Progress on a Si-W ECAL Detection and Readout Interconnects

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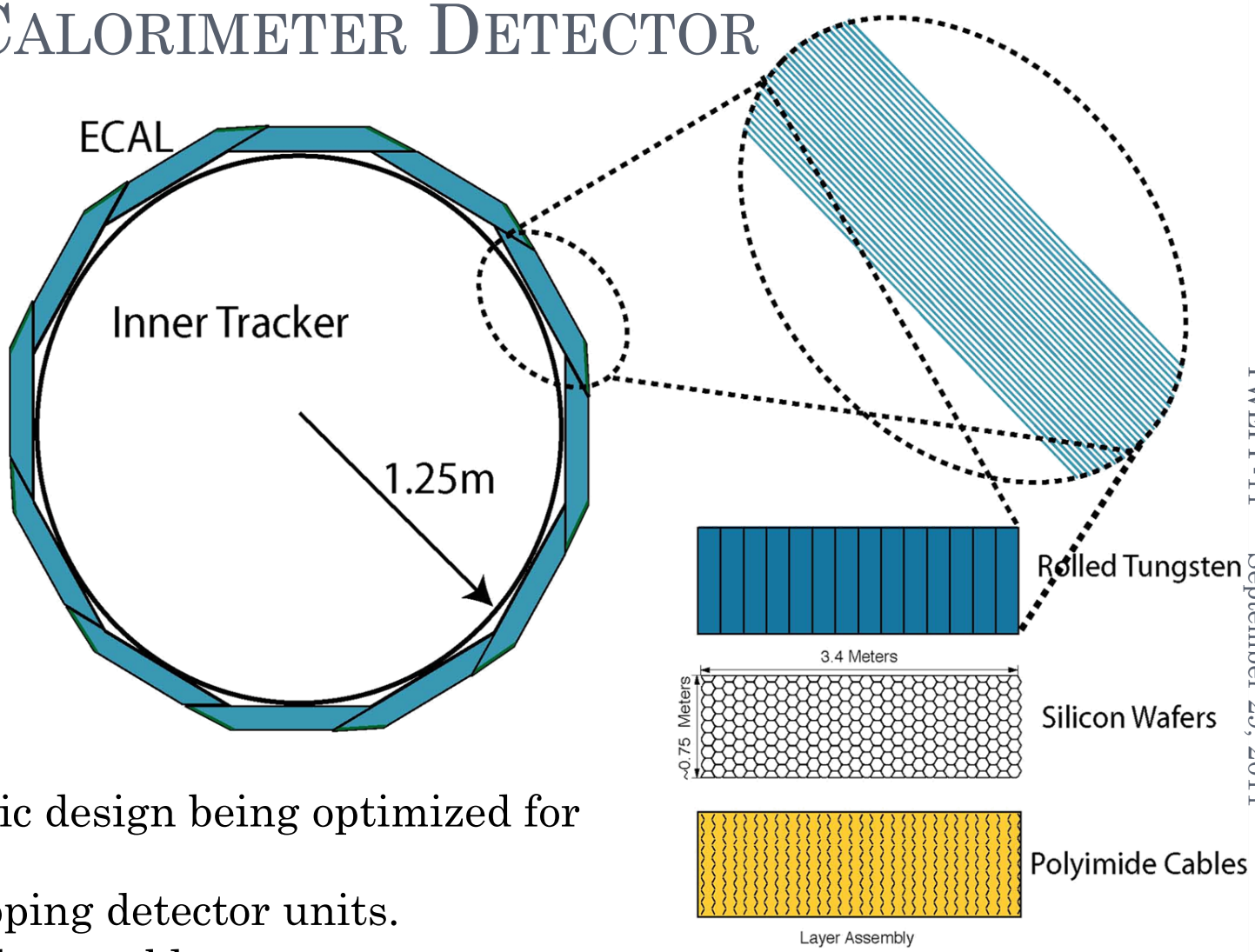
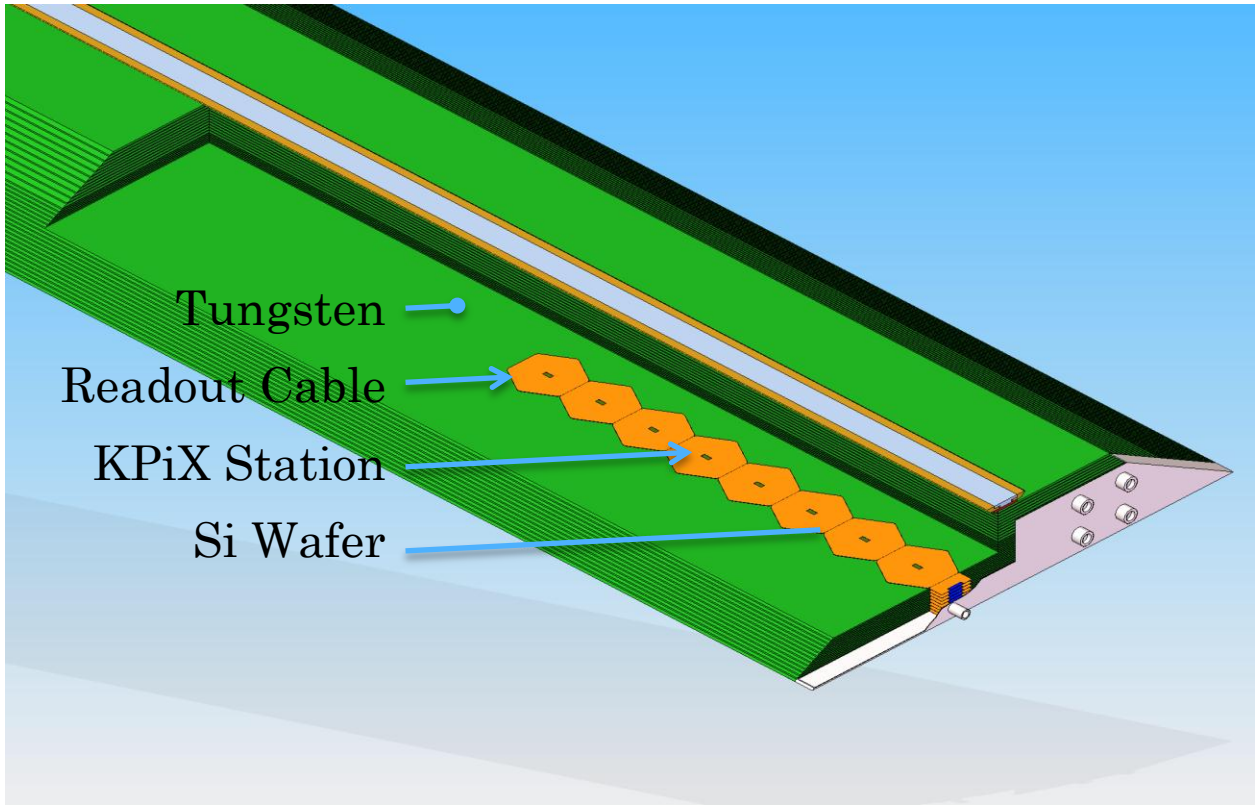
Si/W Calorimeter Detector



- A generic design being optimized for SiD.
- Overlapping detector units.
- Layered assembly.
  - Tungsten
  - Si detector wafers
  - Readout cables

Si/W Calorimeter Detector

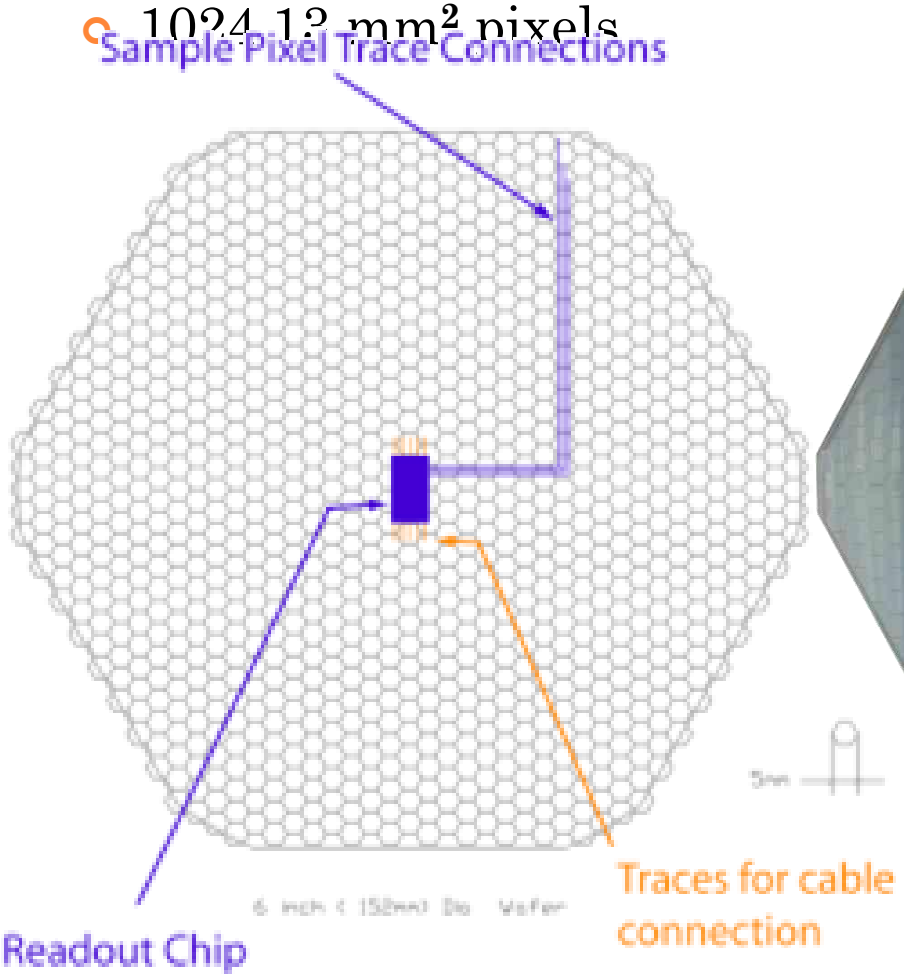
- Single module components



- Now a quick look at these components.

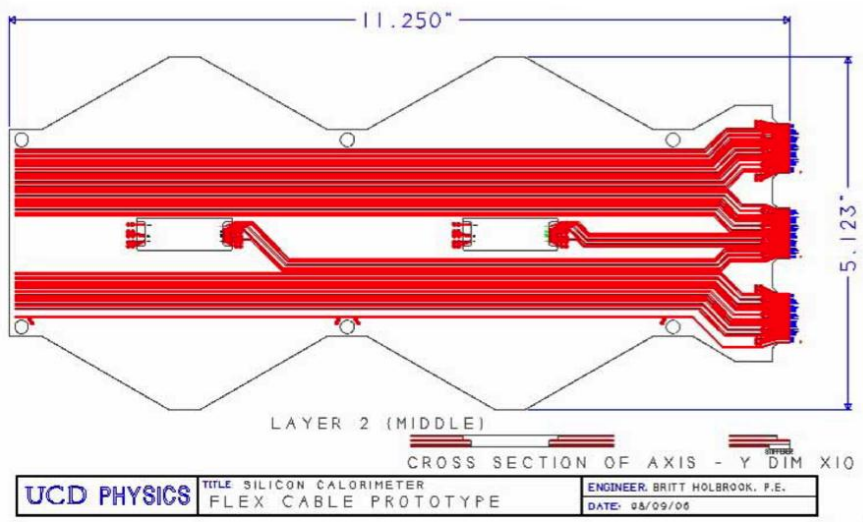
Hamamatsu Detectors

- Wafer
- 6” wafer
- 1024 13 mm² pixels
- Receives KPiX and readout cable.

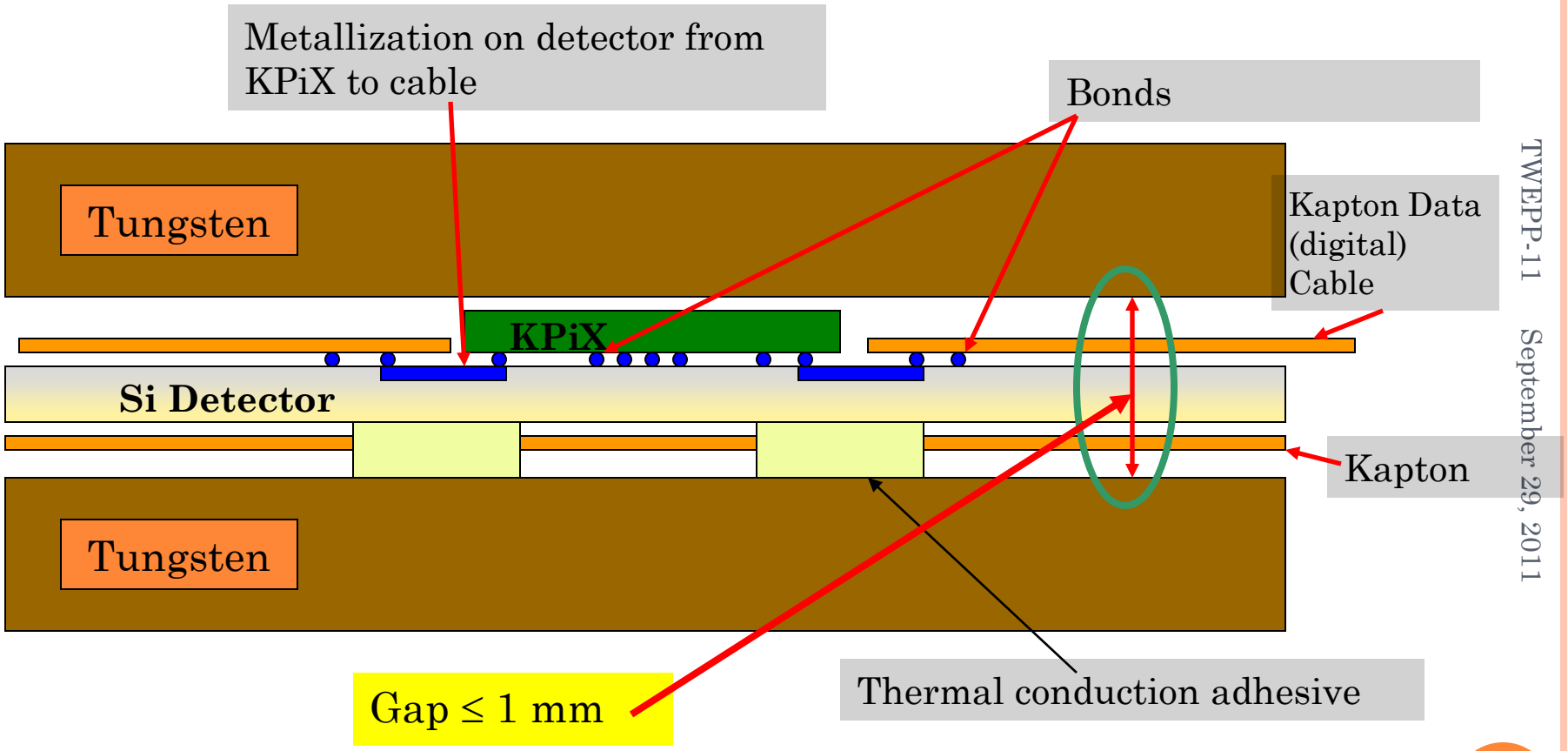


Kapton Readout Cable

- Data transfer from KPiX, through wafer, to cable.
- Single station version shown on right.
- Two station version shown below.
- Two "tongues" in center of hexagon.
  - Bonds to wafer underneath.
  - Leaves room for KPiX.



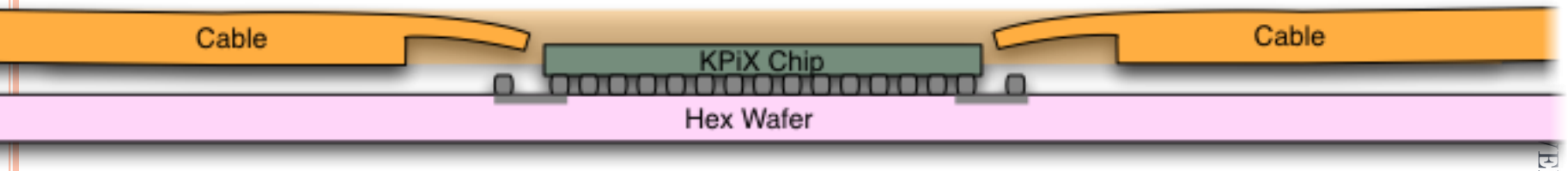
Side view of detector layer assembly



This was the general plan in 2006 – no details for bonding!

Bonding Scheme

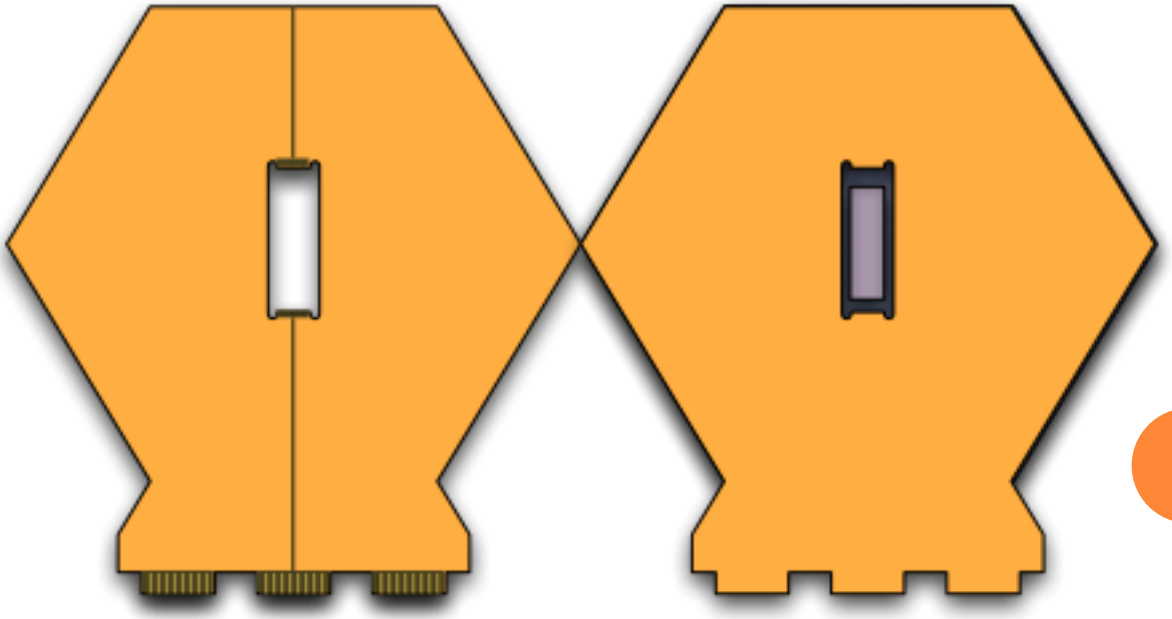
- Here is a diagram showing the bonding scheme.



- And the bonding agenda

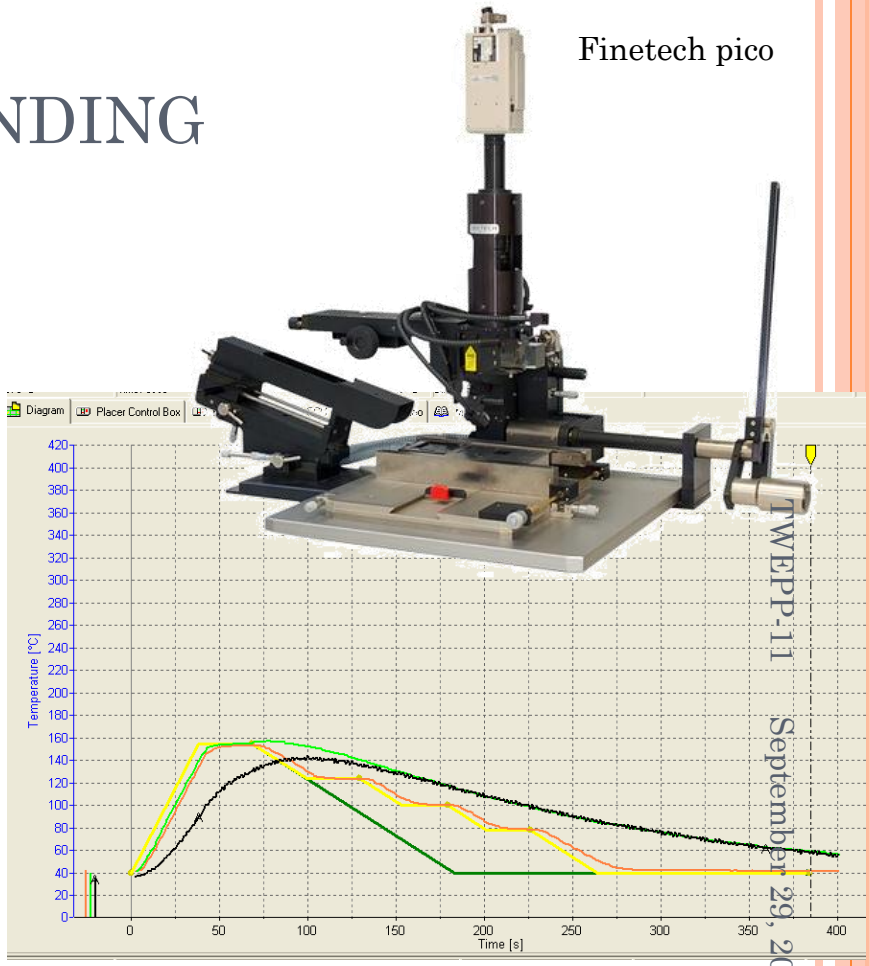
1) Wafer
2) KPiX
3) Cable

- Tools…

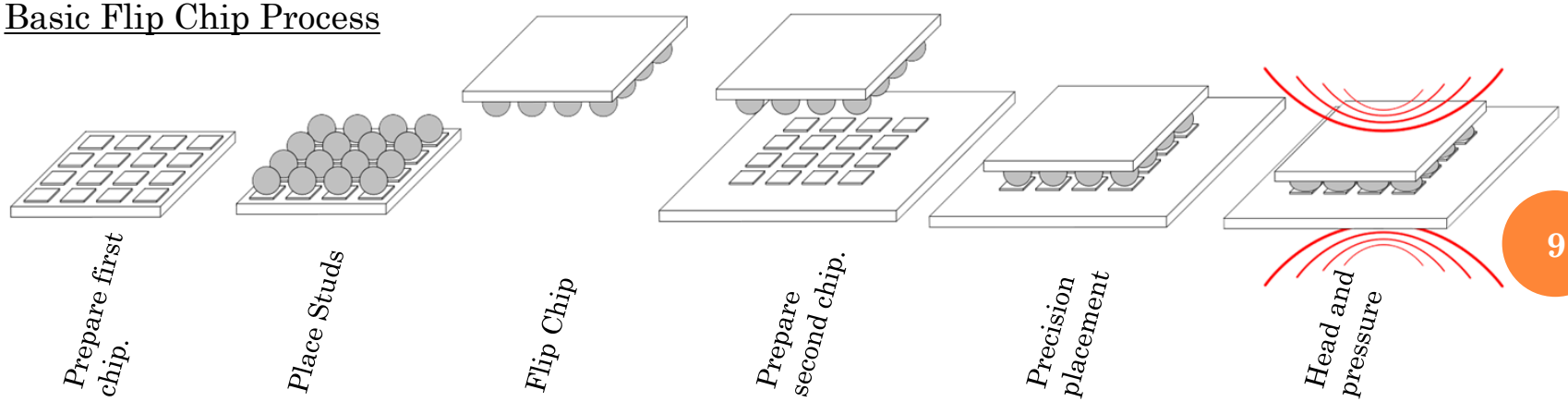


In House Flip Chip Bonding

- This is the machine that allows us to pick up and align the top chip with it's complement.
- See the process below.
- Achievable 5 µm precision alignment and repeatability.
- Fine control of heating profiles.
  - Start/Stop times and temperatures.
- Amazing machine to have!
  - Cut costs.
  - Cut down time.

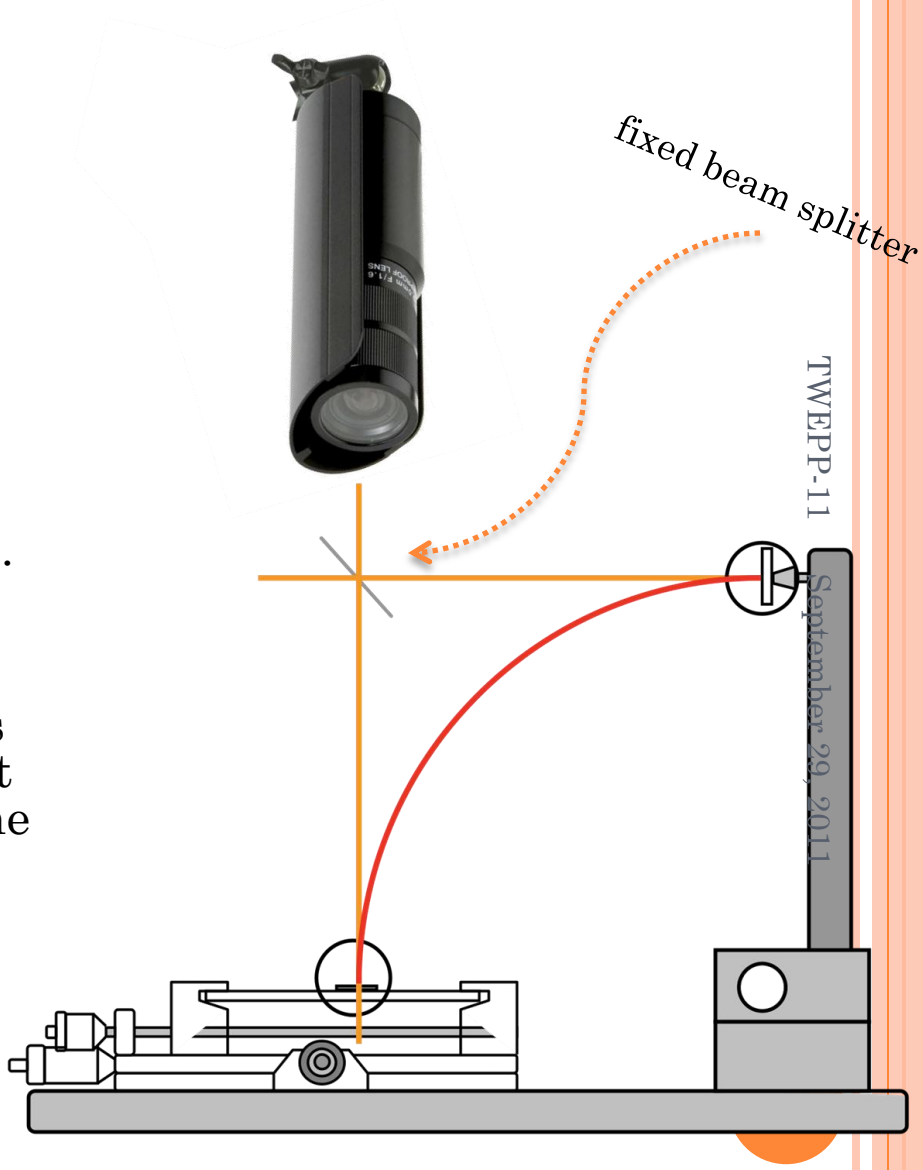


Basic Flip Chip Process



Alignment System

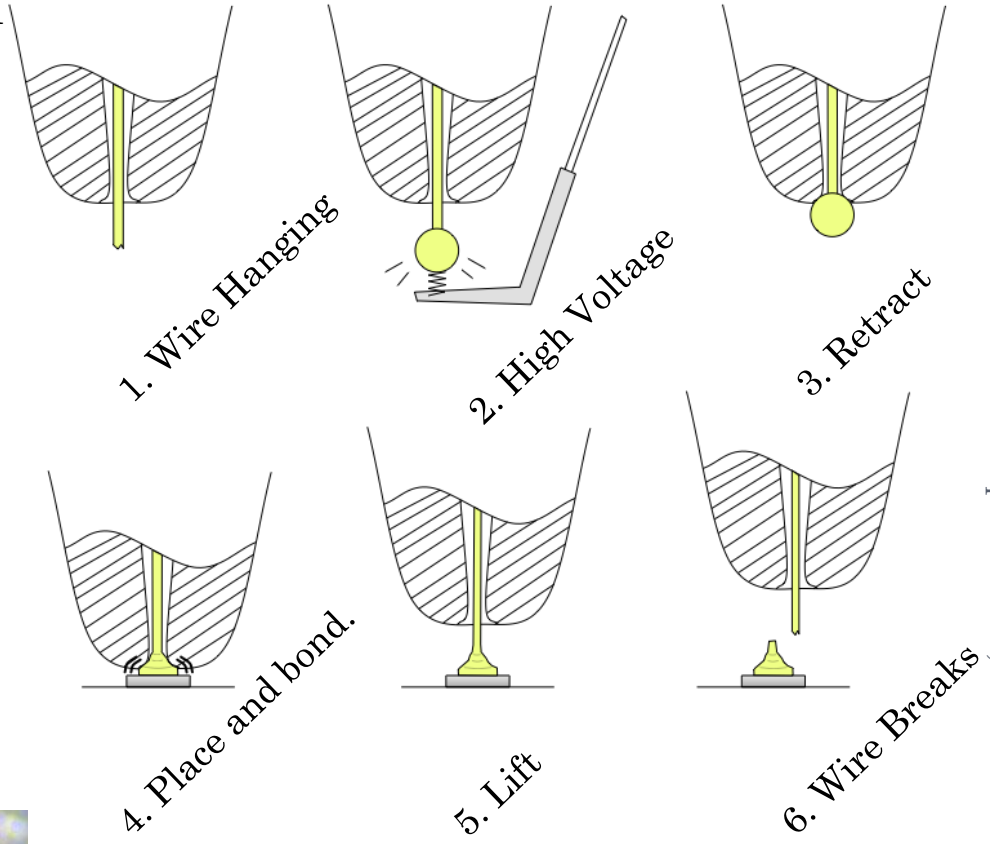
- The system uses a beam splitter to allow imaging of your top and bottom chips at the same time.
- Table floats on compressed air and is held in place my an electromagnet.
  - Fine, graduated x,y,z adjustment.
- Engineering a "what you see is what you get" motion.
  - Once visibly aligned, user rotates the top chip down and places it at exactly the position seen using the overhead camera.
- This is the keystone piece of equipment in our facility.
  - Utilized for each of the following techniques.

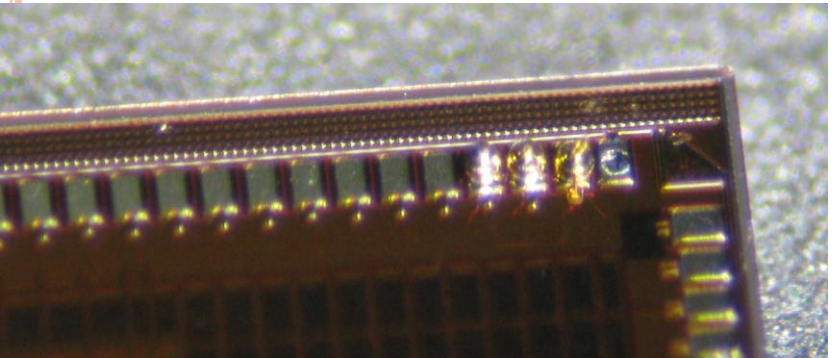


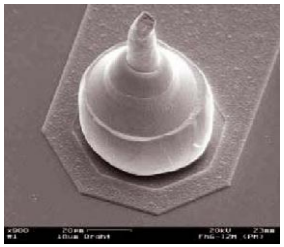
Gold Ball Bonding

Gold Ball Stud Bonding

- West Bond gold ball bonder in house.
  - Manual ultrasonic ball bonder.
- Great for prototyping.
  - No wet processes.
  - Fast (200 studs/hour)
- Less sensitive to metal stack of pads.
- Very low resistance.
  - 320 °C, 160 g/ball
- Well understood for most projects at hand.
- Ball size
  - 104 ± 4 µm Ø
  - 178 µm min. pitch.

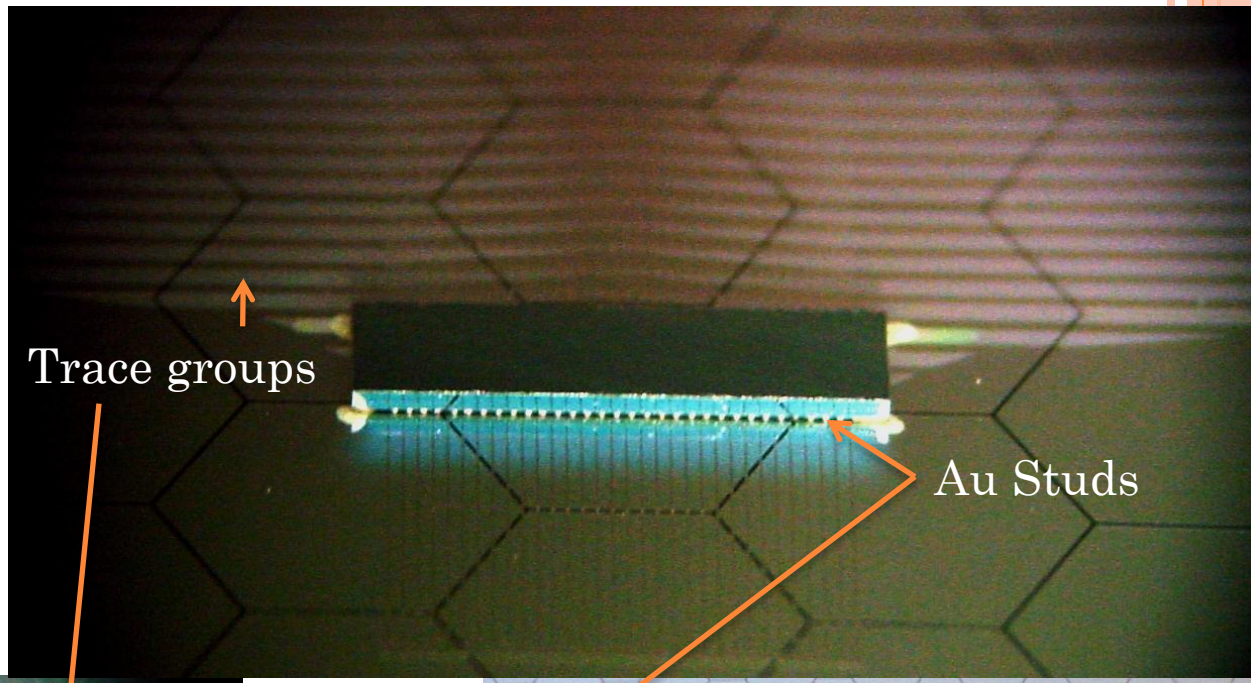


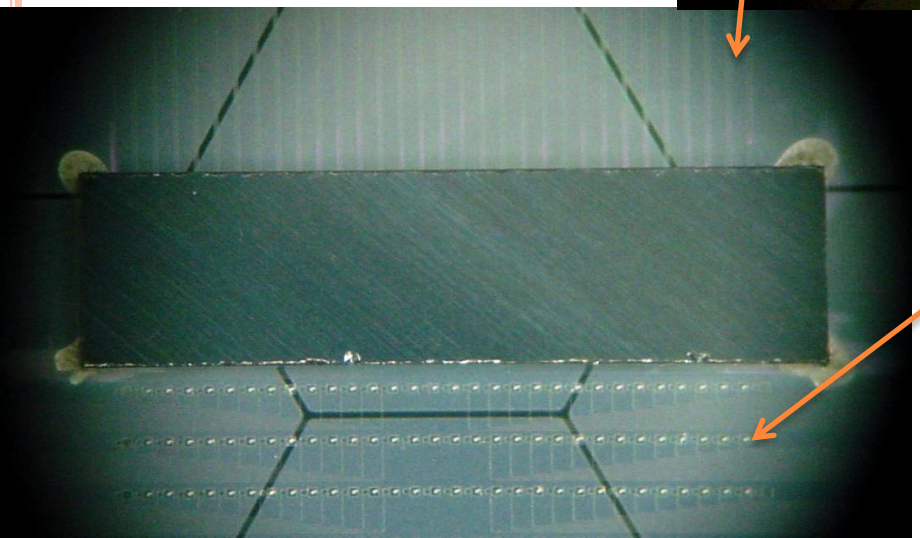


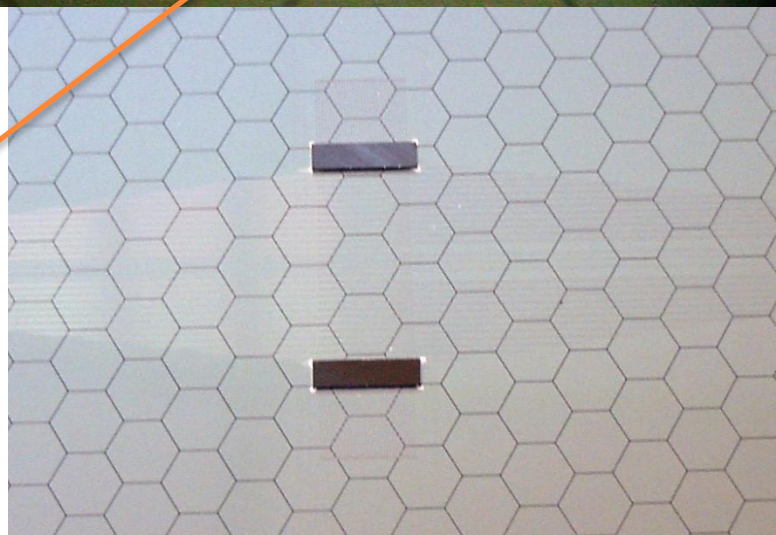


Au Ball Bump Bonding to Hamamatsu Sensors

- Visible application of Au balls.
- Was doomed to fail
  - Structure under bond pads damaged by pressure.
- Short term lesson:
  - Don't use Au balls
- Long term lesson:
  - Don't put circuitry under bonding pads (for Au).



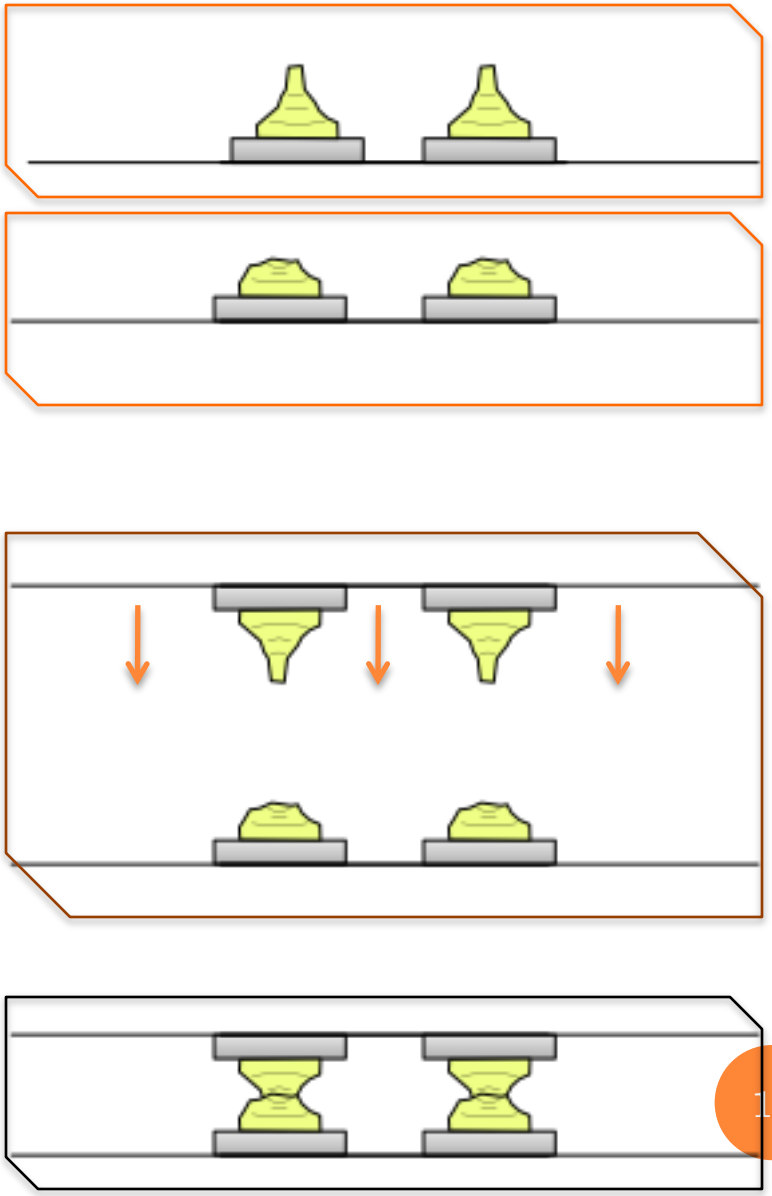




Double Gold Stud Ball Bonding

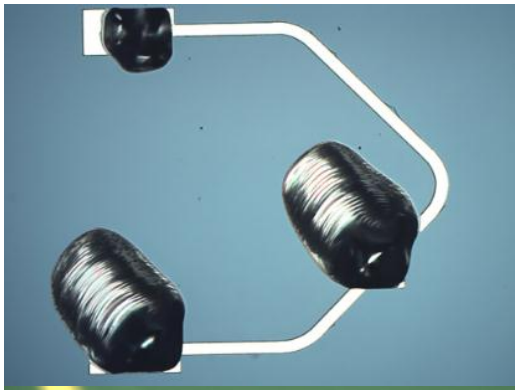
- Not traditional gold ball on top of a gold ball.

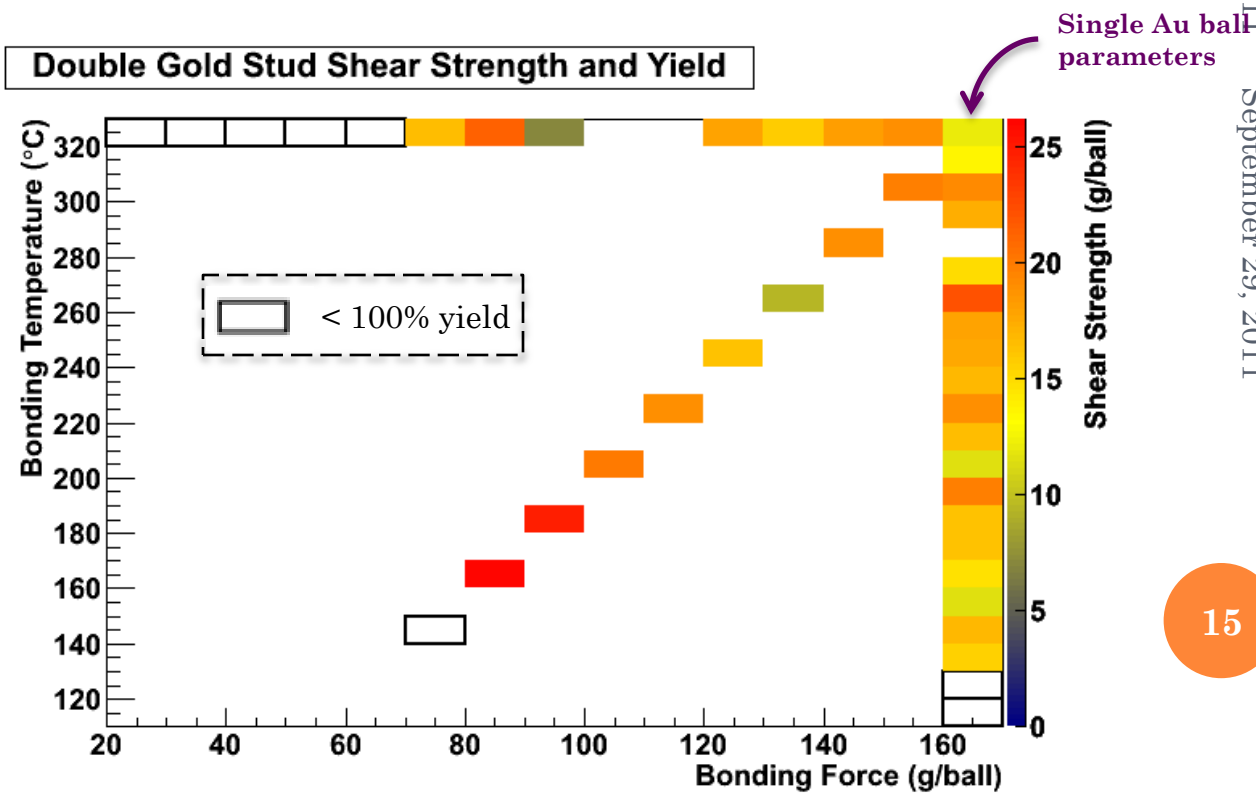
- Gold studs on each chip to be bonded.
- Coin one set of studs.
- Thermocompression bond.
- Goal
  - Take advantage of Au-Au bond properties.
  - Bond to two pads with metal stacks otherwise unsuited for Au thermocompression.



Double Gold Stud Ball Bonding

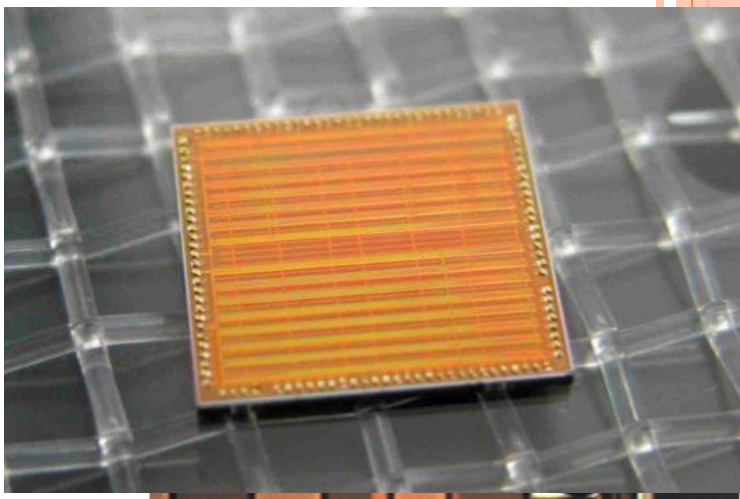
- Optimistic results.
- Quantifying bond with yield (% < 10 mΩ) and shear strength.
- Successful parameter bounds:
  - 70 g/ball (@ 320 °C)
  - 130 °C (@ 160 g/ball)
  - 160 °C @ 80 g/ball
- Failures usually *not* found at ball-ball interface.
  - Trace break (Cr-Al-Cr-Au)
  - Si break
  - Reported shear strengths lower bounds.
- Great promise for projects that have pressure and/or temperature requirements.

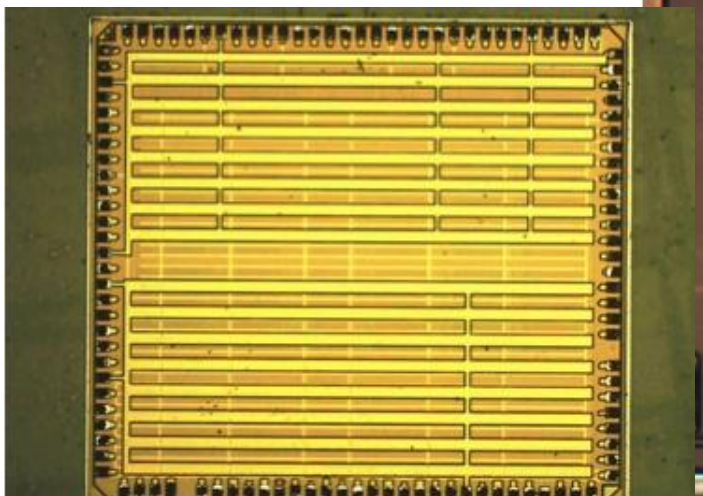


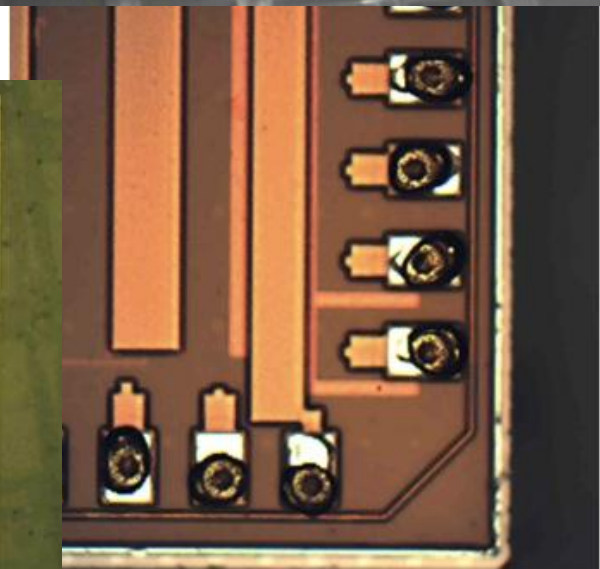


12 μM Au Wire

- Outfitted ball bonder with 12 μm (0.5 mil) gold wire.
  - Project specific: LAPPD
  - PSEC: waveform sampling ASIC
  - 4.4 mm x 4 mm
  - 130 μm pitch
  - 62 μm pad width
  - 118 pads
  - Al pads



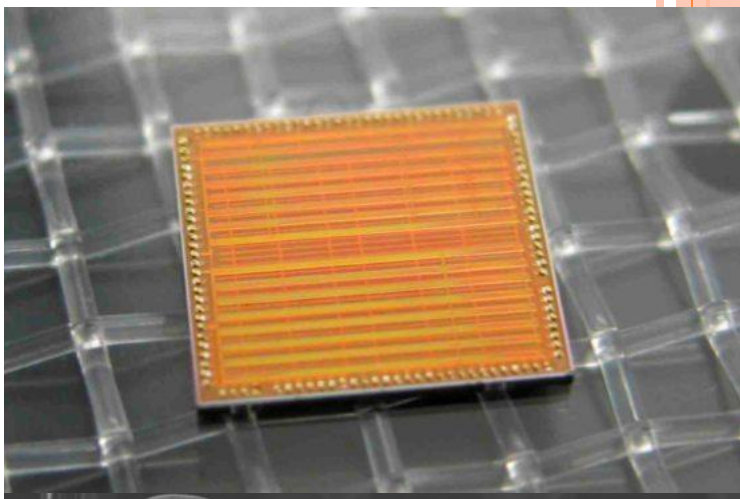


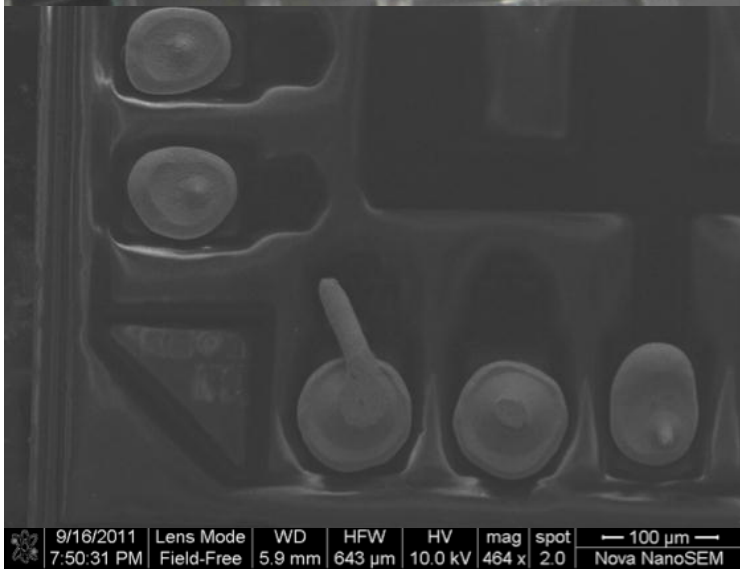


Thank you to: Henry J. Frisch, Gary S. Varner, Jean-Francois Genat, Mircea Bogdan, Eric Oberla

12 μM Au Wire

- Outfitted ball bonder with 12 μm (0.5 mil) gold wire.
  - Project specific: LAPPD
  - PSEC: waveform sampling ASIC
  - Al pads.
- Fickle beast.
  - Wire is less forgiving.
  - Sonication properties.
  - Suffer in speed.
  - Still working to master process.
- Comparison
  - Half wire thickness.
  - 87 ± 4 μm width (104 ± 7 μm)
  - ~120 μm min. pitch (178 μm)

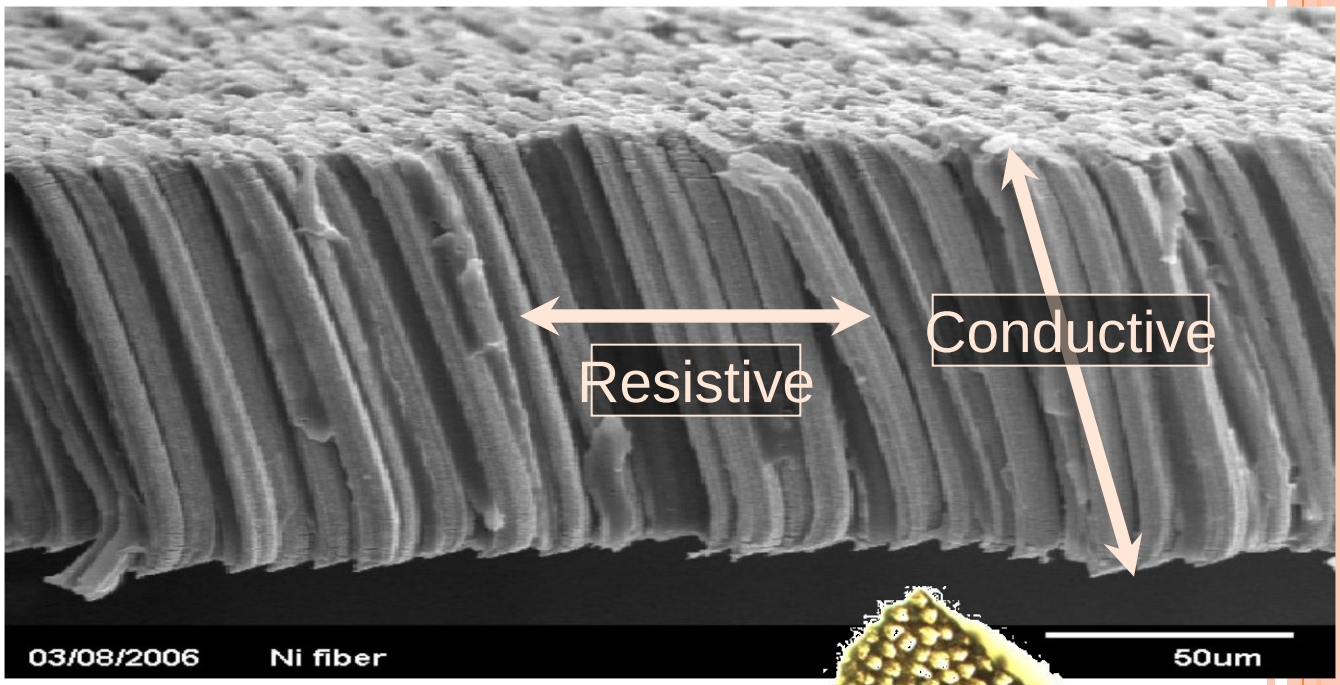




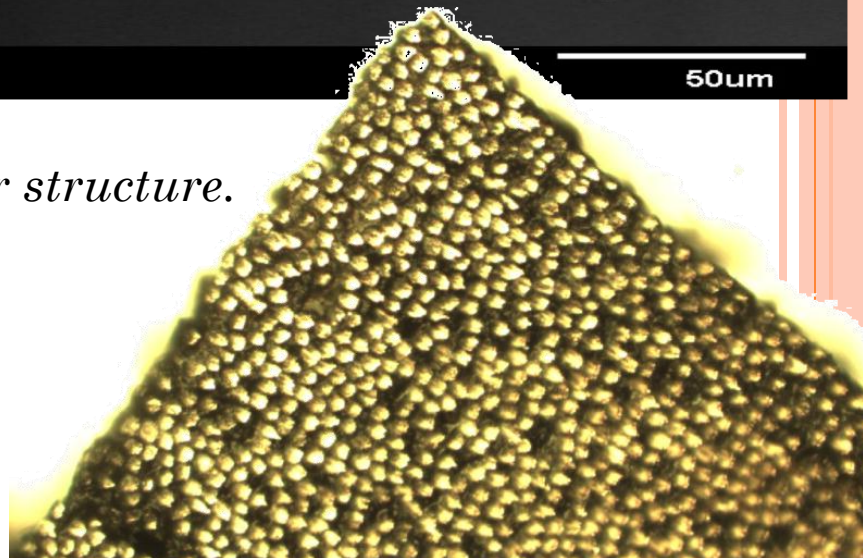
Anisotropic Conducting Film

Thermoplastic Conducting Adhesive

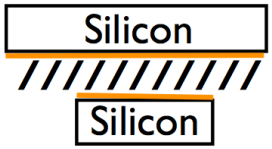
- **Btech**corp
- Metal fibers in a polymer matrix
- ~2 x 10^7 fibers/in^2
- Low Cure pressure: 50 psi
- Thermal Conductivity $\geq$ Cu.
- Smaller resistance
- Cheaper.



Nickel fiber structure.



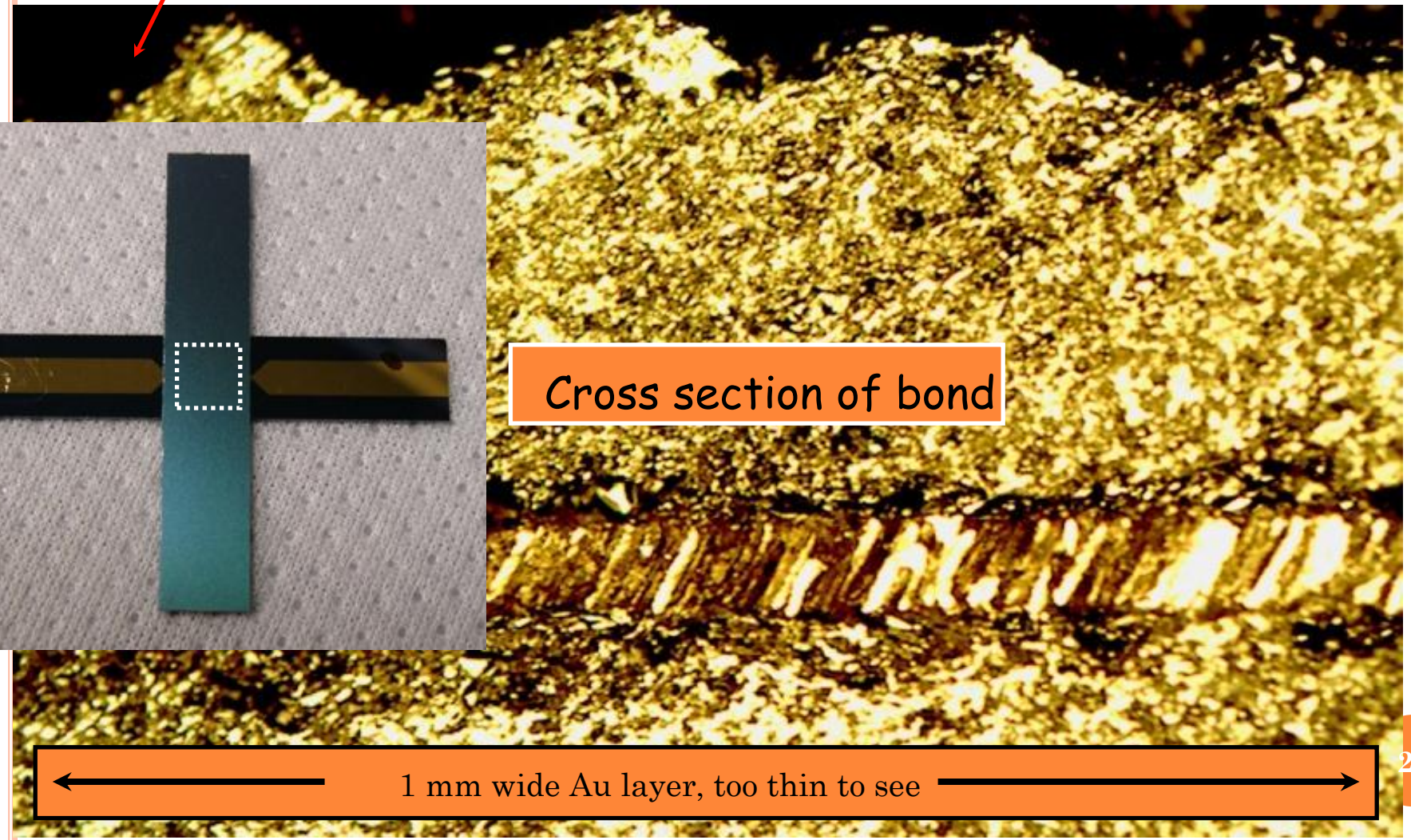
40x40 bond 11-22-10



Gold layer

Btech

Edge chips from slicing

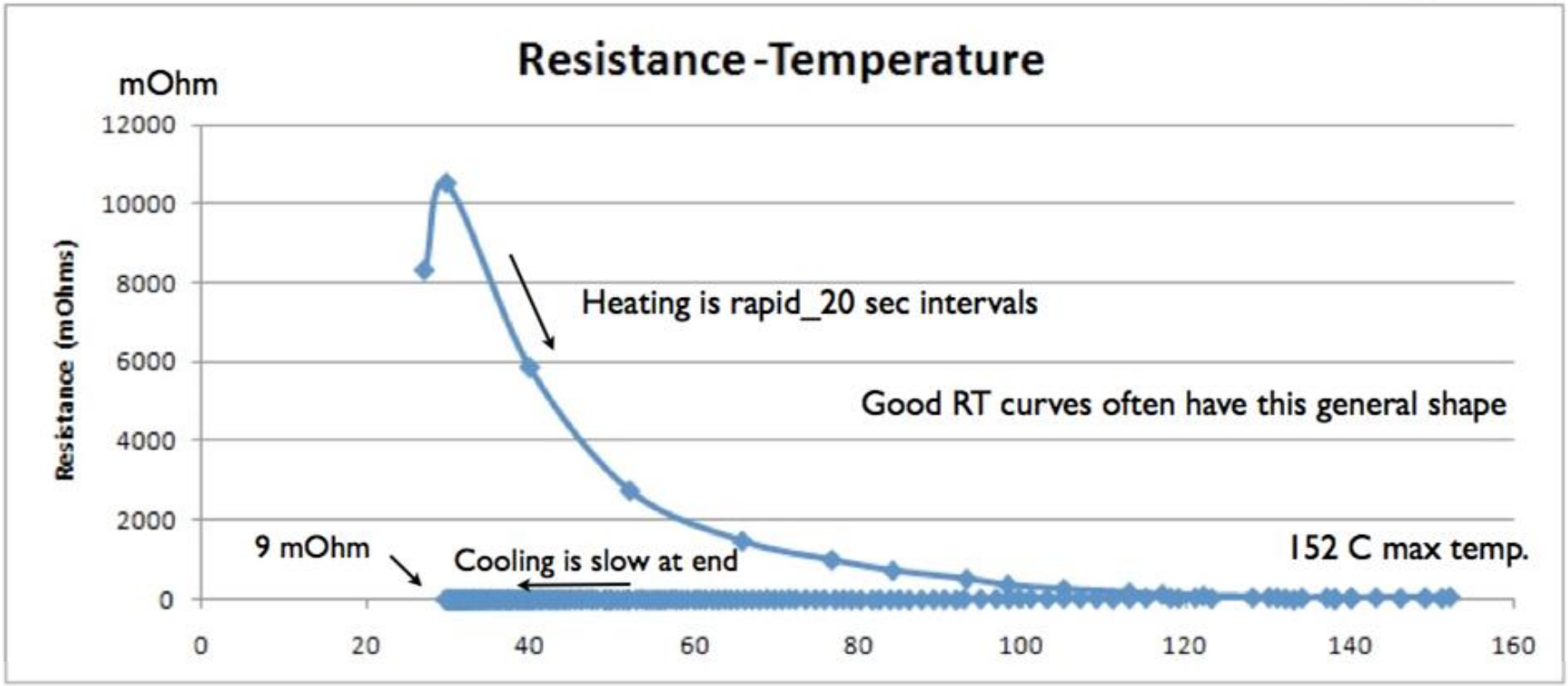


BTECH – RESULTS – SINGLE PAD

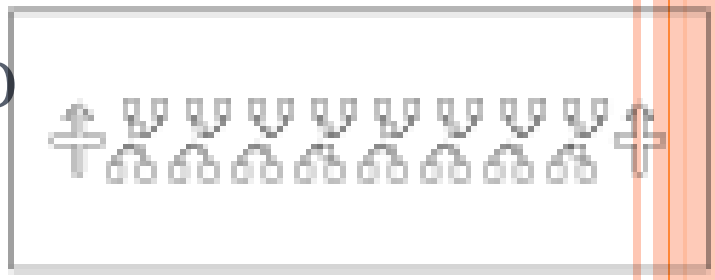
- The three larger pads (508, 762, 1016 µm) had resistances in the ten milliohm range: 4.5, 9, and 14 mΩ
- Five of six 254 µm pads had resistance < 1 Ω;
  the other was 3 Ω.
- Can watch as the resistance finalizes low.
- Proof of low resistance connections.
- Proof of small pad size bonds.
- Bonds can remain low resistance for months.

30x30 mil Au cross, 52.6 psi.
One hr. at 20 sec. intervals.

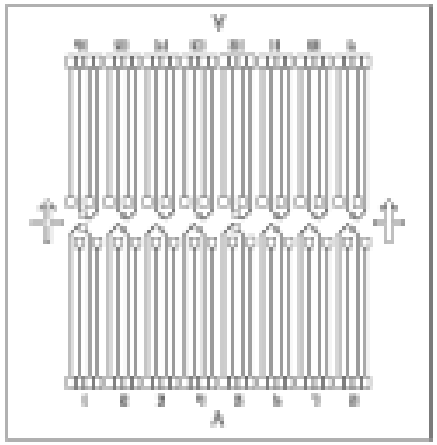
762x762 um

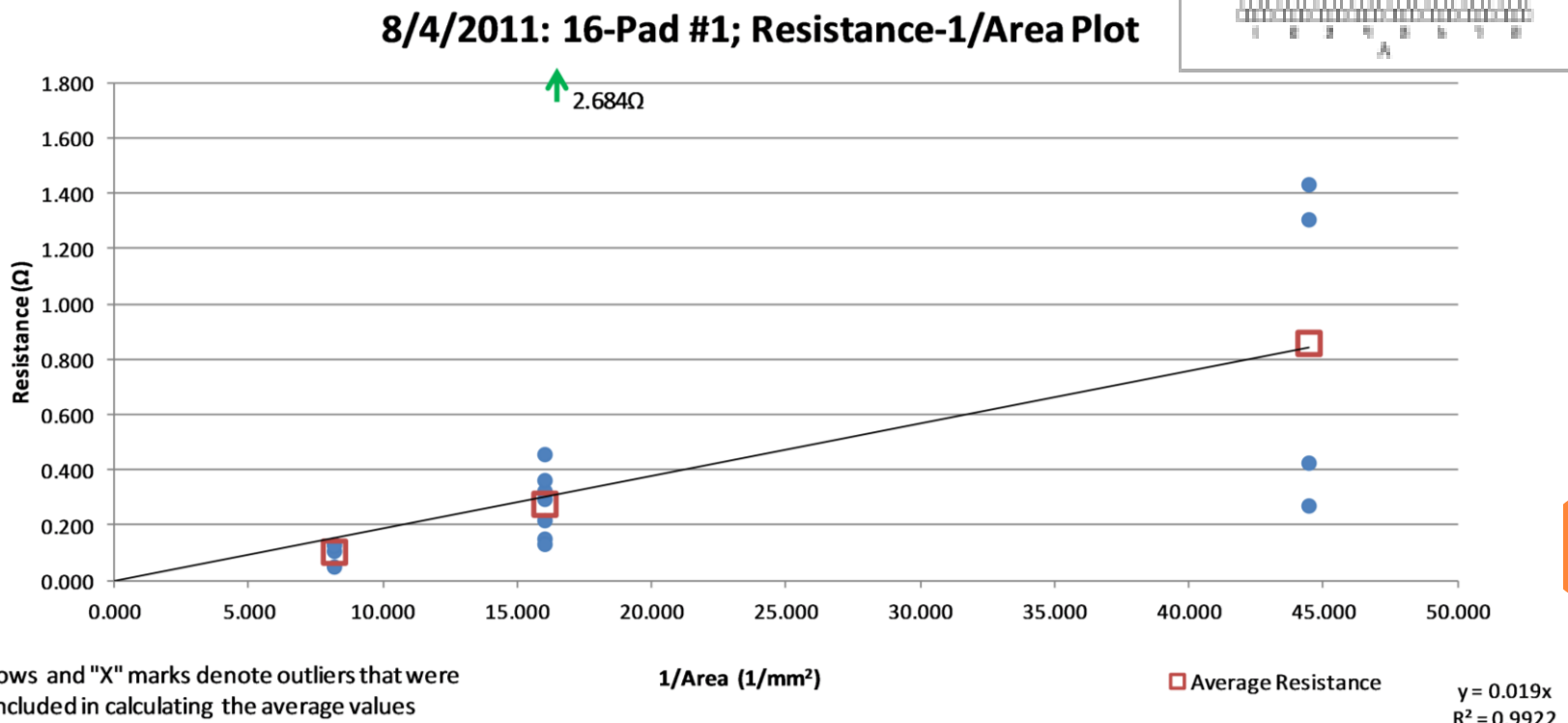


BTECH – RESULTS - MULTIPAD



- What Btech was meant for.
- The trend in four wire resistance follows expectations of inverse area.
- There is a large spread in results.
- There are outliers in most trials (no contribution to fit)
- Fixed at (0,0)





Solder Bonding

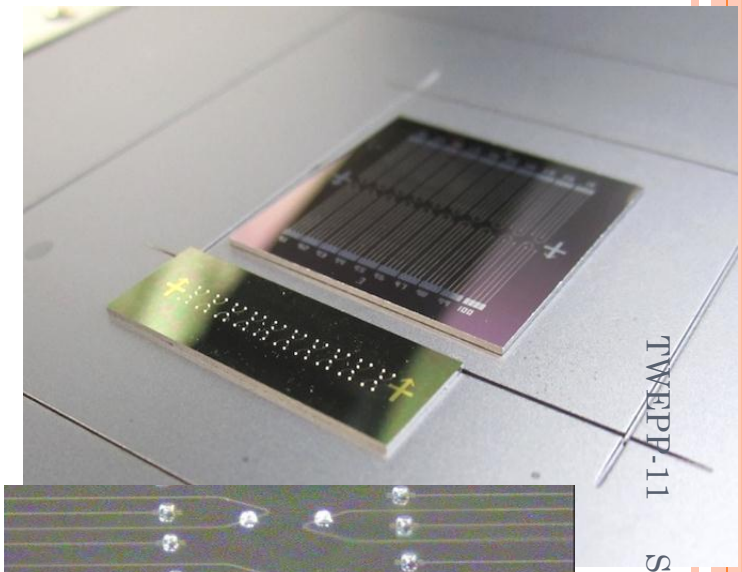
Requirements for Solder Bonding

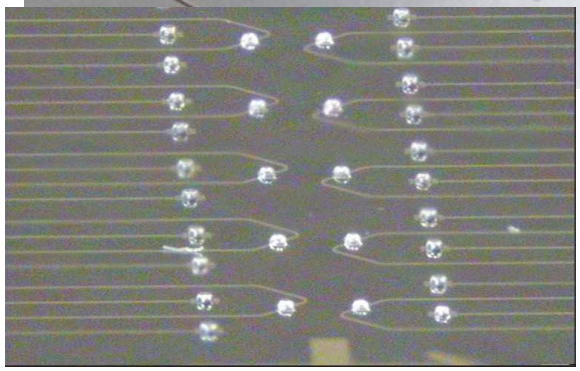
- Overcoming Oxidation
  - Basic Flux
  - Forming gas.
    - Removes oxides to enhance how wettable and bondable surfaces are.
    - 95% Nitrogen, 5% Hydrogen
  - CVInc provides our solder ball placement.
  - This includes a zincate process.
    - Remove aluminum oxide.
    - Deposit Ni (bonding)
    - Deposit Au (barrier)
  - Achieve good high temperature solder bonds.
    - High Temp SnPb
      - Melting point 183 ˚C
  - Achieve good low temperature solder bonds.
    - Low Temp InAg
      - Melting point 143 ˚C
      - Δ 40 ˚C

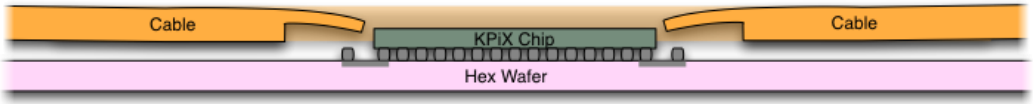
- Solder reqs for KPiX:

Test Chip Bonding

- Twenty pad dummy chips.
- Free floating top chip w/ solder.
- Contact heating from bottom.
- Need to iterate through the steps of the KPiX assembly.
  - Bonding KPiX at high temp.
  - Bonding flex cable at low temp.
- Can both solders exist on the hex wafer?
  - Not bonded low temperature solder must survive the high temperature solder bond.
  - Then high temperature SnPb solder bonds must be cycled at the InAg solder temperature.

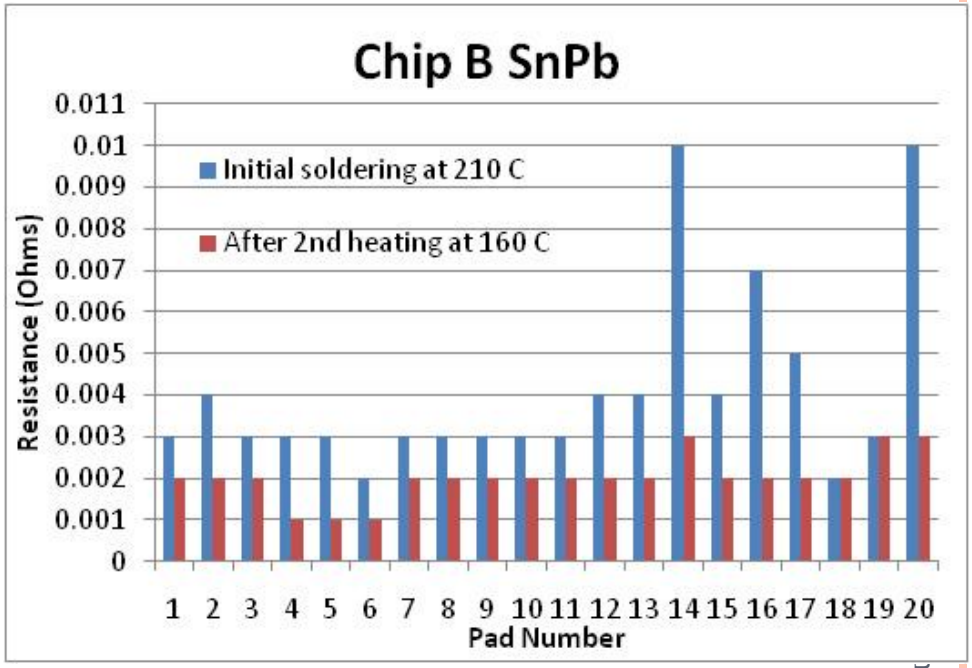






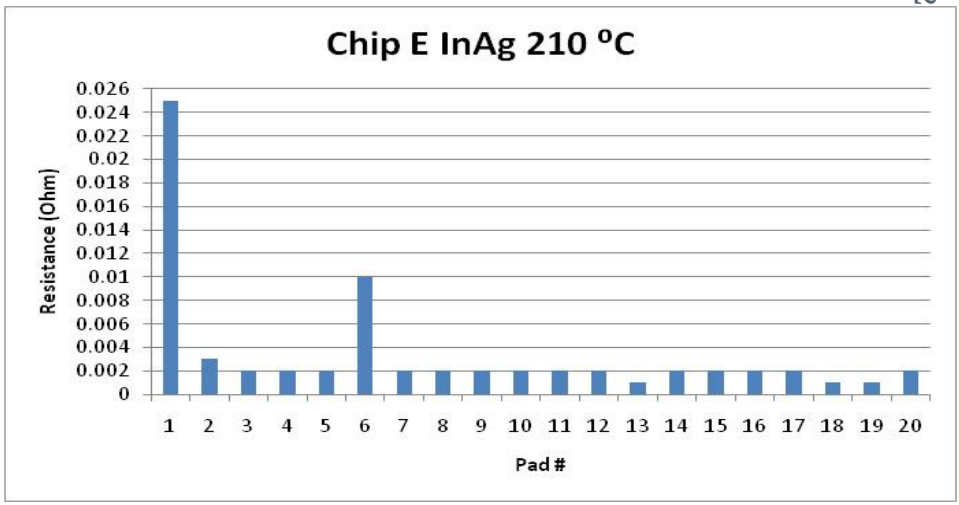
SnPb (High Temp) Solder

- Melting point: 183 °C
- Chip B soldered with 210 °C, then re-heated to 160 °C
- Successful mΩ solder bonds.
- Bond quality not diminished by low temperature heat cycle.



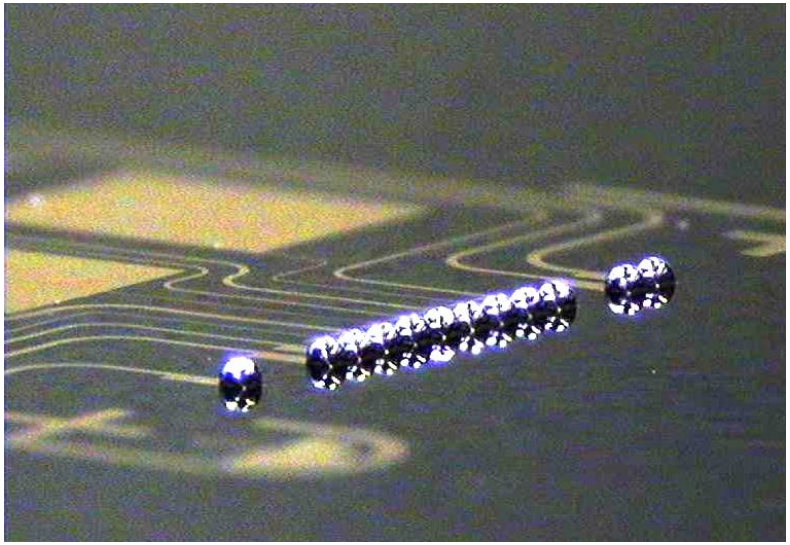
InAg (Low Temp) Solder

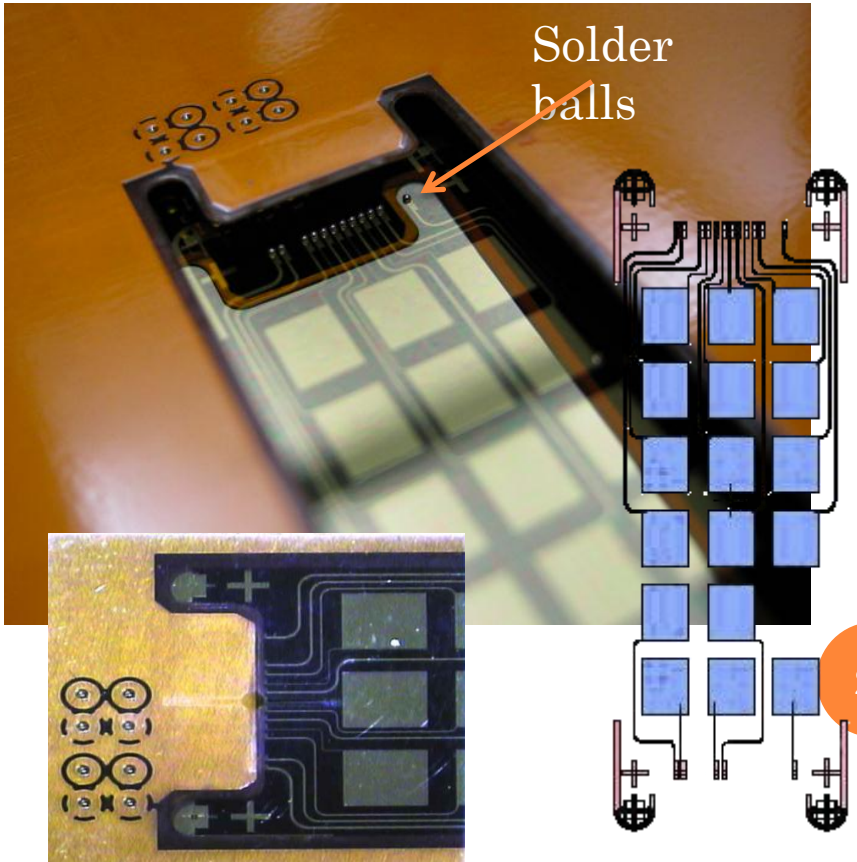
- Solder: 97% In 3% Ag
- Melting point: 143 °C
- Successful mΩ solder bonds at low temperature.
- Successful solder bonds when cycled to 210 °C before bond.



Back to ECAL assembly

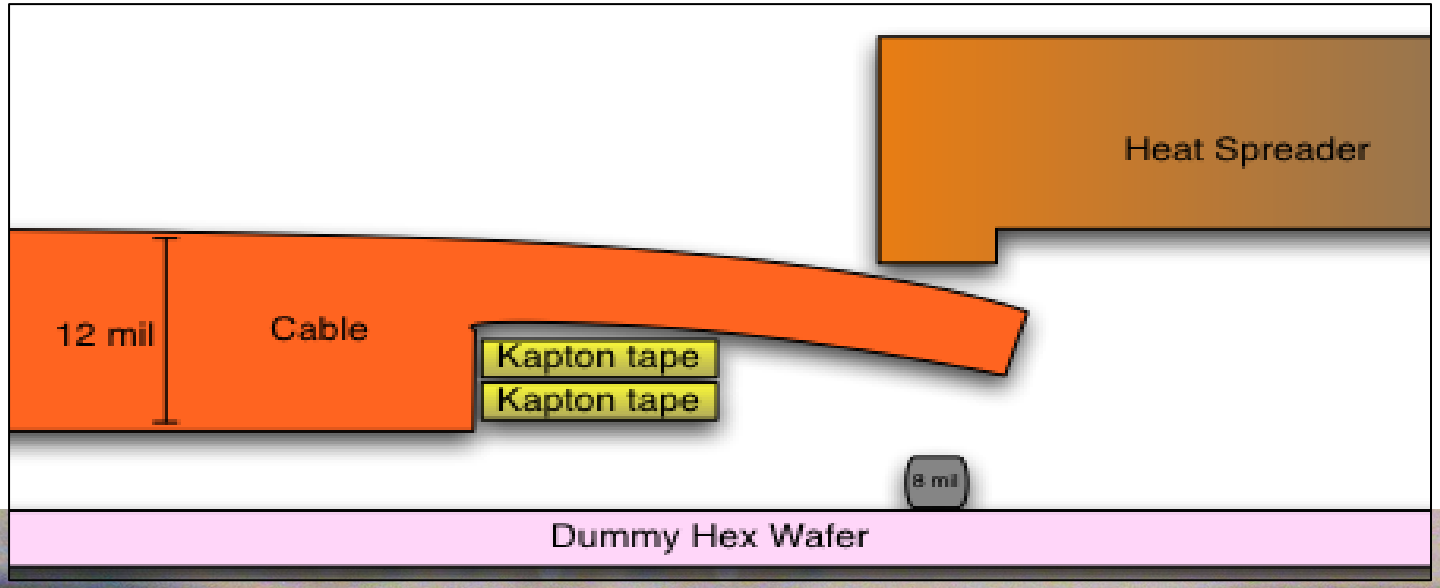
- After dummy chips, it was on to trials with prototype sensors and dummy hex wafers.
- Again placed by CVInc.

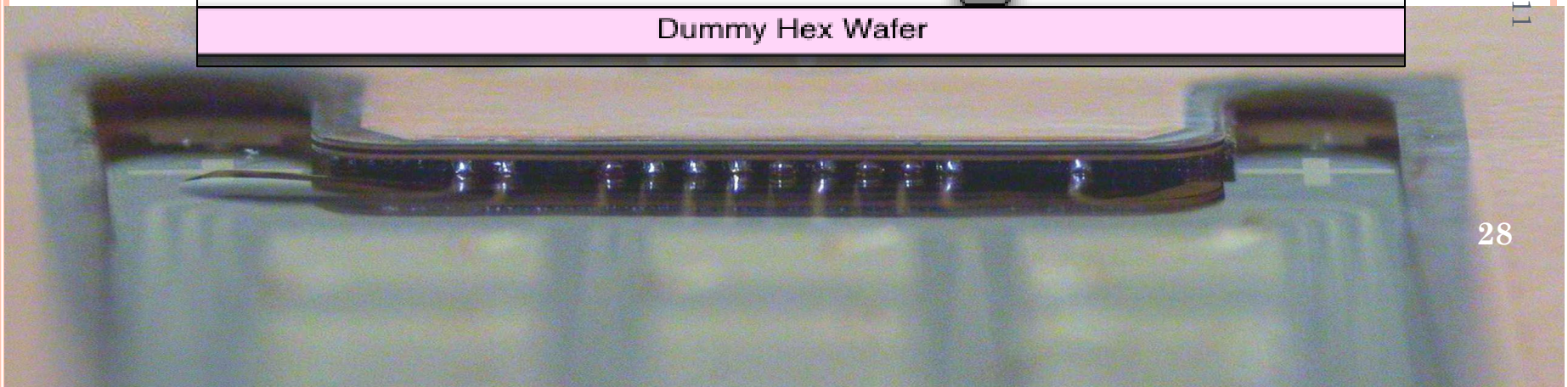




Good News, Bad News

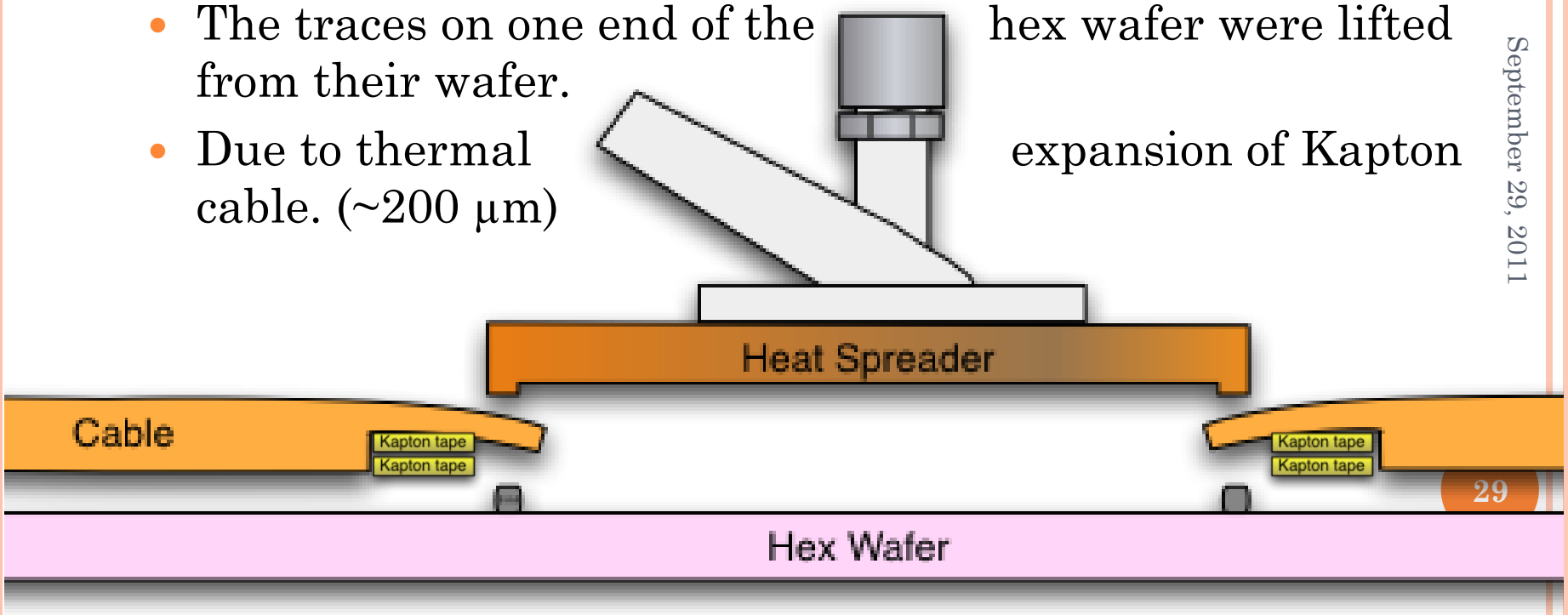
- Good News:
  - Successful bond achieved after developing spacing/compression controls.





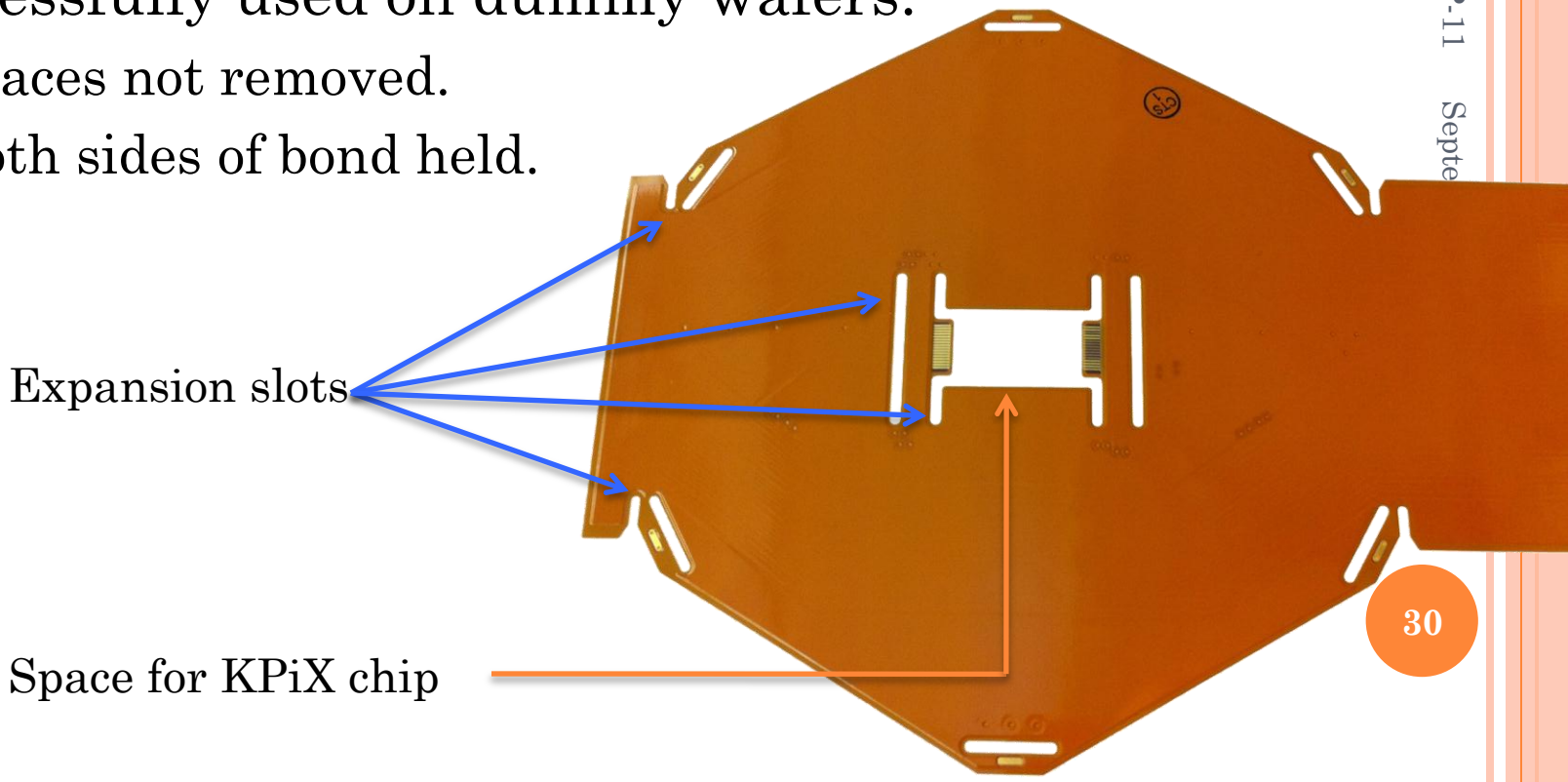
Good News, Bad News

- Good News:
  - Successful bond achieved after developing spacing/compression controls.
- Bad News:
  - The traces on one end of the hex wafer were lifted from their wafer.
  - Due to thermal expansion of Kapton cable. (~200 μm)



Mod Flex Cable

- Slots cut into the kapton flex cable allows sections of the cable to involved with bonding to remain in place during heating in light of CTE mismatch
- Successfully used on dummy wafers.
  - Traces not removed.
  - Both sides of bond held.



Conclusions and Outlook

- Assembly of the ECAL components are being developed as fast as the components are being supplied.
- Overcome all problems we've been presented so far.
- Next on the list:
  - Our Hamamatsu detectors are non-bondable!
  - An invisible barrier?
  - Disrupts zincate process.
- Continued development of other interconnect technologies like double gold stud bonding for HEP applications.