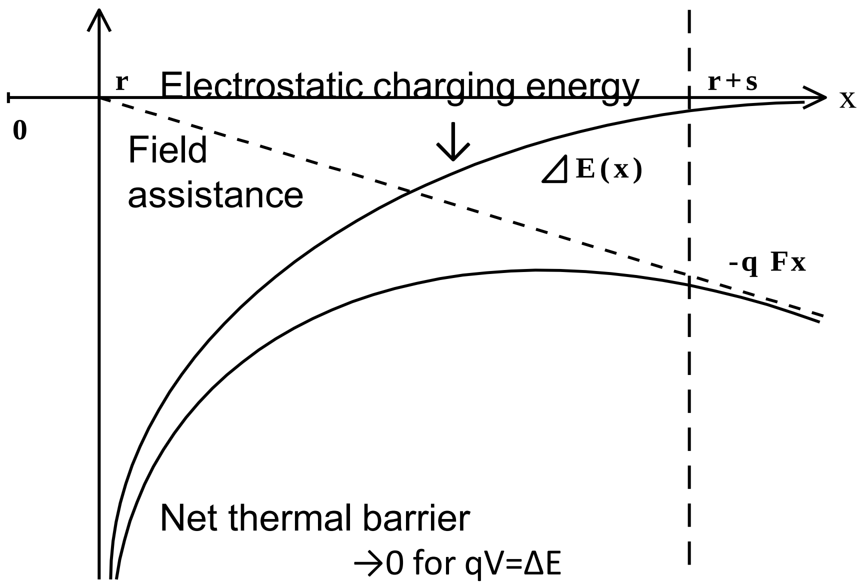
Nanoparticle Charging: the Coulomb Block (Morris)

Spherical nanoparticles, radius *r*, separation *s*
Electrostatic charging energy:

$$\Delta E = \frac{q^2}{4\pi\varepsilon r} \rightarrow \frac{q^2}{4\pi\varepsilon}\left[\frac{1}{r} - \frac{1}{r+s}\right]$$

- The Coulomb blockade effect, which requires an external field or thermal source of electrostatic energy to charge an individual nanoparticle, and is the basis of single-electron transistor operation

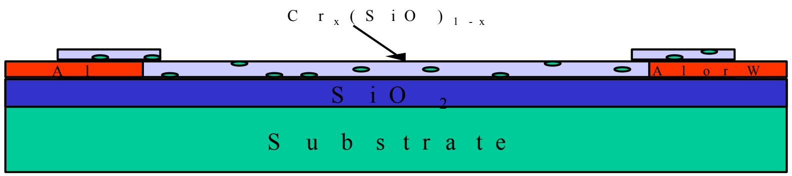




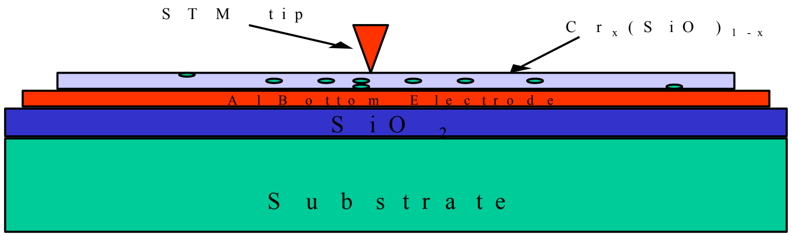
I-V characteristics of $Cr_x(SiO)_{1-x}$

(Wu & Morris)

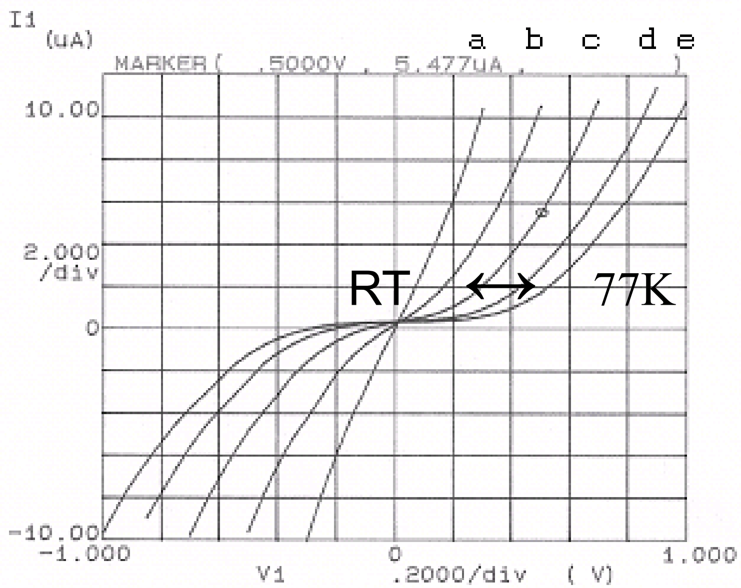
Electrical characteristics typical of Coulomb Blockade devices

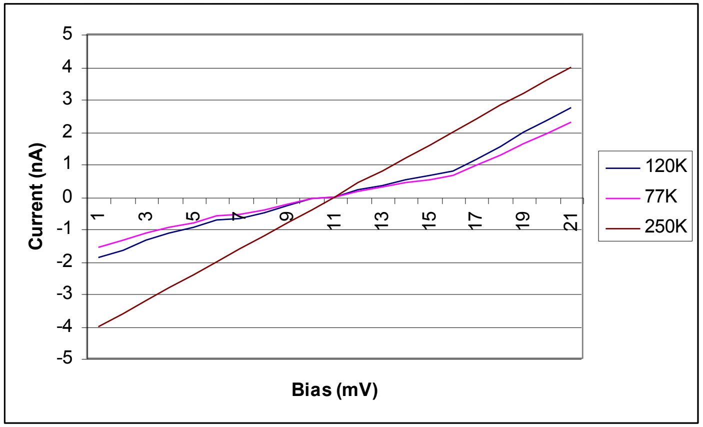


(a)



(b)



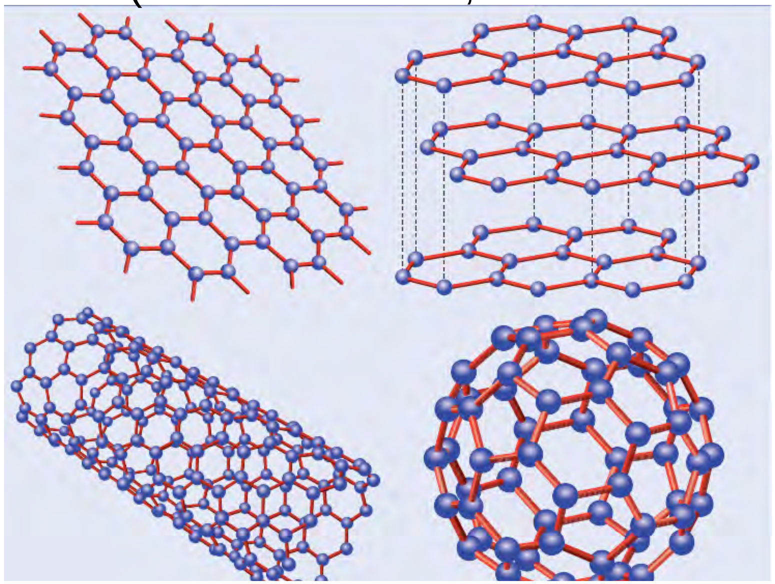


Coulomb effects “wash out” at room temperature (thermal charging) unless nanoparticles ~ single-nm scale

- Polymer/metal composite example:
  Isotropic Conductive Adhesive (ICA)
- Percolation
- Polymer cure
- Electrical properties
- Reliability:
  - Drop test
  - Galvanic corrosion
- Miscellaneous
  - Magnetic alignment
  - Flip chip underfill filler
- Nanoparticles
  - ICAs
  - Embedded components
- Carbon nanotubes (CNTs) & graphene
  - Electrical & thermal

Carbon Nanotubes (CNTs): SWNTs & MWNTs

(Kureshi & Hasan, J. Nanomaterials 2009, ID 486979)



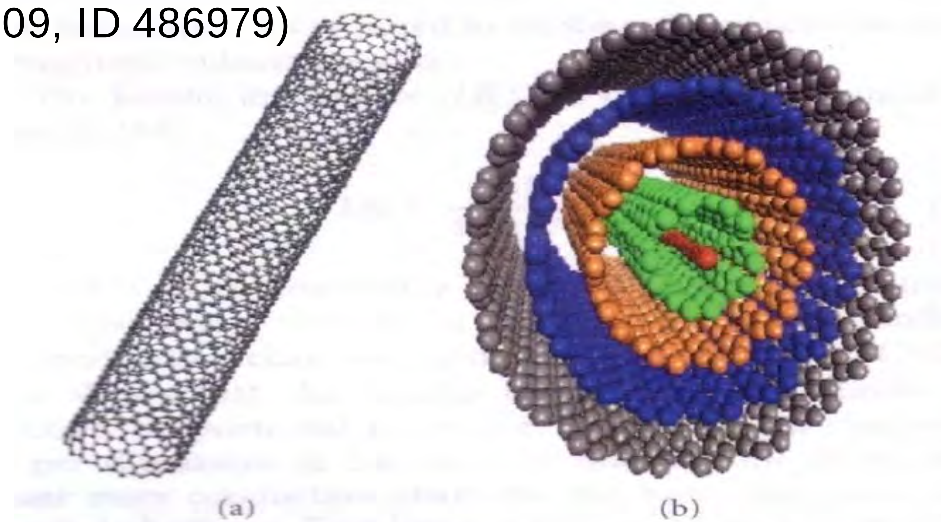


FIGURE 1: (a) Single-walled CNT. (b) Multi-walled CNT.

Kyoung-Sik Moon et al, ECTC'08

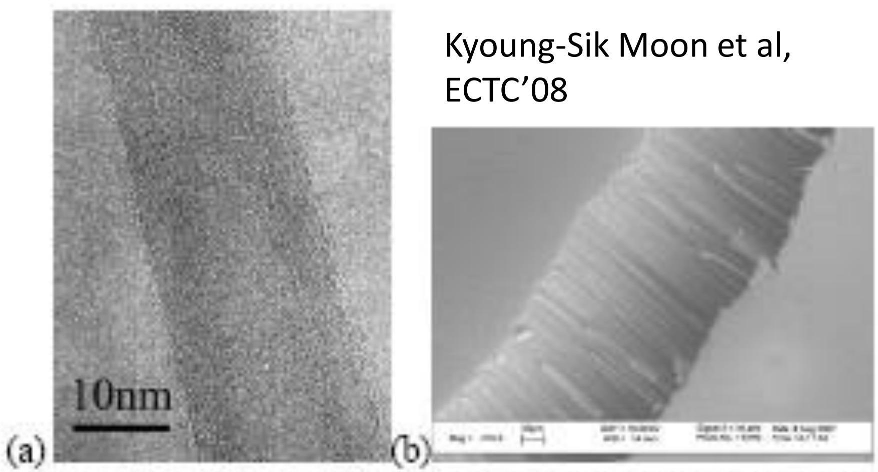
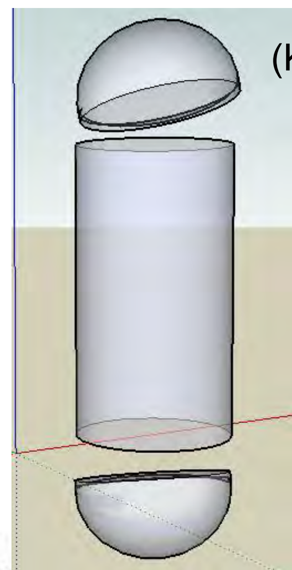


Figure 1. (a) TEM and (b) SEM images of aligned MWCNTs used.

(Kunduru et al)



Lee et al, ECTC'05

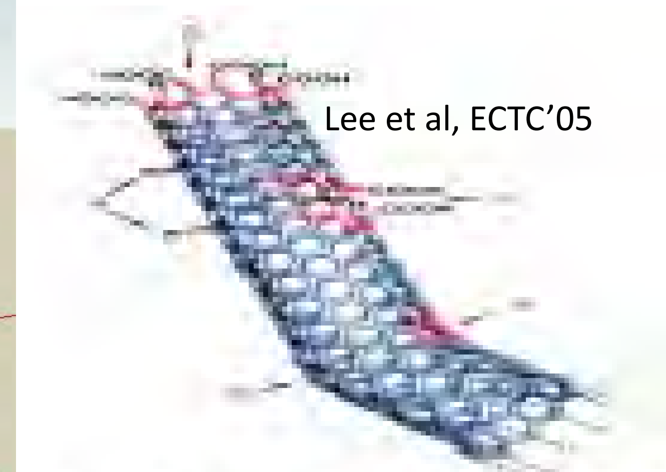
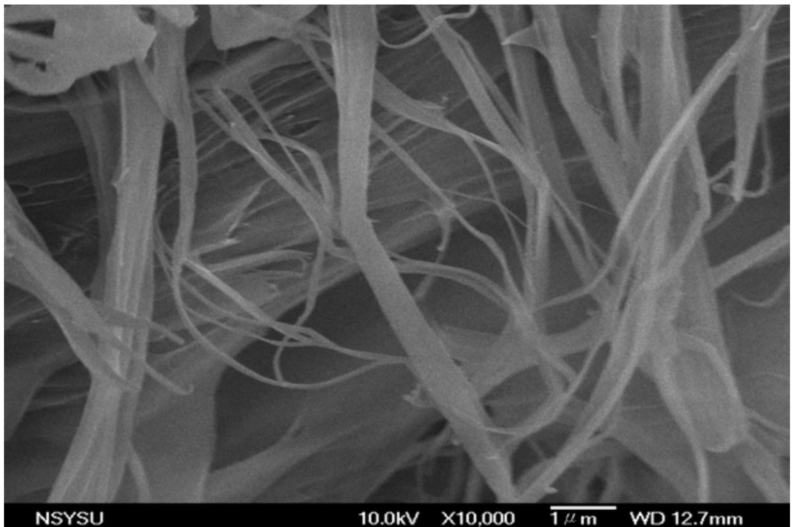


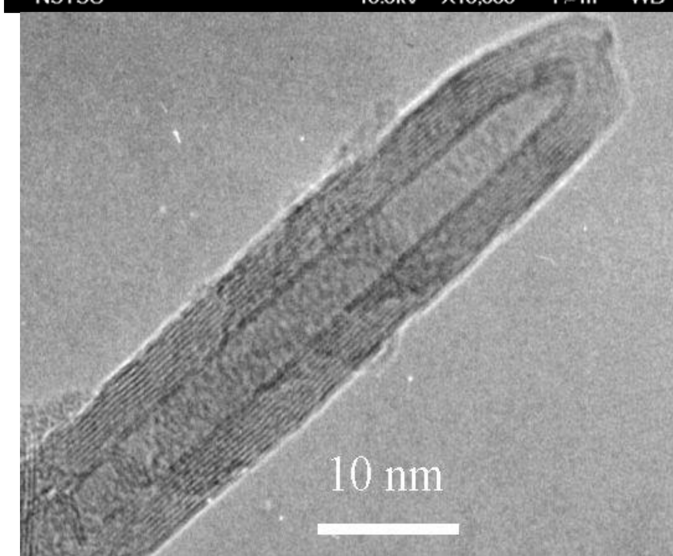
Figure 1. Acid-modified surface structure of CNT

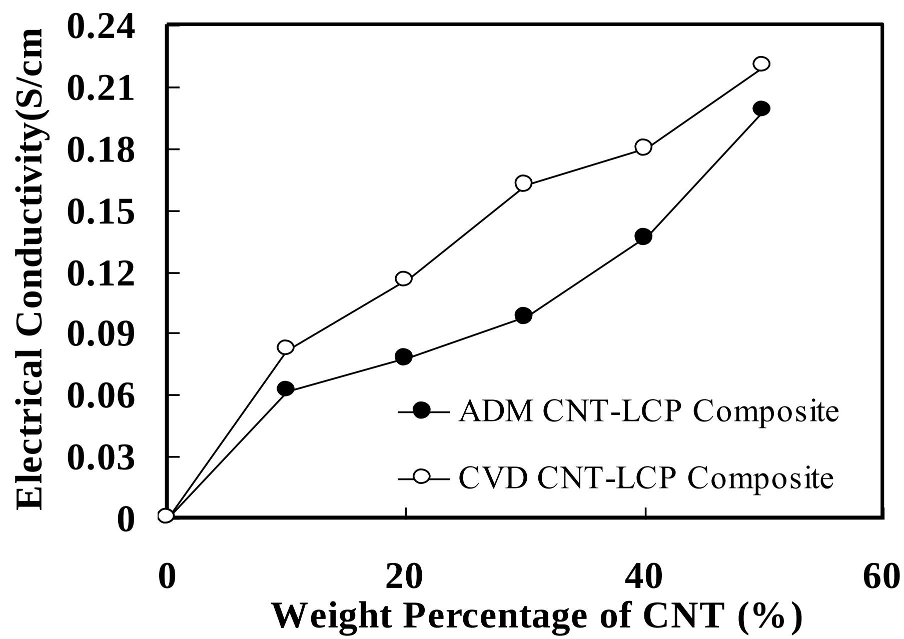
EMC Shielding

MWCNTs (Cheng et al)

CNTs in LCP







Shielding Improvement (Ionic Liquid) at low CNT content

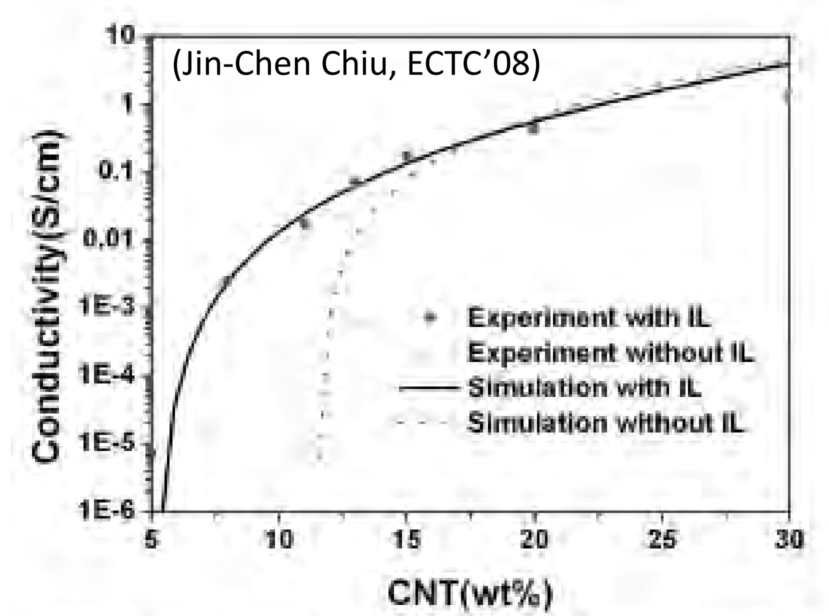


Figure 7 Conductivity of the MWCNT/PI composite at various weight percentage of MWCNT

CNT Composites Conductivity

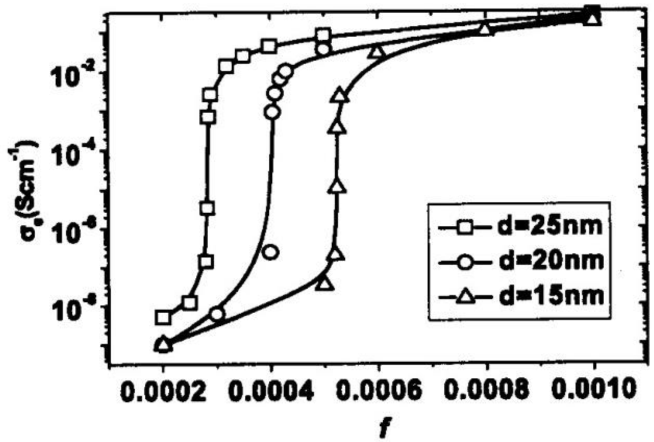


Figure 4. The dependence of the effective conductivities on CNT diameter d with different volume fraction f, with $\sigma_m = 10^{-9}$ S cm^{-1}, $\sigma_s = 1.85$ S cm^{-1}, $\sigma_c = 1850$ S cm^{-1}, $L = 2.5 \times 10^4$ nm, $t = 2.5$ nm.

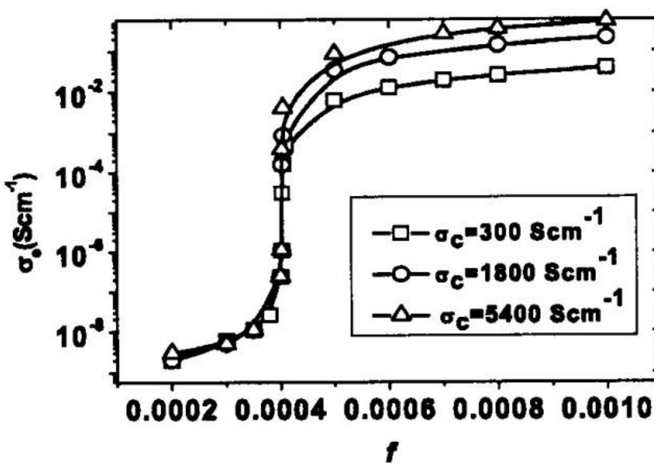


Figure 5. The dependence of the effective conductivities on CNT conductivity with different volume fractions f, with $\sigma_m = 10^{-9}$ S cm^{-1}, $\sigma_s = 1.85$ S cm^{-1}, $L = 2.5 \times 10^4$ nm, $d = 20$ nm, $t = 2.5$ nm.

Yan et al, Nanotechnology 2007

Oh et al, Nanotechnology, 19 (2008) 495602 (7pp)

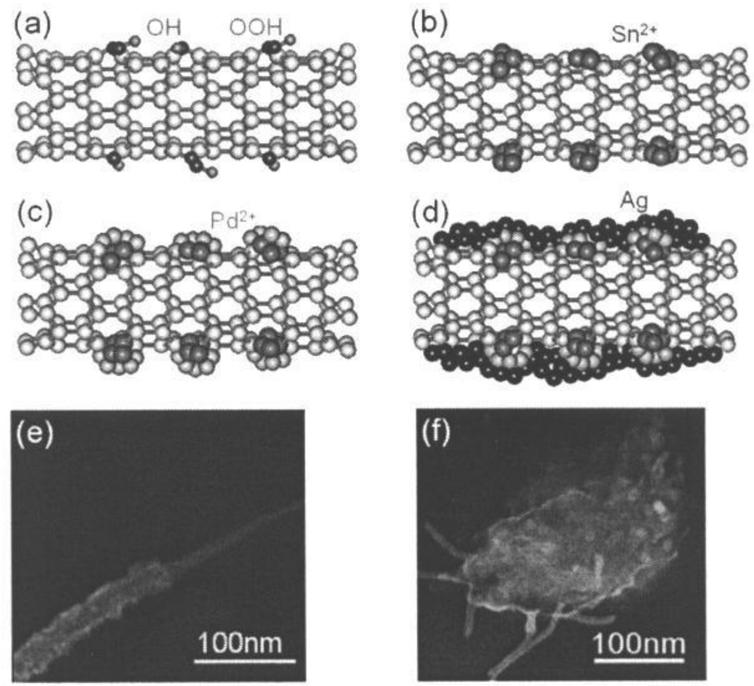


Figure 3. A schematic of electroless silver plating on carbon nanotubes: (a) carboxyl group functionalized nanotubes by the acid treatment process, (b) Sn^{2+} sensitization, (c) preactivation of nanotubes by Pd^{2+}, (d) electroless silver plating, (e) SEM image of the electroless-plated silver on a single MWNT, (f) a lump of silver sandwiching multiple MWNTs.

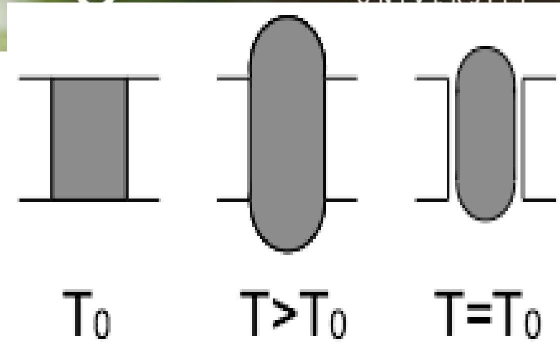
TSV reliability issues

(Sinha et al, NMDC 2010)

a) *Cu filled via at normal temperature*

b) *Copper expansion can fracture the oxide layer above*

c) *Delamination as a result of thermal cycling*



(Metallic) SWNT thermal expansion coefficient

(Jiang et al, J. Eng Materials & Technology, 126 (2004) 265-270)

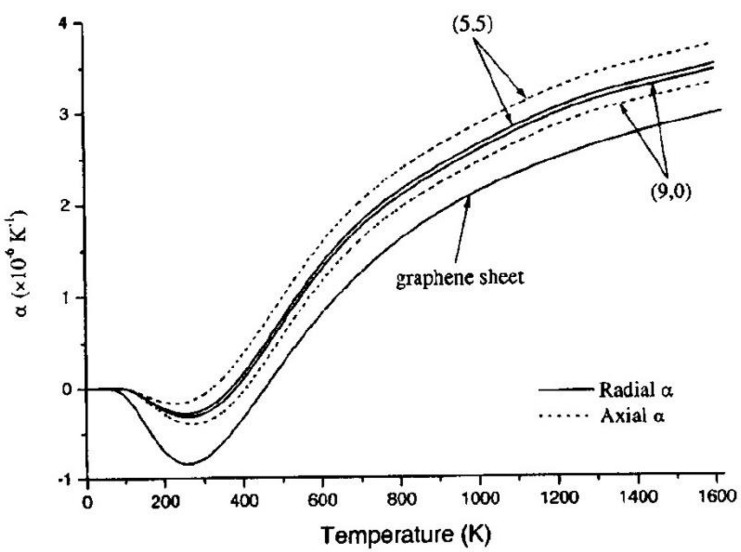


Fig. 2 The temperature dependence of the radial and axial coefficients of thermal expansion for (5,5) and (9,0) carbon nanotubes together with that for a flat graphene sheet

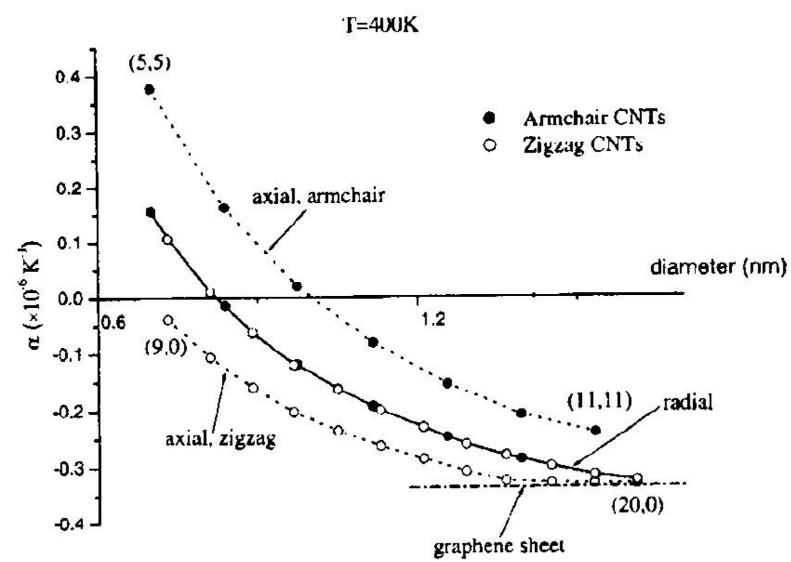


Fig. 4 The diameter-dependence of the coefficients of thermal expansion for armchair and zigzag carbon nanotubes at 400 K

Thermal Management in Microelectronics: Graphene & CNTs

Balandin, Advancing Microelectronics, 38(4) July/August 2011, 6-10

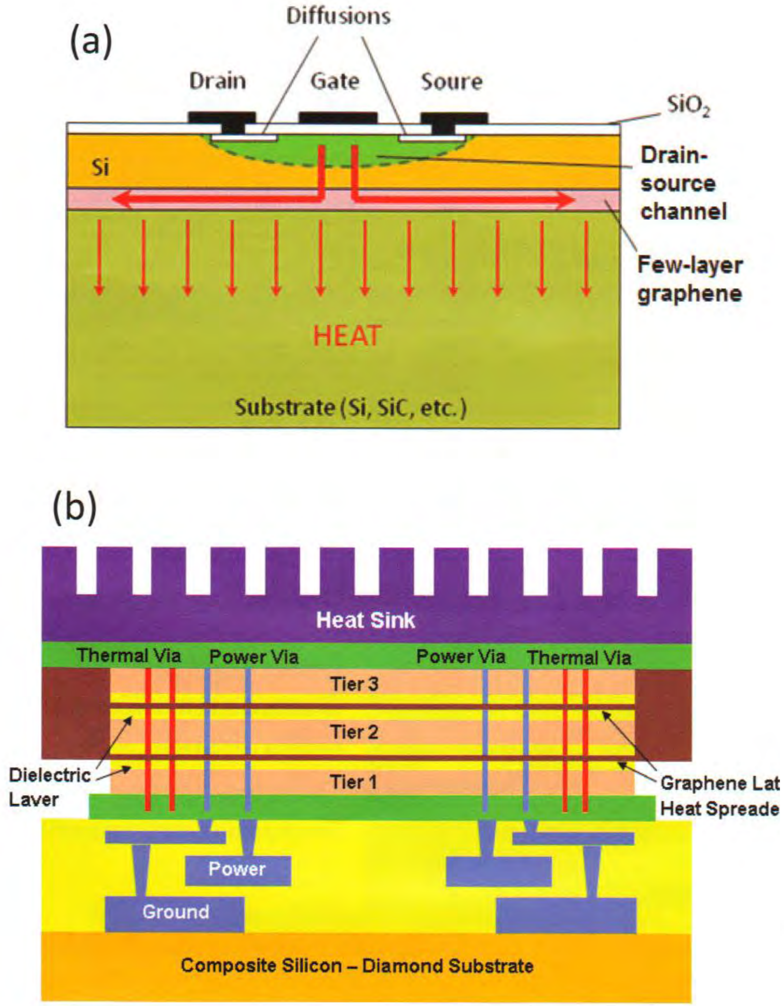
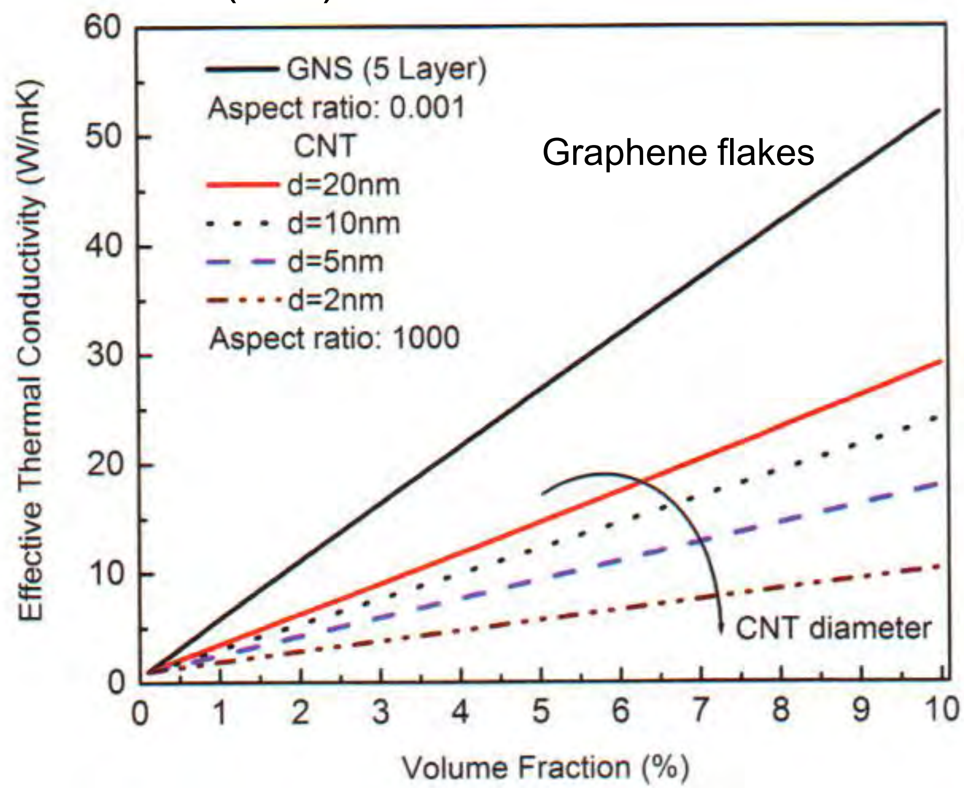


Figure 4: (a) Schematic of the graphene lateral heat spreaders, and (b) graphene heat-spreaders incorporation into the 3D electronic chip.

Thermal Interface Material (TIM) thermal conductivities



Graphene flakes & CNTs in polymers

Figure 2: Comparison of the calculated effective thermal conductivity of TIMs with garphene flakes, marked as GNS, and CNTs. It is assumed that K_f/K_p~1000, which is characteristic for typical carbon fillers and polymer matrix materials.

- Polymer/metal composite example:
  Isotropic Conductive Adhesive (ICA)
- Percolation
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  - Drop test
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  - ICAs
  - Embedded components
- Carbon nanotubes (CNTs) & graphene
  - Electrical & thermal

Questions?