Development of Interconnect Technologies for HEP Applications

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WIT2010, LBNL,Feb 4, 2010

The Need for Development

The last round of detectors typically had at most one layer of bump bonds and an array or two of wire bonds. There were yield issues but the needs were mostly met. The situation in the next decade will be different:

1. Complex multi-layer attachments
2. Internal flex cable busses running between detector sub-units.
3. Wide variety in pad pitch, array size and mechanical strength.

Solutions exist for most of the assemblies being considered …

… but, are they available to you for your prototyping needs?

1. Vendors are not willing to take on small custom jobs. Or they demand large $$.
2. It is difficult to work closely with vendors and solve problems because they protect their proprietary processes.
3. Long turn around time slows down progress.

Interconnect Technology at UC Davis

We acquired a flip-chip bump-bonder in 1993 as part of the DOE Infrastructure Program. This machine was used for bump bonding CMS forward pixel prototypes among other projects.

Since then we have started exploring other new techniques for interconnection of electronics and detectors/cables.

A recent DOE ARRA grant has encouraged us to enhance our capabilities and develop a wider spectrum of technologies.

In this talk, we describe two R&D projects as examples of diverse needs and also discuss some generic development.

Si/W ECal R&D Collaboration

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SLAC

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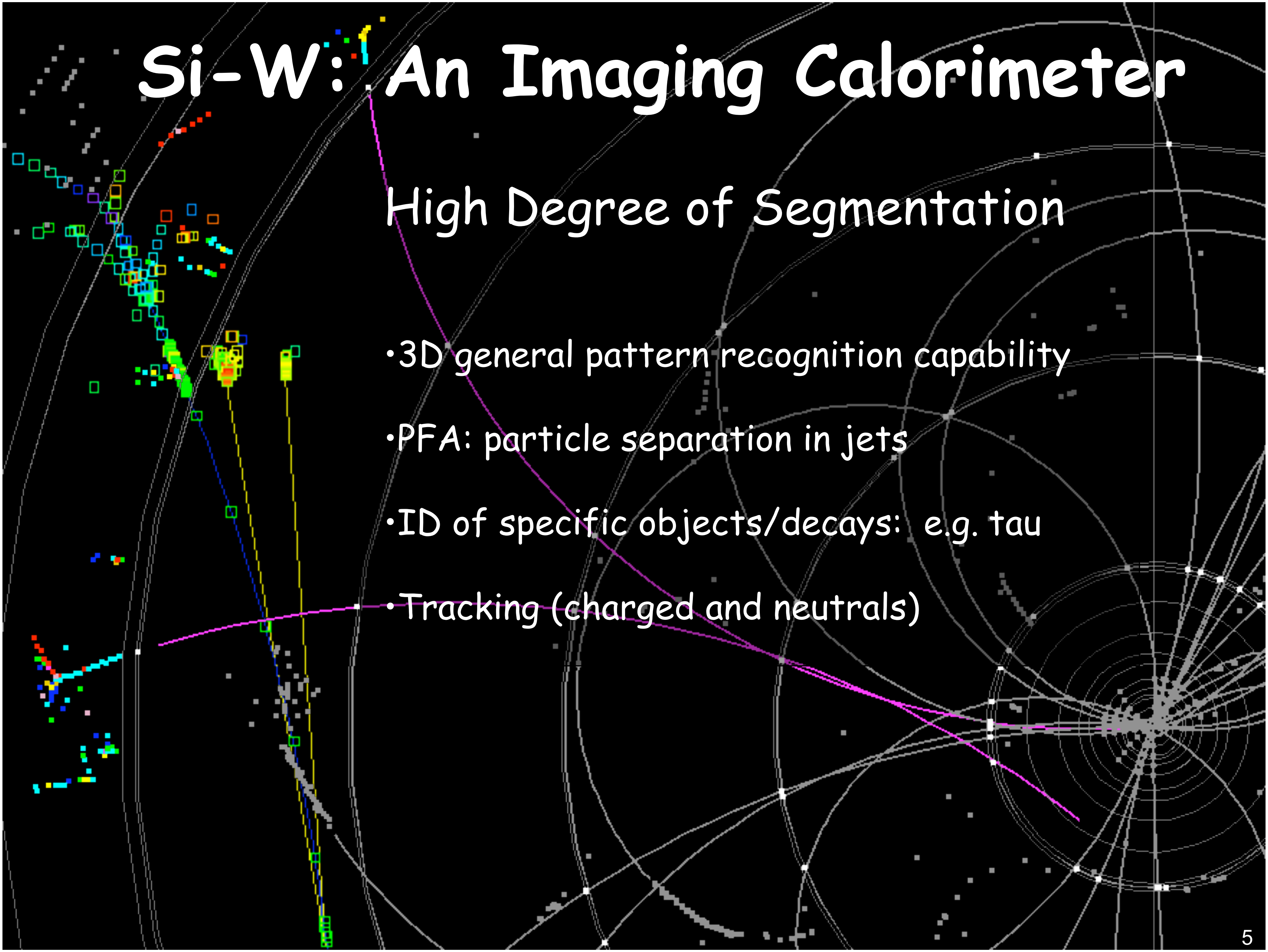
LAPP Annecy

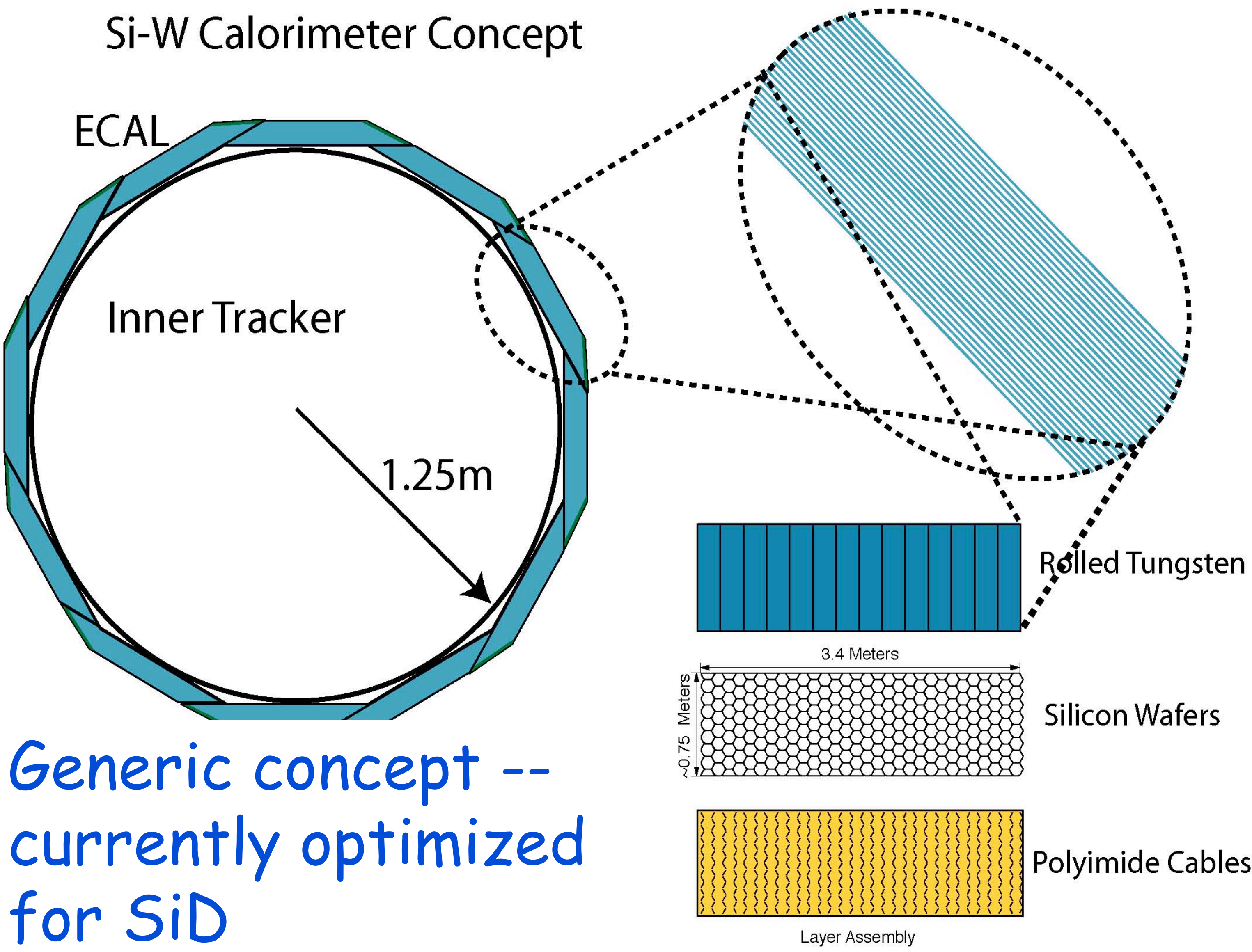
Si-W: An Imaging Calorimeter



High Degree of Segmentation

- 3D general pattern recognition capability
- PFA: particle separation in jets
- ID of specific objects/decays: e.g. tau
- Tracking (charged and neutrals)

Si-W Calorimeter Concept



Generic concept -- currently optimized for SiD

__Baseline configuration:__

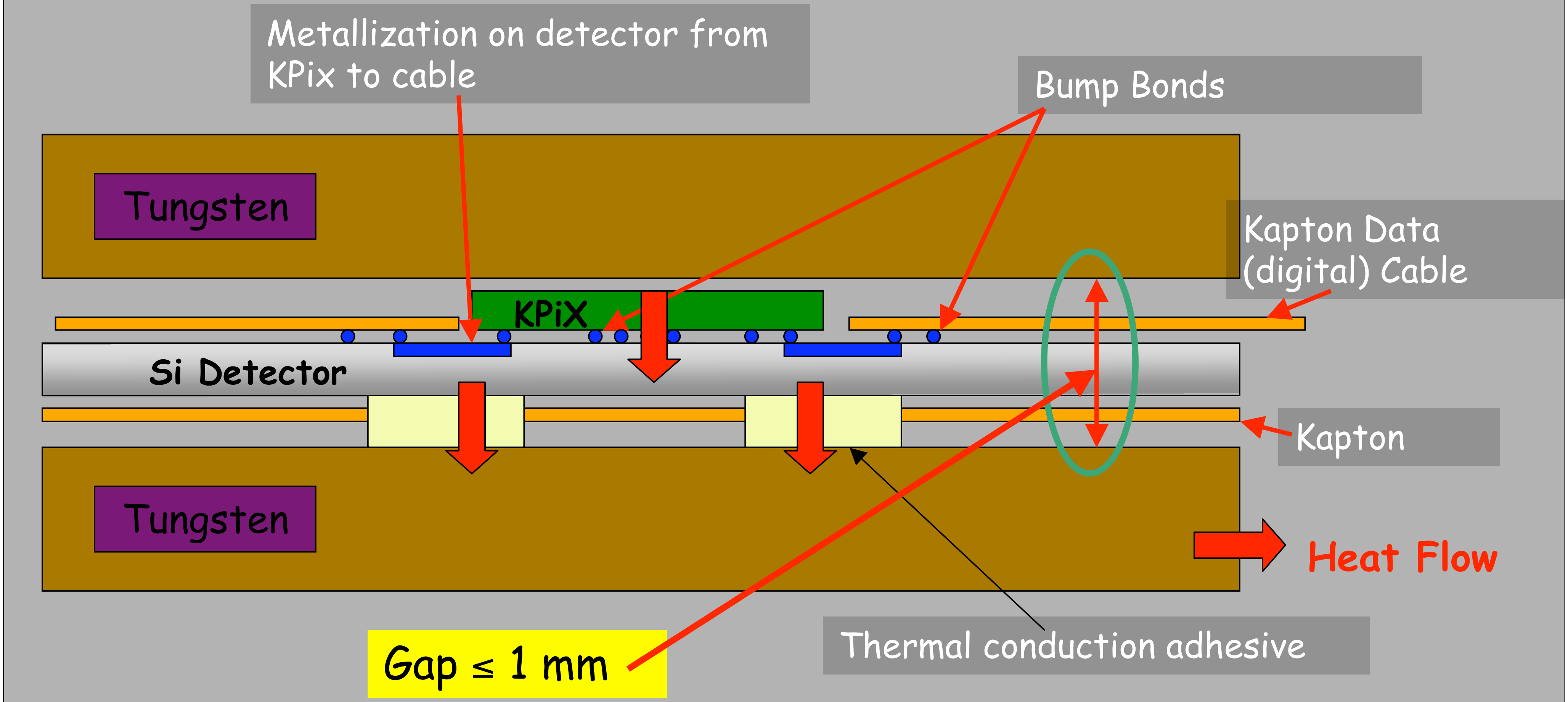
- transverse seg.: 13 mm^2 pixels
- longitudinal seg:

$(20 \times 5/7\ X_0)$
$+ (10 \times 10/7\ X_0)$

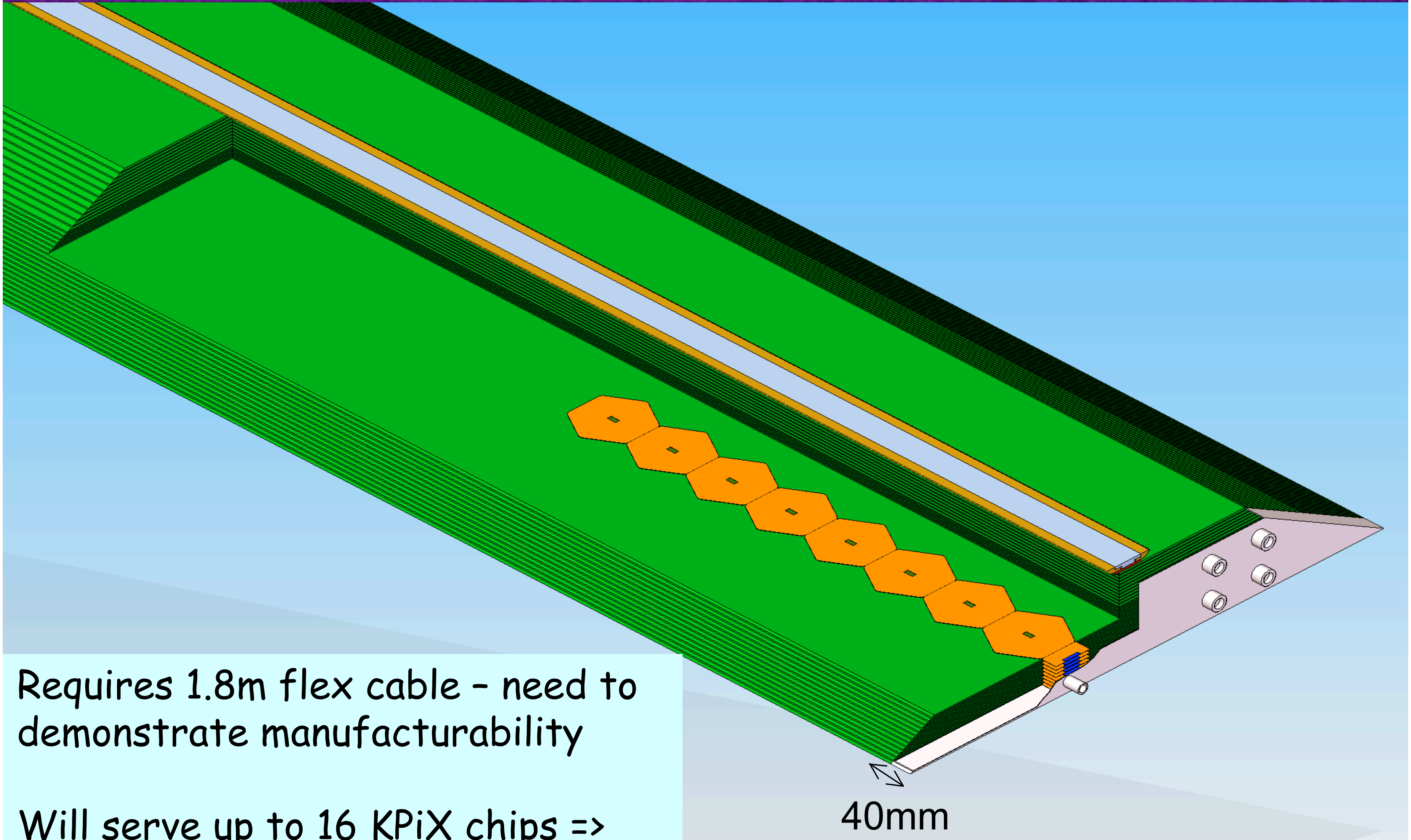
⇒ **17%/sqrt(E)**

- 1 mm readout gaps ⇒ 13 mm effective Moliere radius

Readout gap cross section (schematic)



Module Design



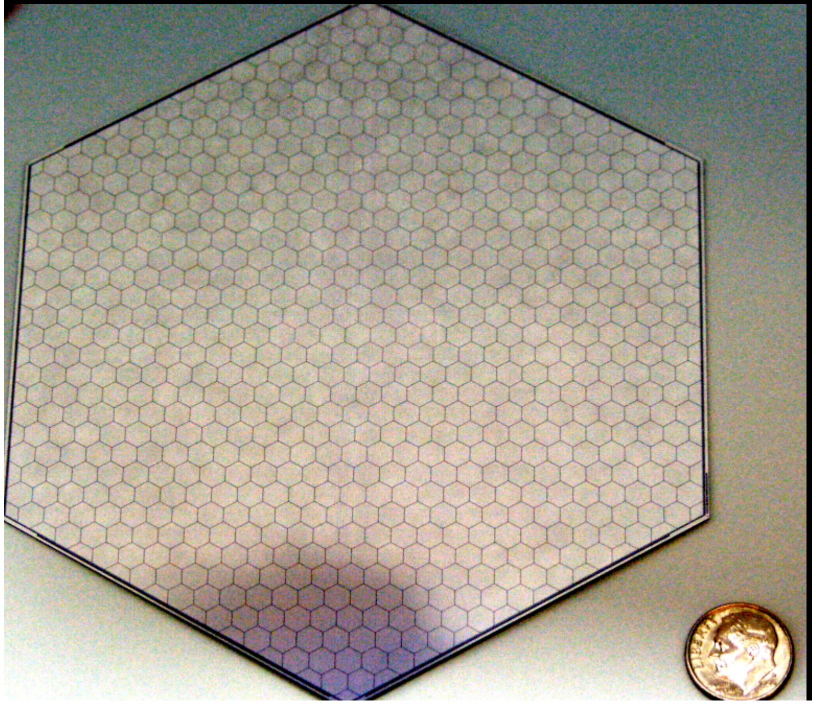
Requires 1.8m flex cable – need to demonstrate manufacturability

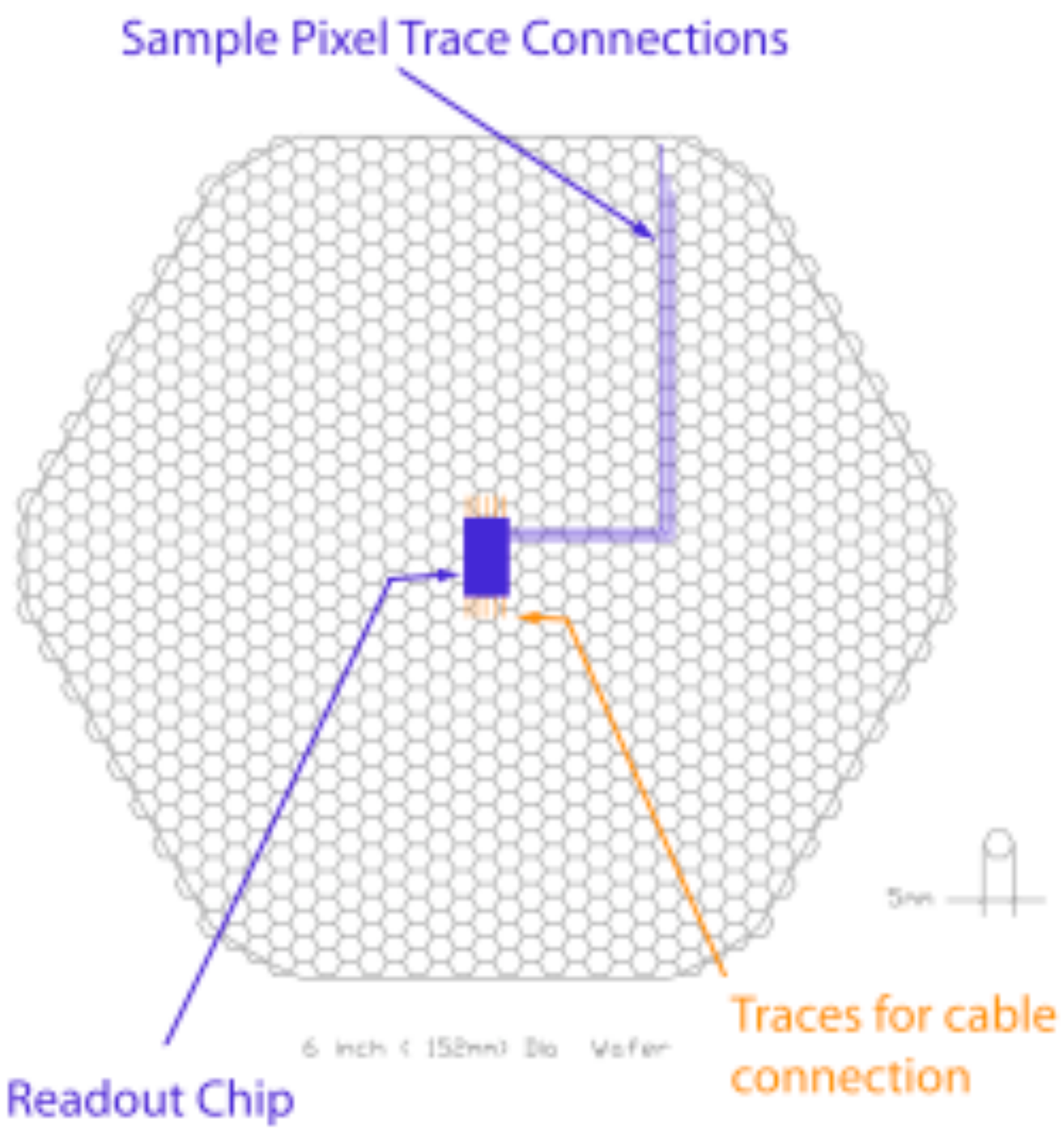
Will serve up to 16 KPiX chips =>
~200 cables/connectors per side

Si Detector

Wafer

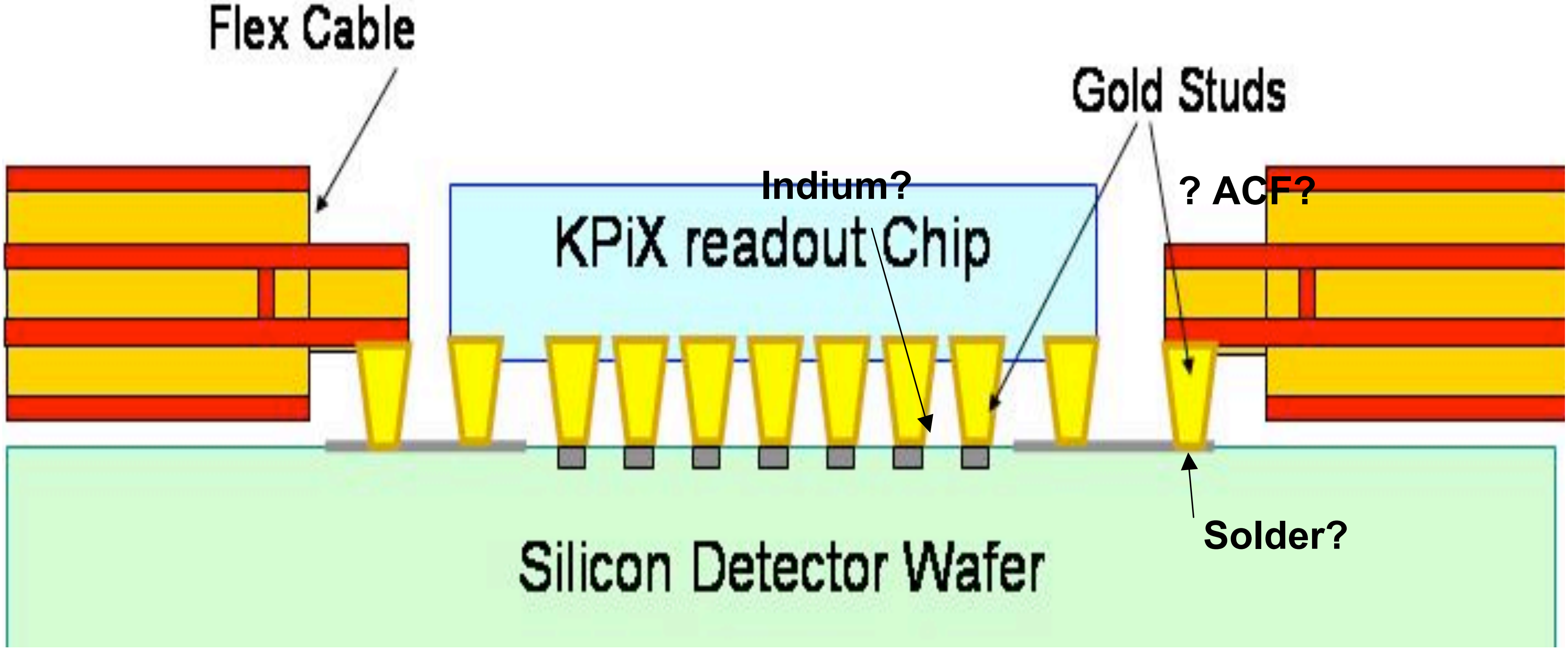
- 6 inch wafer
- 1024 13 mm² pixels
- Hamamatsu Prototype (ver2) sensors in hand (40 wafers)





Interconnect issues: Technologies being considered

	Prototyping	Production
KPiX to Sensor	Gold Stud Bonding	Indium/Solder Bump Bonding
Flex Cable to Sensor	Solder Balls Conducting Epoxy ACF	ACF?



Track Trigger for CMS @ SLHC

J.P. Chou, U. Heintz, M. Narain, M. Segala, N. Vlamis, *Brown University*

M. Mannelli, *CERN*

J. Alexander, J. Dobbins, L. Fields, T. Lutz, N. Rider, A. Ryd, J. Thom
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M. Chertok, R. Erbacher, B. Holbrook, R. Lander, J. Thompson, M. Tripathi
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W.E. Cooper, M. Demarteau, G. Deptuch, J. Hoff, M. Johnson, R. Lipton, T. Miao, L. Spiegel, S. Tkaczyk, M. Trimpl, R. Yarema, Z. Ye, T. Zimmerman, *Fermilab*

A. Chandra, J. Ellison. *University of California, Riverside*

R. Demina, R. Flight, Y. Gotra, S. Korjenevsky, *University of Rochester*

J. Incandela, *University of California, Santa Barbara*

M. Weinberger, *Texas A&M University*

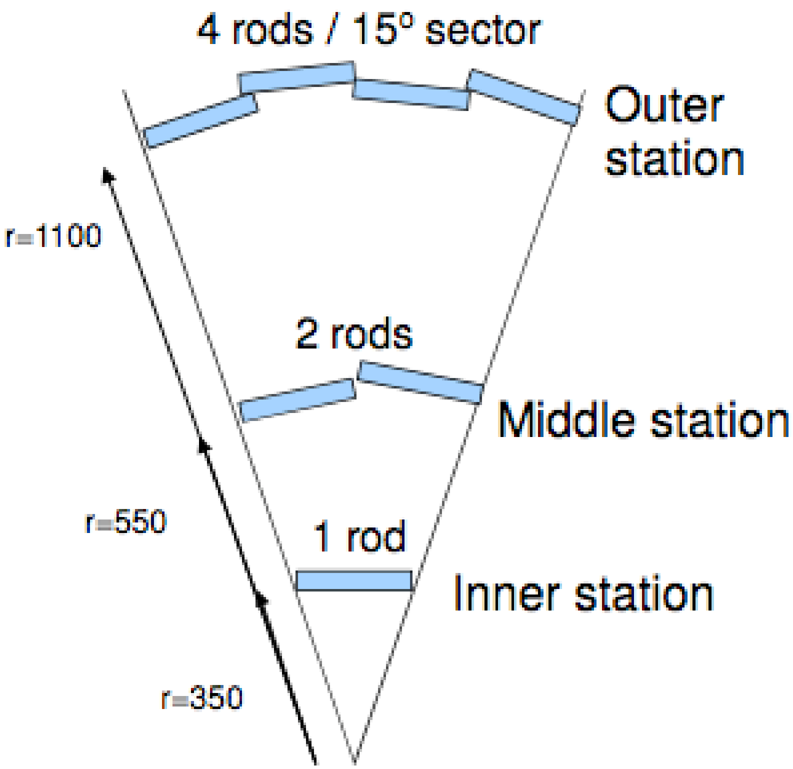
E. Brownson, P. Sheldon, *Vanderbilt University*

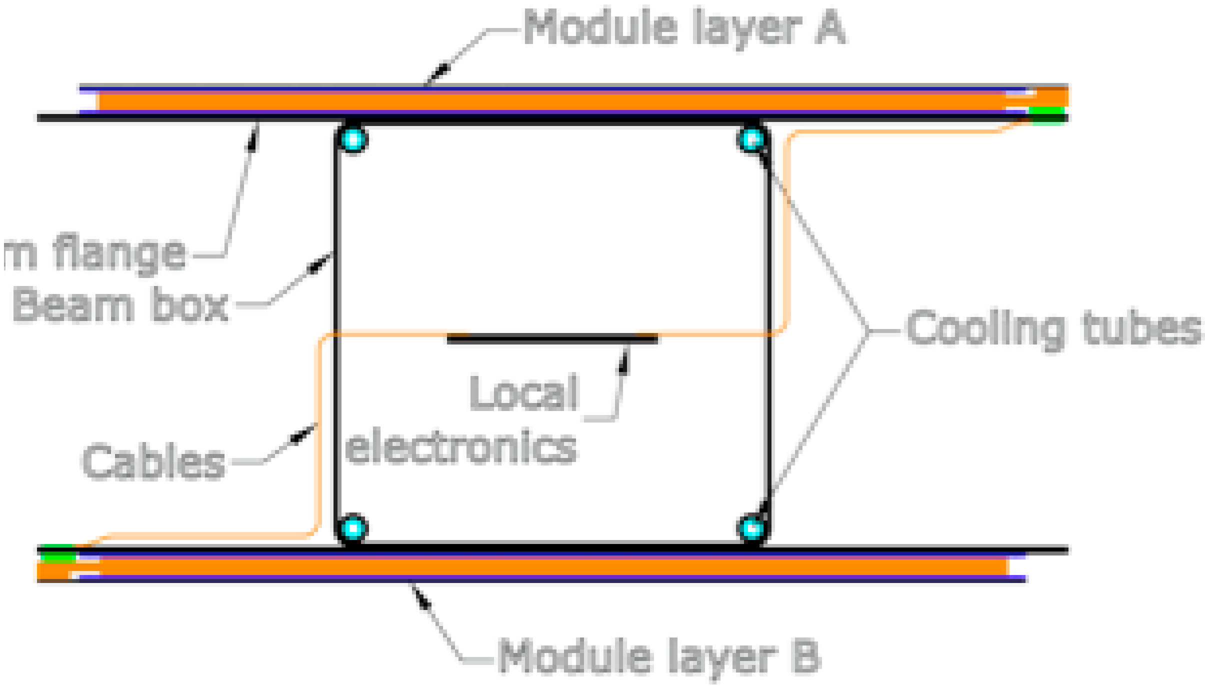
SLHC Track Trigger Concept

Sector based approach to track finding. P_T cut applied at 0^{th} level.

15 degree sectors with 3 layers of double stacks each.

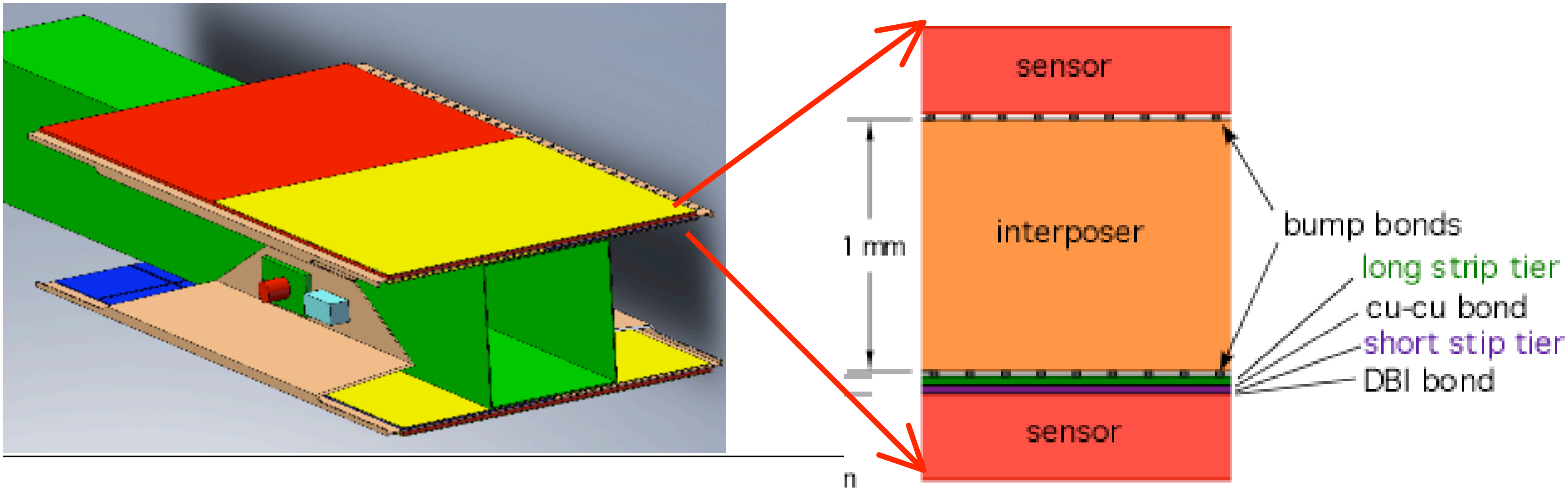
See talks by Manelli, Lipton, Cooper, Alexander, Heintz.





Double Stack Interconnects

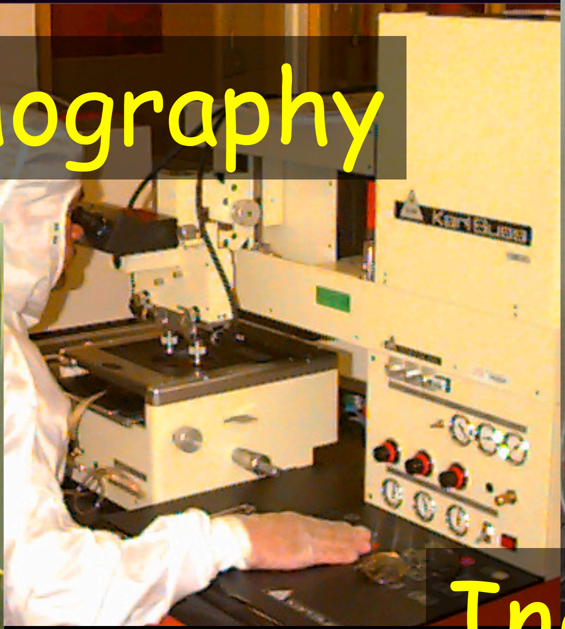
	Prototyping	**Production**
Interposer to Sensor Interposer to 3-D chip	Gold Stud Bonding	Indium/Solder Bump Bonding
Flex Cable Atatchment	Wire Bonding Solder Balls Conducting Epoxy ACF	?



Areas of R&D in Interconnect Technology

- Single die photolithography for Indium
- Under bump metallization studies
- Smart flex cables
- Conductive epoxy evaluations
- Gold Stud attachment
- Anisotropic Conducting Film attachment
- Flip-chip bonding

Processing at UC Davis

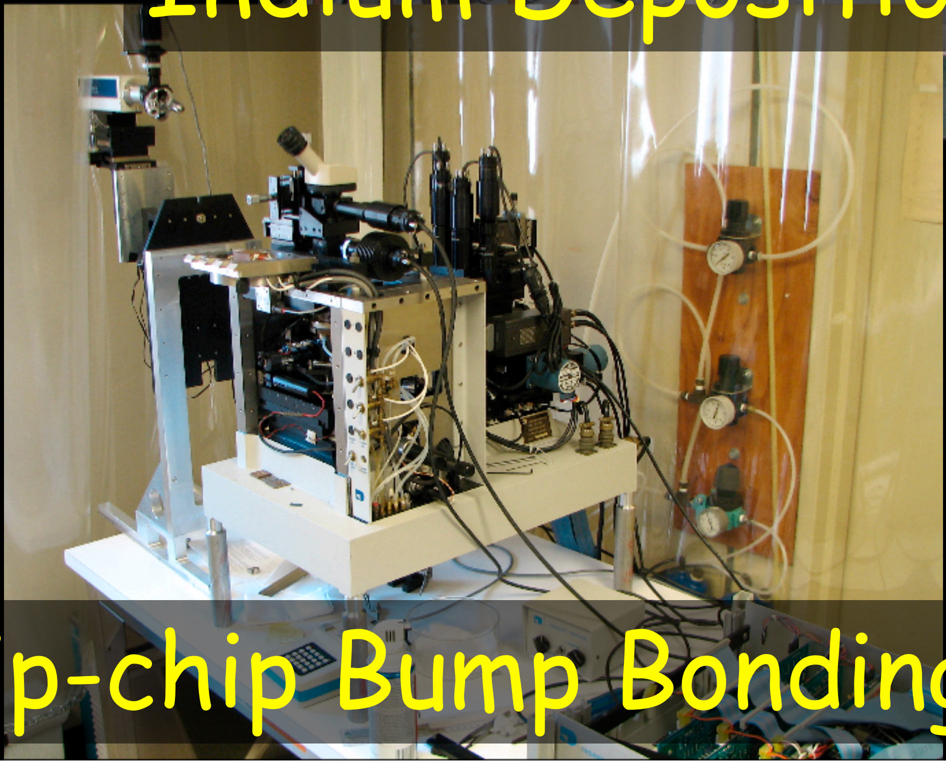


Photolithography

Ti/W Sputter

Indium Deposition

Gold Studs



Flip-chip Bump Bonding

Indium Bump Bonding

Wafer level Indium Bump Bonding is a mature/commercial technology. Best option for small bumps (<10 um).

However, prototypes involve single die photolithography.

We are developing processes involving:

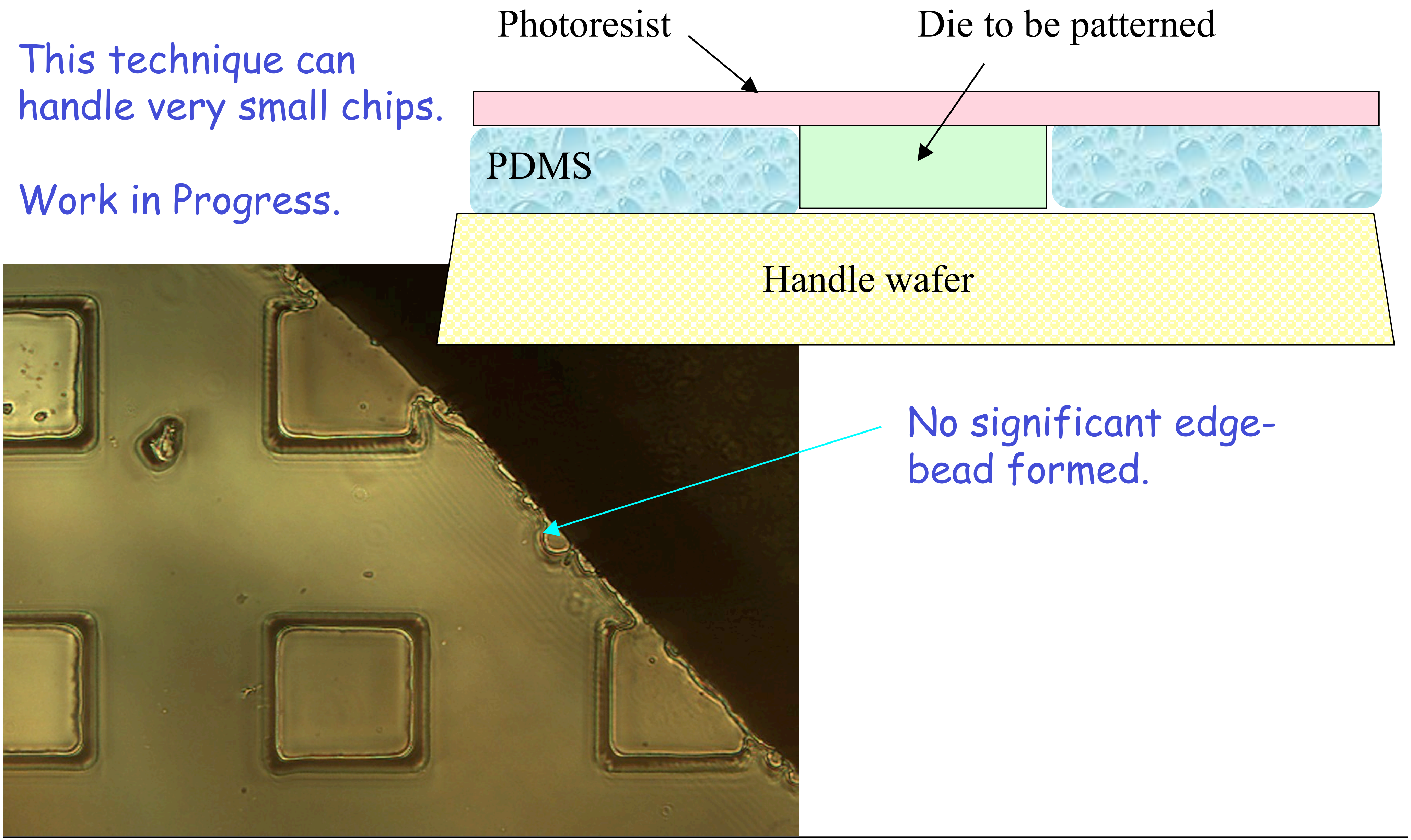
a) silicone films and
b) EDM machined cavities.

Spinning resist on a single die typically results in an edge-bead that prevents Good mask contact.

Polydimethylsiloxane (PDMS)

This technique can handle very small chips.

Work in Progress.



No significant edge-bead formed.

Gold Stud Bump Bonding

- An attractive option for prototyping because no photolithography is required for forming studs. Minimum bump size typically ~50 um.

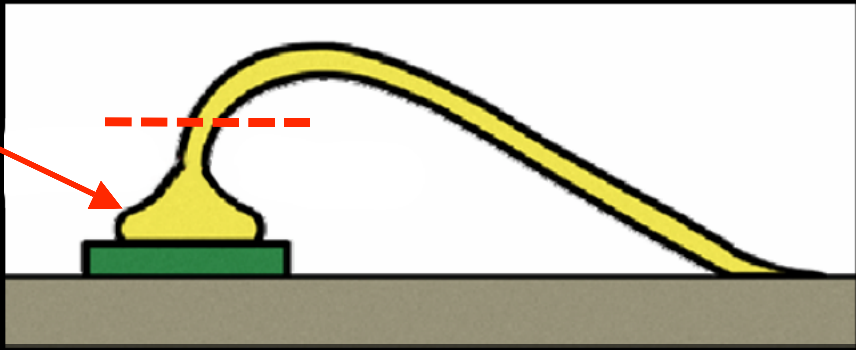
- However, the opposite chip requires surface treatment if it has typical aluminum pads.

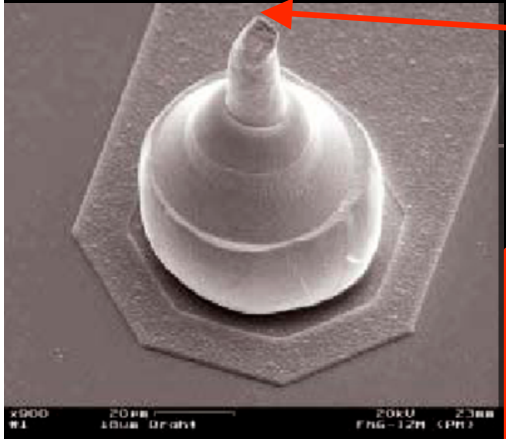
- Not a problem for Si-W (opposite “chip” is a large wafer) or CMS 3D Track Trigger (interposer is custom made with Au).

- Au-Au bonding is possible, but so far the attempts have been for large bond pads (>100 um).

Gold Stud Formation

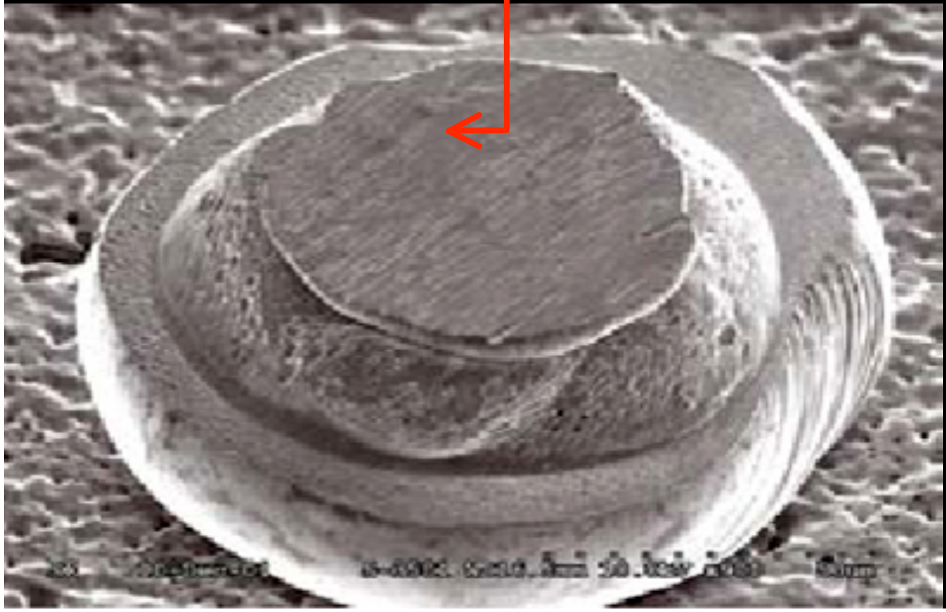
Step 1: A ~25 μm gold wire is bonded to the pad.

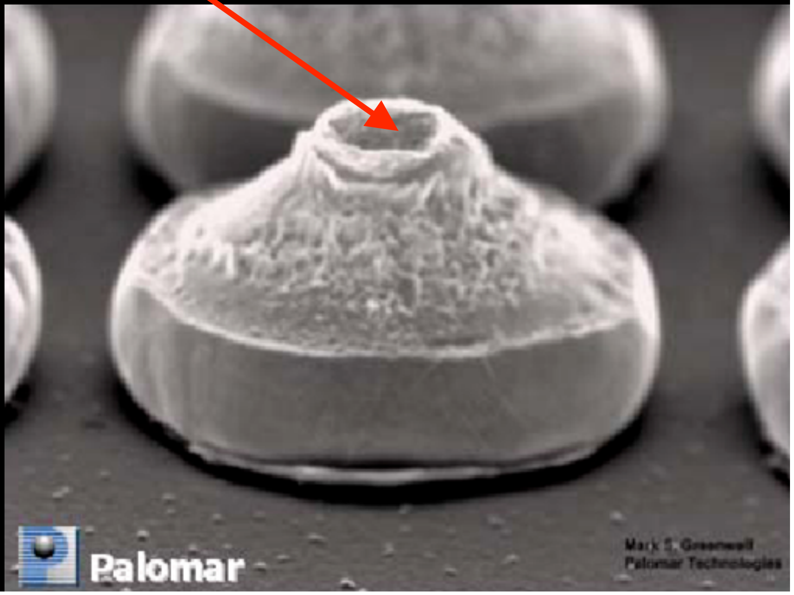




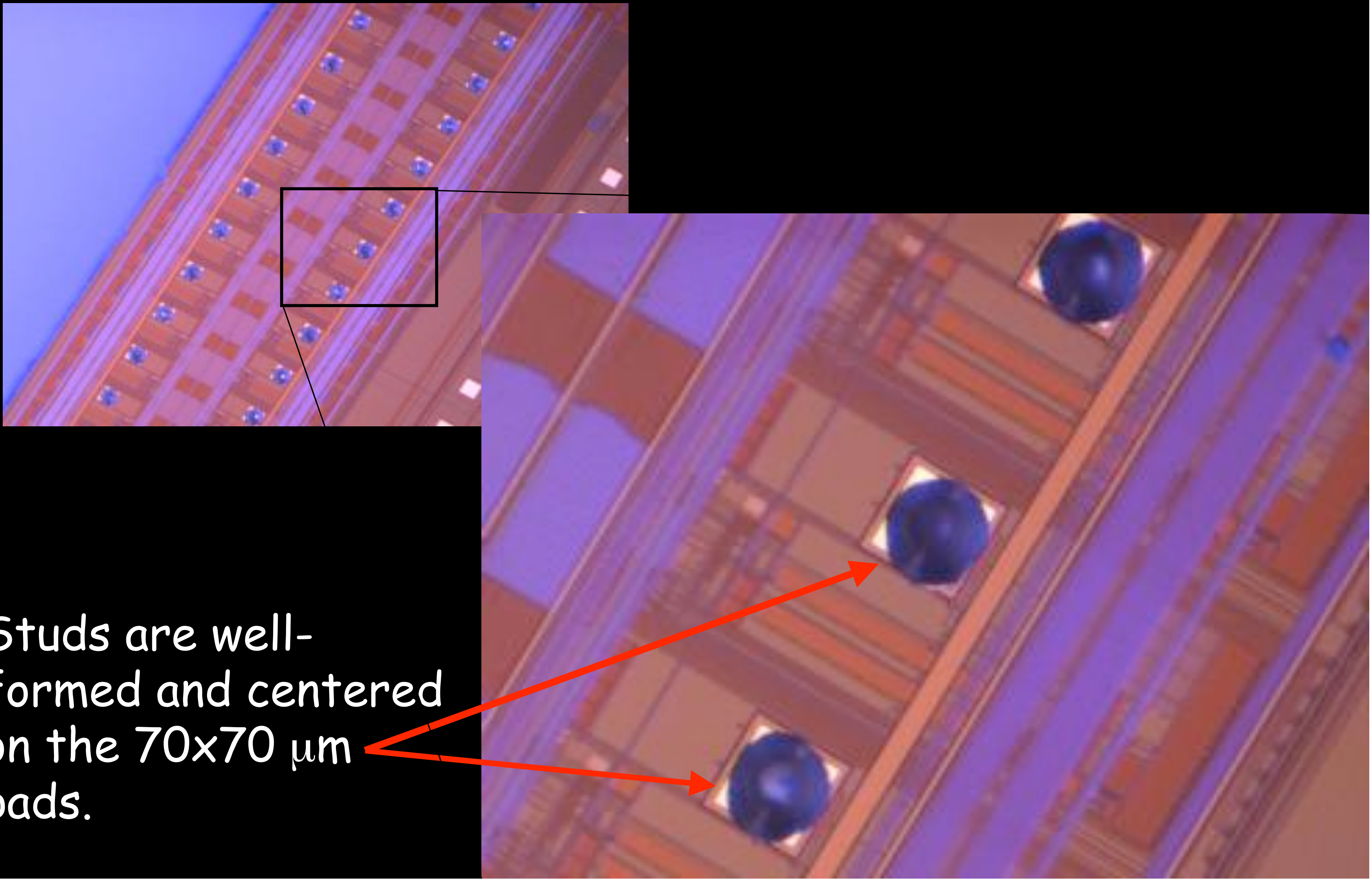
Step 2: The wire is snapped off.

Step 3: The stud is “coined” (flattened) to provide a better shape. Alternately, the wire is pushed back into the ball after snapping. The result is a matted surface.



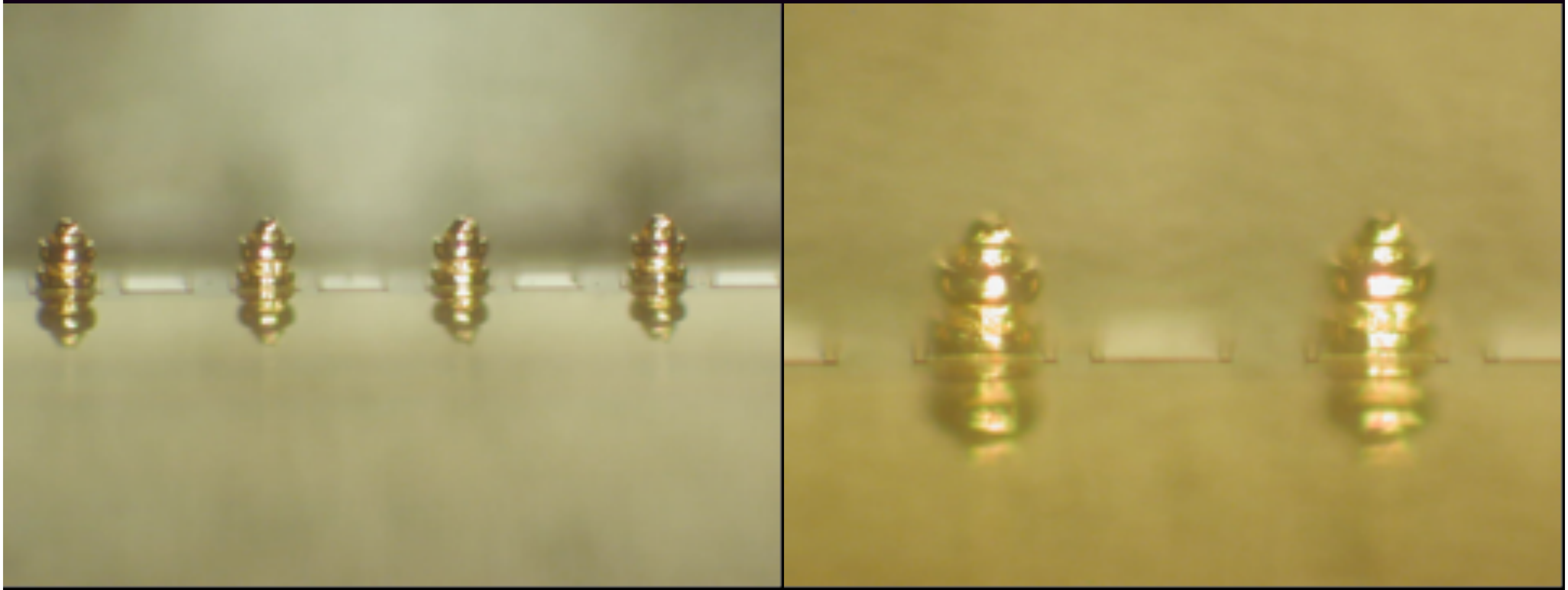


KPiX with Gold Studs



Studs are well-formed and centered on the 70x70 μm pads.

Double Studs on test wafers



	ball diameter - um	*ball height - um*	*shear strength - grams*
count	10	10	10
average	58.4	66.0	21.0
stdev	1.0	.76	1.1

Gold Stud Attachment

Three possibilities:

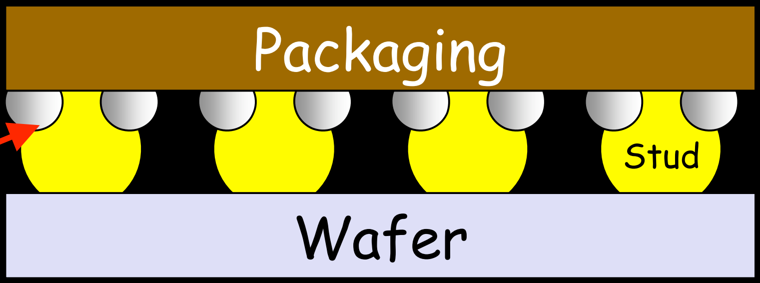
1. Conducting Silver Epoxy. High degree of bump height uniformity required. No limit on number of bumps. Low temp and pressure. Good success for large pads (>100 um). Work in progress for 50 um pads.

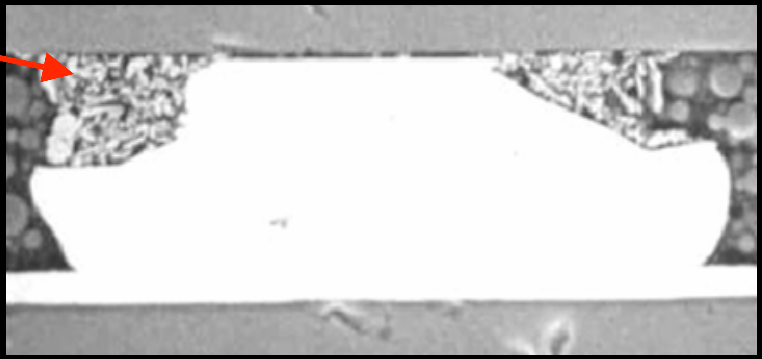
2. Thermo-compression. Typically, high temp and pressure: 300-350C and 150-200g/bump. Machine limit ~100-200 kg => Limits total number of bumps.

3. Thermosonic. Lower temp and pressure: 150C and 75g/bump. Limit on total number of bumps because of the limit on total deliverable ultrasonic power without breaking the chip.

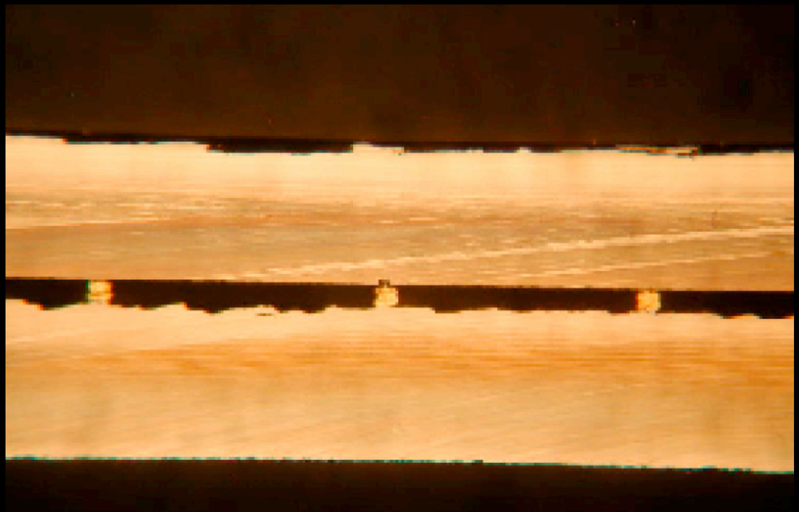
Adhesive Attachment

The tips of the studs are dipped into a conductive epoxy.
(Alternately, epoxy "dots" can be dispensed on the opposite wafer).

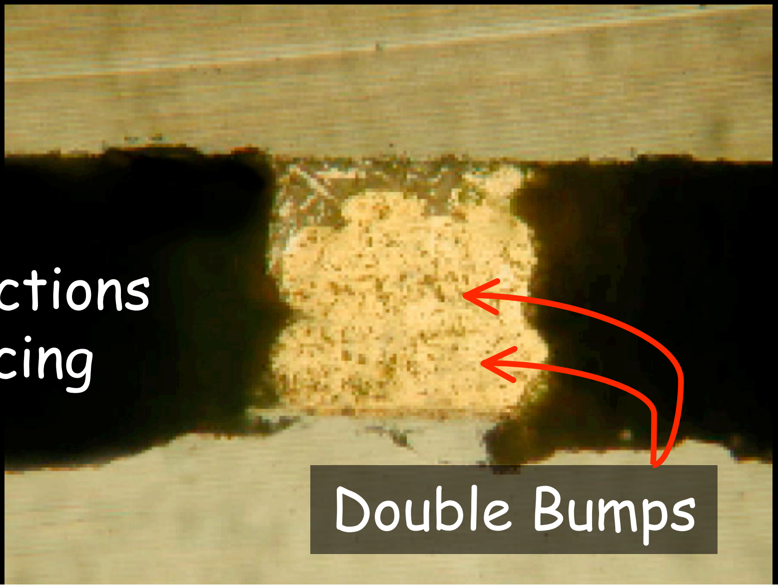




After a flip-chip alignment, the chips are compressed.

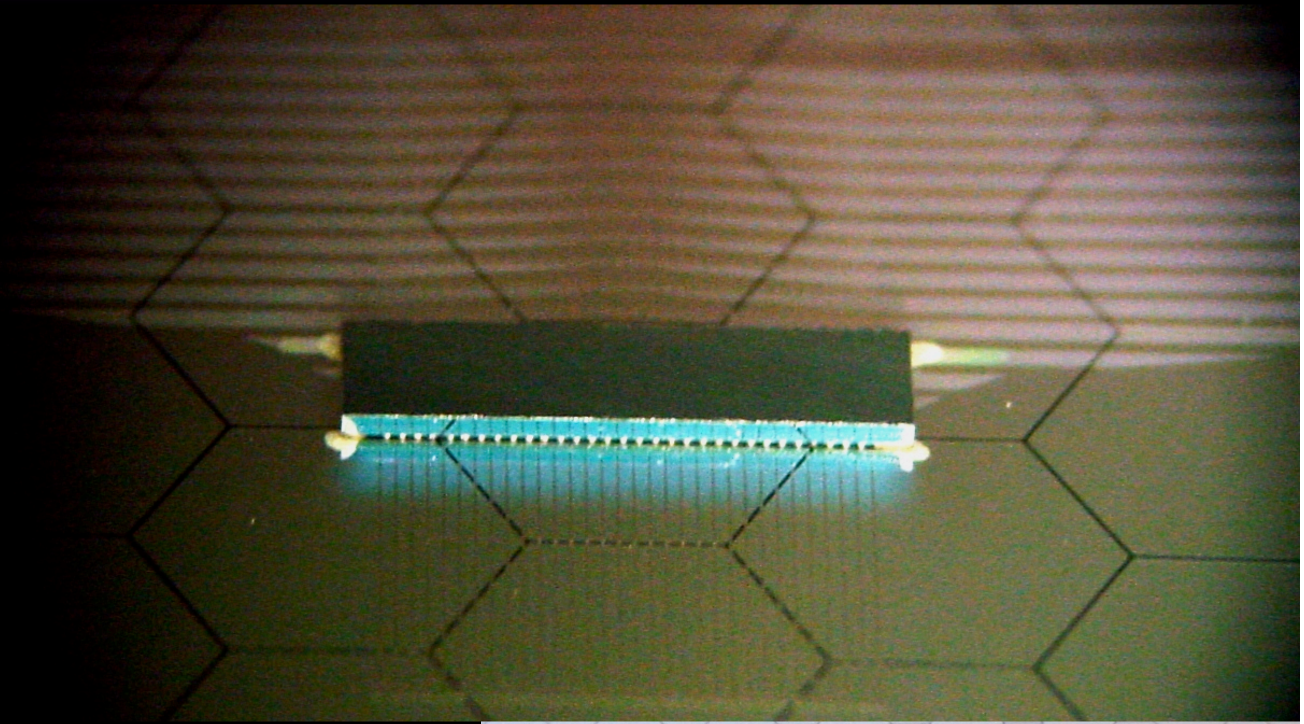


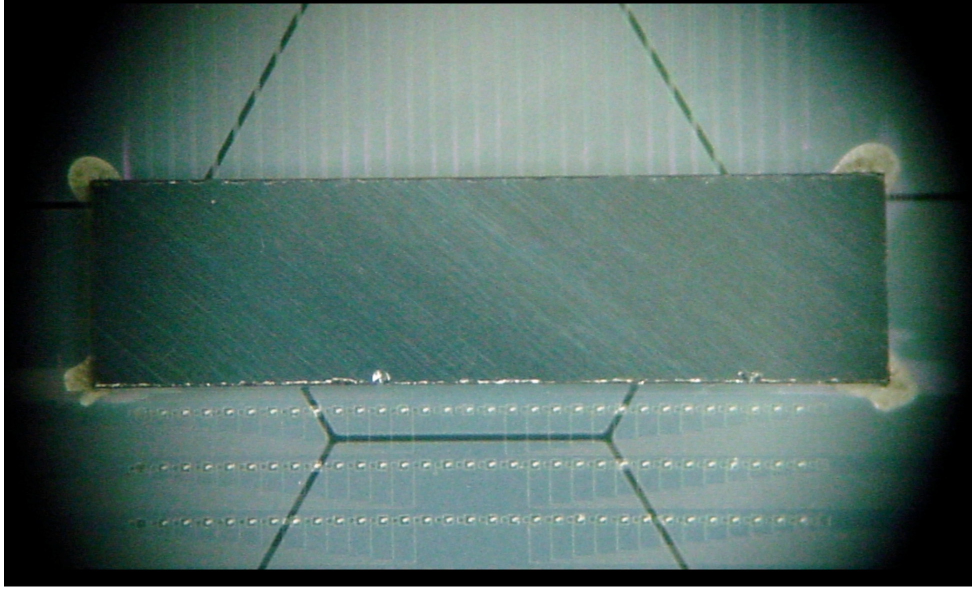
Cross sections after slicing

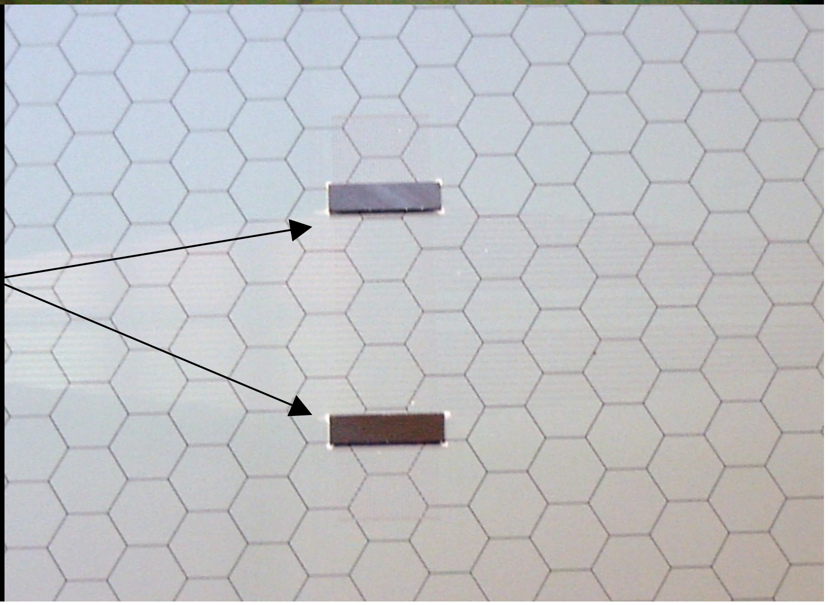


Bump Bonding KPiX to Hamamatsu

Epoxy attachment is mechanically sound but yields high resistance per bump.



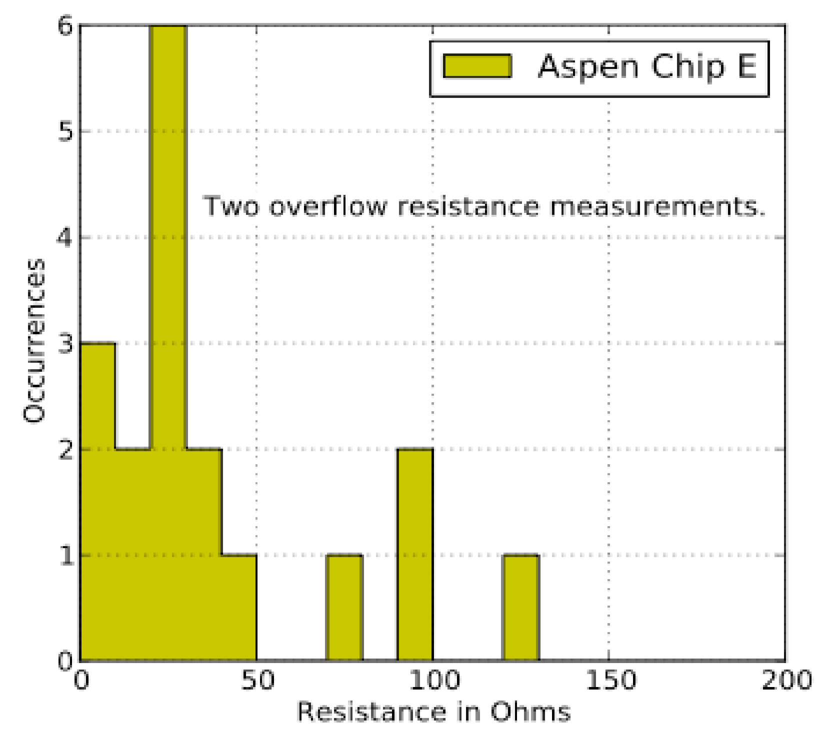


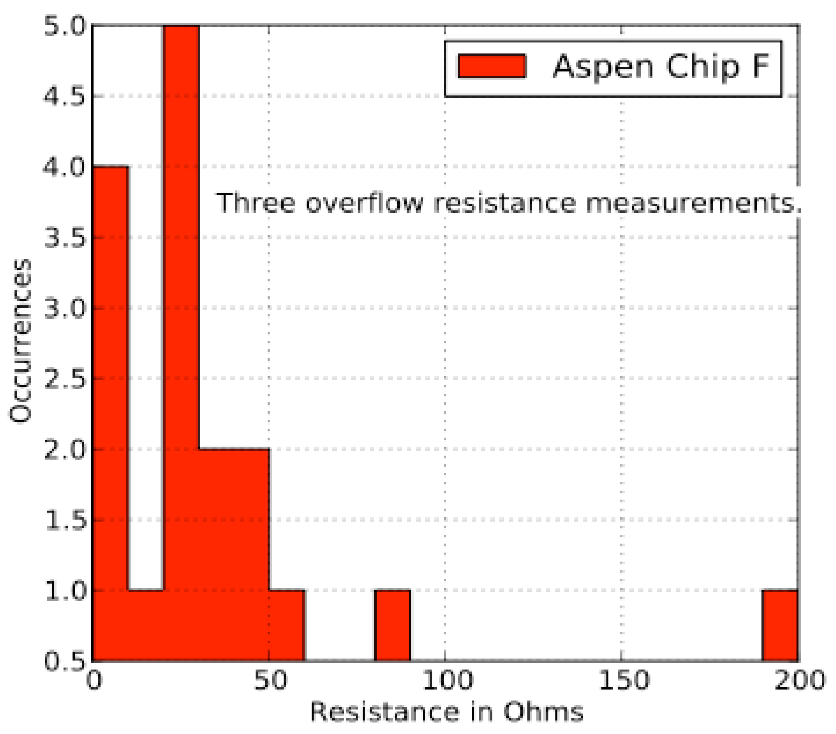


KPiX Chips

Au-Epoxy

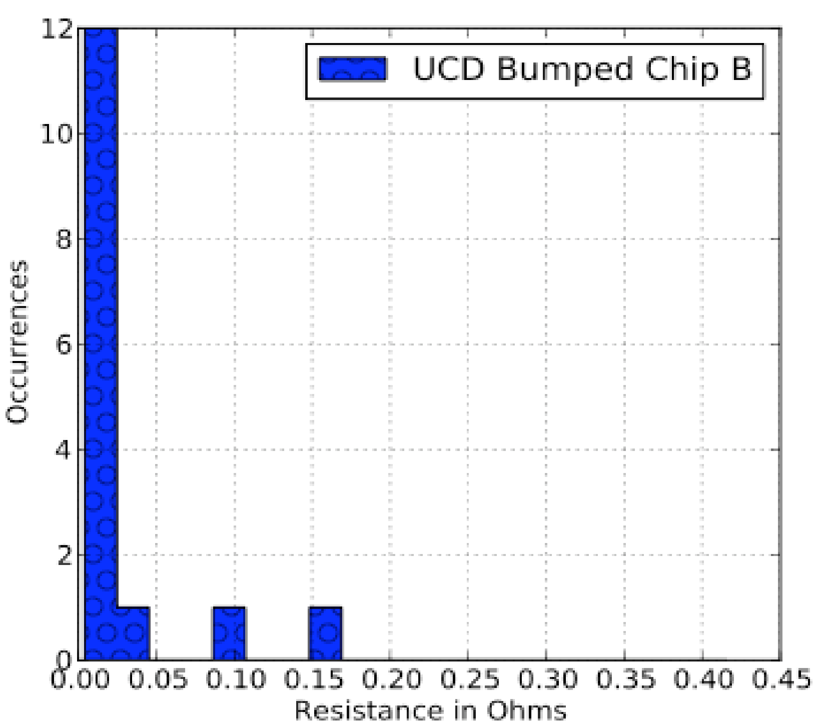
High R!

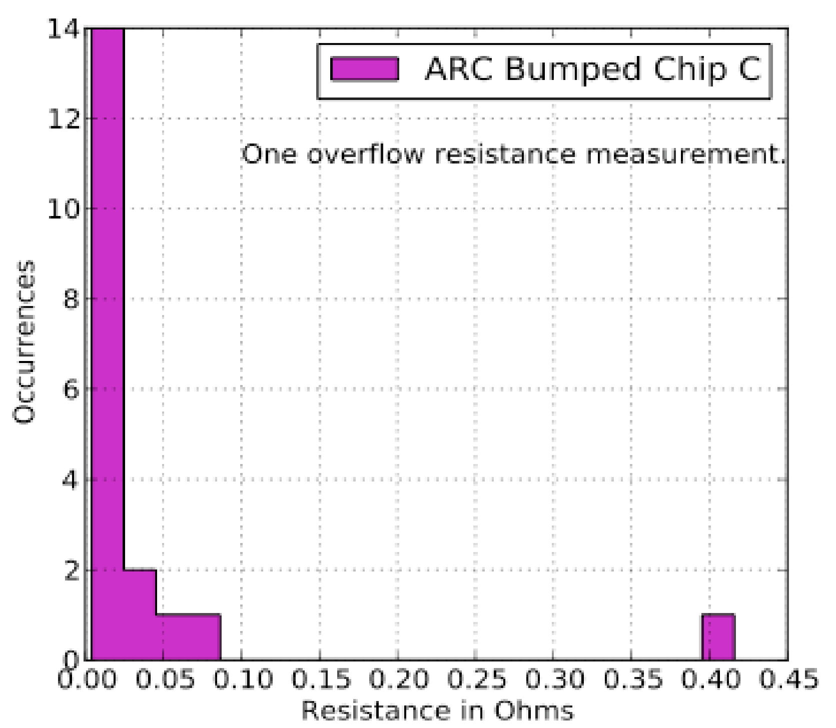




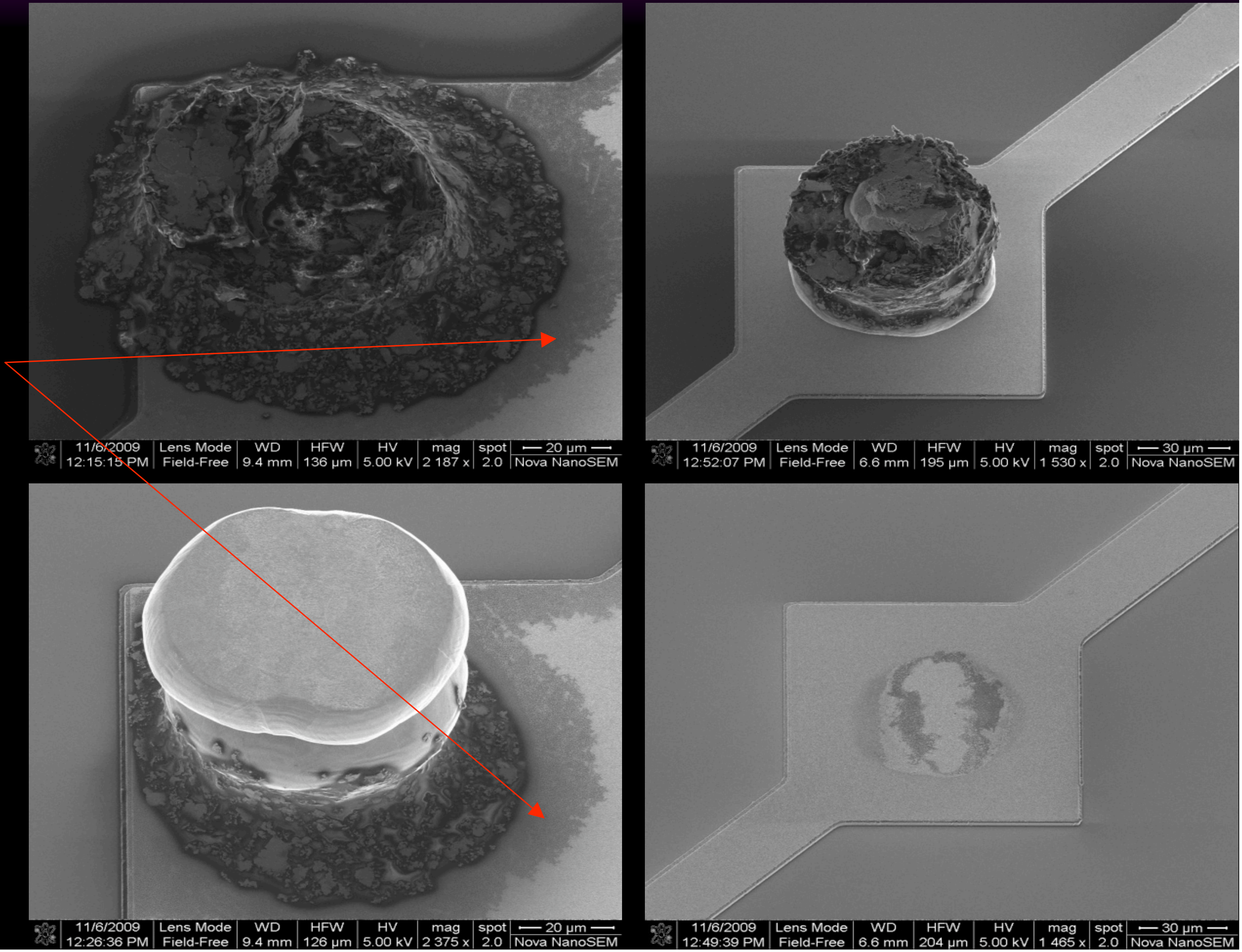
Au Thermo-Compression

Low R.



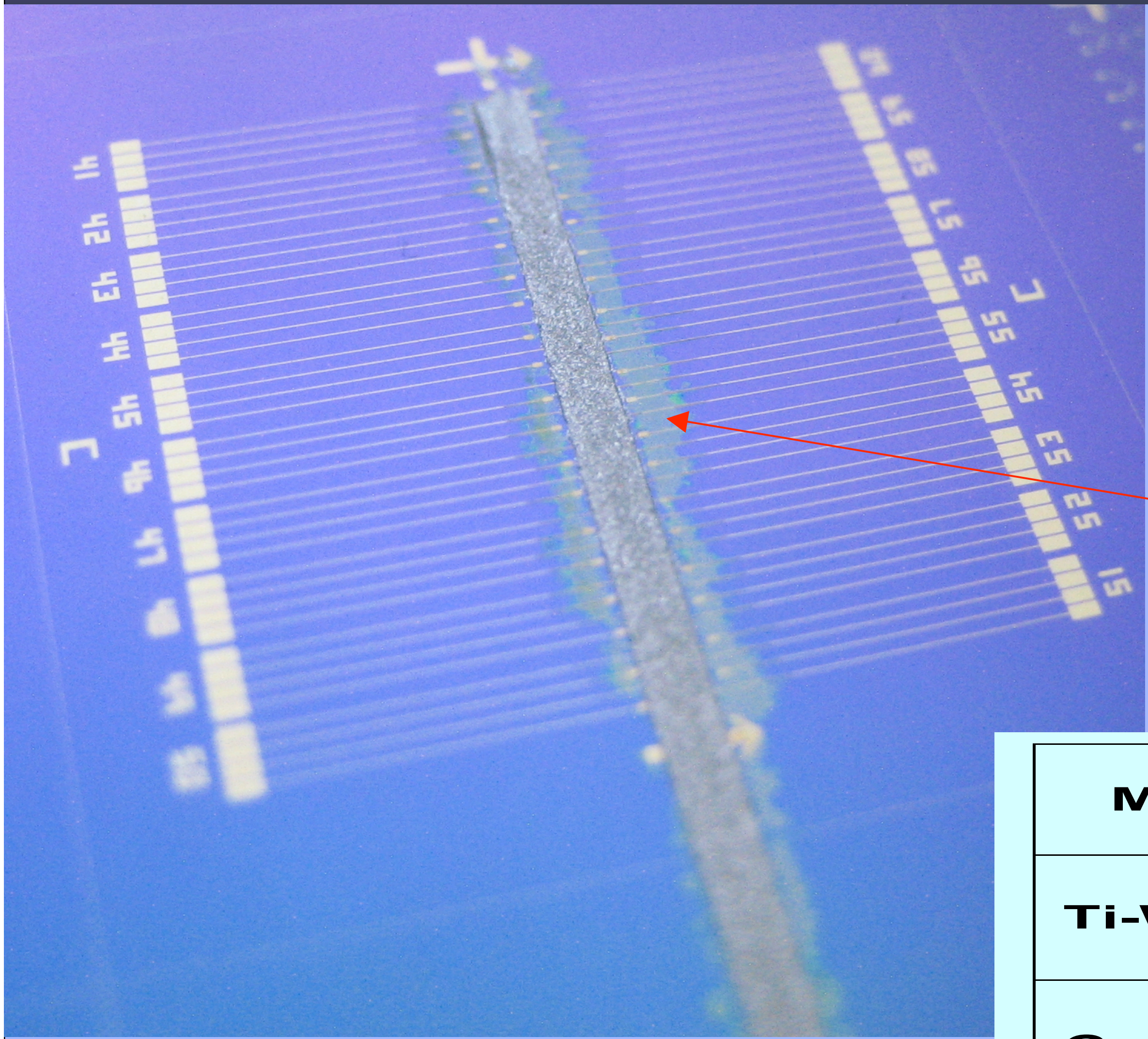


Bleed-out suspected for poor AU-epoxy contact



Bleed-out

Under-Bump Metallization Studies



Bleed-out

Metal-Stack	Mean Resistance
Ti-W / Al	25 Ω
Cu / Cr / Al	8-10 Ω
Au / Cr / Al	10 mΩ

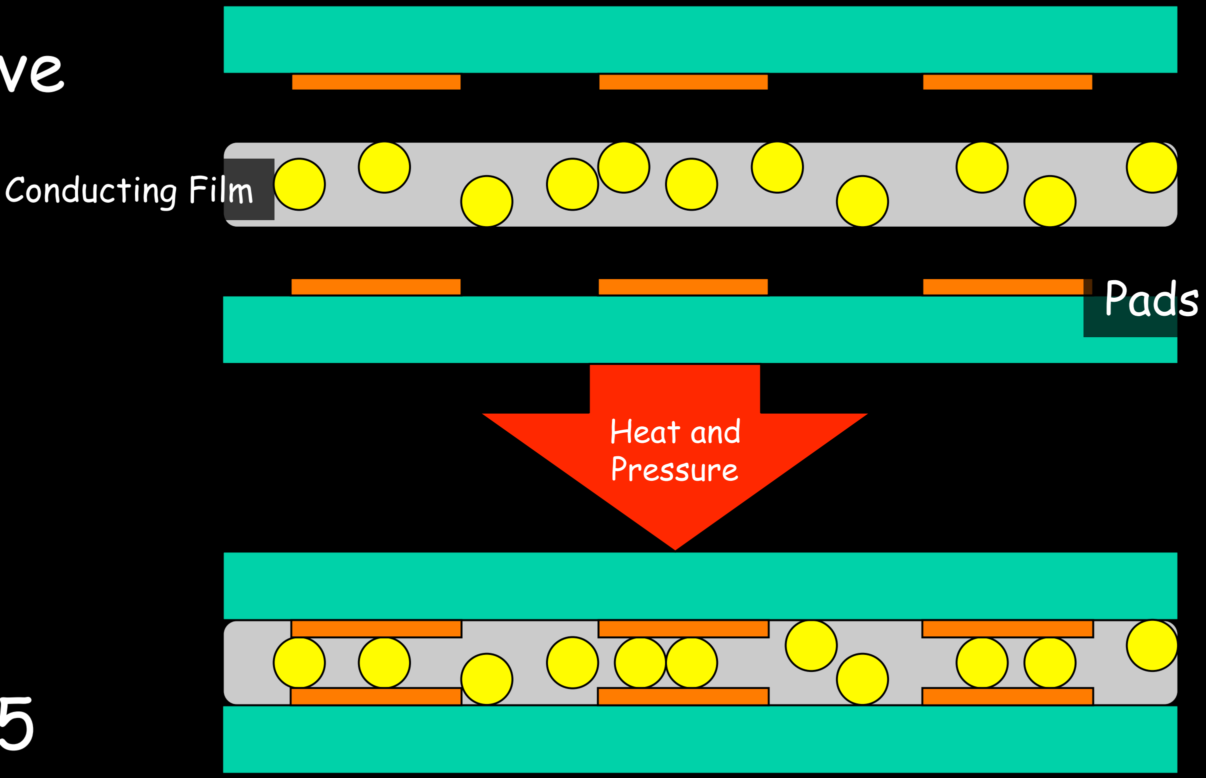
Z-Axis Conducting Adhesive

3M: 7303 ACF Adhesive

~45 μm particles
~75 μm film thickness

≥250 μm pad pitch

Bonding Conditions:
140°C @ 260 PSI for 25 secs



Cairns et al, SID Digest, 2001

Contact resistance ≤0.2 Ω (for flex-cable to PC board).
≤0.2 Ω maintained after 80°C for 1000 hours or 25°C for 4 yrs

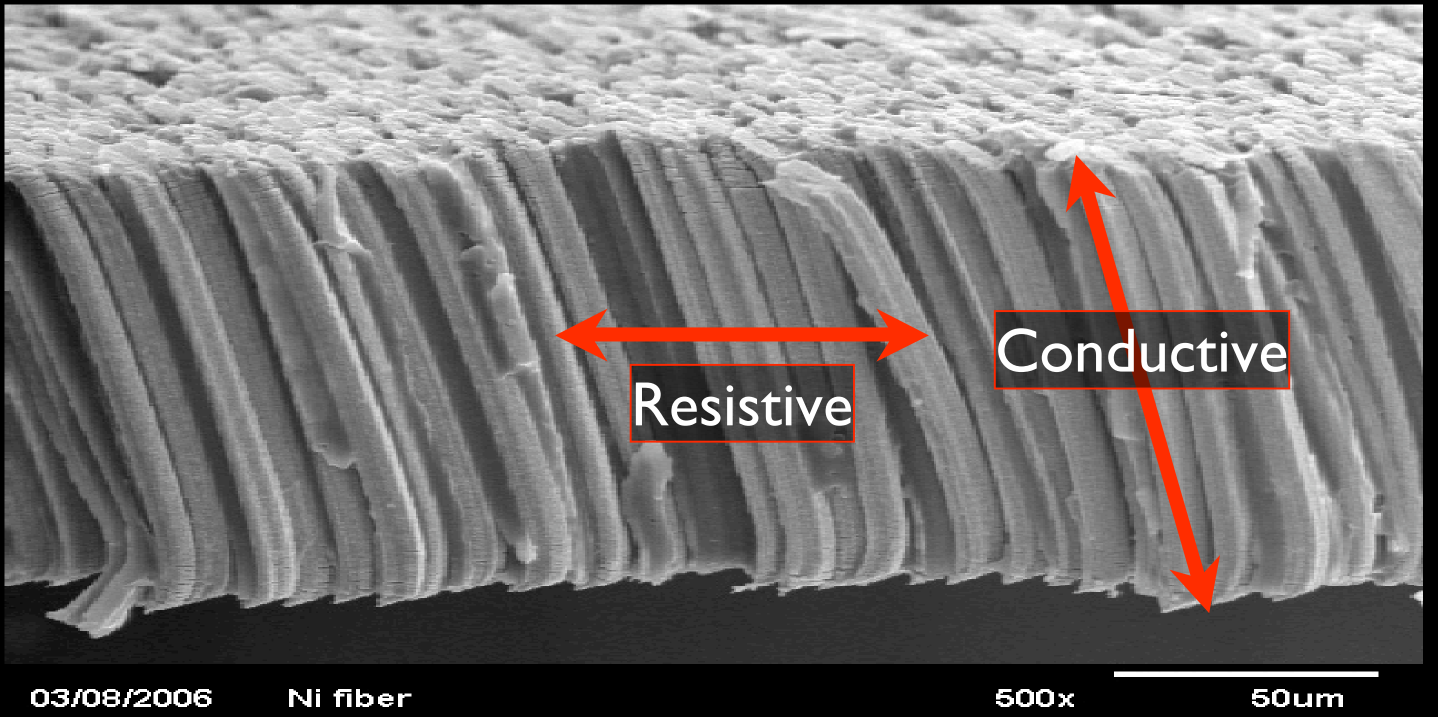
Flex cable to wafer attachment is not common => R&D.

Thermoplastic Conducting Adhesive

Btechcorp:

Metal fibers in a matrix
~2 x 10^7 fibers/in^2

Low Cure pressure: 50 psi

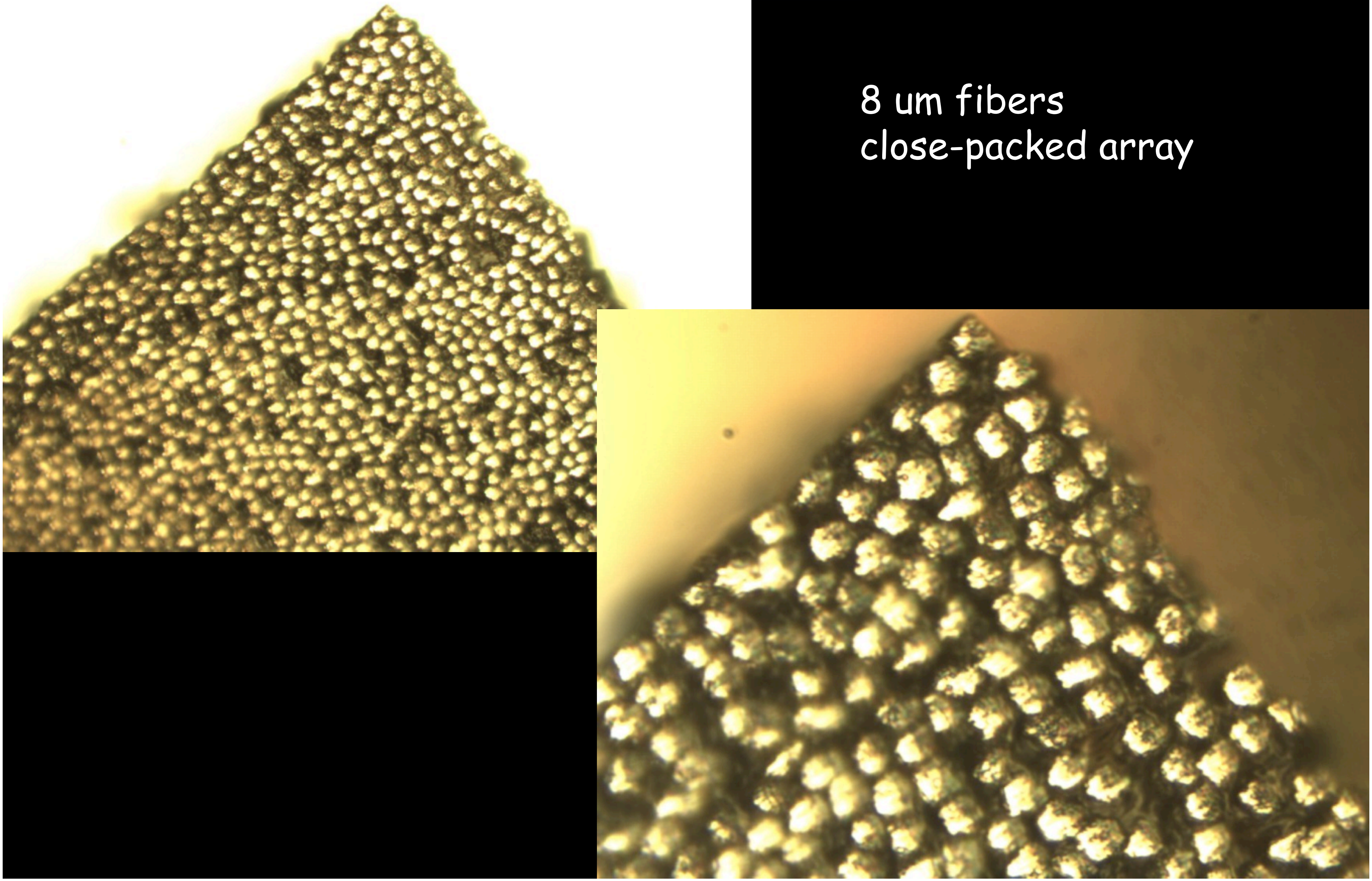


Nickel fiber structure.

Thermal Conductivity ≥ Cu. Smaller resistance
Cheaper.

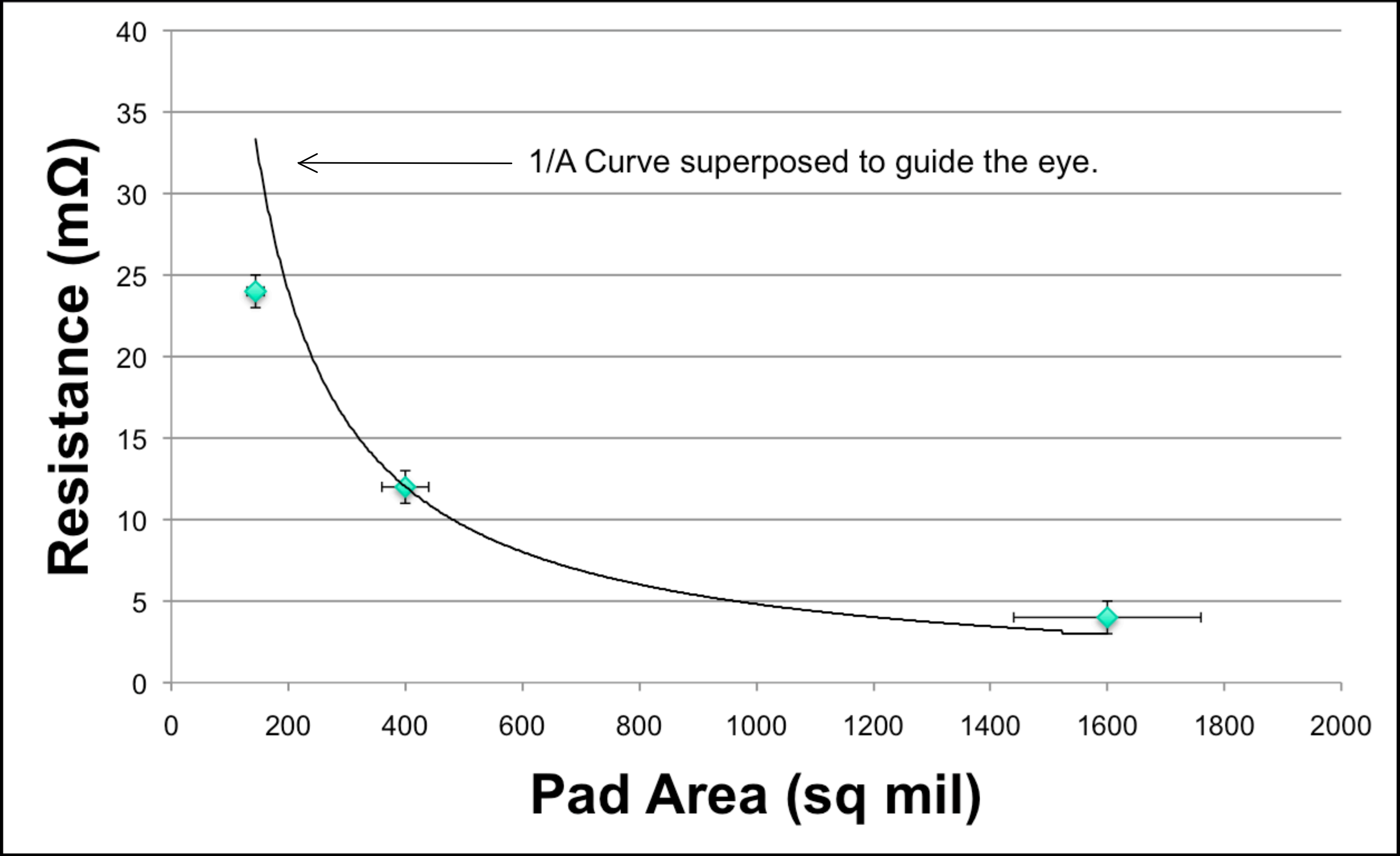
Sub mm bonding has not been attempted widely. Needs R&D.

ACF Up Close



8 um fibers
close-packed array

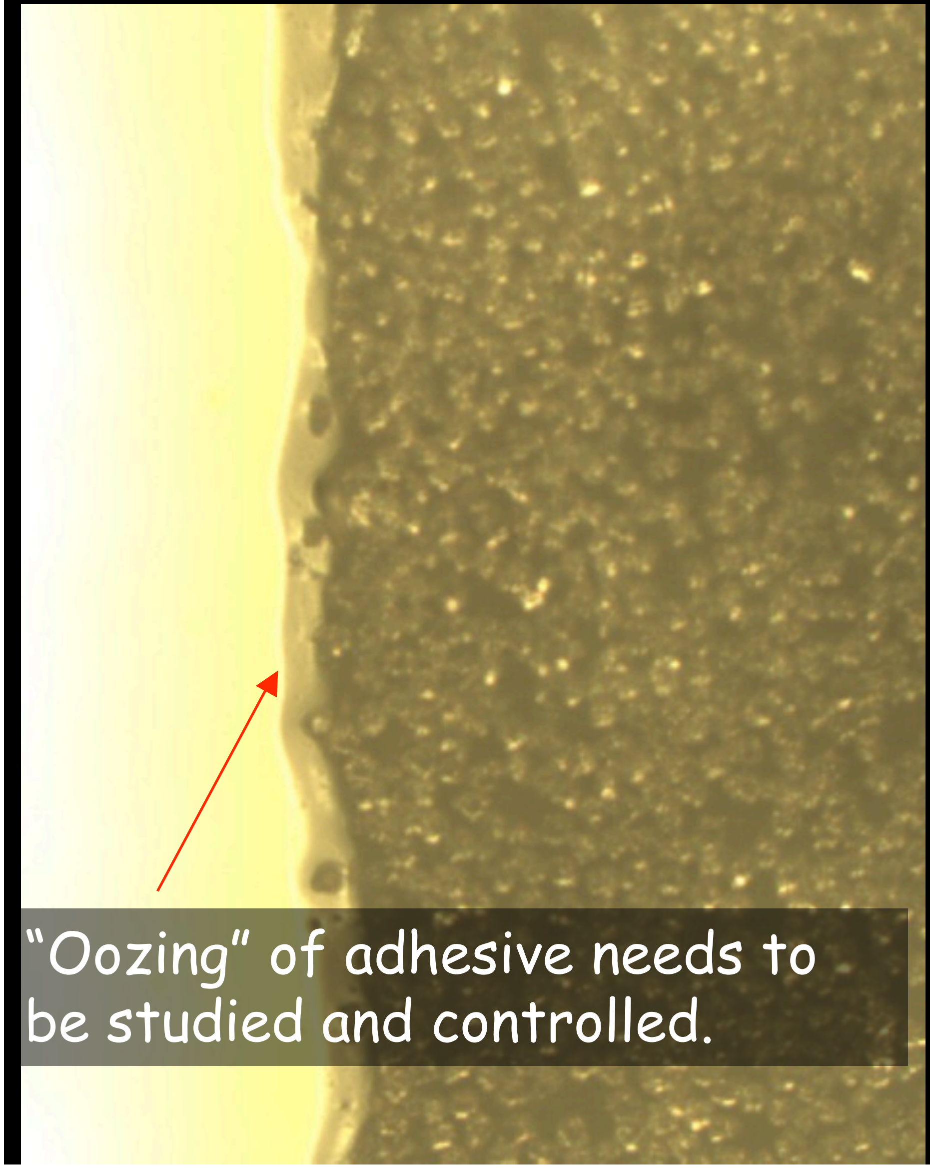
Initial Results



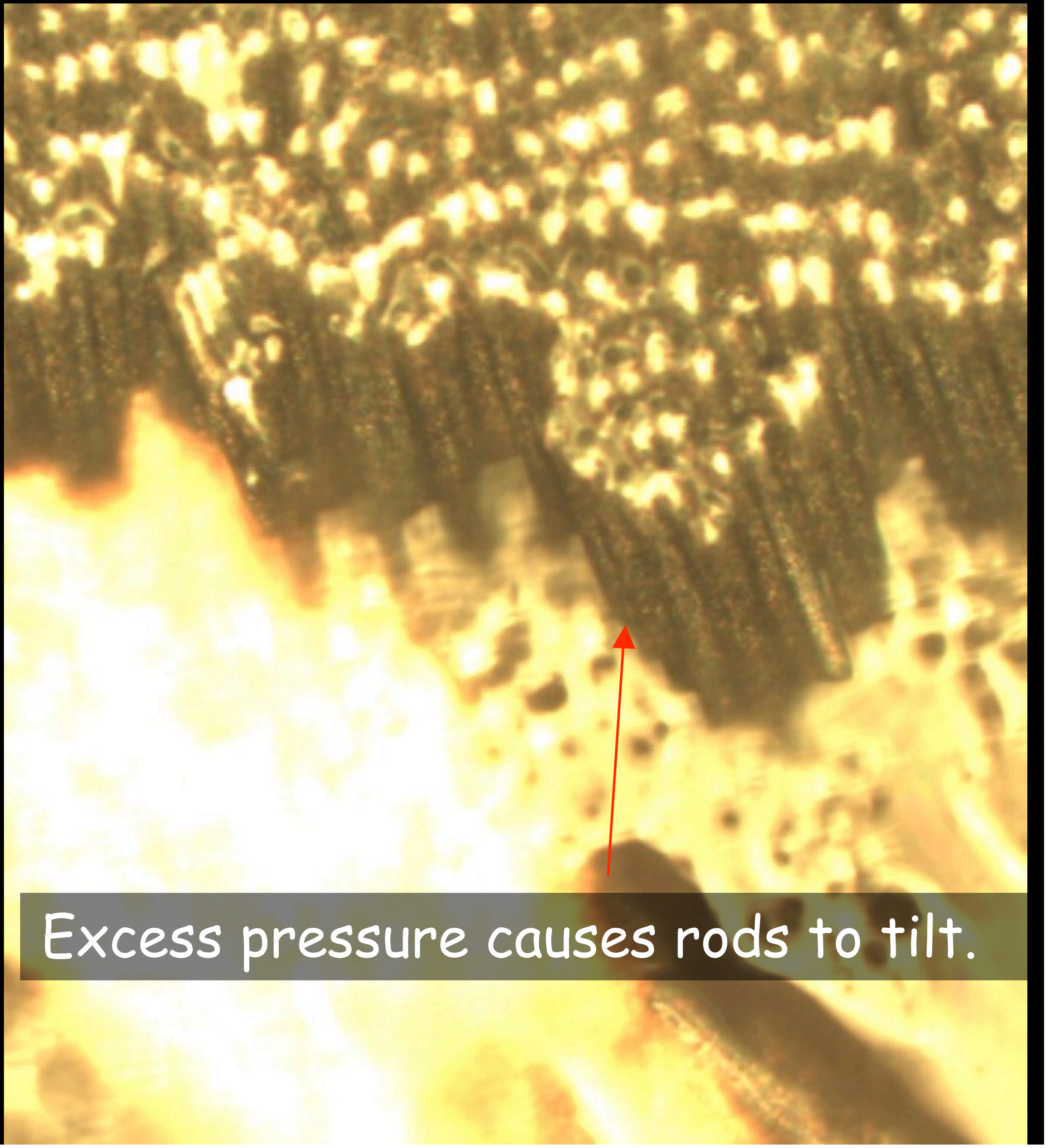
The results are promising. Goal for Flex Cable pads (100 sq mil) is ~100 mΩ, which is achievable.

Possible problems in ACF Bonding

- **ACF bonded to transparent glass** allows for observation under a microscope

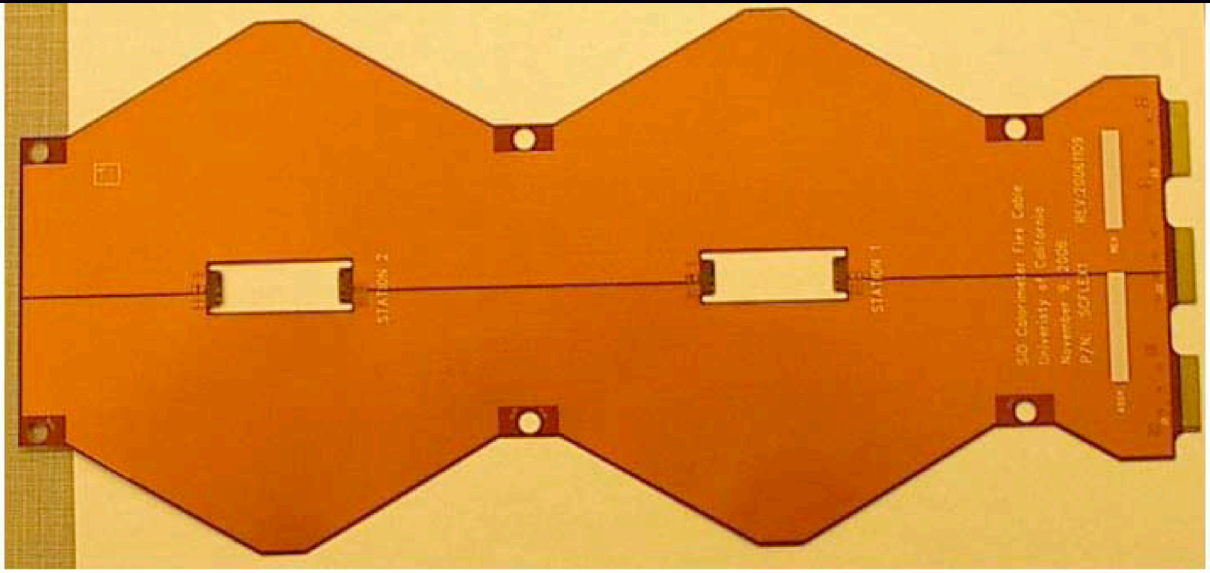


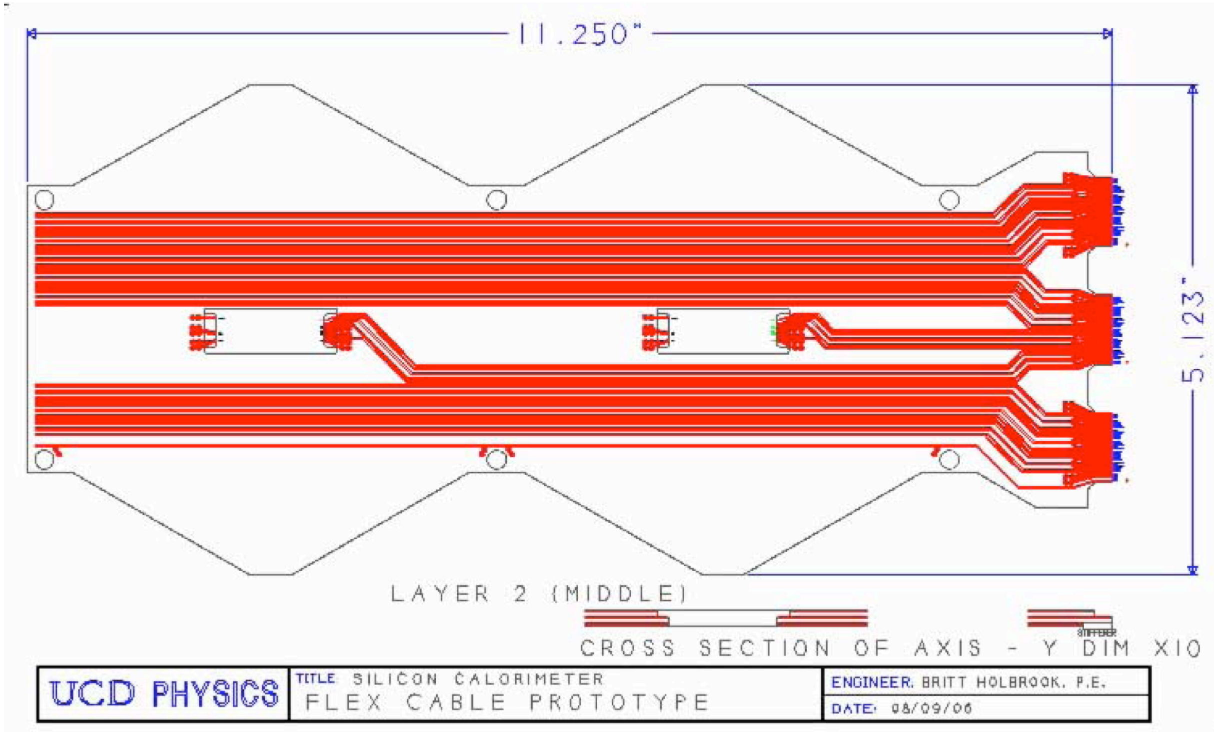
"Oozing" of adhesive needs to be studied and controlled.



Excess pressure causes rods to tilt.

Readout flex cable for Si-W



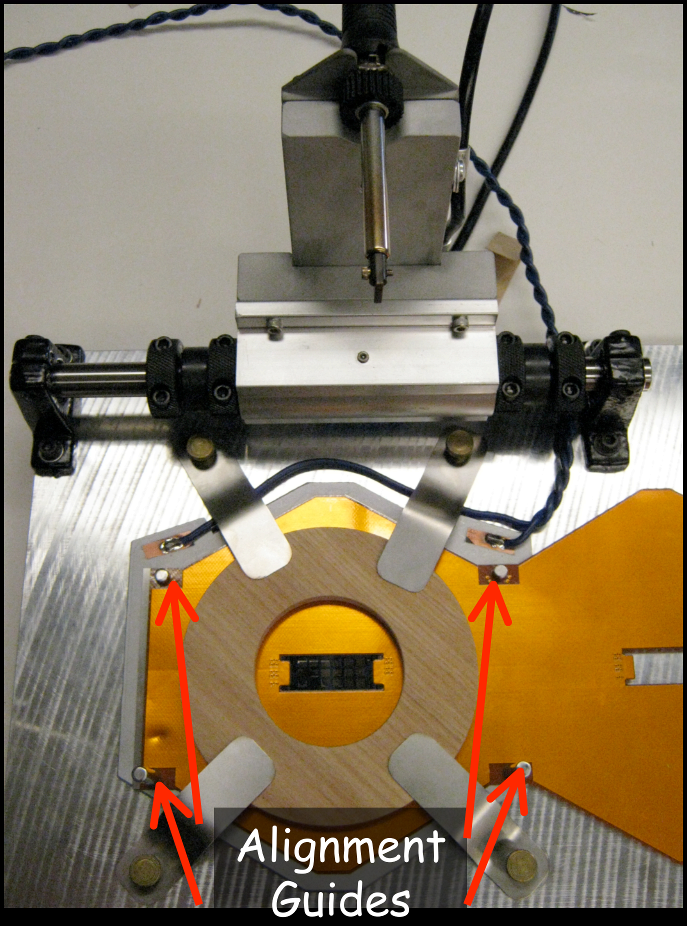


2 chip stations

Buried digital signal layer between power and ground planes

Two “lips” per KPiX from the buried layer for attachment to silicon wafer.

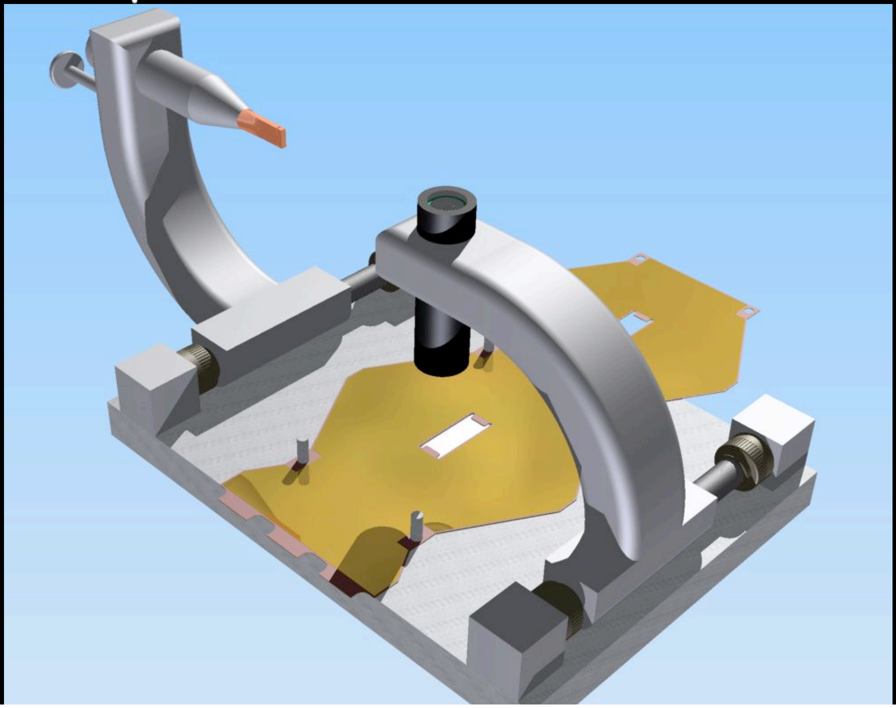
Custom Alignement and Bonding Jig



Swinging heating arm.

Adjustable Factors:

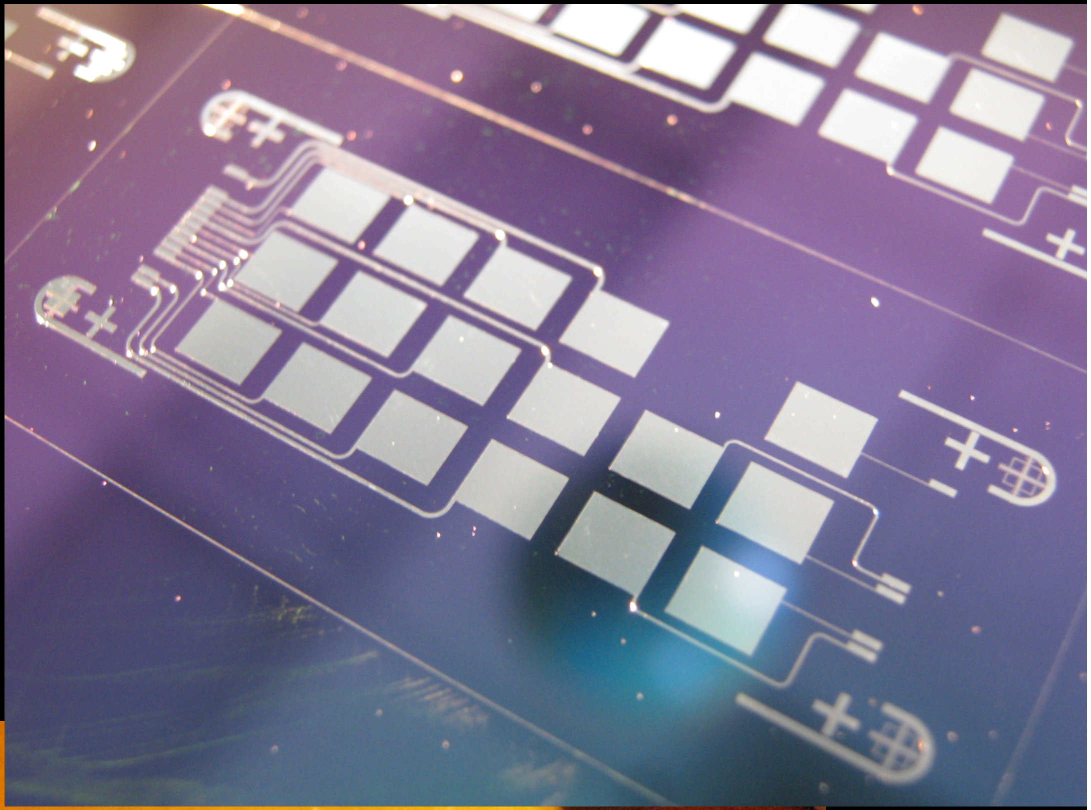
- Preheat wafer and flex cable.
- Tip temp
- Tip position
- Tip angle
- Pressure



ACF manufacturer supplies ideal parameters. Testing requires adjustment toward them.

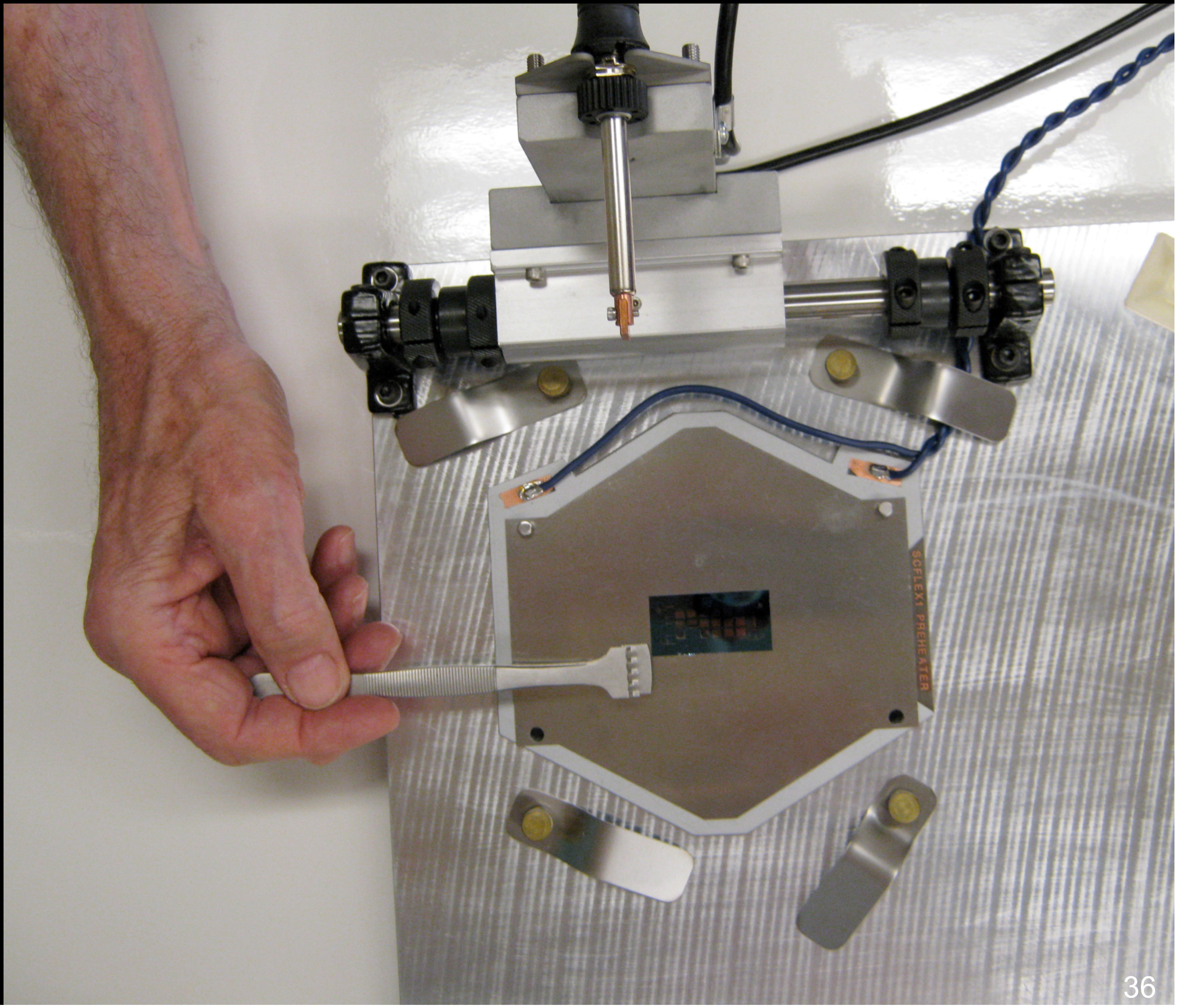
Test Wafer

- Hamamatsu wafers too expensive to test on.
- Ti-W test wafer mimics the read portion of the Hamamatsu wafer.
- Large pads for read out where bump bond positions would be.



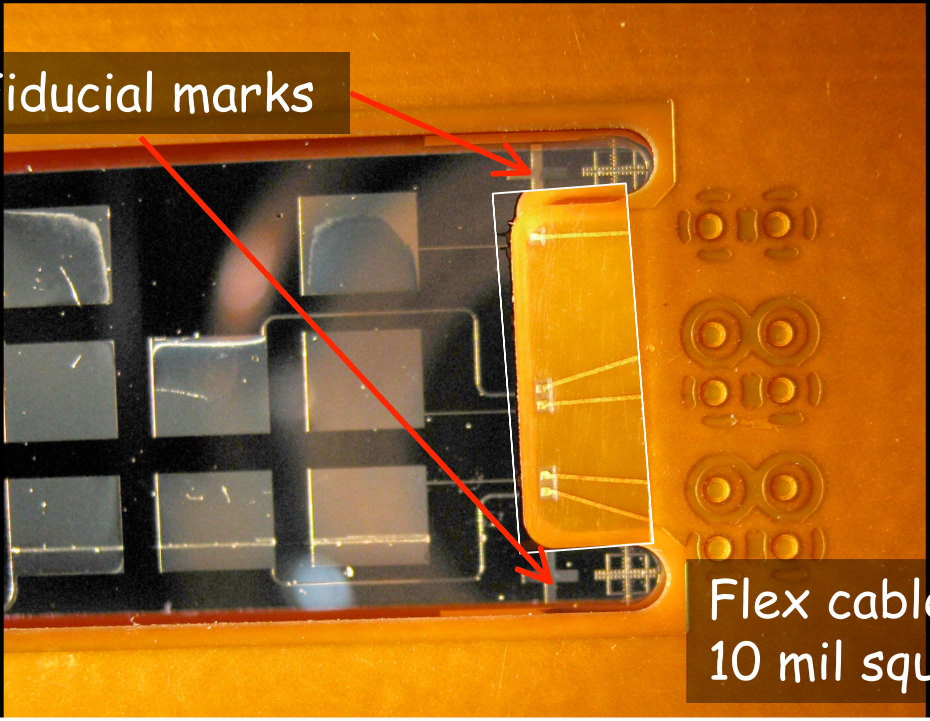
Wafer alignment via EDM shim

- A metal shim has been produced using precise electrical discharge machining
- Jig alignment posts hold metal shim in place.
- Shim holds wafer in cutaway.
- Guide posts align all pieces automatically.

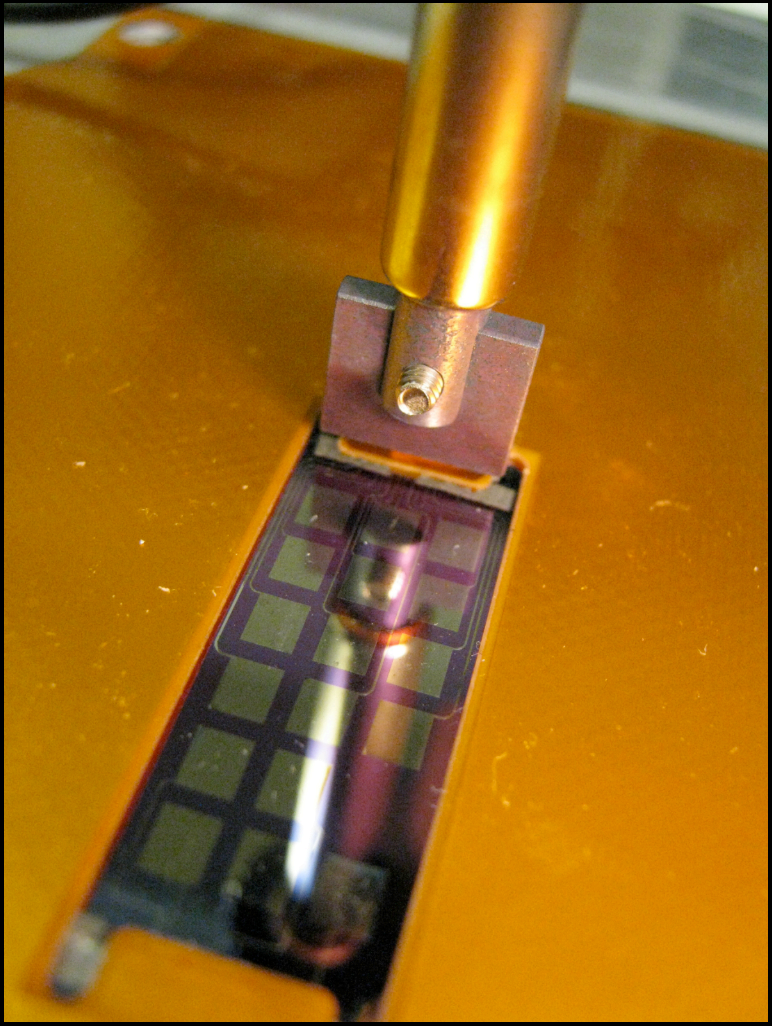


Precision Alignment

- ACF does not need alignment.
- Flex cable and wafer do.

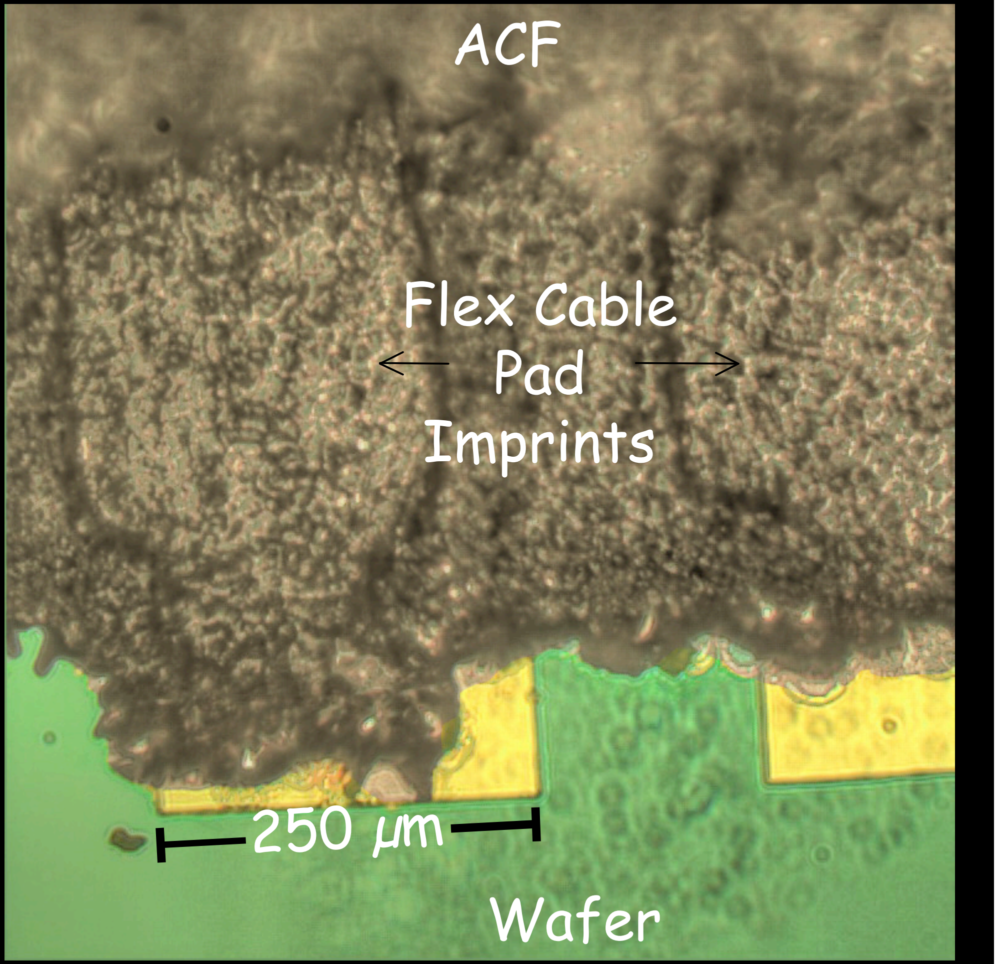


Flex cable pads revealed.
10 mil square pads



First results from ACF Attachment

- Flex cable and wafer do.
- Flex cable, jig, and wafer all align to ±20 microns.
- Full cable to be bonded in stages.

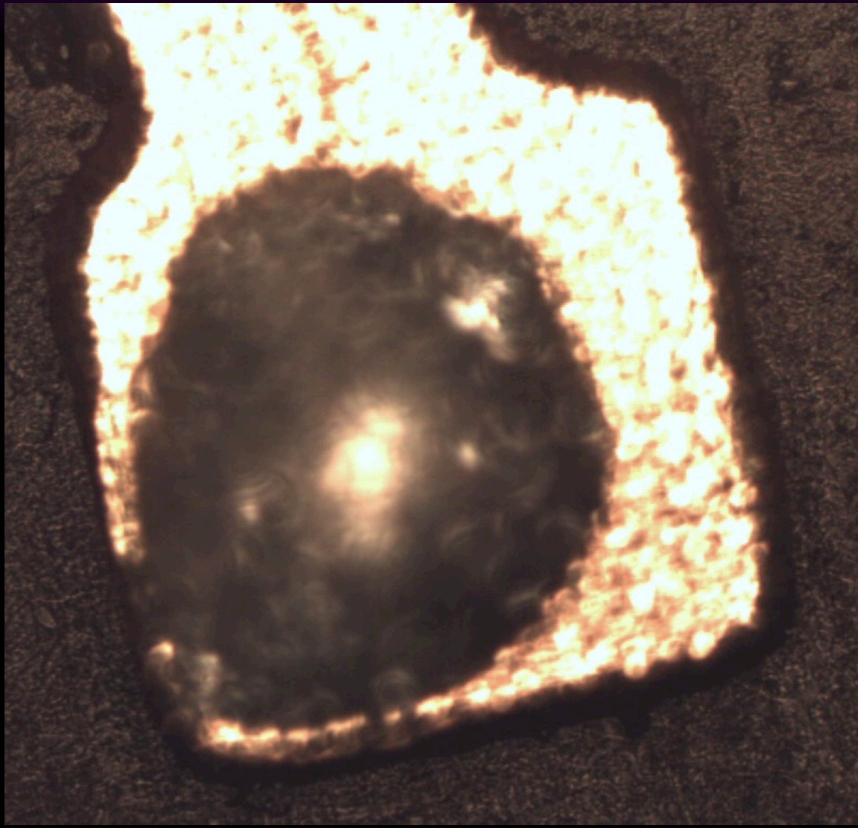


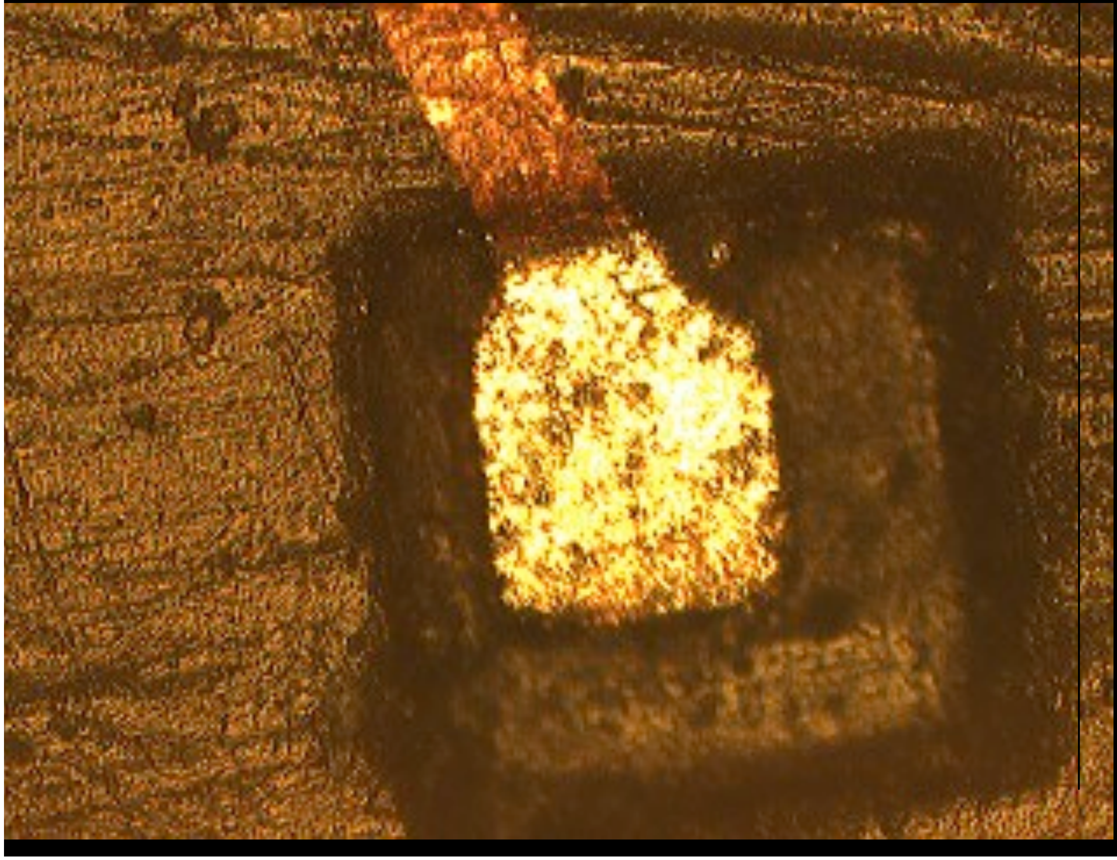
Indentation on ACF from Flex Cable pads after detachment of bonding surfaces.

Silver Epoxy

Groups of pads in flex cable reside ~20 μm deep in overlay well.

Silver epoxy can be applied using stencils (holes in shim metal).





Solder balls "pick-n-place" being invesigated.

Summary

Ongoing work for Specific Detector R&D

- Flex Cable Development
- Gold Stud Bonding
- ACF attachment
- Flip-chip bonding
- Solder Ball and epoxy stencils

Generic R&D for Interconnect issues

- Single die photolithography for Indium (PDMS substrate)
- Under bump metallization studies
- Smart flex cables
- ACF and conductive epoxy evaluations