Wire Bonding: Understanding Ultrasonic Welding

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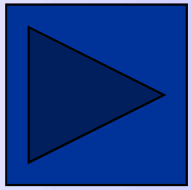
Ball Bonding Animation



Source K&S

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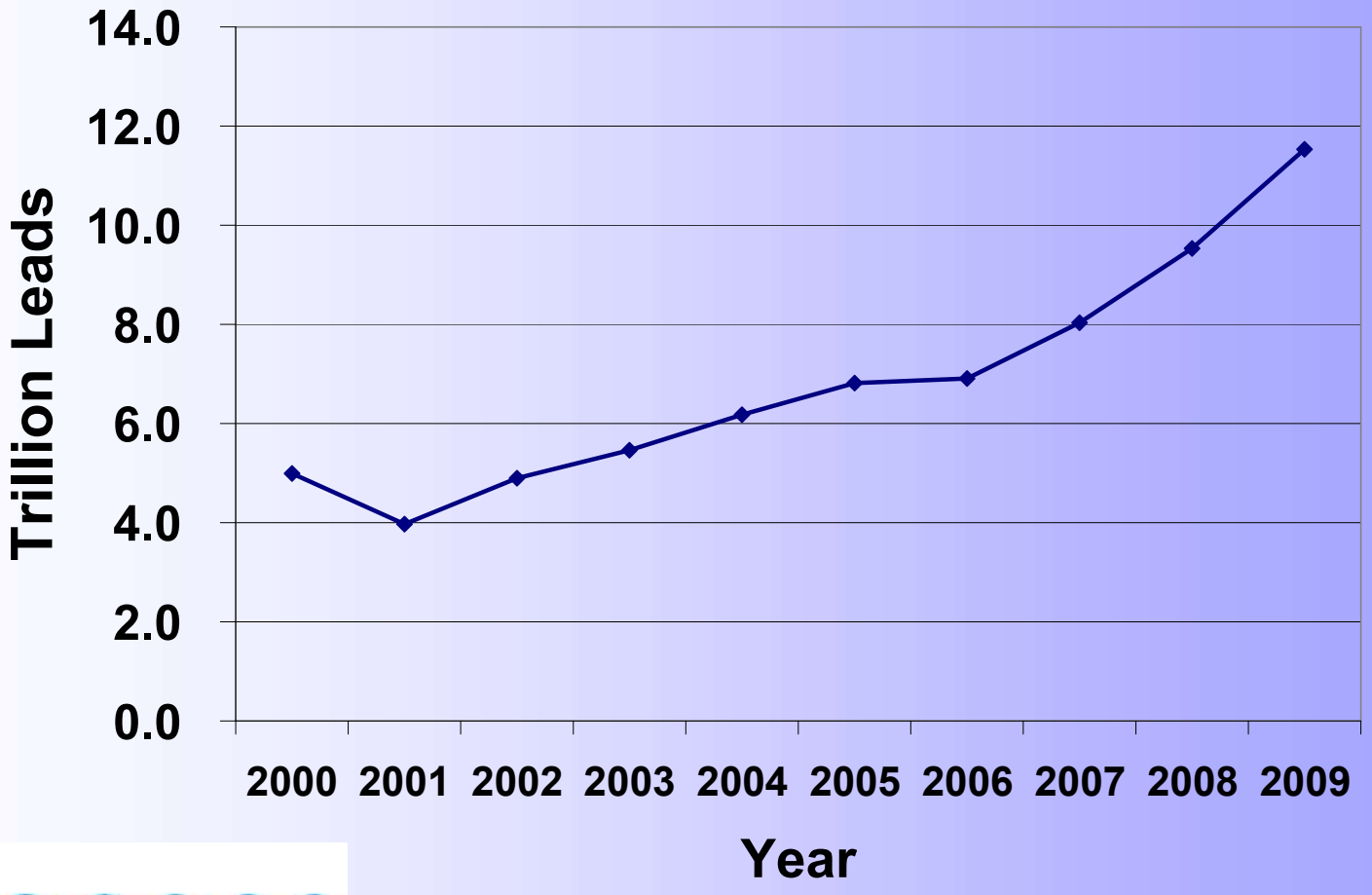
Electronics Packaging Peripheral Leadcount



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Gold Price in $

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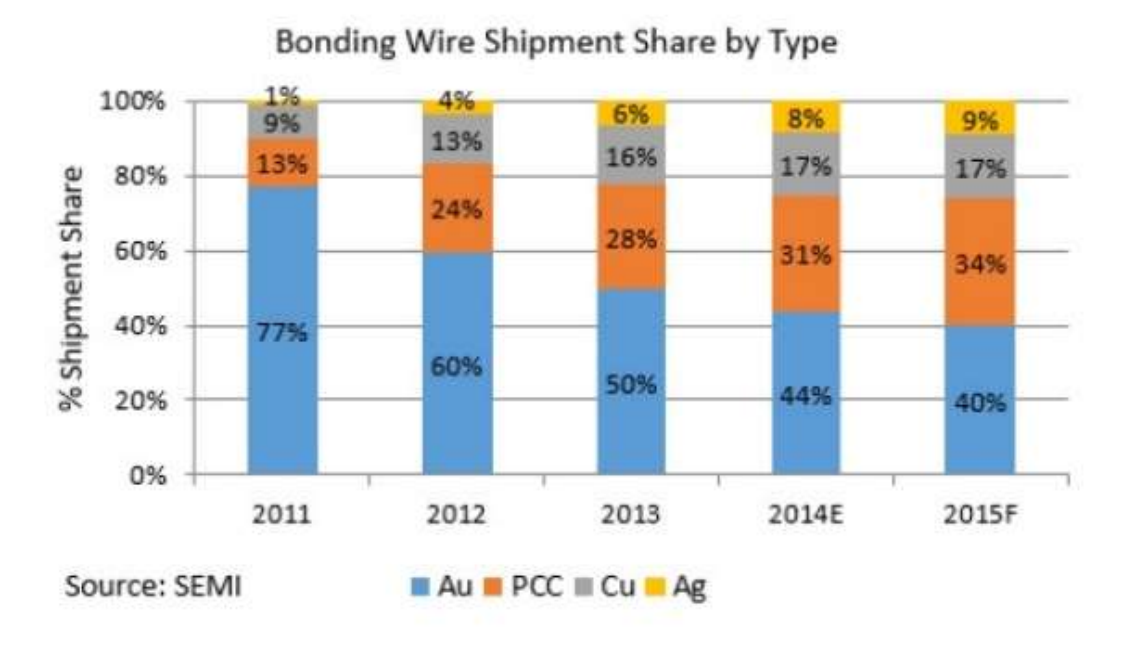
Costs and Market Status



- 2014 > 20 billion meters total wire shipments
- > 10 Trillion wires @2mm/wire
- 2014- 48% Cu + PCC (>9.8 billion meters)
- Growth and market share continue to rise

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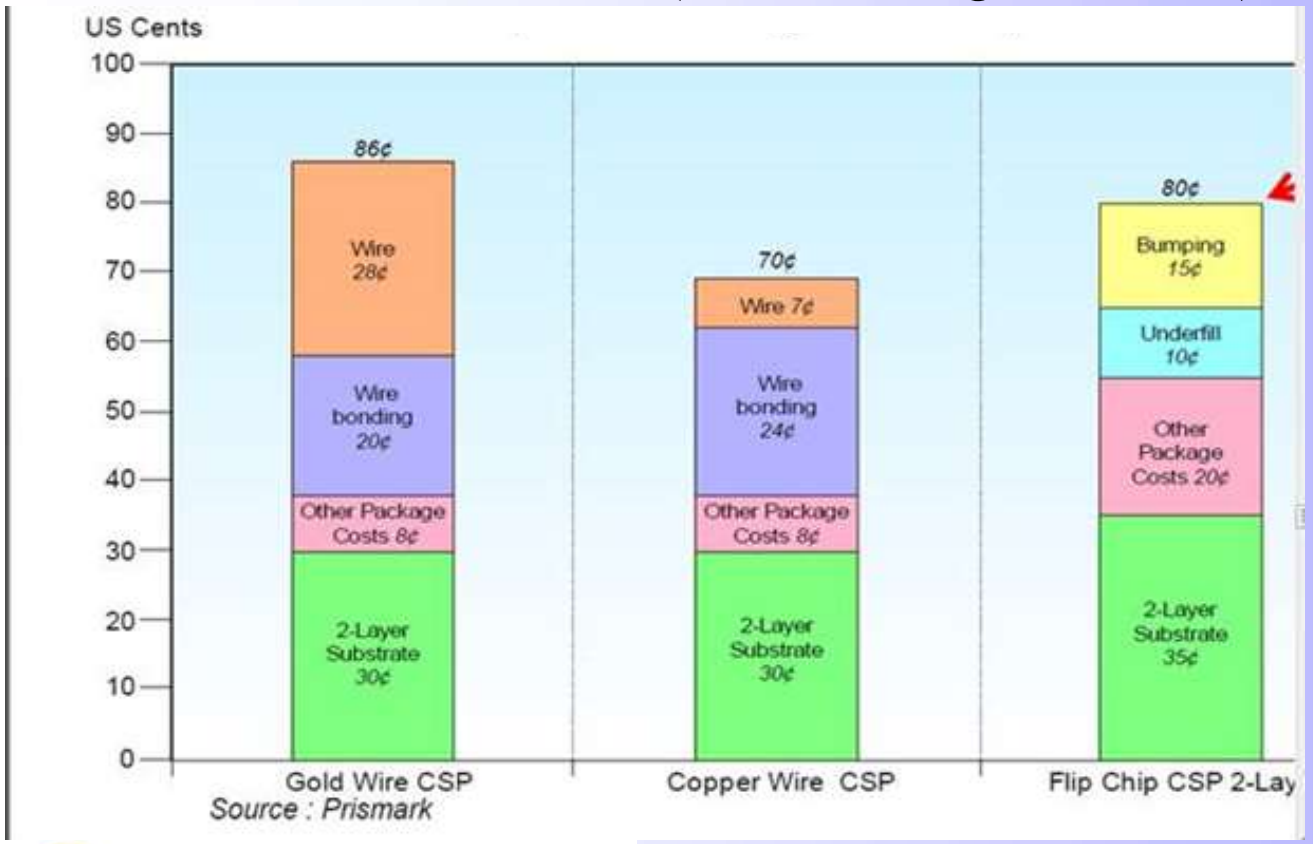
Comparison of 500 lead CSP Packaging Cost

(assumes High Volume)



Following five years of decline, gold wire shipments increased in both 2016 and 2017 though represent just 37 percent of the total bonding wire shipments in 2017

Tech Search Int and SEMI announcement 4/18/2018

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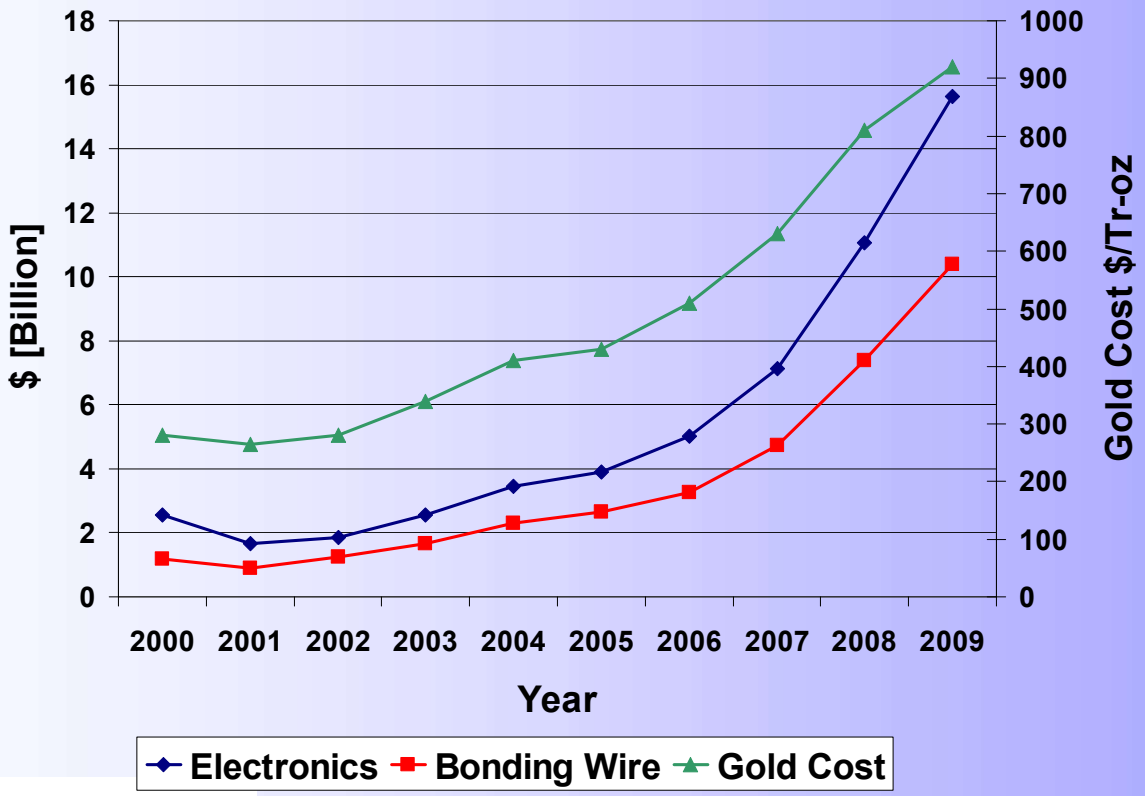
Gold Usage in $



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How much gold is in 1 bonded wire?

- Assumptions
  - 150 mils (3.75mm) wire length
  - 1 mil (25µm) wire diameter
  - Gold Price $1124.57/tr-oz (9/3/2015)

- Answer
  - $0.00135

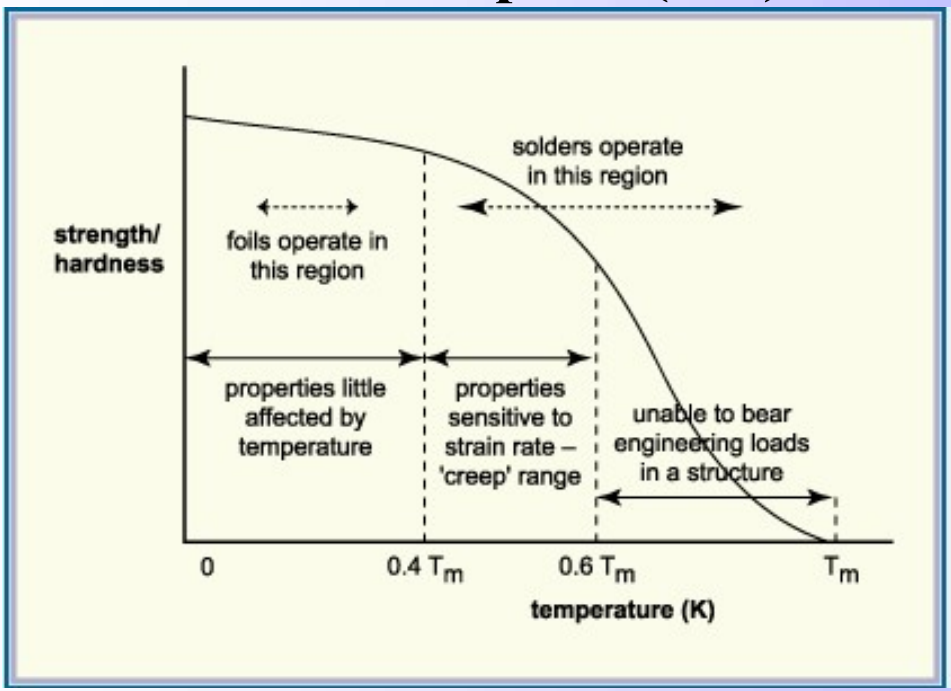
- But trillions of wires still= billions of $

Welding

- Wire bonding is a welding process
- In welding two metals are joined by the formation of an intermetallic nugget that is an alloy composed of the two base materials. There is no intermediate material required as in soldering or brazing.
- The intermetallic is an normally stronger and more brittle than either of the two base materials.

Why do we bond Al @ RT and Au at 150^{0}C?

The Homologous Temperature the % of the melting point (MP) in ^{0}K



			% Homologous Temp	
	MP[C]	MP[K]	Room Temp	150^{0}C
Al	660	933	31	45
Au	1064	1337	22	32
Cu	1084	1357	22	31
AuSn(Eutectic)	280	553	53	77
PbSn(Eutectic)	183	456	64	93

Calculation
660C + 273=933 K
18C (RT)+273=291K
291/933= 31%

Ultrasonics allows "easier" deformation by unlocking dislocation movement mechanisms

Wire Bonding is Welding

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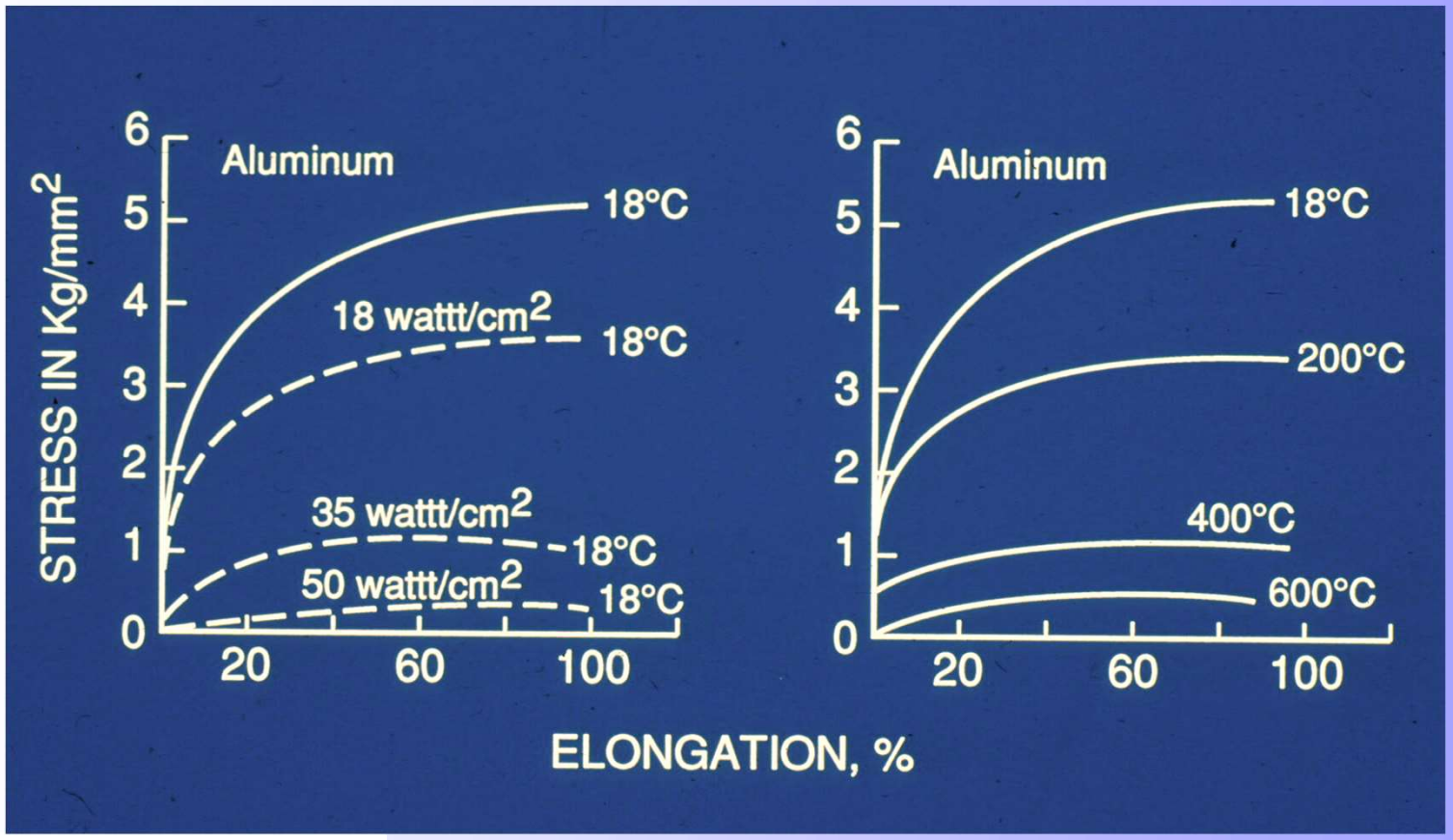
Thermal & Ultrasonic Softening of Al

[after Langenecker]



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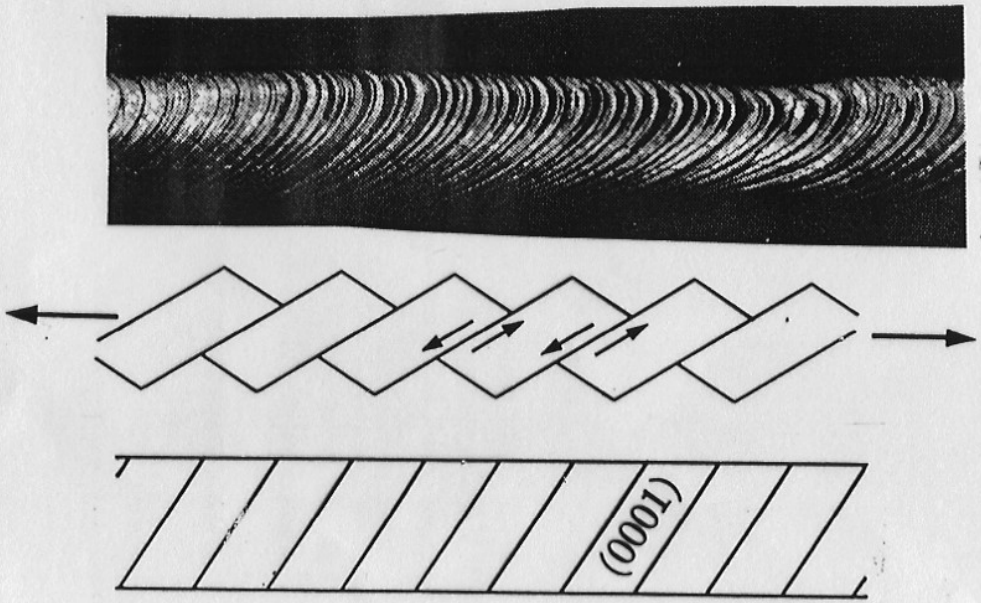
EFFECT OF DEFORMATION

SLIP OCCURS ON PREFERRED PLANES, SINGLE CRYSTAL MODEL

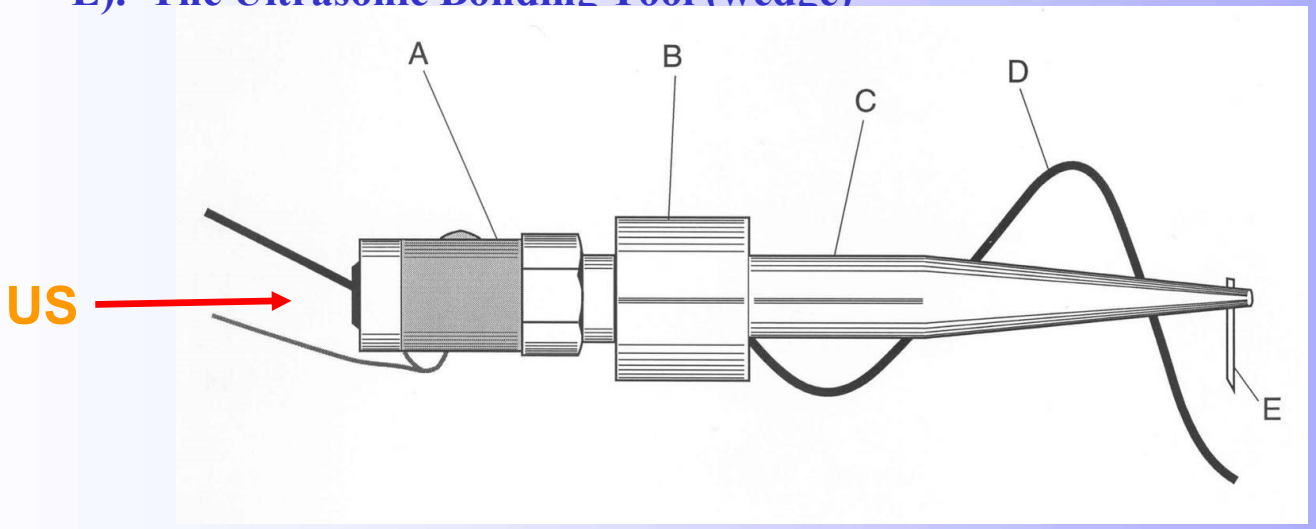


Source: Van Vlack

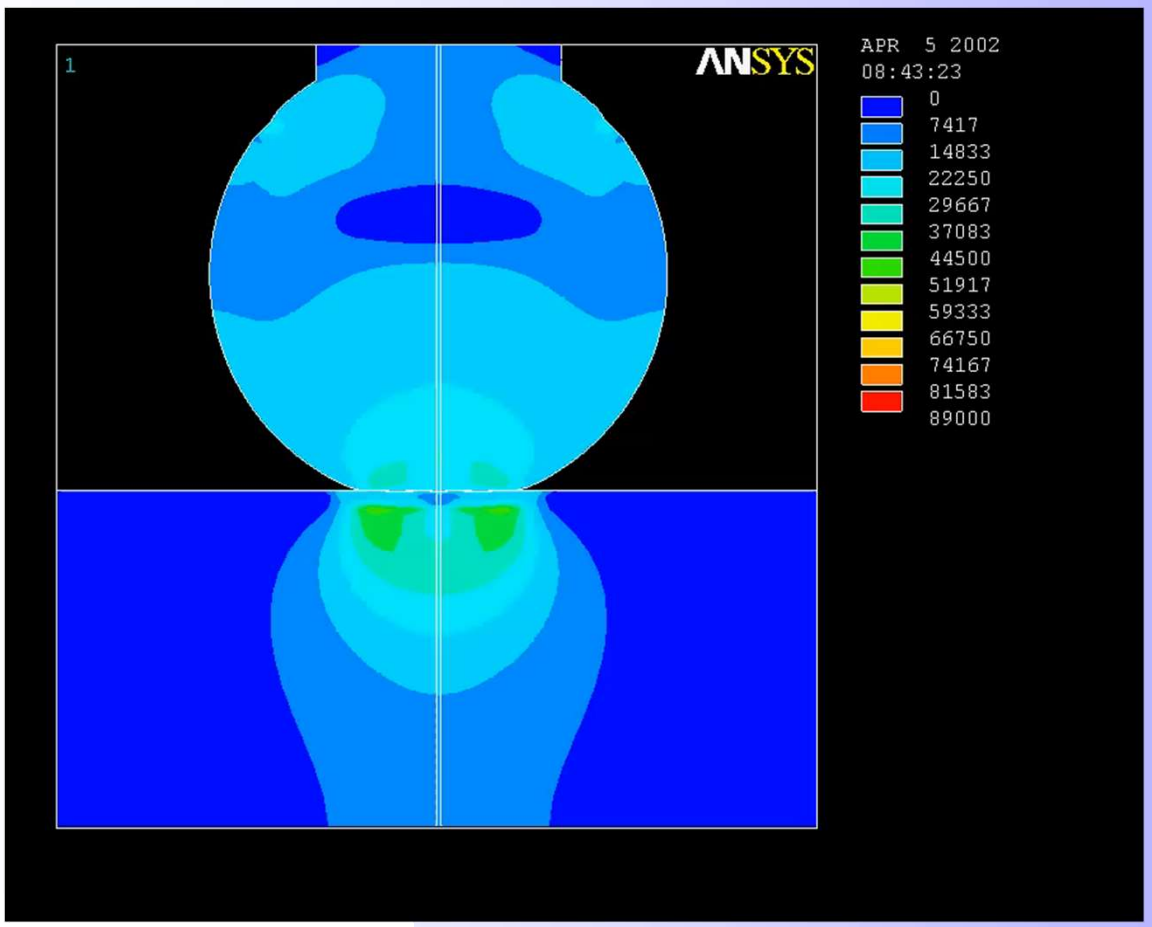
The Classical Ultrasonic Transducer:

(The left arrow indicates electrical US power input)

A). The Electro-Mechanical (PZT) Transducer
B). The Clamp
C). The Horn with Taper at End (taper amplifies US wave)
D). The Ultrasonic (mechanical) Wave-Form
E). The Ultrasonic Bonding Tool (wedge)

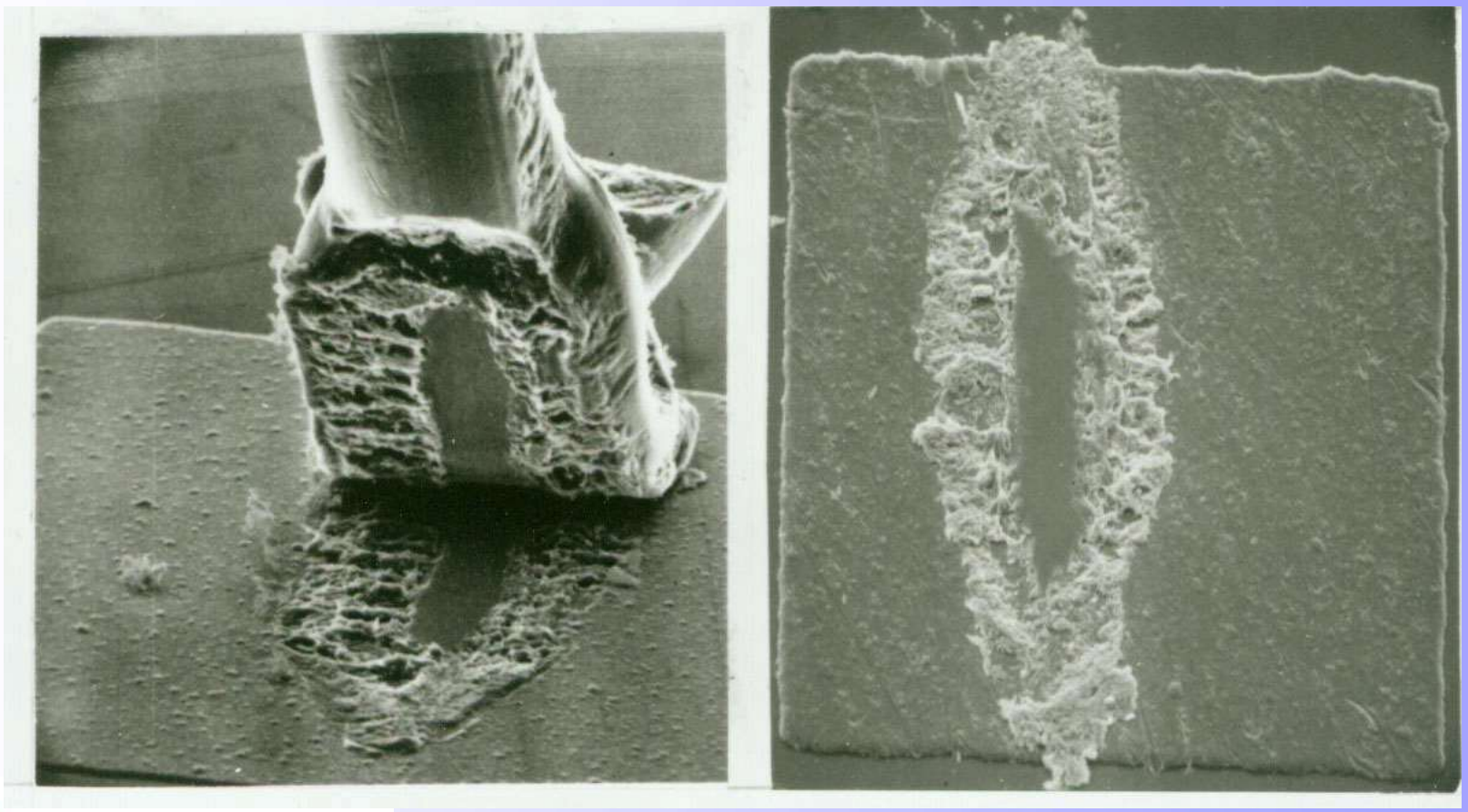


The Effect of Ultrasonics on Bonding



(Private
Document from
G. Schulze, K&S)

A Lifted up Al Wedge Bond, and its Pad, Revealing How the Weld was Formed



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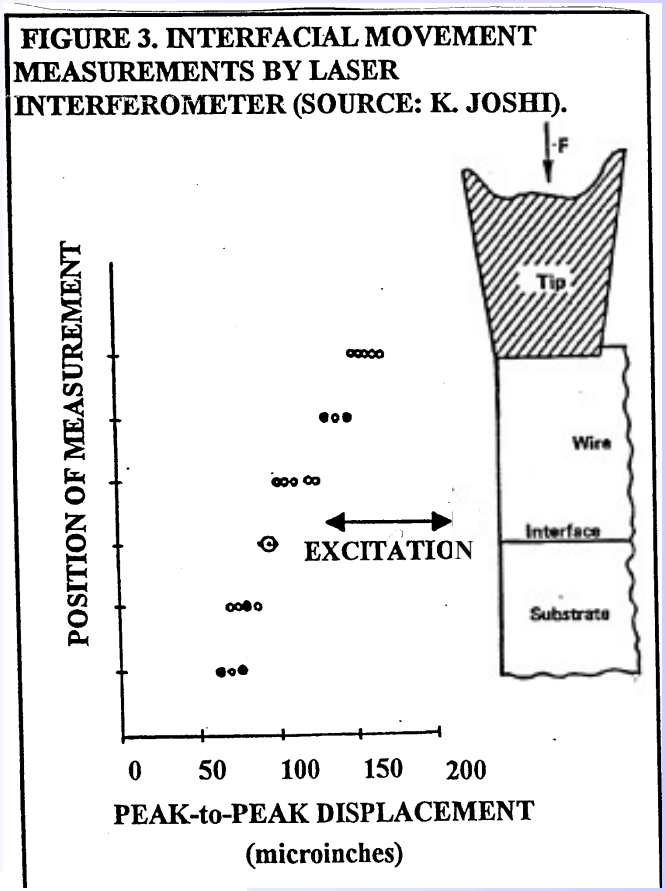
Interfacial Movement



Note- No Displacement Discontinuity at Interface

The interface "PINS" almost immediately, bonding is not friction welding

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Constant Current or Constant Voltage?

- For impedance based systems Ohms Law is V=IZ where Z is the system impedance
- The best predictor of bond strength is ultrasonic amplitude, the displacement of the tip. Amplitude is proportional to I, the driving current

For Constant Current mode:

- During bonding Z increases as the bond pins to the surface and grows
- As Z increases the current stays constant therefore V also increases. Displacement is constant.

For Constant Voltage mode:

- During bonding Z increases as the bond pins to the surface and grows
- As Z increases Voltage is constant, therefore I must decrease. Displacement decreases as the bond forms.

- For fine pitch ball bonds constant current gives better control of the ball deformation and smaller bond variations.
- Some people believe that stitch bonding is better with constant voltage mode.
- Newer machines allow mode choice for each bond.

Summary

- Wire bonding is a welding process.
- Two metals are joined to form an alloy.
- Ultrasonic energy allows “easy slip” on preferred deformation planes within the metals crystal structure.
- Deformation mixes the metals non-uniformly. Not the equilibrium phases described by the phase diagram.
- Time-temperature allows the mixture to relax into the stoichiometric equilibrium chemical phases described by the binary phase diagram