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.
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 its 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

- Prepare first chip.
- Place Studs
- Flip Chip
- Prepare second chip.
- Precision placement
- Head and pressure
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 by 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.

![Double Gold Stud Shear Strength and Yield](image-url)

Single Au ball parameters

- < 100% yield

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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.
  - $87 \pm 4$ µm width ($104 \pm 7$ µm)
  - ~120 µm min. pitch ($178$ µm)
ANISOTROPIC CONDUCTING FILM
THERMOPLASTIC CONDUCTING ADHESIVE

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

Nickel fiber structure.
Cross section of bond

Edge chips from slicing

1 mm wide Au layer, too thin to see

Silicon

Gold layer

////// Btech
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.
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)

8/4/2011: 16-Pad #1; Resistance-1/Area Plot

*Arrows and "X" marks denote outliers that were not included in calculating the average values

\[ y = 0.019x \]

\[ R^2 = 0.9922 \]
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.

Expansion slots

Space for KPiX chip
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.