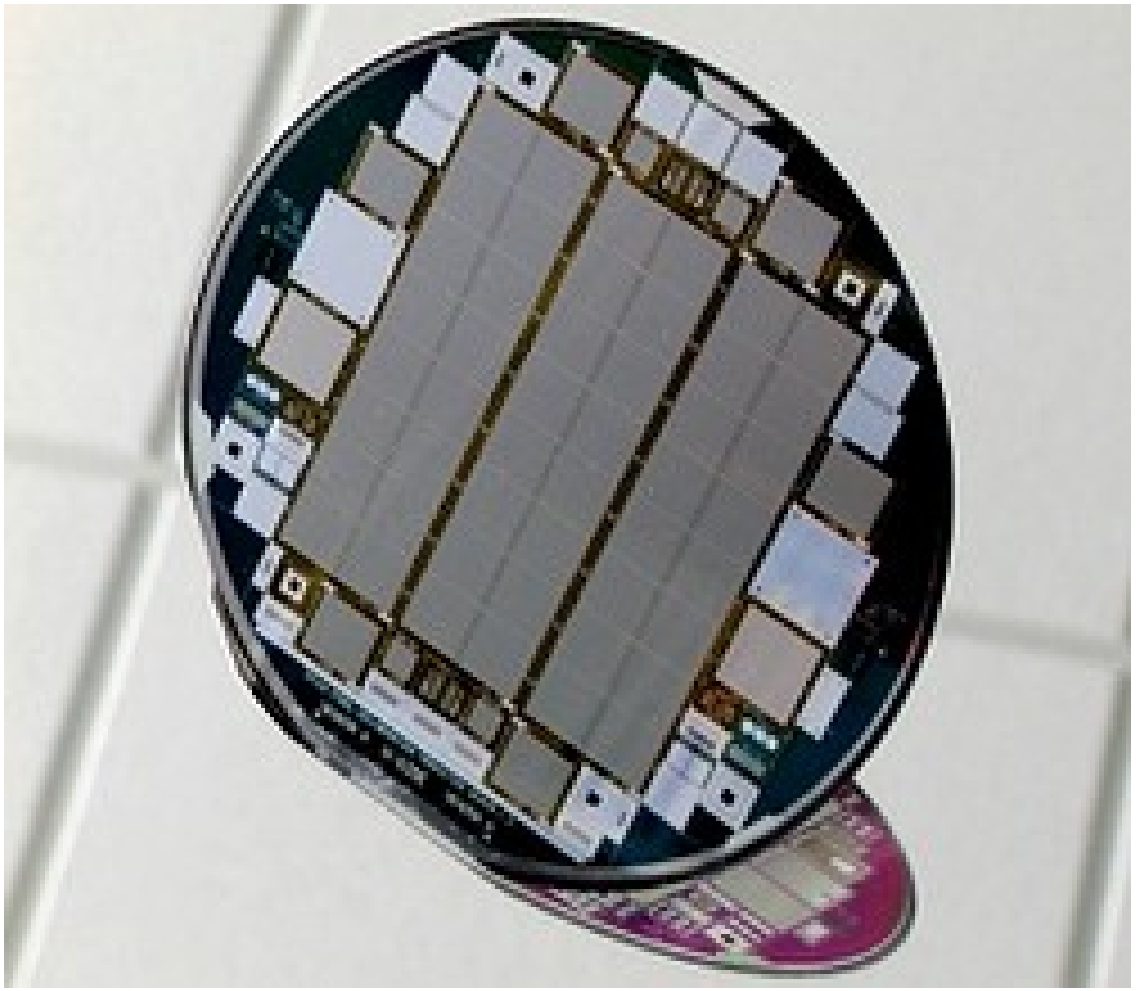
Bump bonding studies

Jan Hampe, DESY FEC
Daniel Pitzl, DESY CMS
PSI visit, 25.1.2012

- Bump bonding at IZM would be the most expensive task in the pixel upgrade project.
- Search for alternative:
  - Bump placement without wet chemistry and lithography: solder ball technique from PacTech!
  - Flip chip bonding at DESY: which bonder to buy?
- First results on pixel test structures.

CMS Pixel Sensors



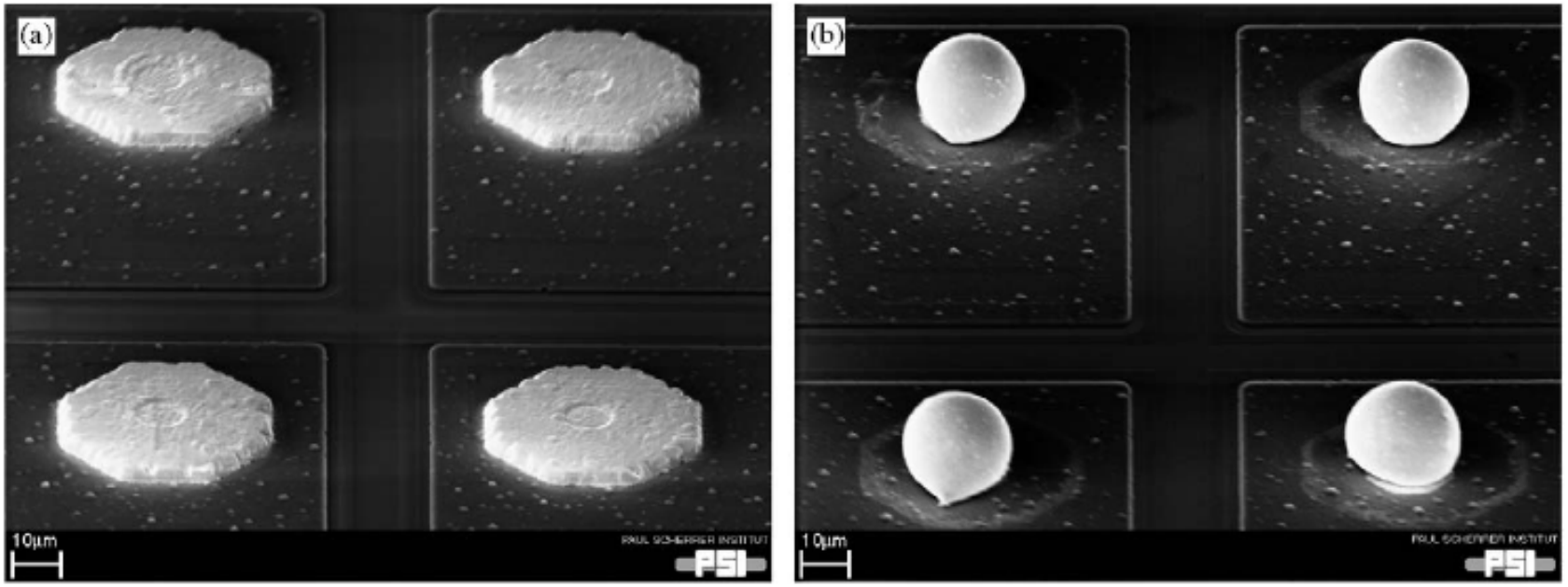
design: Tilman Rohe, PSI

- 60 wafers under production at CIS (Erfurt)
  - standard CMS pixel sensor design (double sided, n-in-n, p-spray insulation).
  - for Karlsruhe, INFN, CERN/Taiwan, MRI, Purdue, DESY.
  - 5 wafers with increased bump pad passivation opening: 30 µm, for DESY.
  - Delivery in Feb 2012.
- Full sensors for first bump bondings.
- Single chip sensors for tests with new ROCs.

CMS Pixel bump bonding

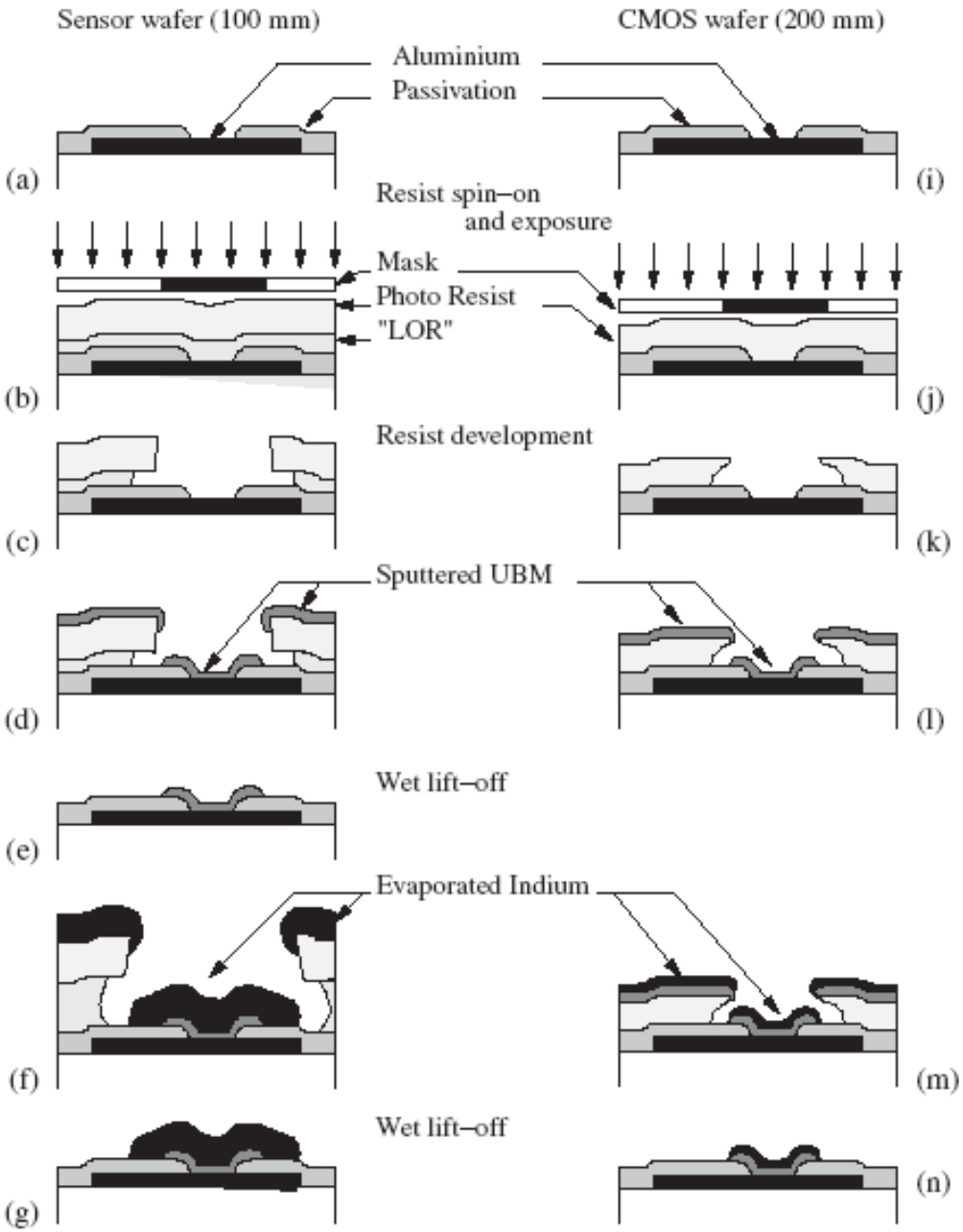
Deposit bump material
in a planar process:
sputtering,
photo lithography,
etching:

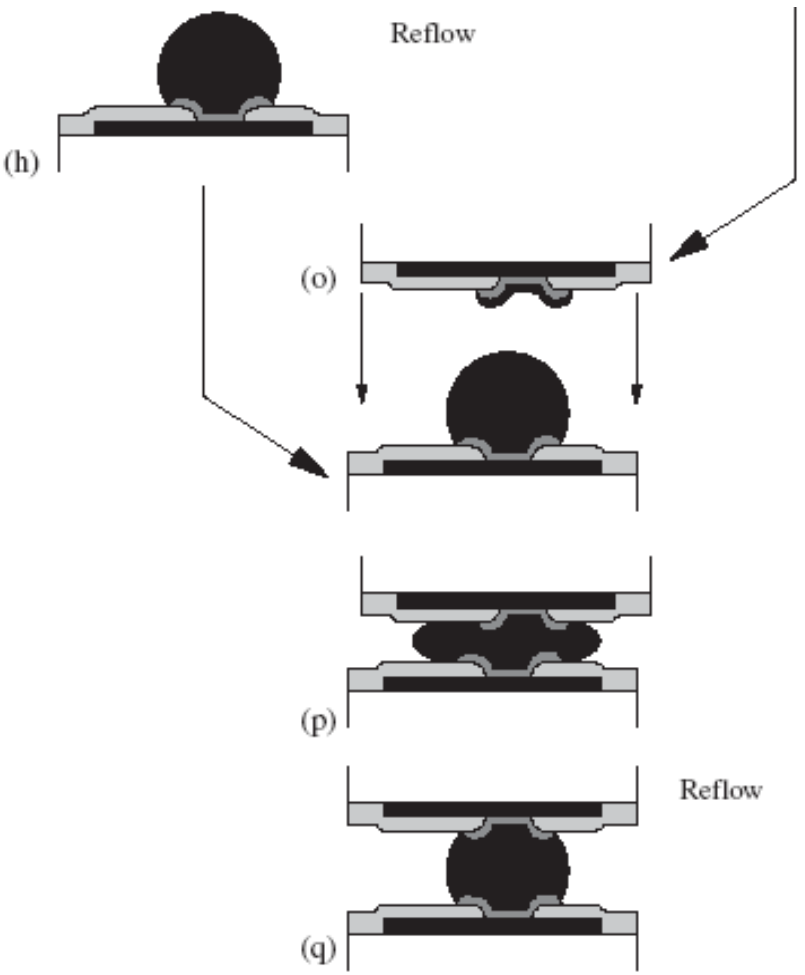
Form bumps by melting
in a re-flow oven:



PSI process uses Indium: low melting point at 156.6°C.
Not favored by industry: brittle, long term stability?

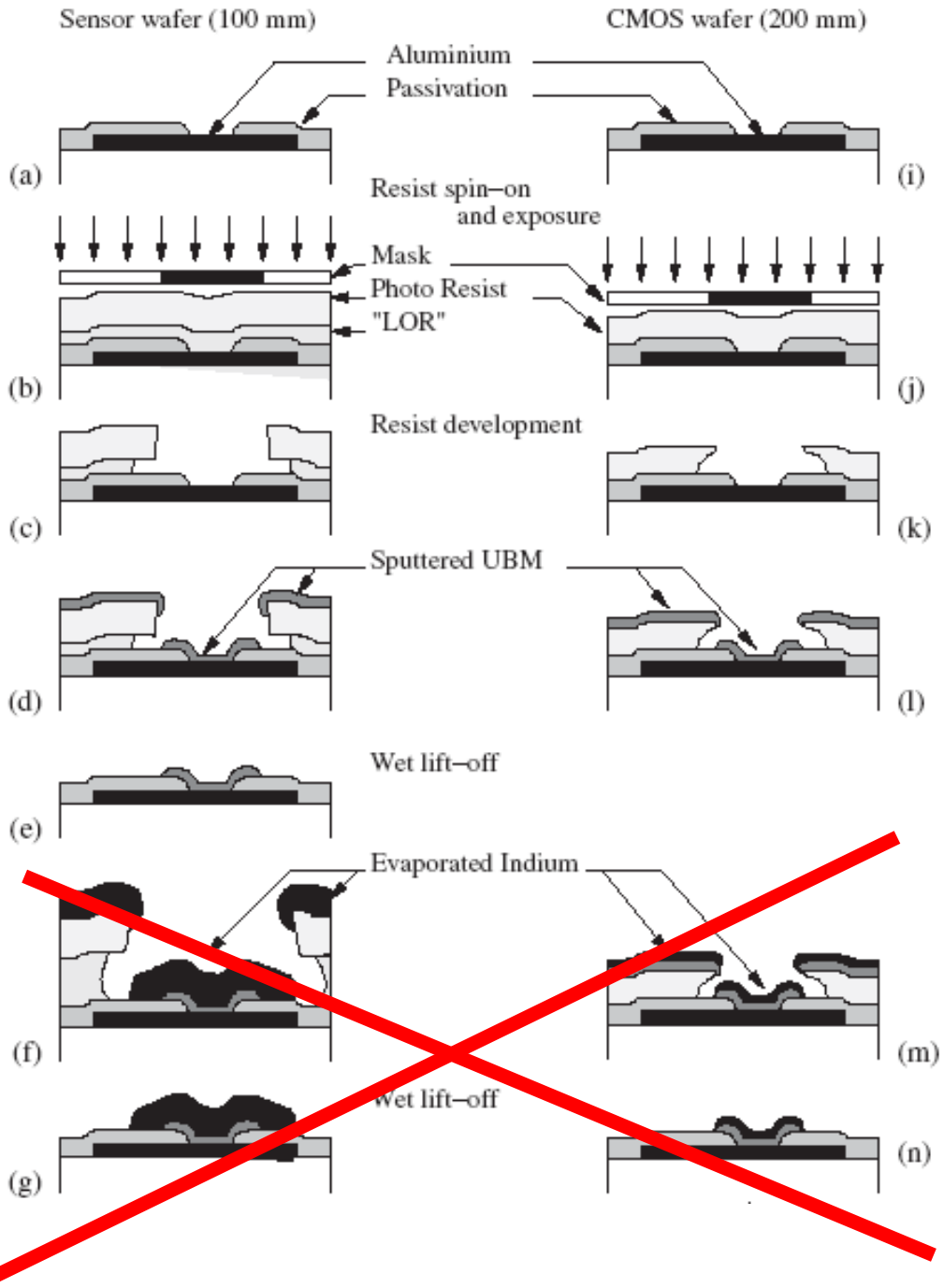
Bump deposition and flip chip bonding



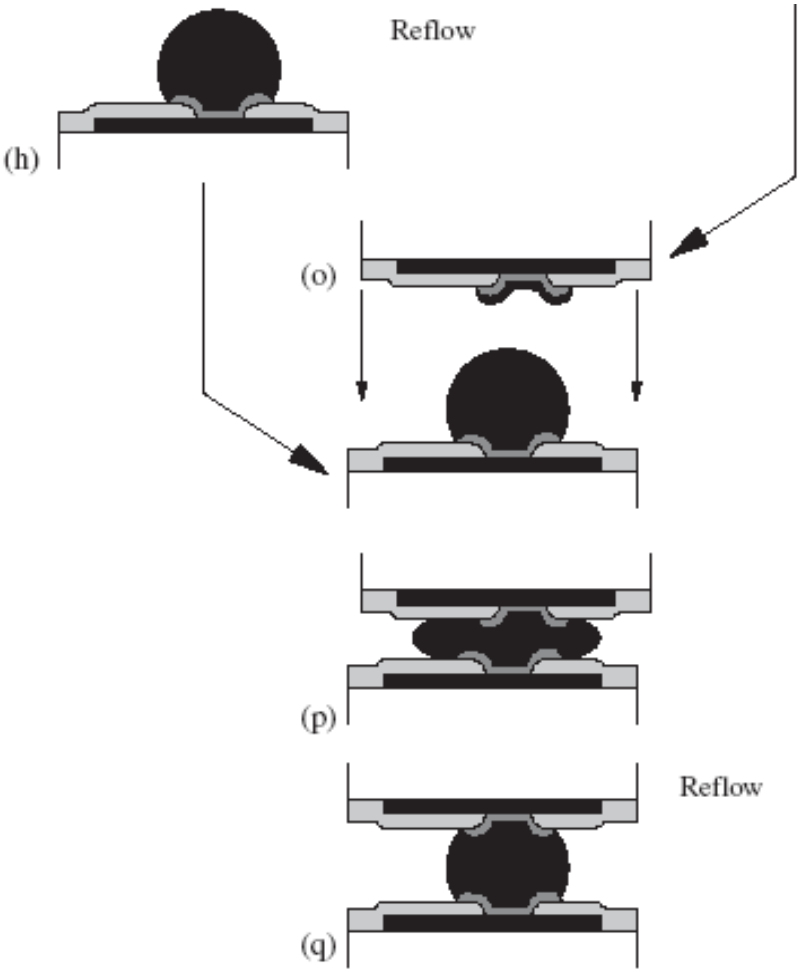


Ch. Broennimann et al.: Development of an Indium bump bond process for silicon pixel detectors at PSI NIM A565(2006)303-8

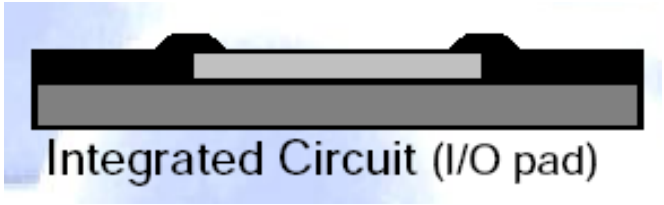
Alternative

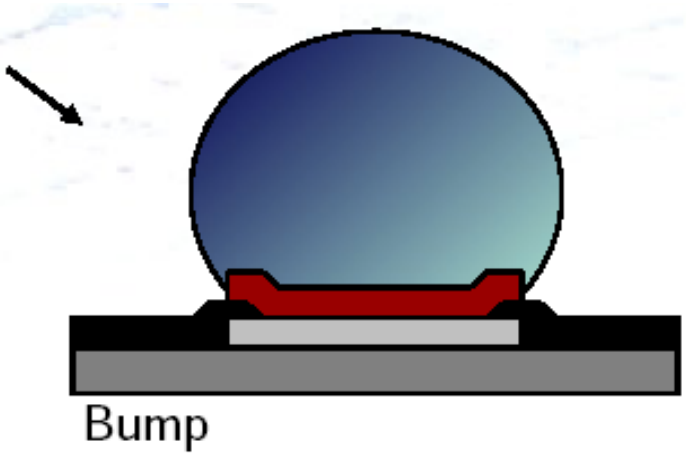


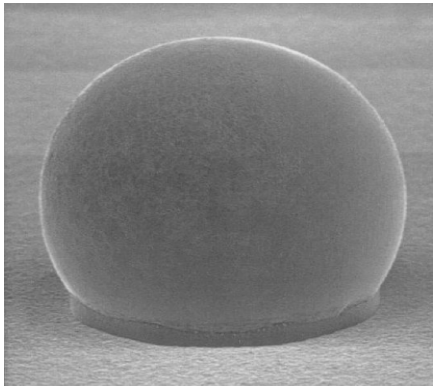
- Still need under-bump metal UBM
- Deposit bump ball directly
- Flip chip bond as before

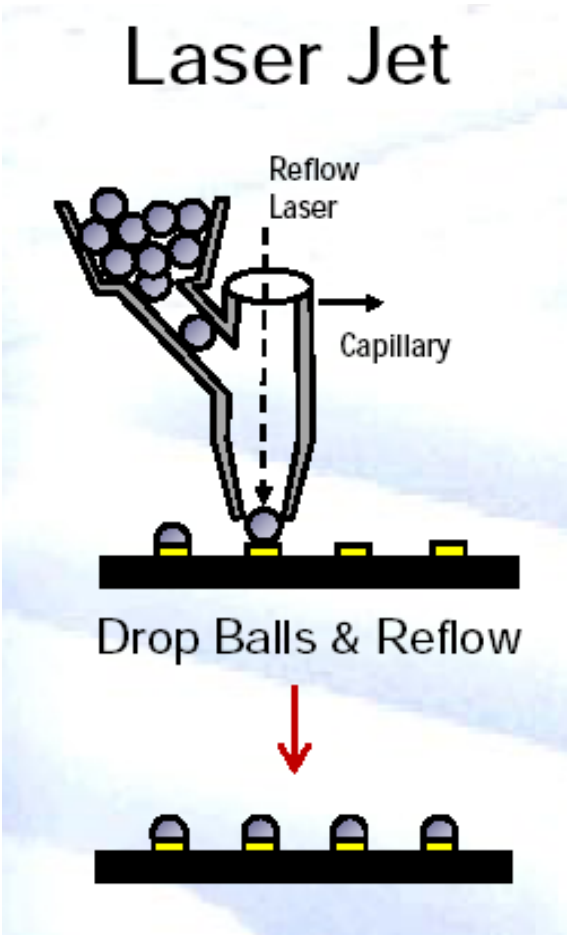


PacTech solder ball laser jet









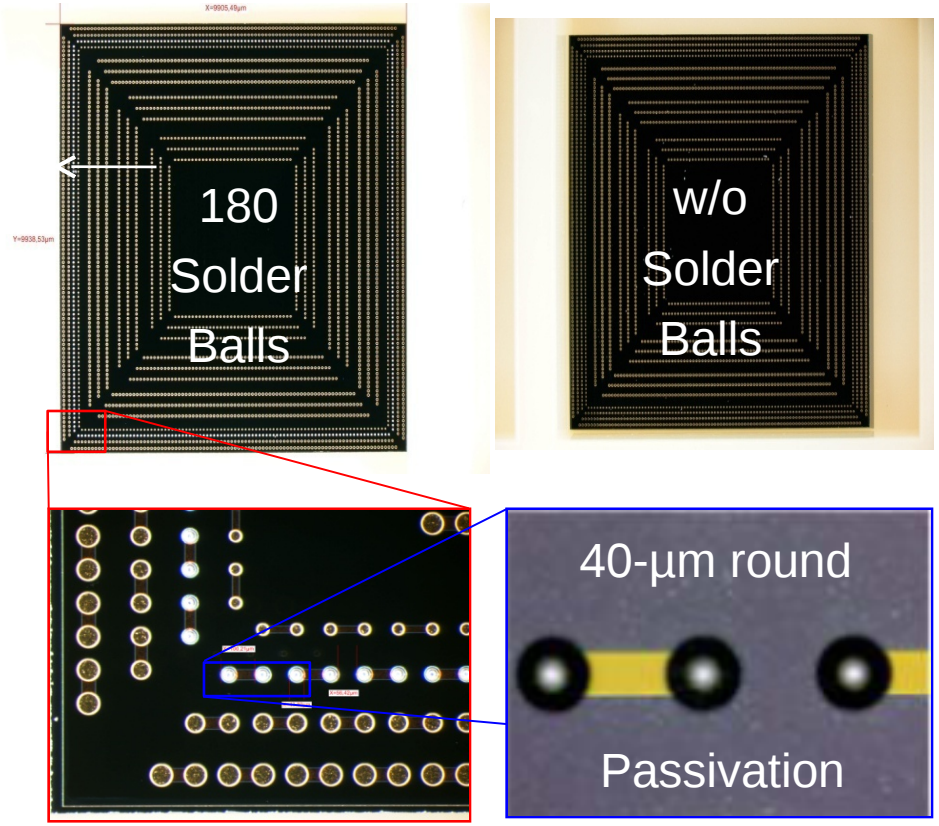
- Start with high-precision balls.
- 40 µm balls at 80 µm pitch possible now.
  - 30 µm balls being certified.
- Drop through capillary towards pad.
- Melt by laser pulse during fall.
- Solidify on pad.
- Step-motor controlled.
- 5 balls / second.

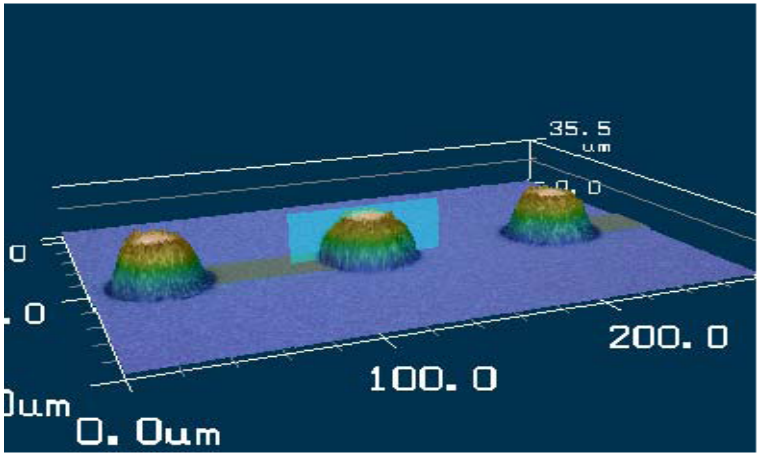
http://www.pactech.de/index.php?option=com_content&view=article&id=154&Itemid=21 pub 68

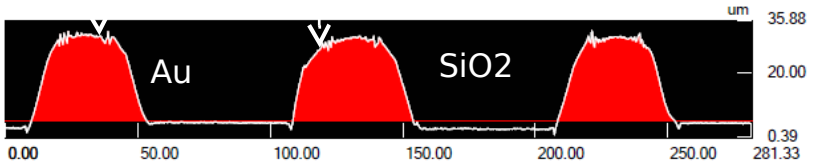
PacTech test structures

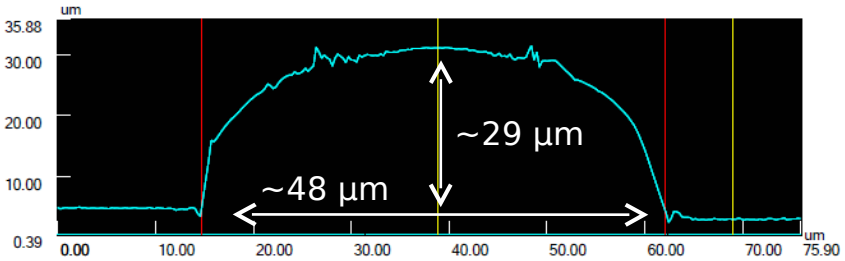
Pac 2.7 Wafer from Pac Tech GmbH

- Two 200-mm Wafers with 275 Chips each
- 5-µm electroless Ni/Au UBM on both
- 40-µm SAC305 Solder Jetting with SB2 on one
- Wafer Sawing & Chip Singulation







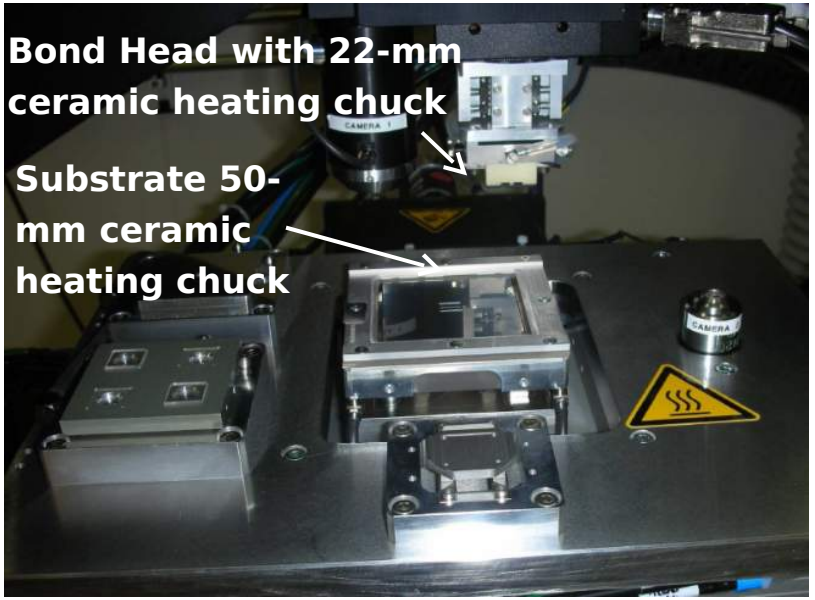


Available since Dec 2010.
Used with 4 machines/vendors.
Only 180 bumps / chip.
Diagnostics difficult.

Bump bonding tests with Kadett at SET

Flip-Chip Bonder *Kadett* from S.E.T.

High-Accuracy
Placement
&
Semi-Automatic
Device Bonder



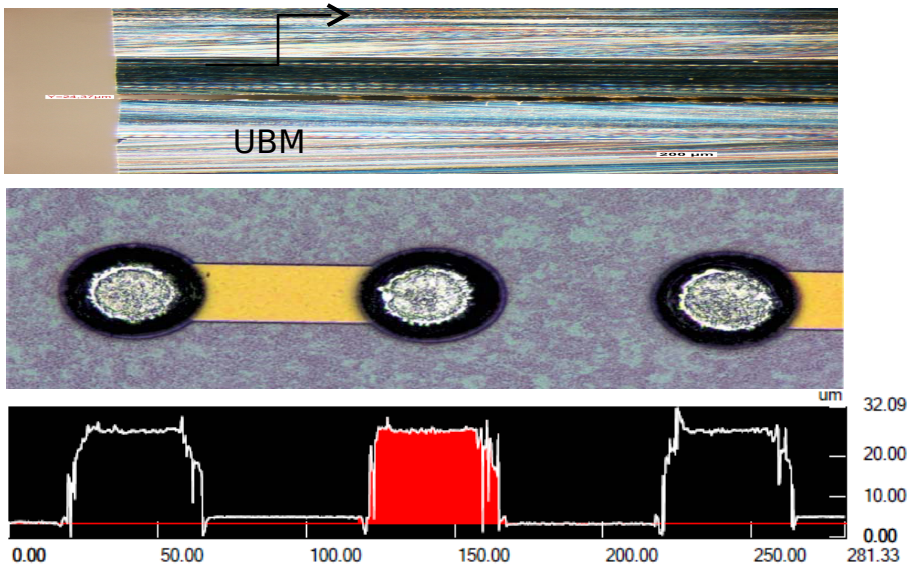
Tacking-Cycle Parameters:

automatic Alignment: diagonal B2B

Chip & Substrate Heating: 25 ... 200°C, 0 ... 20 s

Force Adjustment: 1 ... 6 kg, 5 ... 20 s

example: 1 kg in 5 s @ 163°C in 10 s
sheering test:



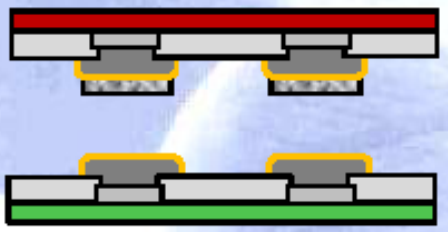
Compression: appr. 8 µm

Shear Force: 1.8 kgf → 55 mN / Bump

Karsten Hansen, DESY FEC

Laser flip-chip bonding

1) Pickup Die & Align
(±5 µm)

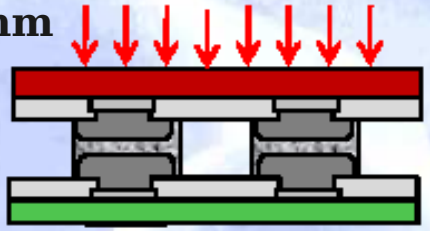


2) Contact
(10kgf)

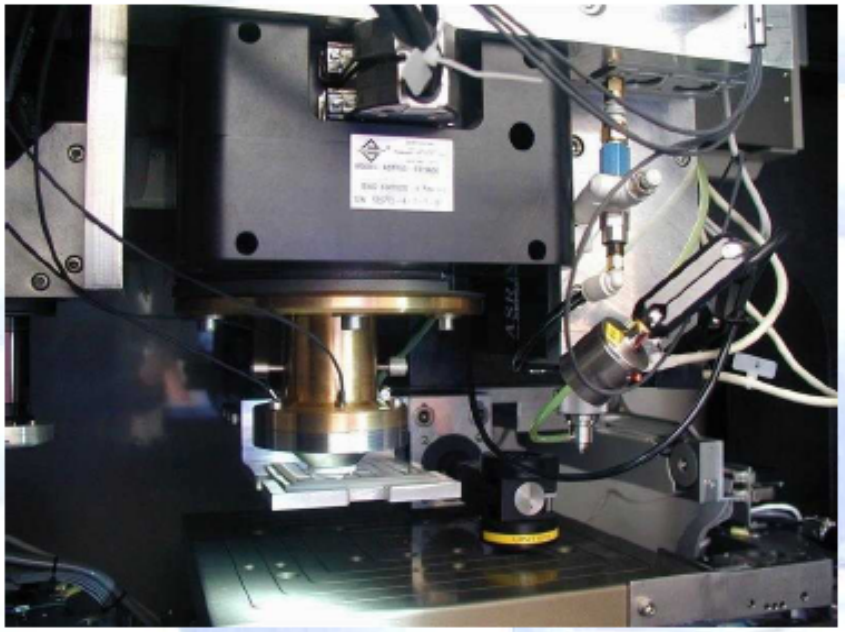
Neodym-dotierter Yttrium-Aluminium-Granat-Laser 1064 nm

3) Laser Reflow

(20msec, $Nd^{+3}YAG$)



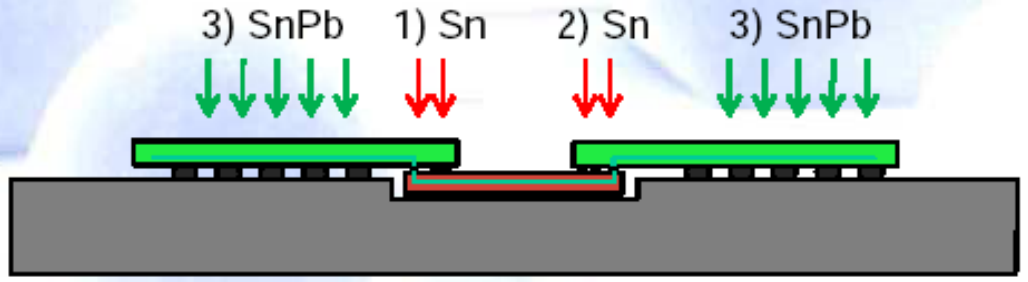
LaPlace Assembly System™ PacTech



Placement accuracy: +/- 15um: 3000 - 5000 UPH
Placement accuracy: +/- 10um: ~2000 UPH
Placement accuracy: +/- 5um: ~1000 UPH
Placement accuracy: +/- 2.5um: ~500 UPH

units per hour

Laser based assembly allows localized heating:



- Selective to individual die
- Energy localized to bumped areas
- Ability to differentiate between solder alloys
- Low stress
- Minimizes IMC (time/temp)

Mp SnPb = 183°C Mp Sn = 232°C

PacTech
publication 66
Nov 2009

PAC TECH
PACKAGING TECHNOLOGIES

Sun microsystems

Pac Tech: SB2 Jet

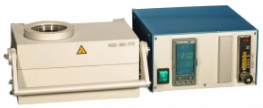
Solder Ball Placer:
pre-formed balls are placed sequentially at 6-7 Hz
fused by laser heating
30 µm balls being certified, 40 µm ordered for test.

SET: FC 150 Flip-chip bonder

Industry standard, expensive, slow.
For placing and re-flow heating. Used at IZM.

SET: Kadett K1

Unitemp: RS-350-110



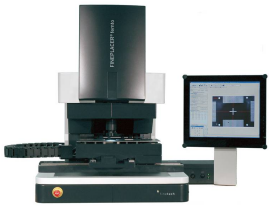
PSI design: cheapest, slow.
no > 50 mm heating chuck available.
Tacking Tests completed on small samples:
> 0.6 g/ball @ 155°C for chip & substrate.
Re-flow tests completed: OK.

Pac Tech: Laplace

RFA 300M

Novel Industry Standard: medium price
laser-assisted, fast.
Tacking Tests completed:
low force with chip at 195°C for 1s.
Reflow Tests completed: OK.

Finetech: FINEPLACER femto



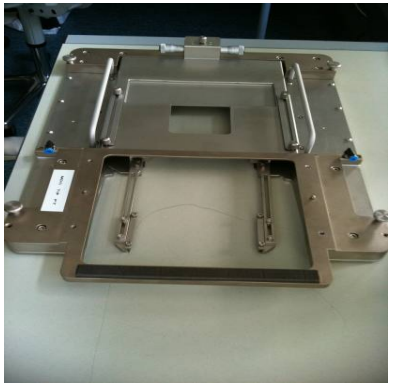
Novel FC 150 competitor: medium price.
Placing and re-flow heating, low-force, fast.
Tacking / re-flow tests under way.

Probe station at DESY FEC

Süss Microtech PA 300 Probe Station

auctioned
from
Qimonda
in Dec 2009

Probe-Card Holder



will order 42 needle probe card for testing ROCs after bump bonding.

up to 300 mm wafers
Semi-Automatic
Shielded
Thermo chuck -40 .. +125°C

Test structures for bump bonding

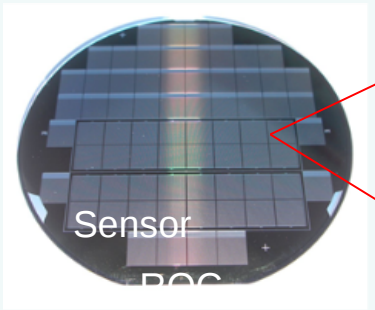
- Designed by I. Diehl, DESY FEC:
  - Contact chains with 160 bumps, sensor and ROC geometries.
- Idea:
  - Measure electrical continuity on external pads,
  - Get statistics in the ‰ range.
- Ordered at CIS Erfurt:
  - 100 mm silicon substrate, 400 µm thick, 20 wafers.
  - 2 masks: one metal layer, one passivation layer
  - pad metalization AlSiCu, under bump metal Ti-Ni-Au.
  - delivery now promised for end of May.
- At PacTech:
  - Thin some wafers to 175 µm or less.
  - Deposit 40 µm bumps on the sensors, dice wafers.
  - Flip chip bonding.

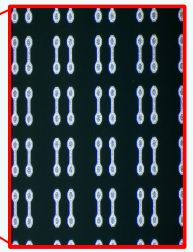
Timeline from April 2011 and reality

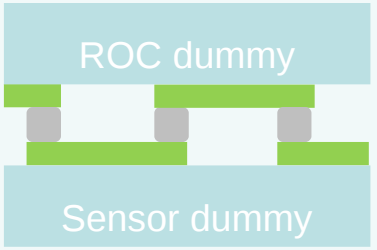
- May 2011: Test structures being produced by CIS Erfurt
  - required 3 iterations: passivation residue on pads
- Jun-Jul 2011: thinning, bump bonding and dicing at PacTech, 40 µm balls. Design and build formic acid chamber for laser re-flow.
  - done by Nov 2011
- Aug-Sep 2011: evaluation at DESY: bump yield. Still to be done.
- Sep/Oct 2011: decide whether to order machines: solder ball placer, flip chip bonder. EU-wide tender and 5 months delivery time.
  - Early Spring 2012 ?
- Winter 2011/12: produce test structures for 30 um balls.
  - Needed? can we do with 40 um balls?
- Spring/Summer 2012: bump bonding tests at DESY, first on test structures, then on pixel sensors and ROCs. Still to be done.
- end 2012: bump bonding established at DESY? Slip into 2013 OK?

Test structures for bump bond tests

Dummy structures for bump bond yield characterization:

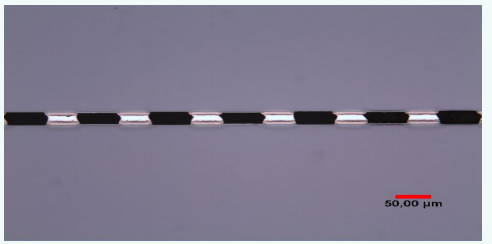






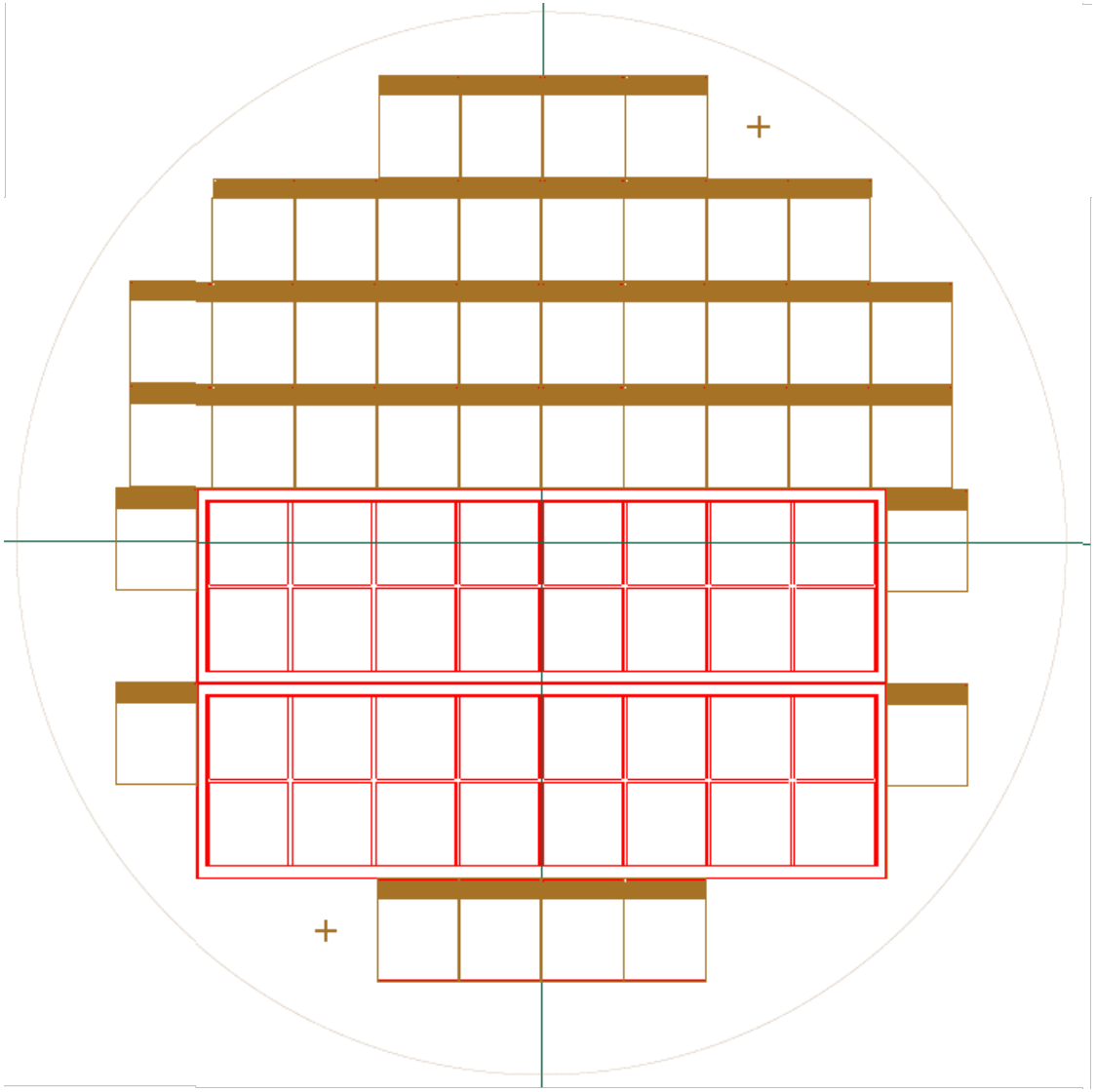
Fabricate at CiS | Bond at PacTech | measure at DESY

Schliffbilder at DESY:



Embedding | Cutting | Polishing | microscope photos

New test structures for bump bonding



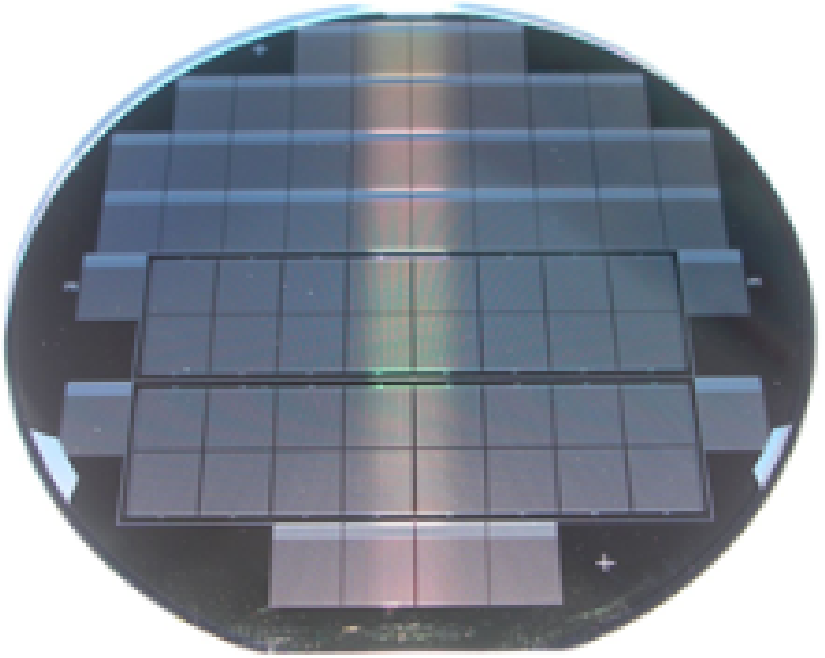
100 mm wafer

2 masks: metal and passivation

2 CMS pixel 'sensor' structures

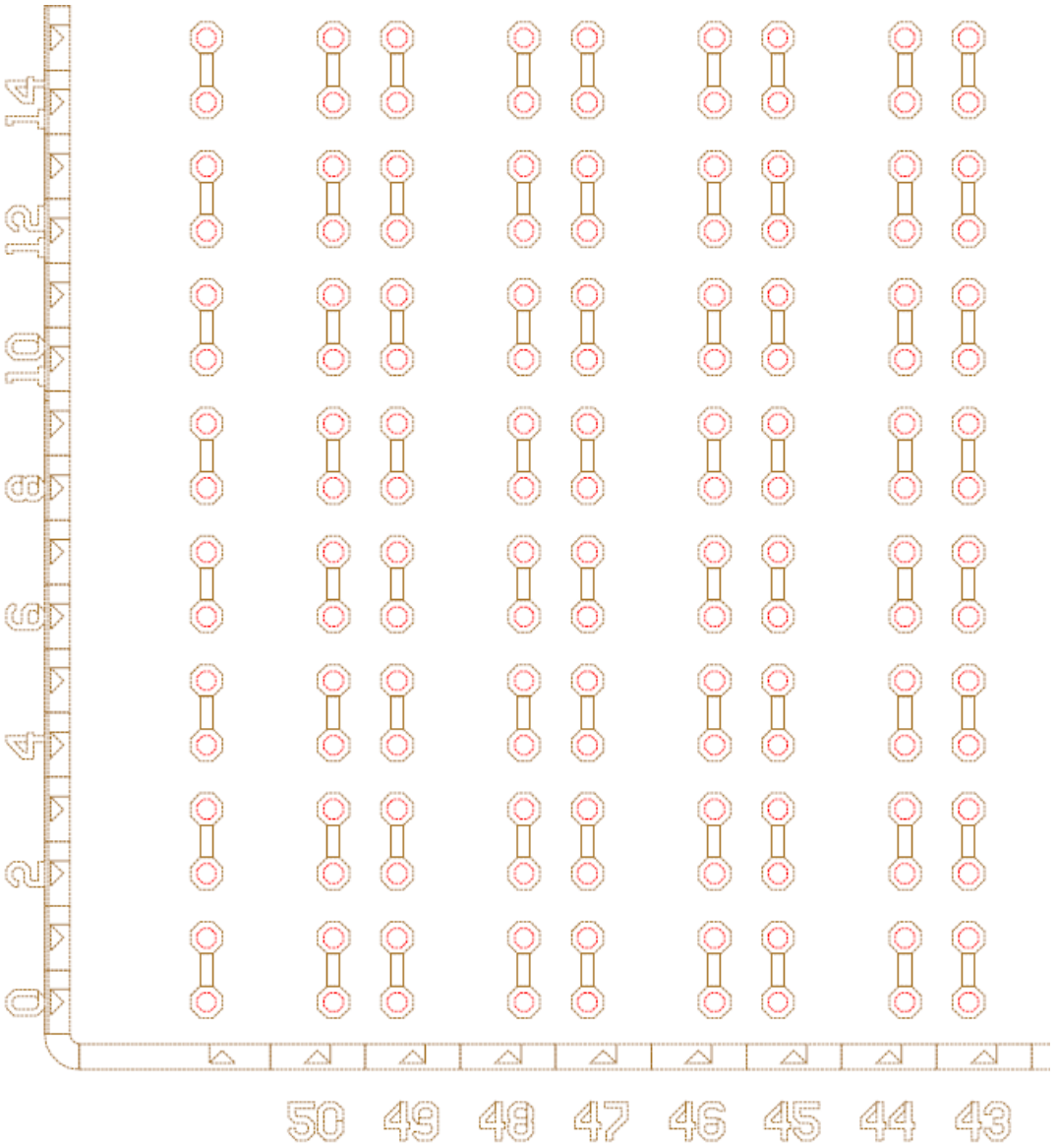
40 'ROC' structures

Produced at CIS Erfurt



Inge Diehl, DESY FEC

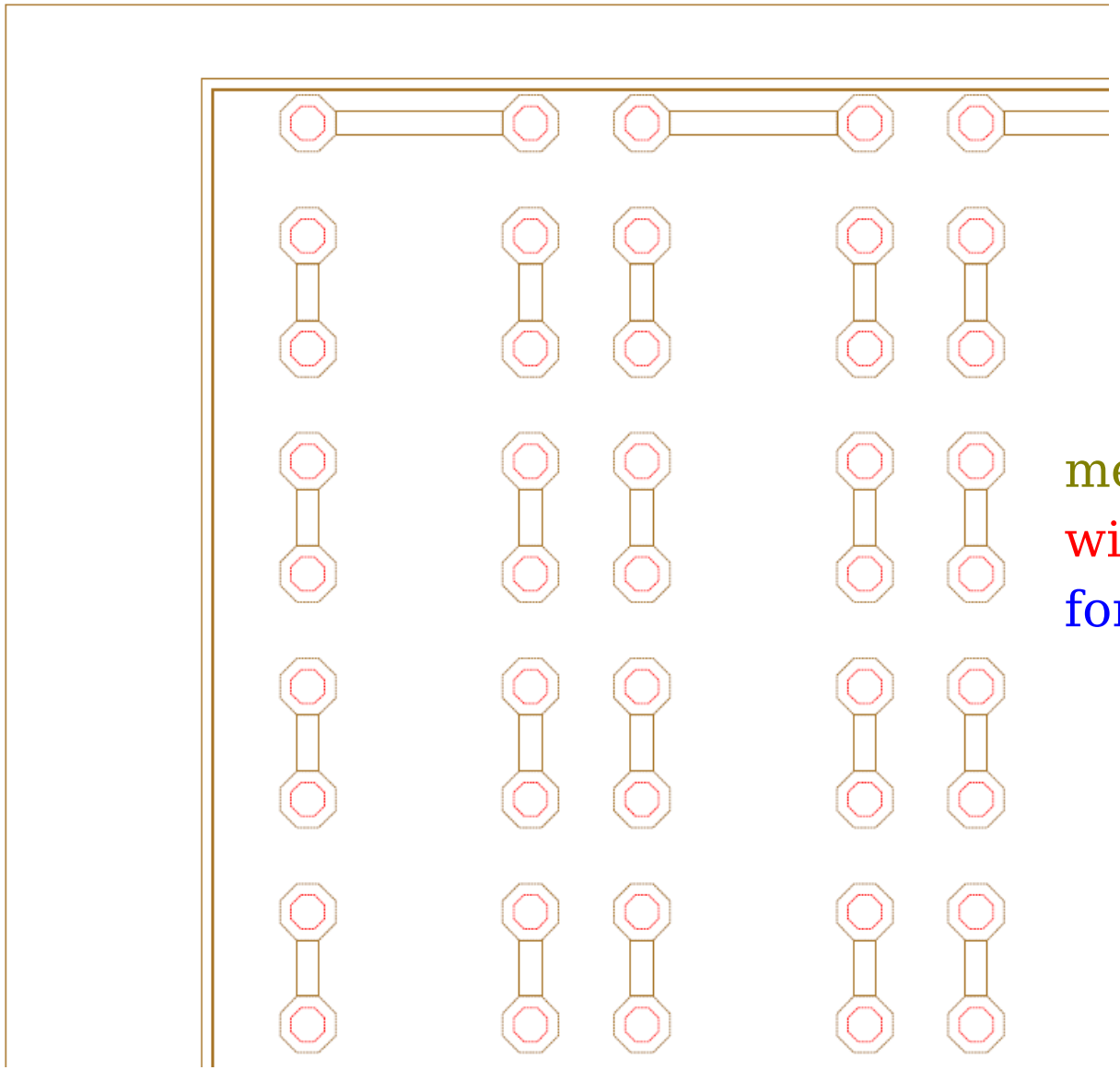
New test structures for bump bonding



pixel sensor structures

these will receive the bumps

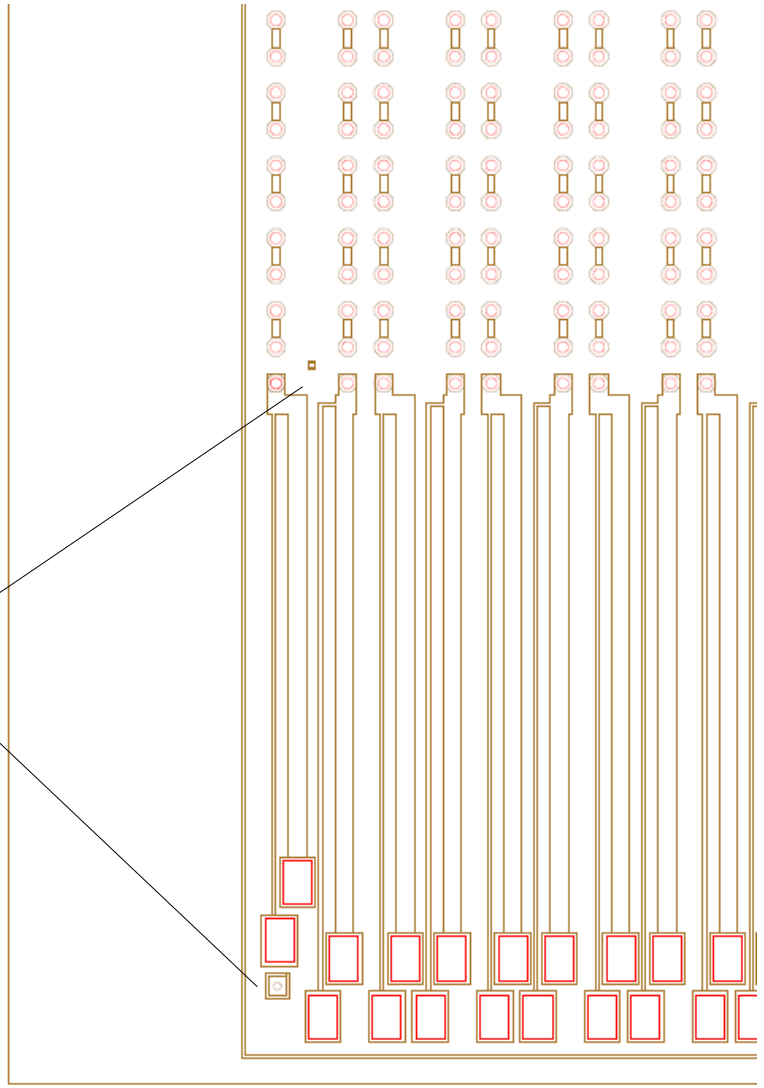
New test structures for bump bonding



double-column chain
pixel chip structures

metal pad 50 µm Ø
window in passivation 30 µm
for 40 µm Ø bumps

New test structures for bump bonding



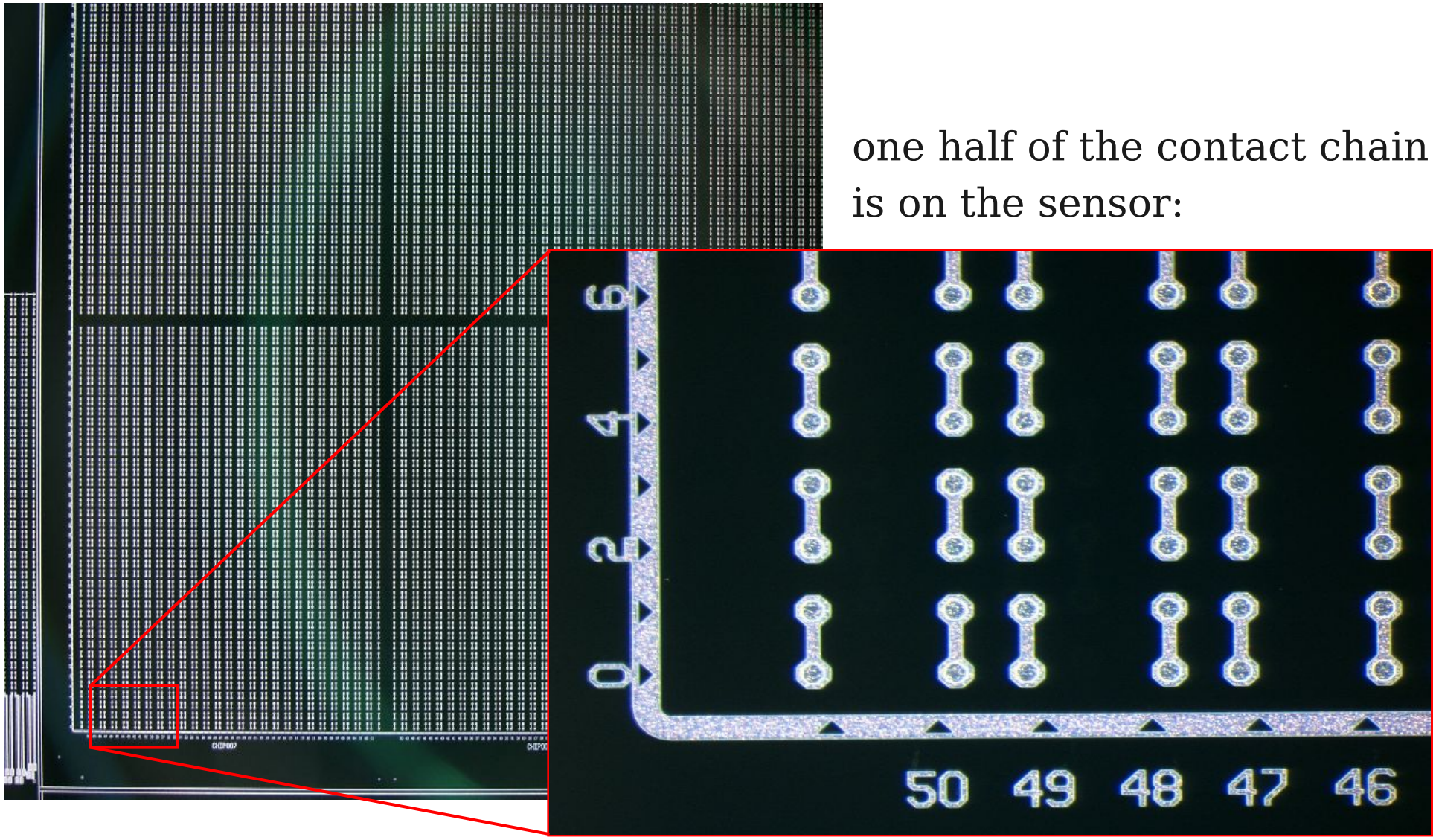
pixel chip structures

alignment marks

test pads for 4-point I-V measurement

'Sensor' test structure from CIS

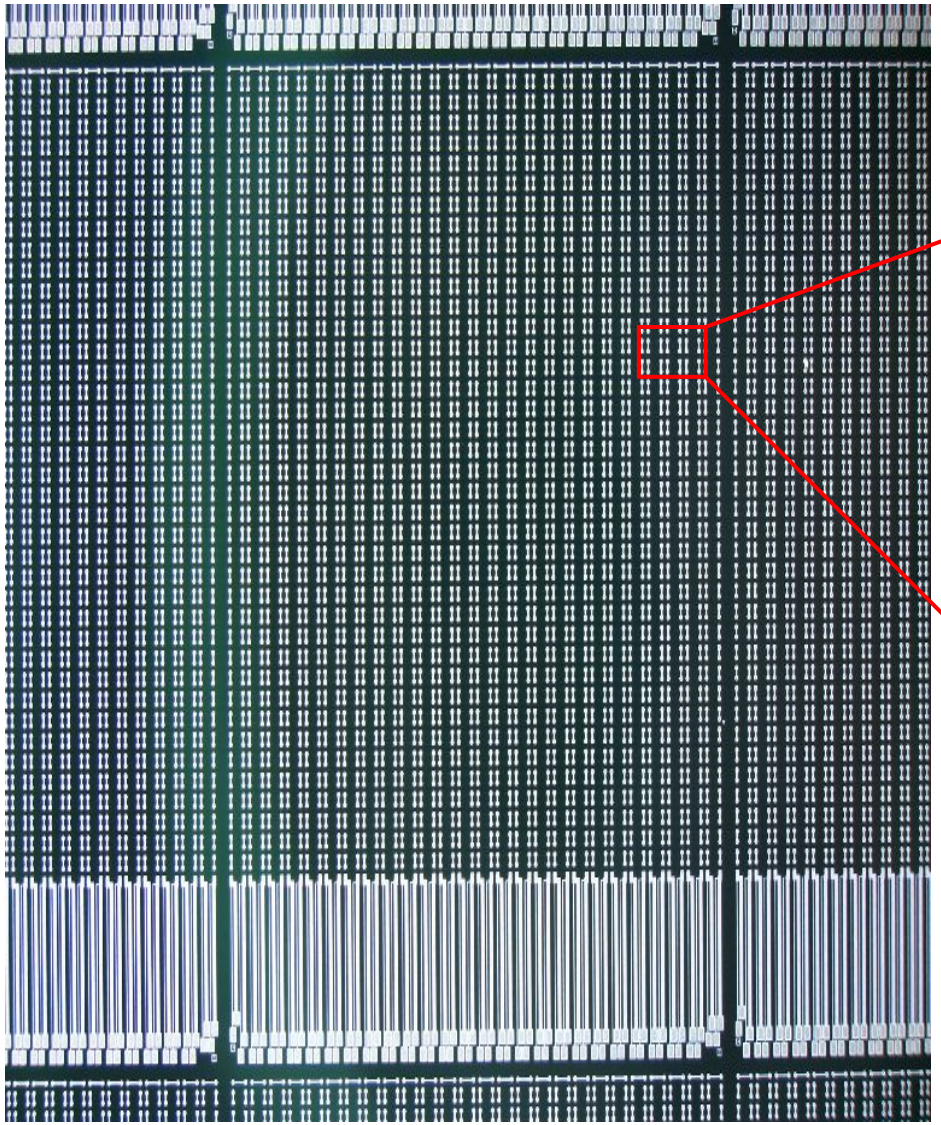
geometry of the barrel pixel sensors



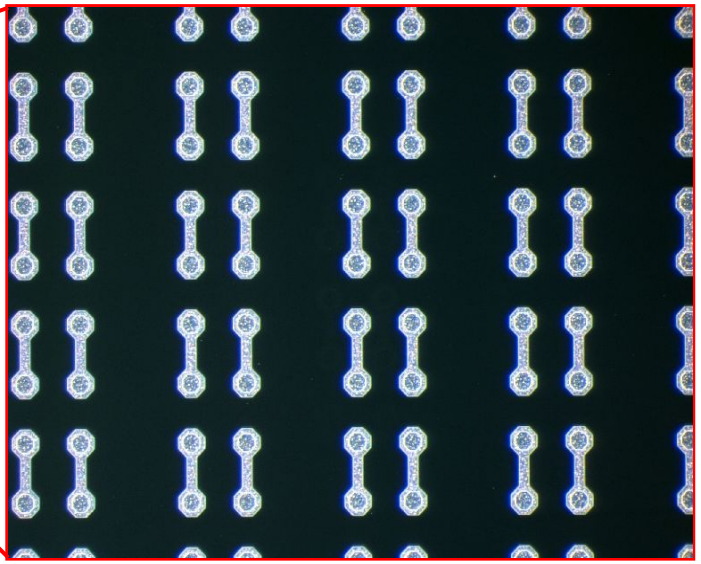
one half of the contact chain is on the sensor:

'ROC' test structure from CIS

on the same wafer, before dicing:

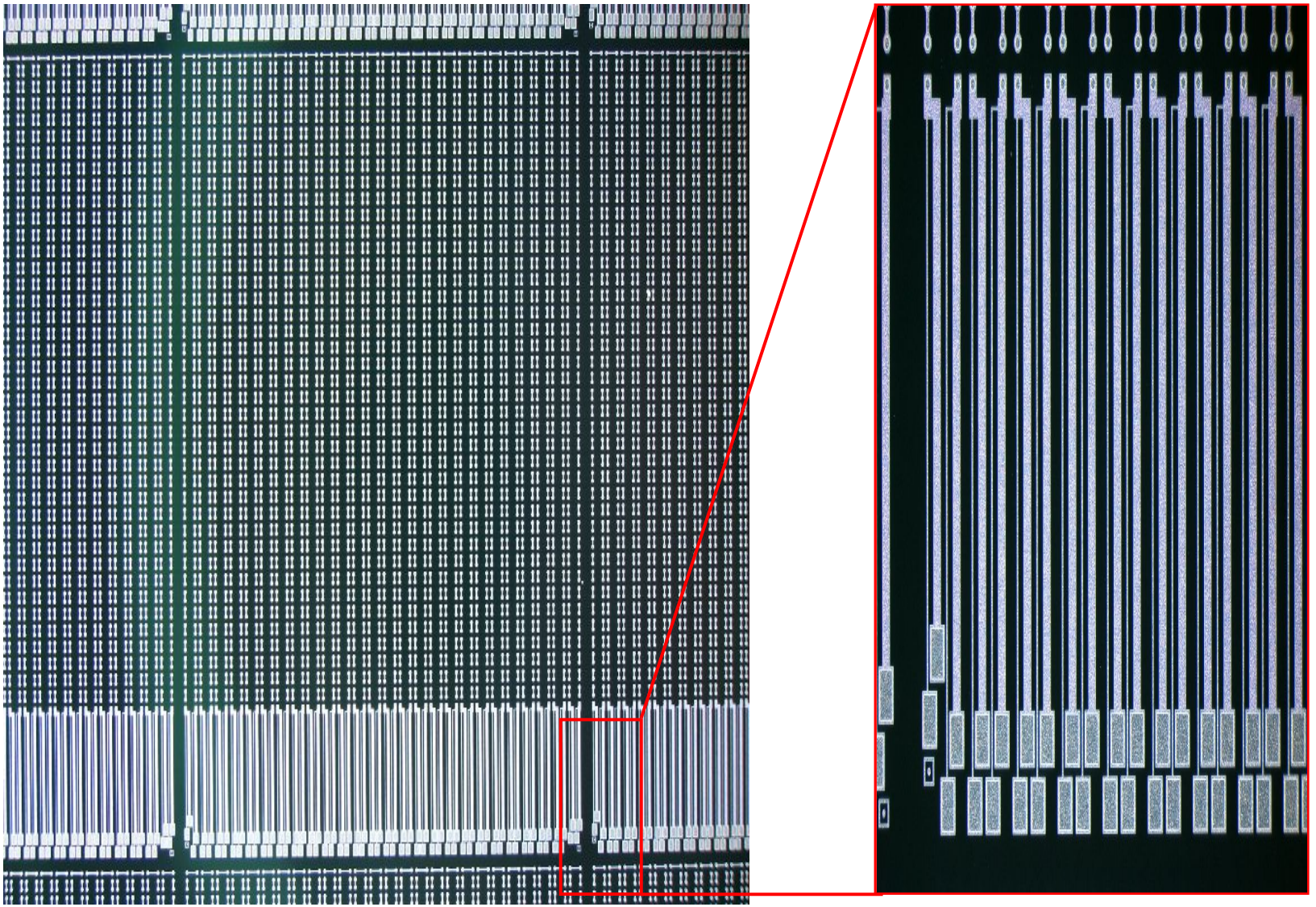


after bump bonding the contact chain is closed on the ROC.



Pad pitch = 100 µm / 200 µm
Pad metal = 50 µm diameter
Passivation opening = 30 µm

4-point conductivity measurement



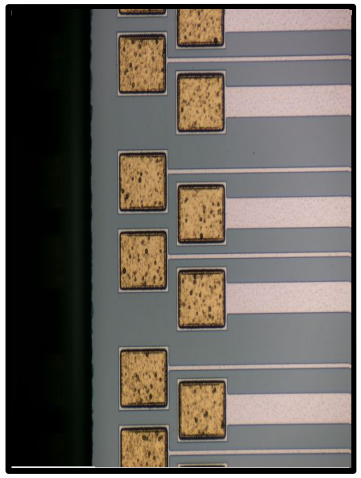
inject current,
measure
voltage drop

probe pads
in the 'ROC'
periphery

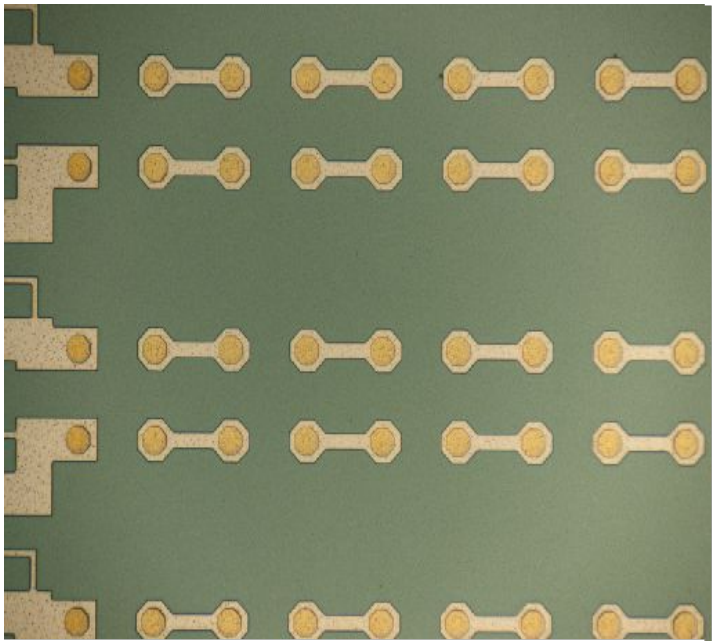
Probe card delivered from Wentworth: 104 needles.
Programmable switching box is ready.

Under bump metal from PacTech

Probe pads with UBM:

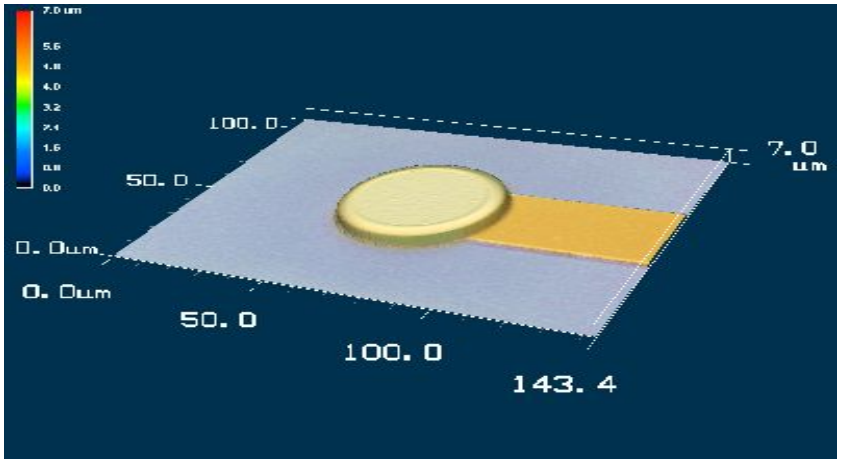


Dummy-ROC with UBM:



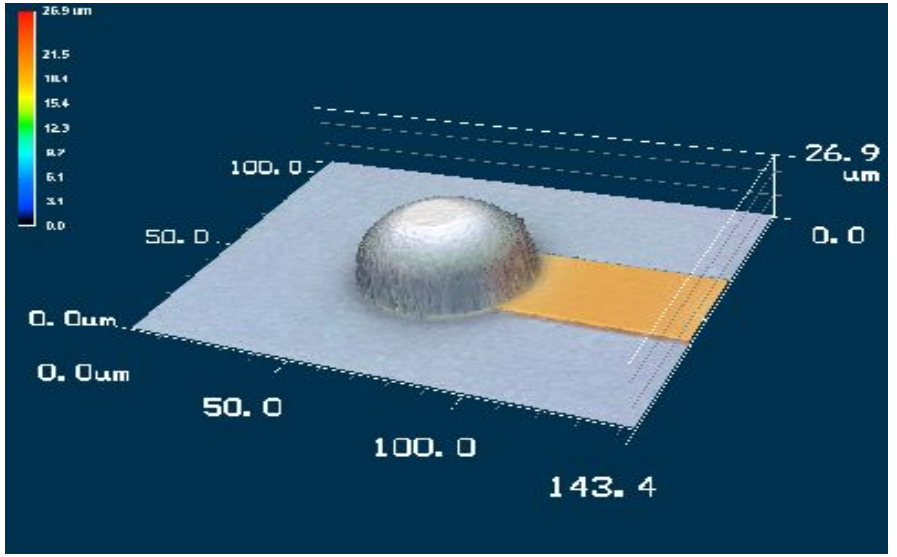
main problem:
residual passivation layer
on the pads from CIS.
1st batch: 15 of 18 wafers bad
2nd batch: ~5% bad
3rd batch: delivered last week
are pin holes a problem?

ENIG UBM:
Electroless Nickel-Gold
5 µm Nickel
50 nm Gold
40 µm diameter

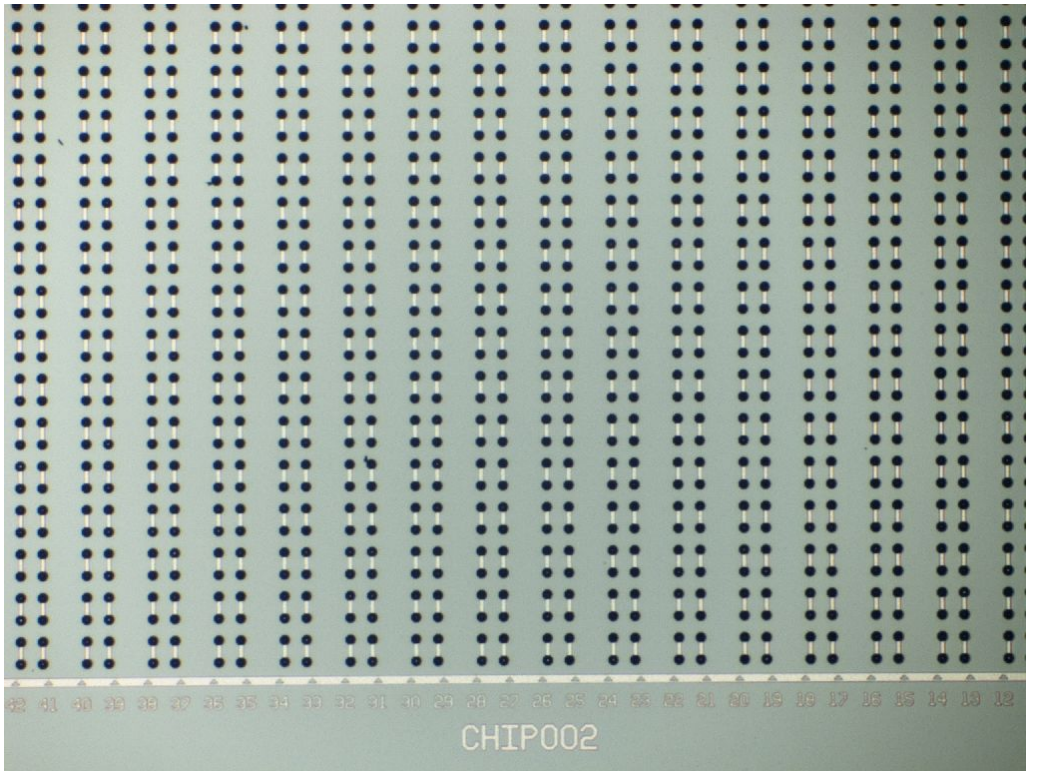


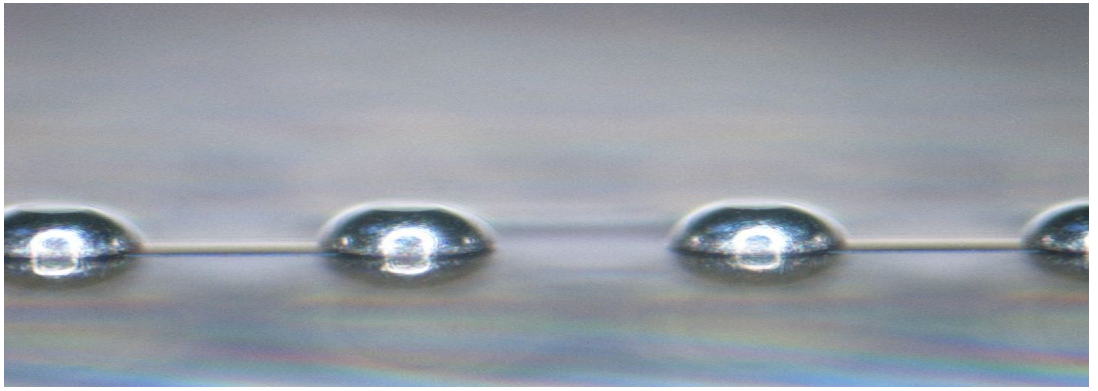
Solder balls placed with PacTech SB2

Pad bumped with
40 µm solder ball,
after re-flow:



'sensor' with solder balls:





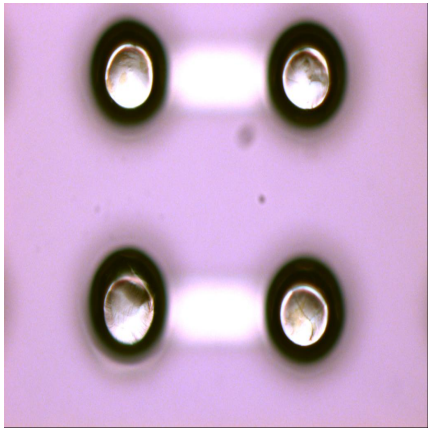
Side view of
bumped
daisy chain
structure

Laster re-flow with PacTech LaPlace

After solder placement

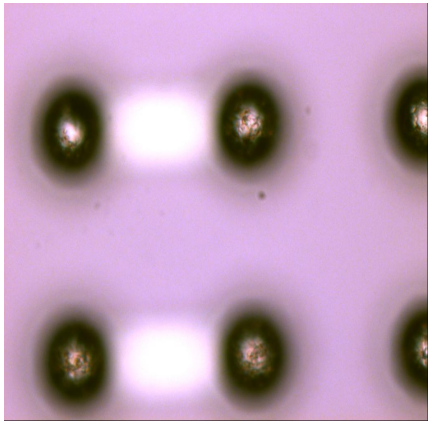
After laser reflow

microscope focus at top of ball:



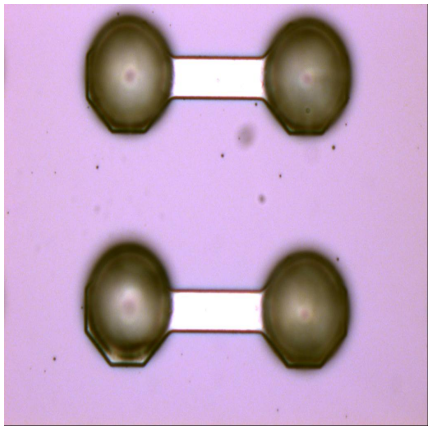
Crater on top

Laser re-flow (10 sec. in formic acid atmosphere)

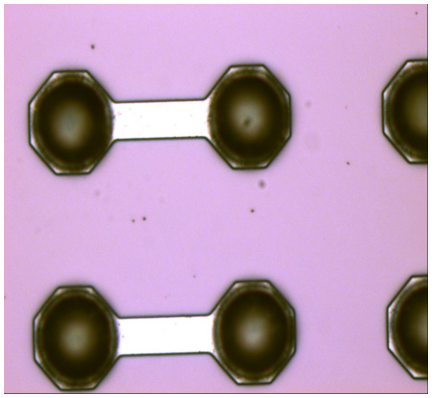


Spherical top

microscope focus at pad:



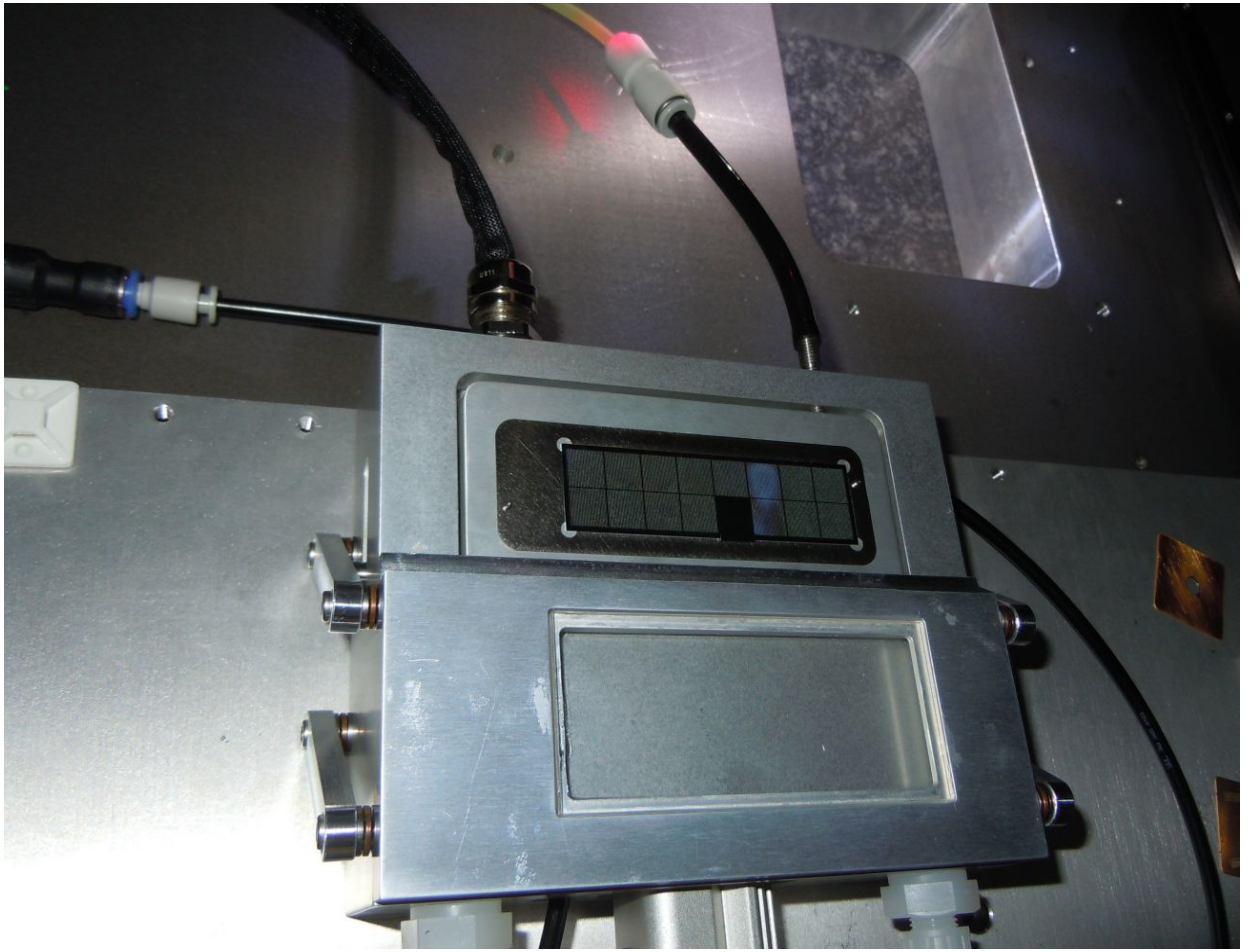
Slightly off-centered



Self-aligned

Formic acid chamber for PacTech LaPlace

Formic acid chamber for LaPlace laser bonder designed and built by PacTech on our request:



Groove for gas inlet and exhaust

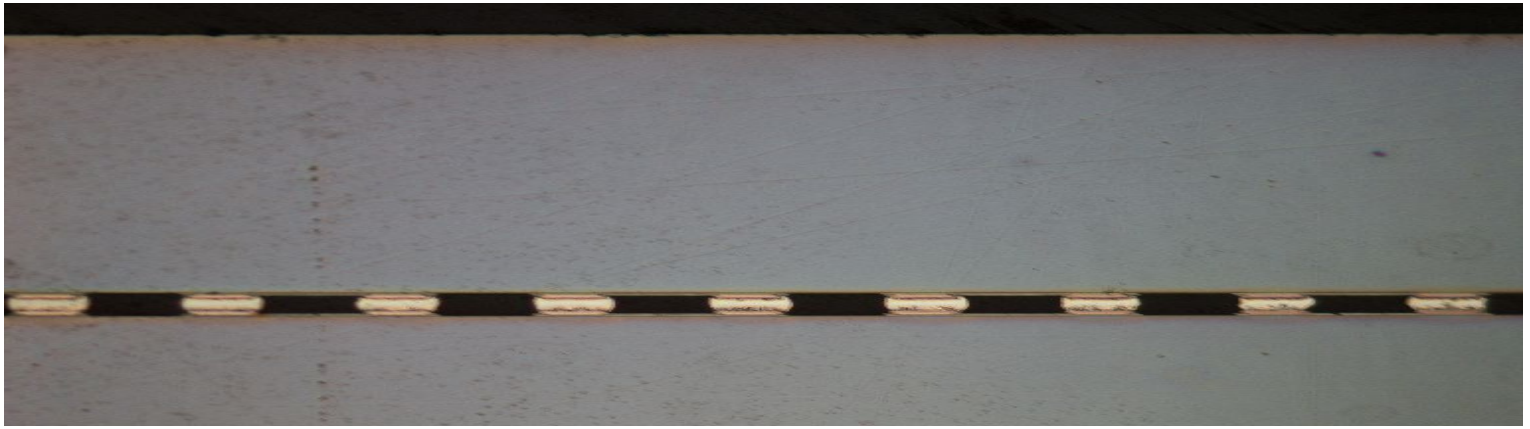
Bumped sensor
Tacked ROC

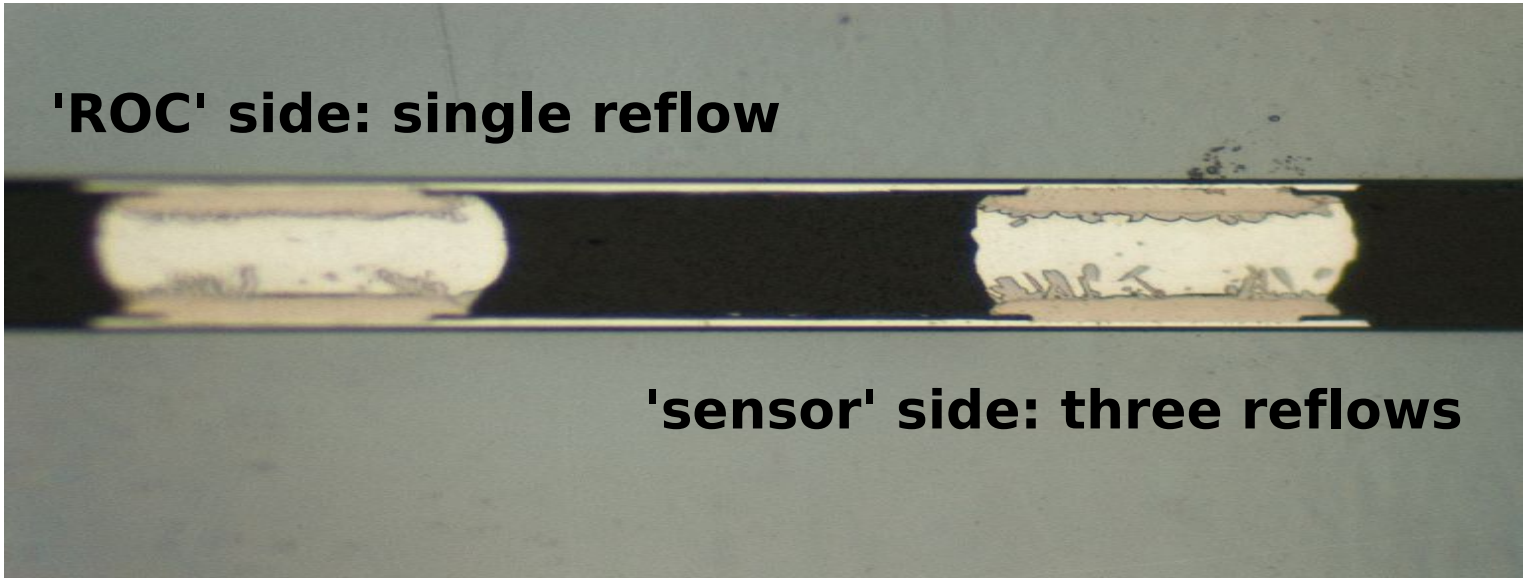
Special glass for high infrared transmission

Sealed automatic cover (open)

Flip chip bonding at PacTech

Schliffbilder:

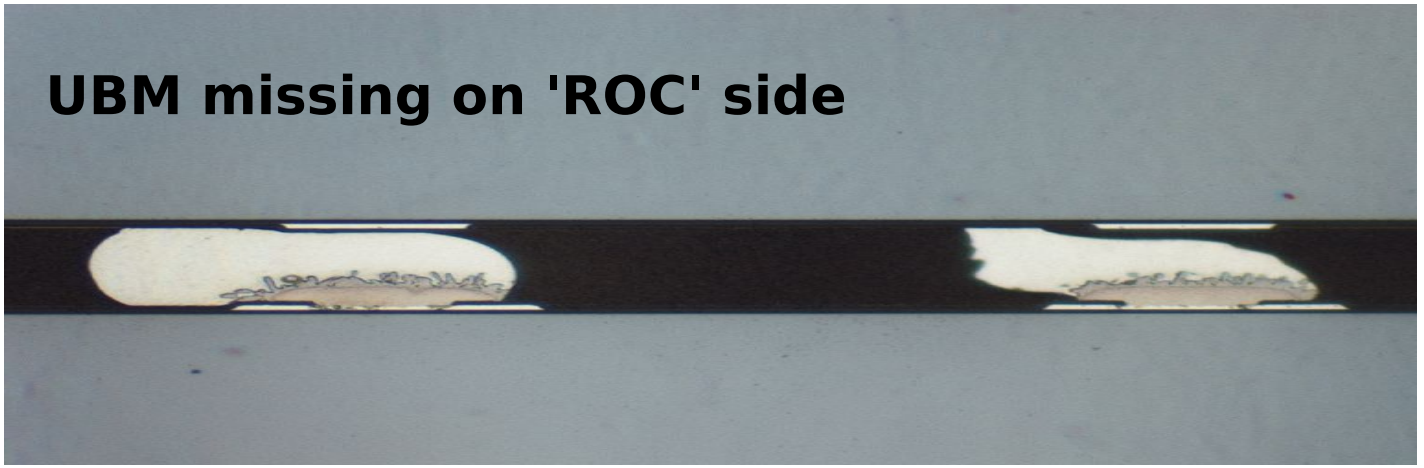




Nickel
Tin
Nickel

CIS problem: residual passivation on pads

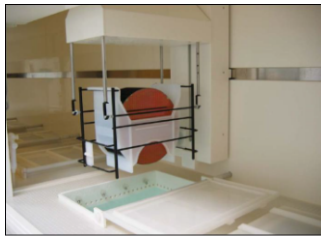
Schliffbild:



Tin
Nickel

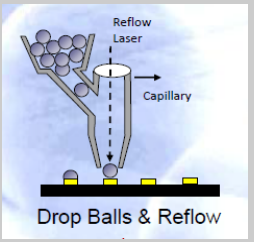
Bare module production at DESY FEC

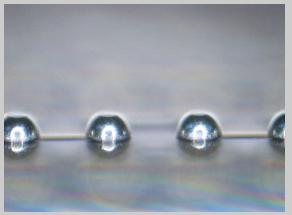
Solder Ball Jetting



ENIG UBM at Pac Tech

SB2 Jet

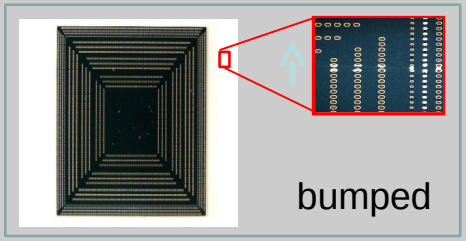




Jetting 40 µm Solder Balls

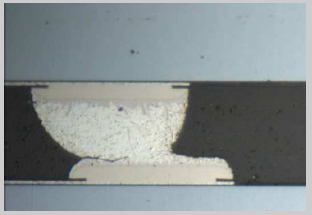
Flip-Chip Placement and Re-flow:

LaPlace

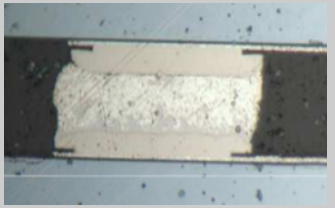


PacTech Test Chip

Schliffbilder:



After tacking



After re-flow

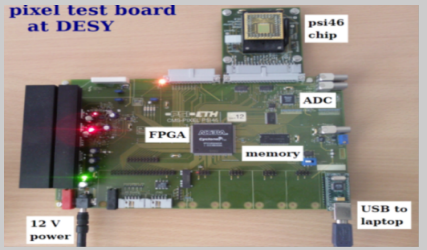
Bare module test on probe station:

Suess PA300

+

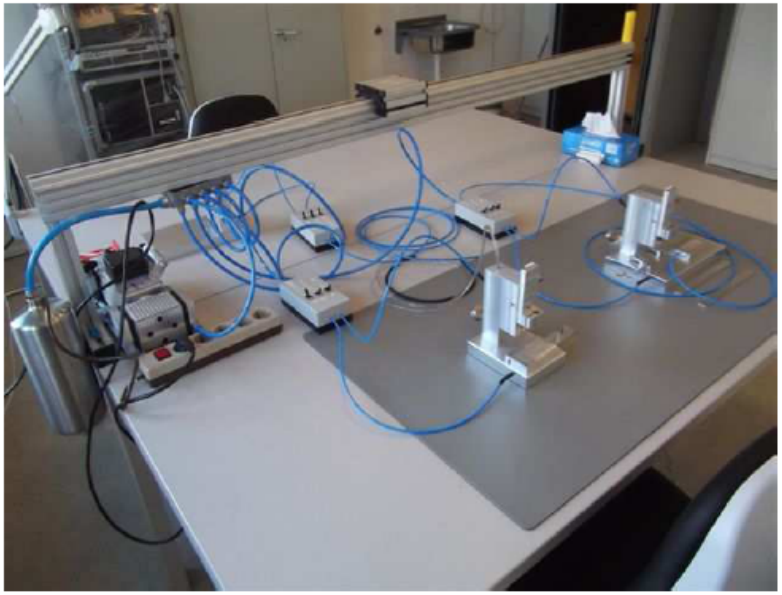
Probe Card (PSI Design)

+



Test Board from PSI / ETHZ

Pixel module assembly tools at Uni HH



Tool rebuilt according to PSI CAD drawings.
Gluing tests on dummy modules underway.