UNIVERSITÄT
HEIDELBERG

Bumping and Flip-Chip of ASICs

Dr. Christian Kreidl

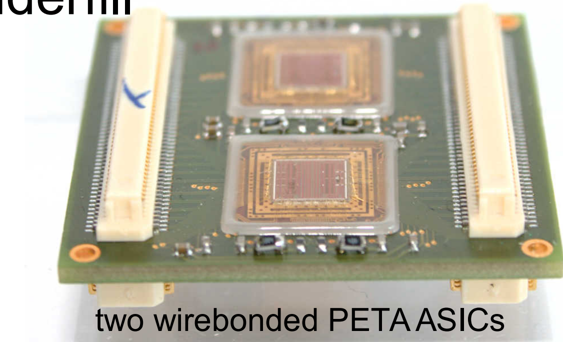
christian.kreidl@ziti.uni-heidelberg.de

HighRR Seminar

08.03.2017

Flip-Chip vs. Wirebonding

- Advantages of Flip-Chip
  - reduced chip footprint on substrate
  - compact modules
  - robust modules: interconnect hidden below silicon, underfill
  - lower inductance due to shorter interconnect path
  - parallel bonding of all signals
- Disadvantages
  - complex process: ubm, bumping, flipping, underfill
  - wirebonding is fast for prototypes
  - industry focuses on wafer processing
  - MPW & single chip bumping difficult
  - prototyping bumped chips: wirebond interposer
  - probestation testing of high bump count



two wirebonded PETA ASICs

four flip-chip PETA ASICs

Bumping Technologies

- Indium
  - small: 20µm pitch, 10µm diameter; electroplated
  - soft, low soldering temperature (<180°C)
- Goldstud
  - 50µm diameter, 70µm pitch
  - modified gold ball/wedge wirebonding process
  - slow sequential bumping process; high force flip-chip; >300°C
- Solder
  - minimum: 20µm pitch, 15µm diameter; standard: 200µm pitch / 100µm dia
  - Chip-on-Board: 300-500µm diameter
  - evaporation, electroplating, screen printing, ball drop, jetting
  - Eutectic, High-Lead, Lead-free solder alloys; >200°C soldering
- more...
  - Cu-Pillar
  - Solid-Liquid Interdiffusion (SLID): High Temperatur (600°C) applications

Solder Bumping Metal Stack

Bumping

Chip

Solderball

UBM

RDL-Metal

RDL-Via

Chip-Passivation

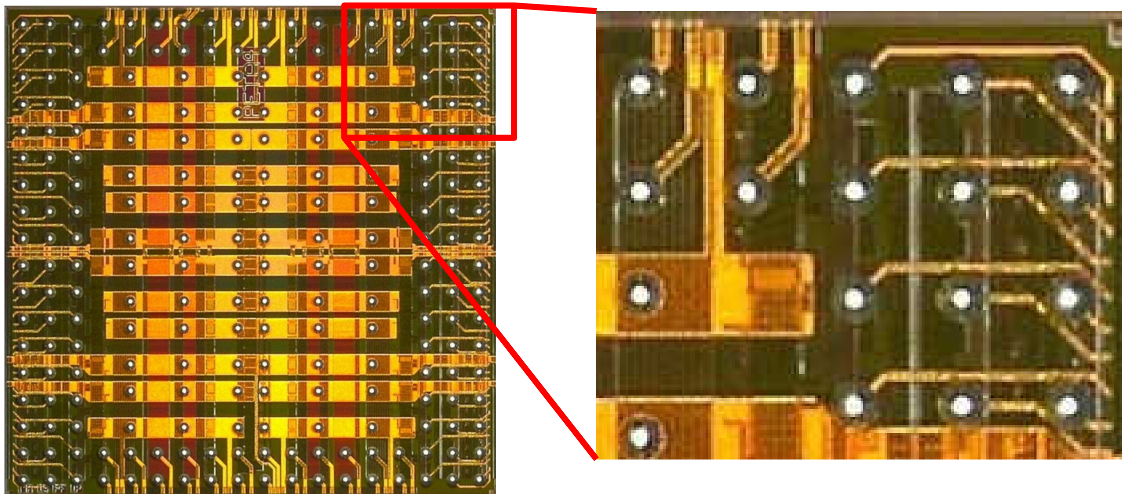
Top-Metal (Al)

Via

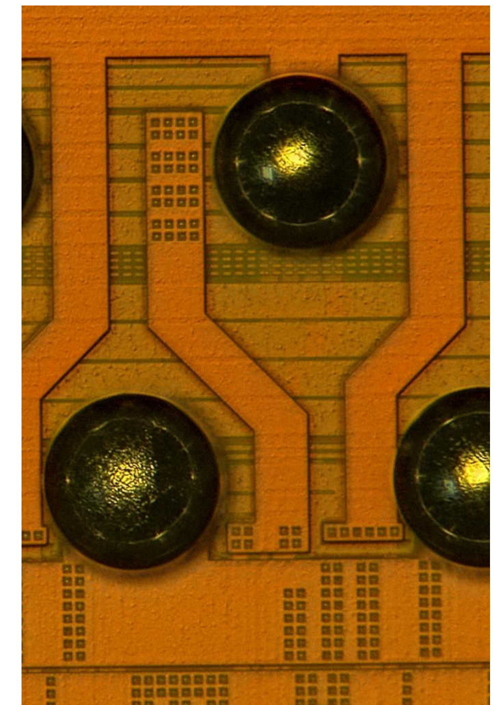
example of solder bumping metal stack (not to scale)

Redistribution Layer (RDL)

- Rerouting from wirebond padframe to bump pad array
  - additional metal/passivation layer ontop of final wafer
  - processed by foundary or bumping provider
- Metal properties vary
  - Al or Cu
  - coarse structures
- Design rules / RDL-layer not part of design kit
  - DRC and LVS rule files need to be extended manually



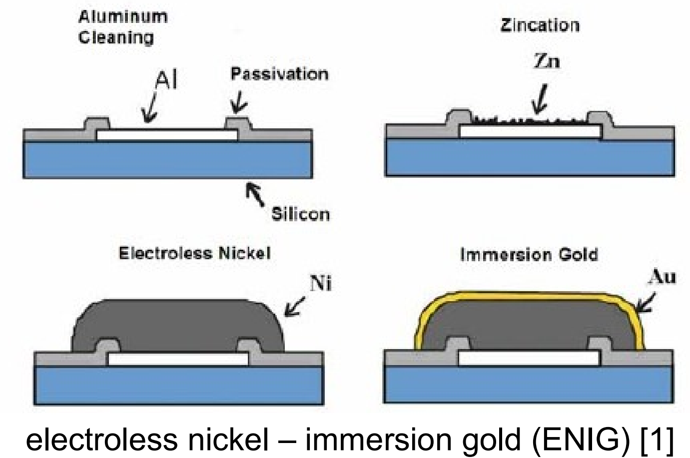
PETA ASIC wirebond rerouting



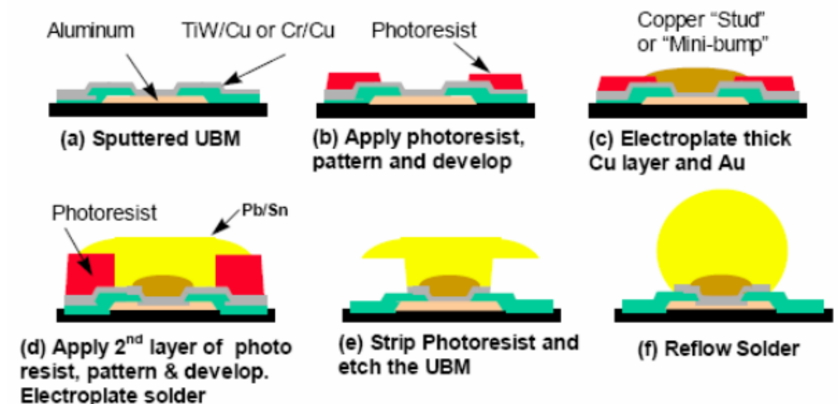
RDL of bump-only DCD ASIC

Under Bump Metallization (UBM)

- Solderable surface required
  - Al-pads are not solder wettable
  - MPW submissions have Al-pads
- Under Bump Metallization (UBM)
  - provides solder wettable surface
- Industry standard
  - multi layers of metal: adhesion, diffusion barrier, wettable, oxidation barrier
  - electroless (ENIG), electroplating, sputtering, evaporation
  - complicated process, masks required
  - waferlevel processing
- Solderable substrate required, too!



electroless nickel – immersion gold (ENIG) [1]



electroplated UBM and solder [1]

Further reading:
Under bump metallurgy (UBM) - A technology review for flip chip packaging
[1] https://www.researchgate.net/publication/242476081

Bumping, UBM and MPW

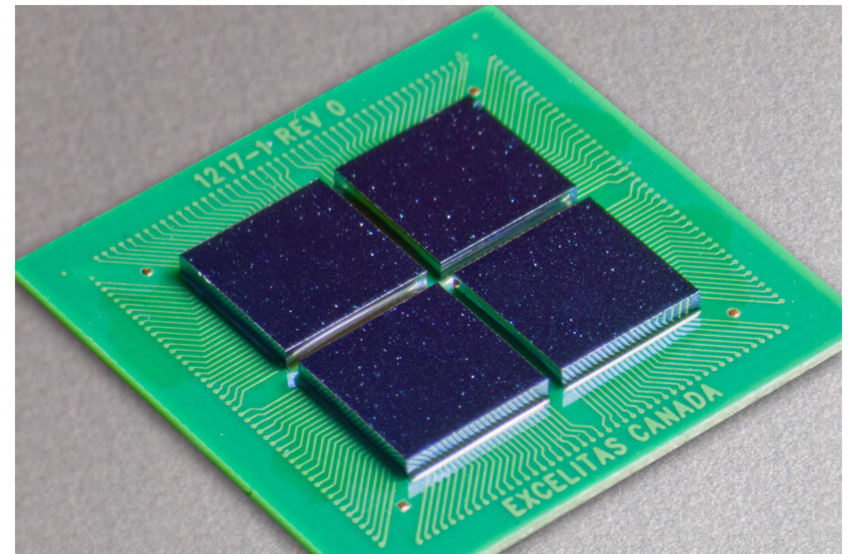
- Bumping of MPW and single chips difficult
  - MPW: no access to wafers, only single chips delivered
    - most bumping technologies process on wafer level!
  - best if MPW offers bumping option
    - bumped single die delivered
    - bumping subcontractors switch often -> designrule, solder changes
    - diff. solder types -> melting temperatures differ
  - single chip handling, manual UBM processing and bumping
    - passivate chip edges and apply ENIG UBM -> time consuming, bad yield
    - solder jetting works well
  - assemble support wafer with single chips and process on waferlevel
    - new, no results yet
- Goldstuds as UBM
  - simple process for single chips
  - gold-solder-intermetallics are brittle

UMC bumping costs

- MPW bumping
  - Masks: 12k EUR
  - Bump process (1 Wafer): 620 EUR
  - Admin+Logistic: 110 EUR
- Engineering Run
  - Masks: 10k EUR
  - Bumping 500 EUR / wafer
  - Thinning 25 EUR / wafer

Underfill

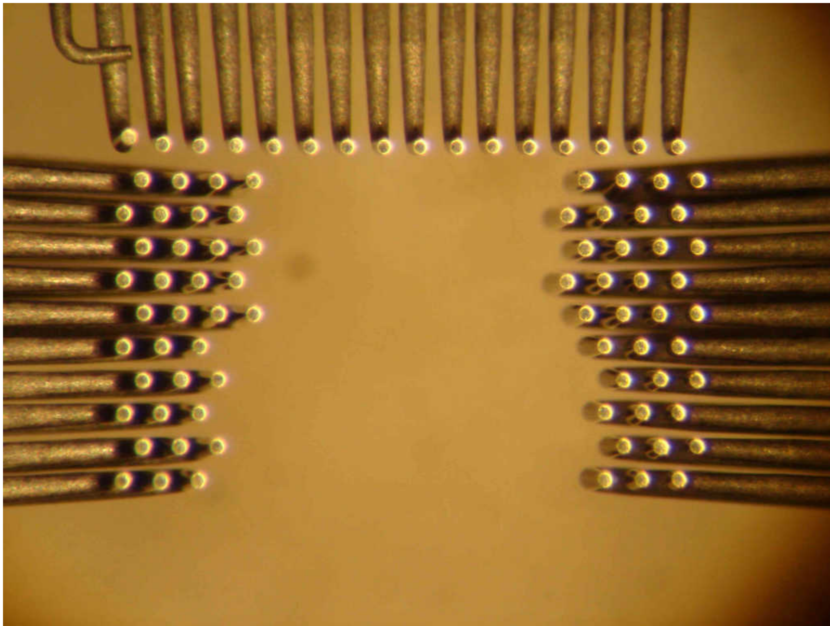
- CTE mismatch of silicon and substrate (ceramic, PCB, ...)
  - mechanical stress on solder joints
  - cracks develop
- Add glue to fill gap between chip and substrate (underfill)
  - glue reduces stress on solder
  - epoxy based, thermal curing
  - medium viscosity
  - apply after flipchip
  - capillary flow



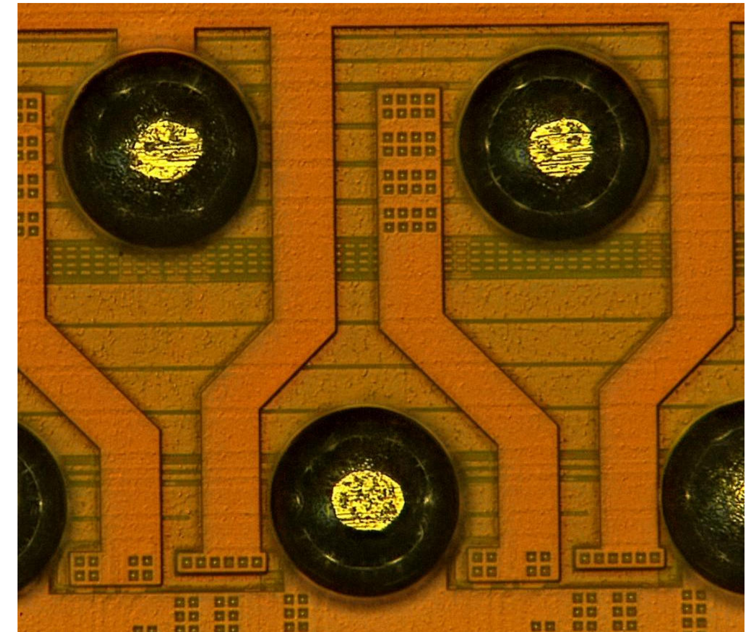
15x15mm² PCB with four underfilled chips

Probecard Testing

- Multiple layers of L-shape probe needles
- Flat needle tips
- Overtravel to break oxide on solder ball -> ball deformation
- Needle cleaning required to remove residues
- Connection problems

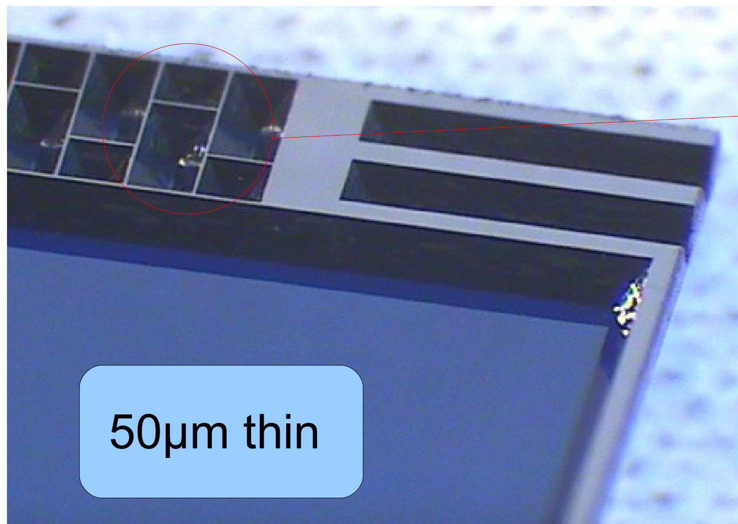


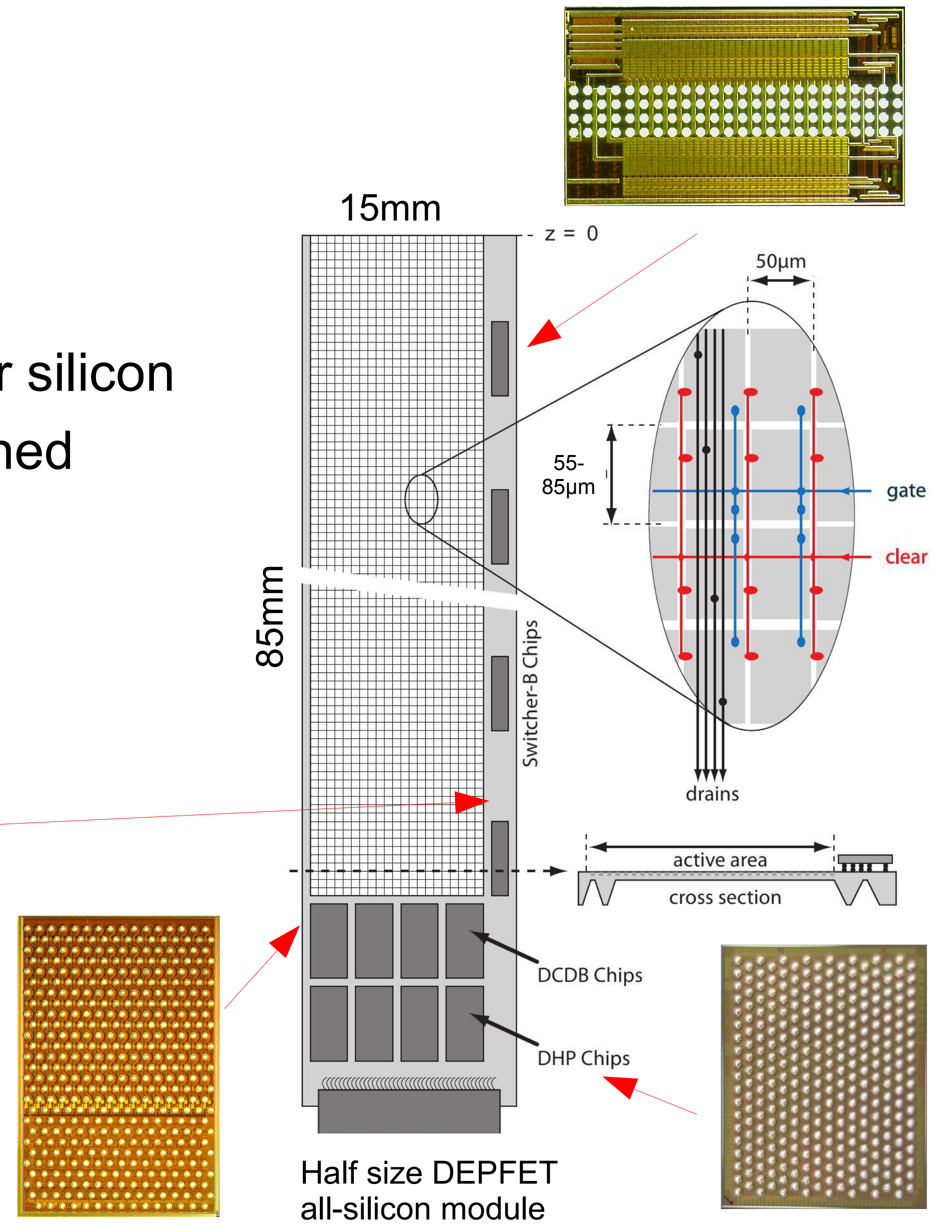
bottomview of probecard needles for solder bump testing.



100μm solder bumps with scratch marks after needle probing

- DEPFET pixel detector
  - Belle tracker upgrade
  - ILC vertex detector
- Self-supporting all-silicon module
  - no interposers: flip-chip onto detector silicon
  - thinning down to 50µm, partially thinned support frame
  - low material budget: 0.18% X0

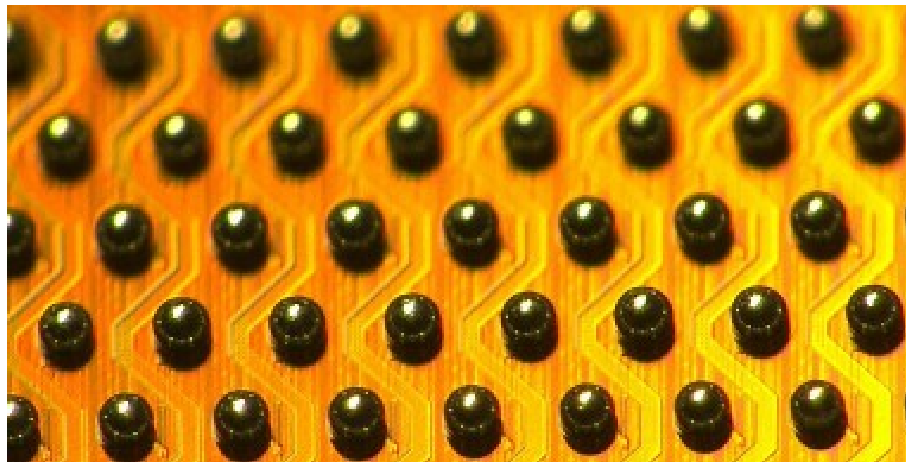




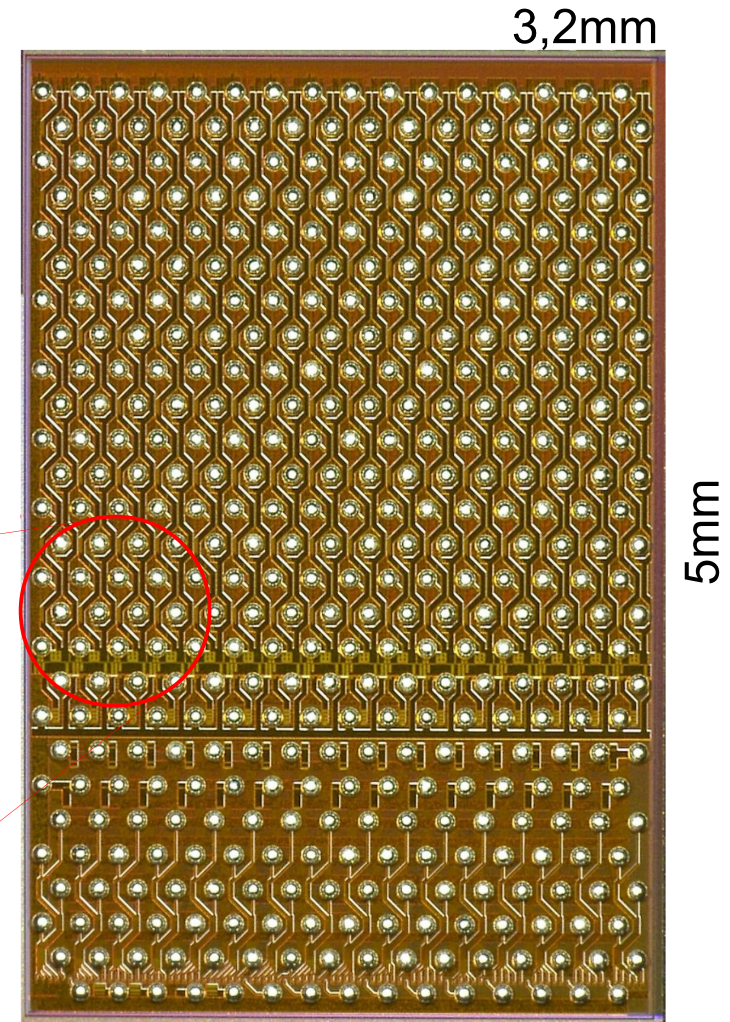
Half size DEPFET all-silicon module

DEPFET ASIC bumping

- Multi-Project Wafer (MPW) Chip Submissions
  - many designs on a single wafer layout -> production cost sharing
  - no access to wafers
  - single chips are delivered
  - limited set of technology options
- DEPFET ASIC bumping
  - DCDB, DHP: MPW bumping
  - SwitcherB: no MPW bumping



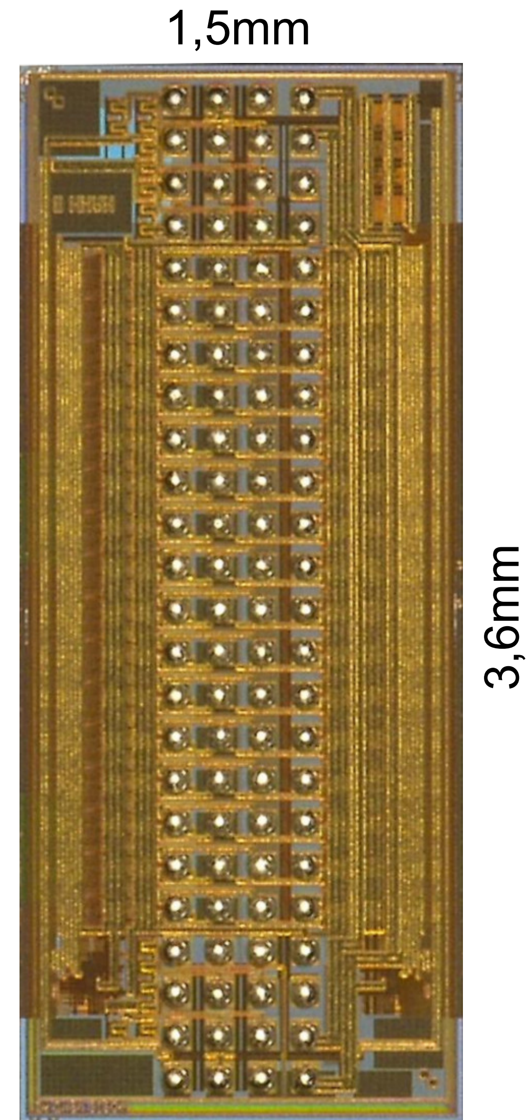
100µm bumps, 200µm pitch



DCDB read-out chip (430 bumps)

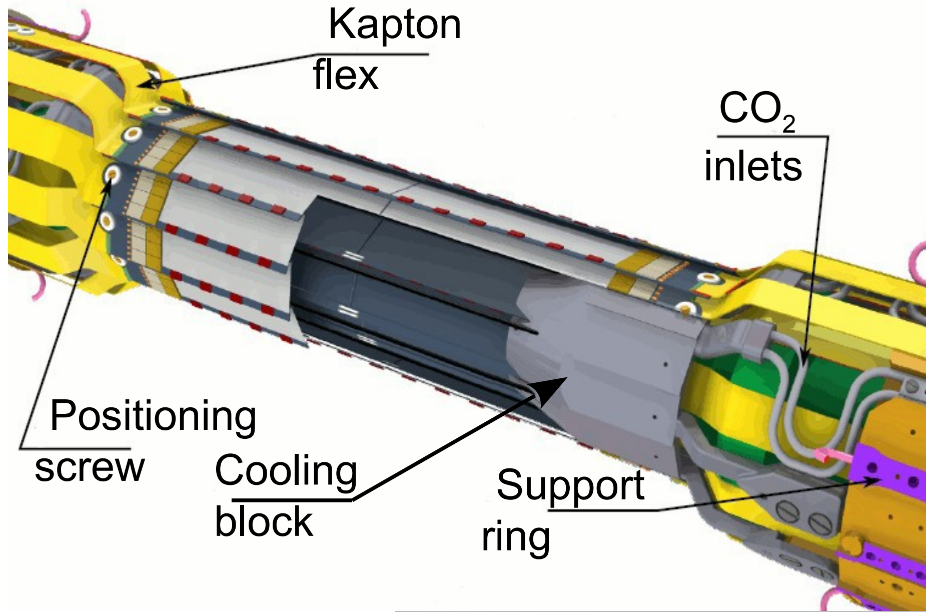
DEPFET ASIC bumping

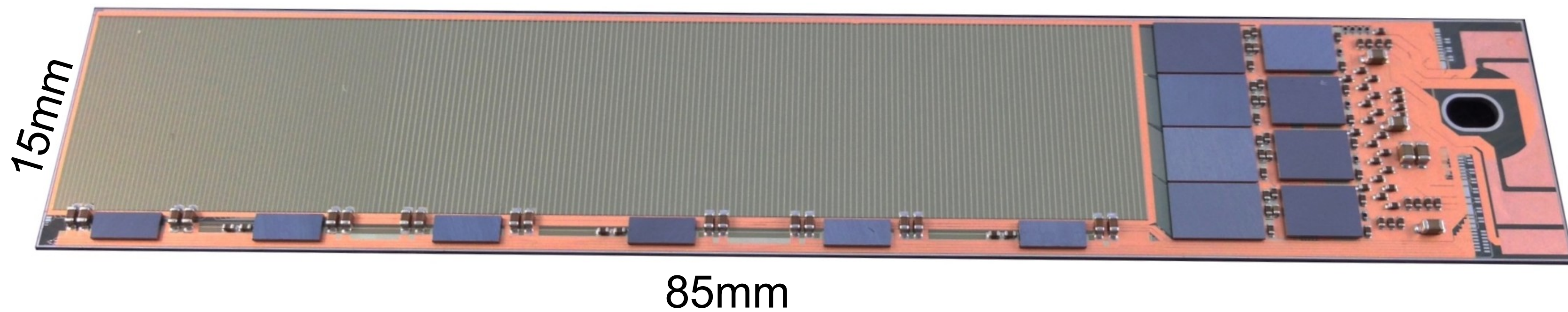
- Bumping technology for SwitcherB required
  - easy-to-use, low infrastructure requirements
  - gold stud thermocompression already available
  - but: high forces on thinned balcony problematic
  - solder bumps: low force
  - solder allows to rework and repair DEPFET modules
- Solder bumping technology
  - most processes optimized for wafer level bumping: screen printing, electroplating
  - solder jetting technology is preferred
  - how to add UBM?
    - gold-stud bumps available



SwitcherB (96bumps); 80µm pad 150µm pitch

Assembled DEPFET Module for Belle-II



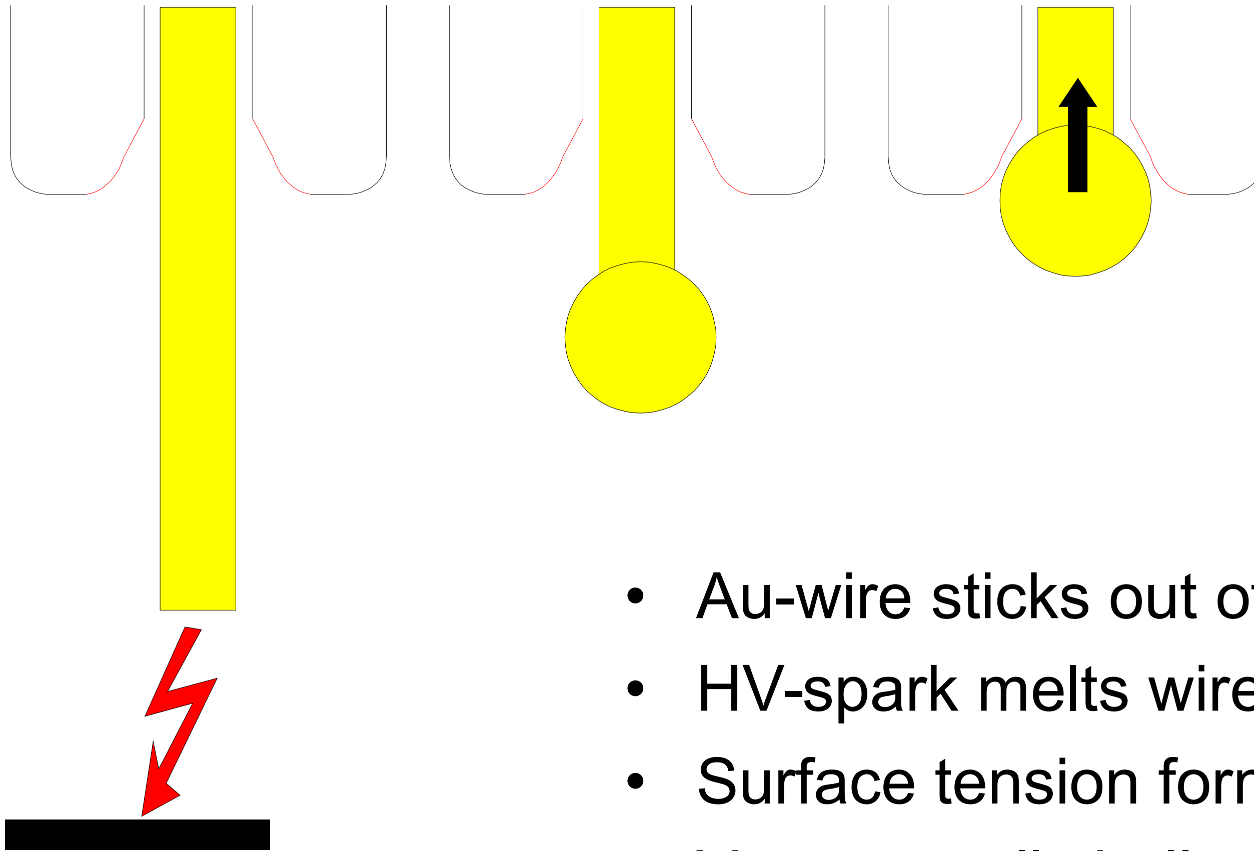


Wire Bonder with Goldstud Bumping

- Half-automatic machine
  - manual placing and aligning of chip (3min)
  - automatic bondprocess (9min/160bumps)
- Modular system
  - Ball-wedge-head for gold bonding and bumping
  - Ball shear tester
  - options: wedge-wedge bondhead, wire pulltester, ribbon bondhead, ...
- Bondprogram convertion tool by SuS
  - draw in wirebonding in Cadence
  - find bumppads in layout

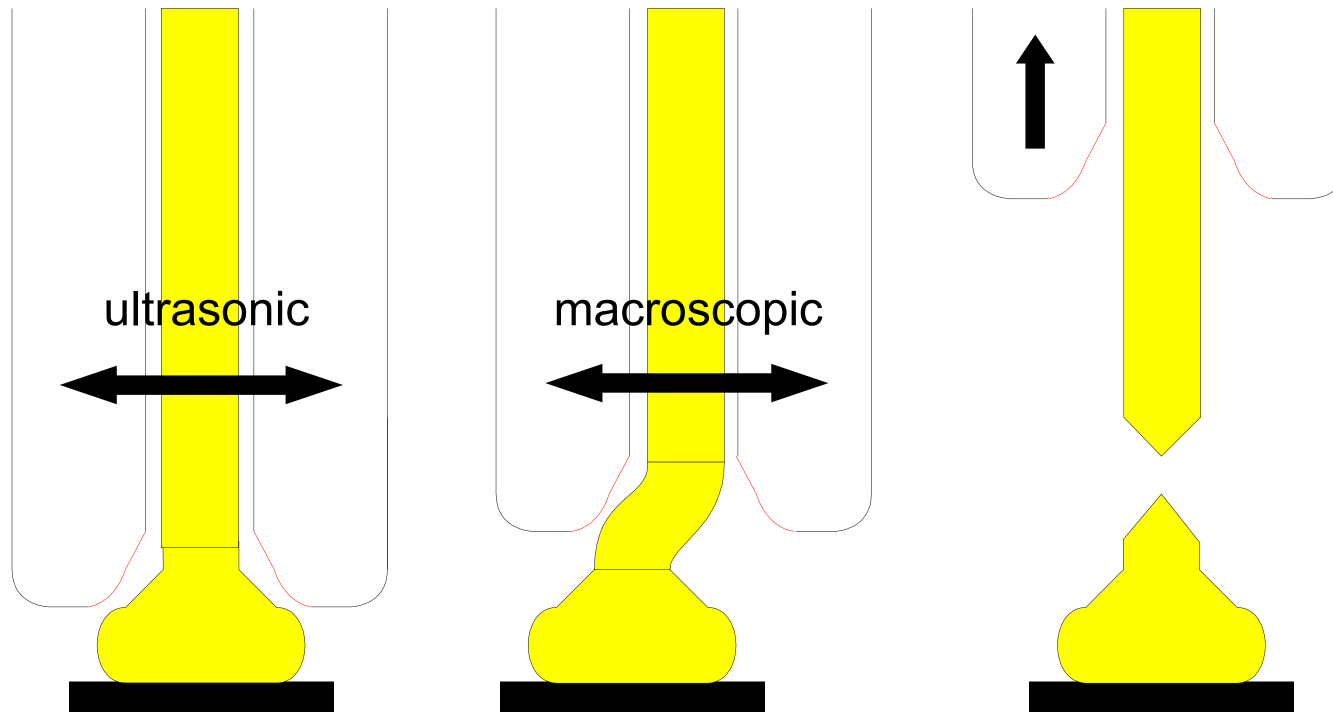
Delvotec 5610

Gold Ball Forming



- Au-wire sticks out of capillary
- HV-spark melts wire (“flame-off”)
- Surface tension forms free-air-ball
- Vacuum pulls ball to capillary

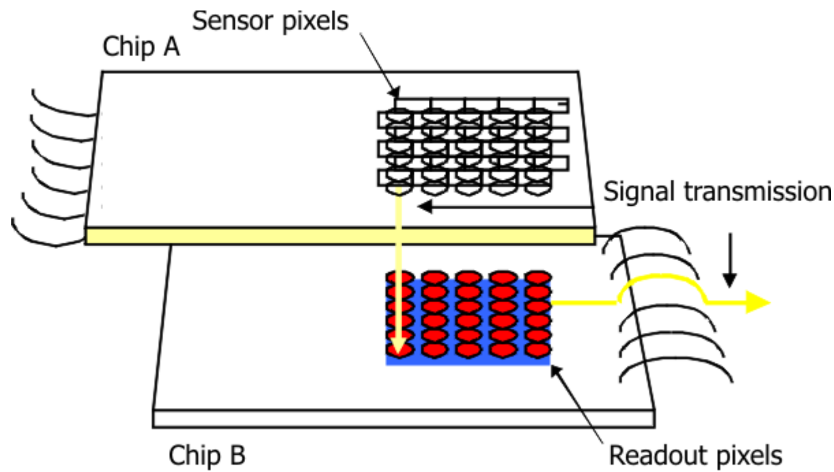
Ball Bonding

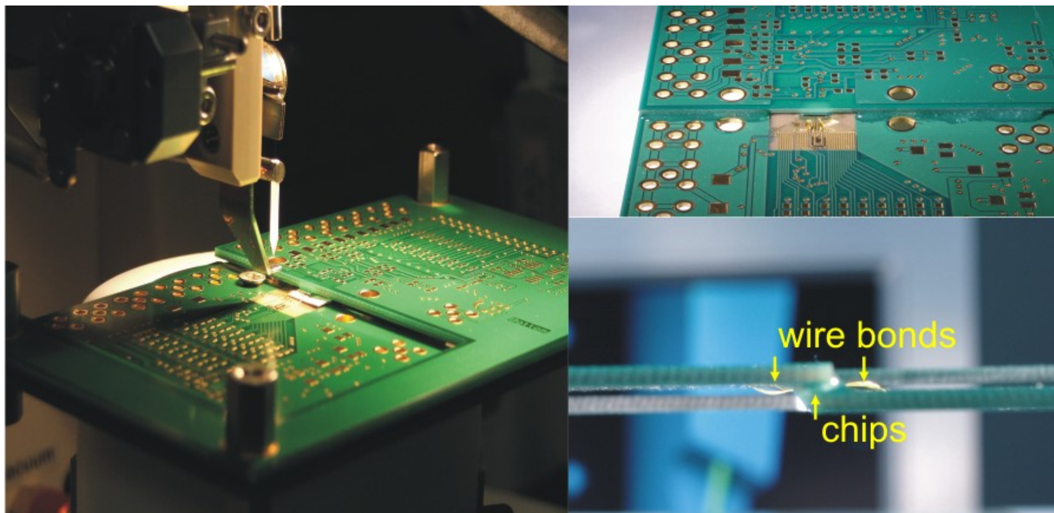


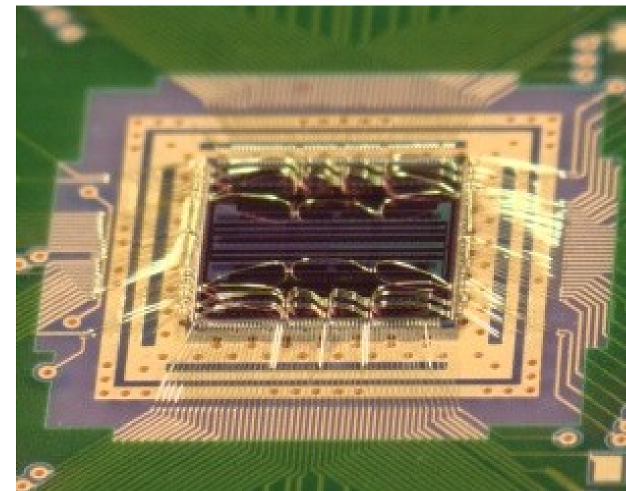
- Capillary presses ball onto Al-bondpad and forms bump
- Ultrasonic to form Au-Al interconnection
- Shear-off wire near the bump
- Pull up capillary and rip off

Ball-Wedge Wirebonding

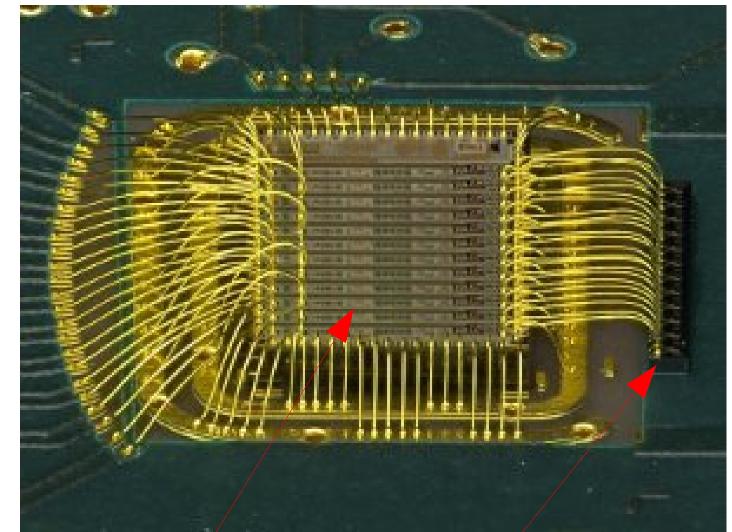
Capacitive Coupled Pixel Detector





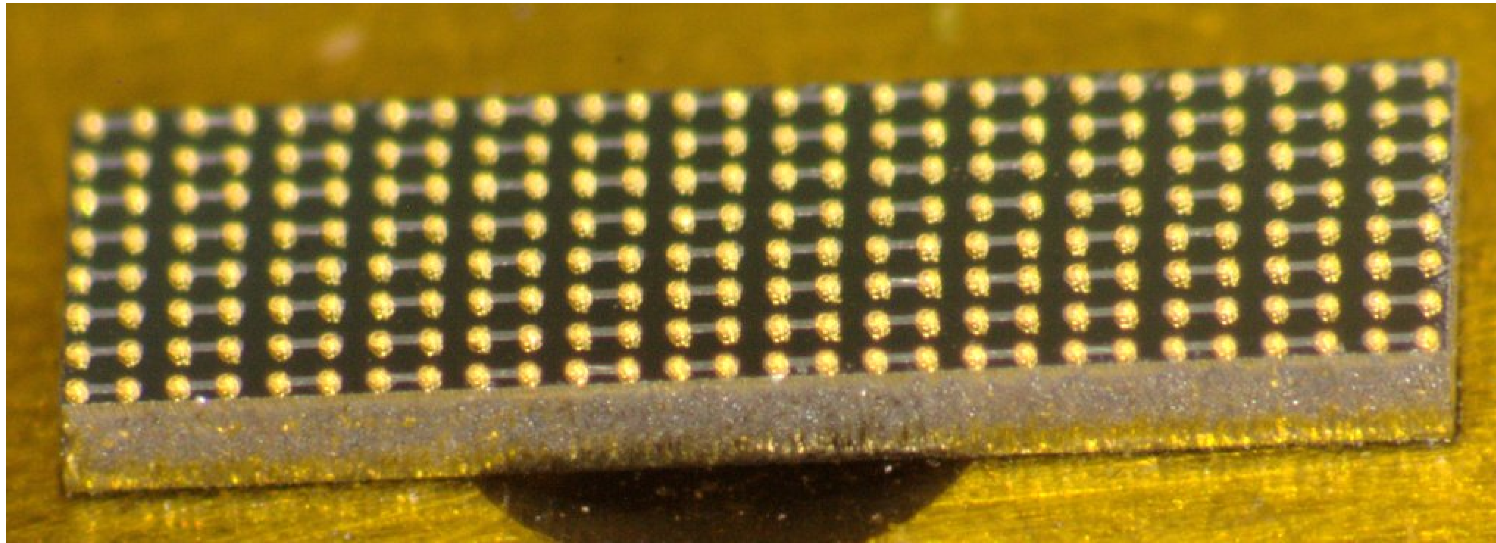


PET Chip with stitch bonds

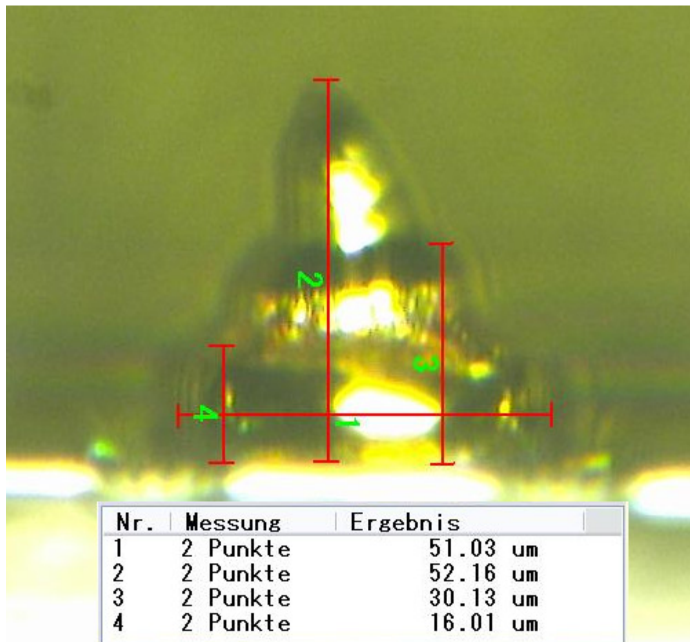


Vcsel driver with diode array

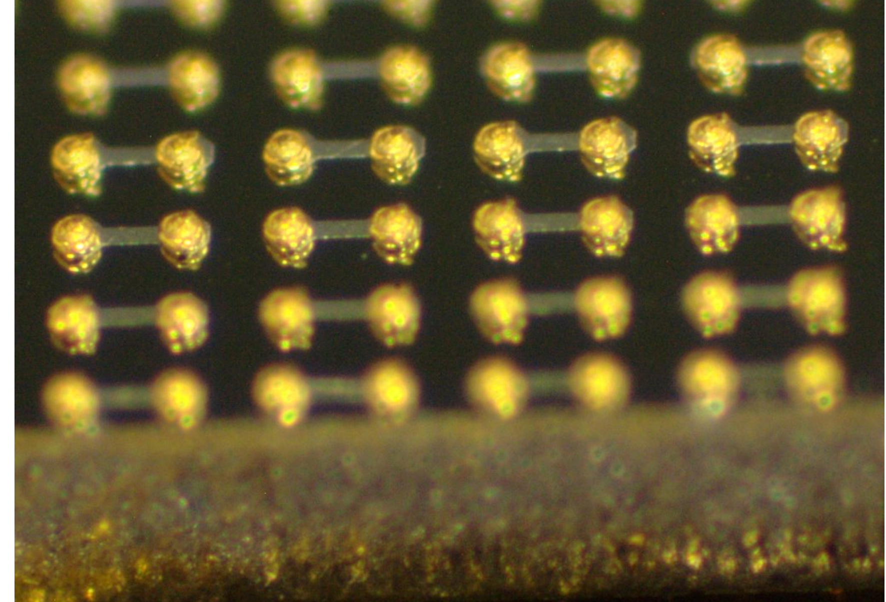
Goldstud Bumps



224 bumps
1,35 x 4,95mm²

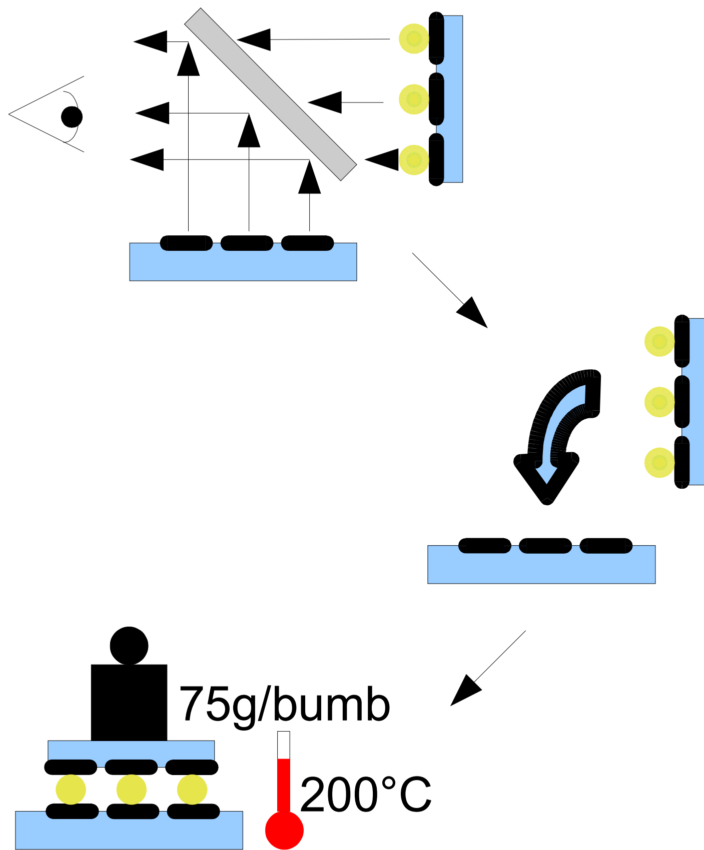


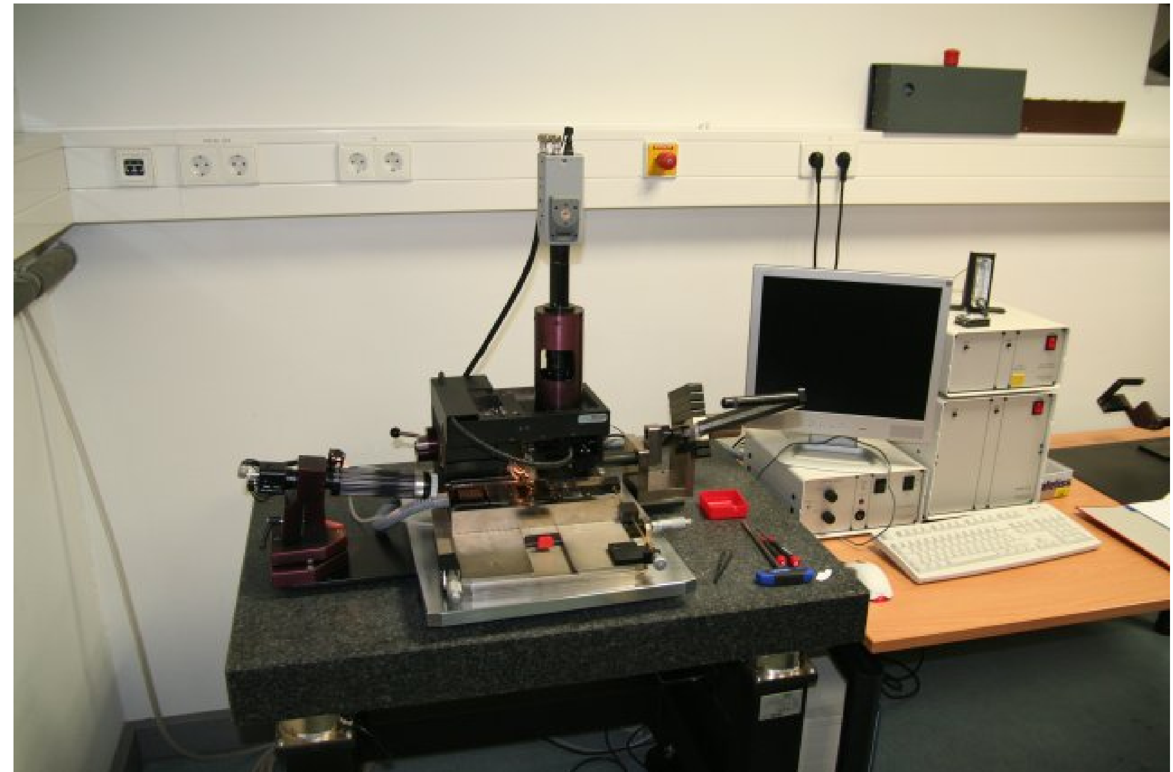
Nr.	Messung	Ergebnis
1	2 Punkte	51.03 um
2	2 Punkte	52.16 um
3	2 Punkte	30.13 um
4	2 Punkte	16.01 um



Flip-Chip

- Pads of substrate and bumps on chip are optically aligned
- Chip is pushed onto substrate
- Temperature profile and static force applied
- Nitrogen atmosphere option for soldering

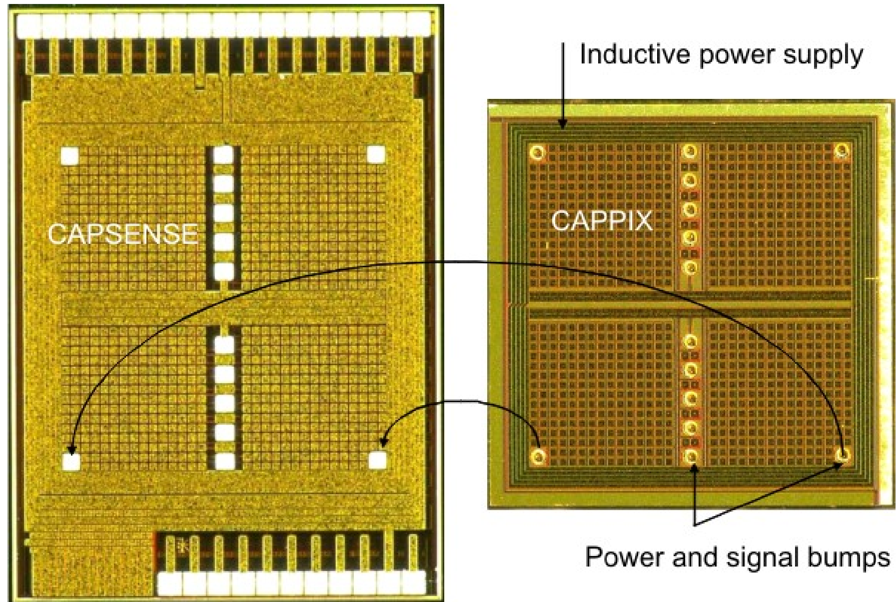


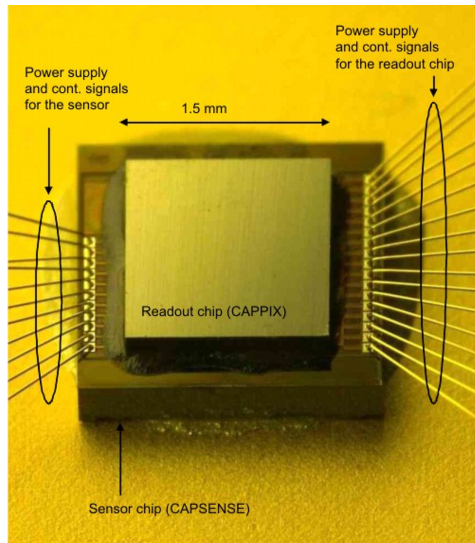


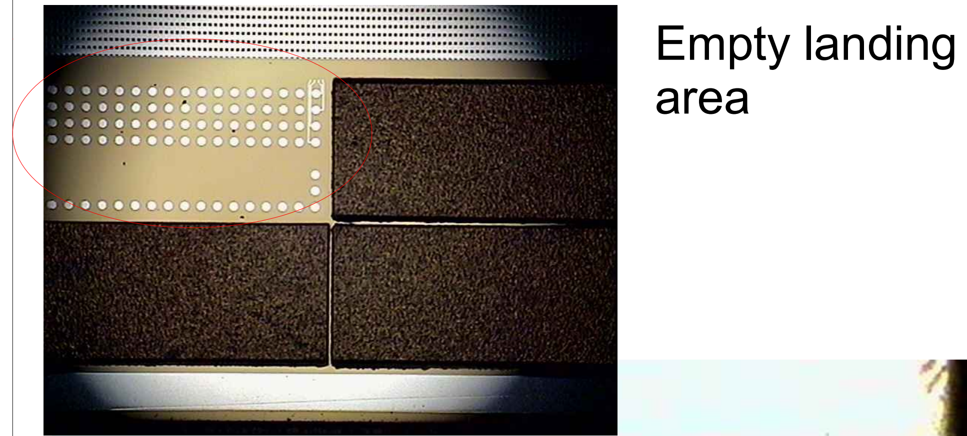
Finetech Lambda, 1µm precision, 400°C, 20K/s, 200N

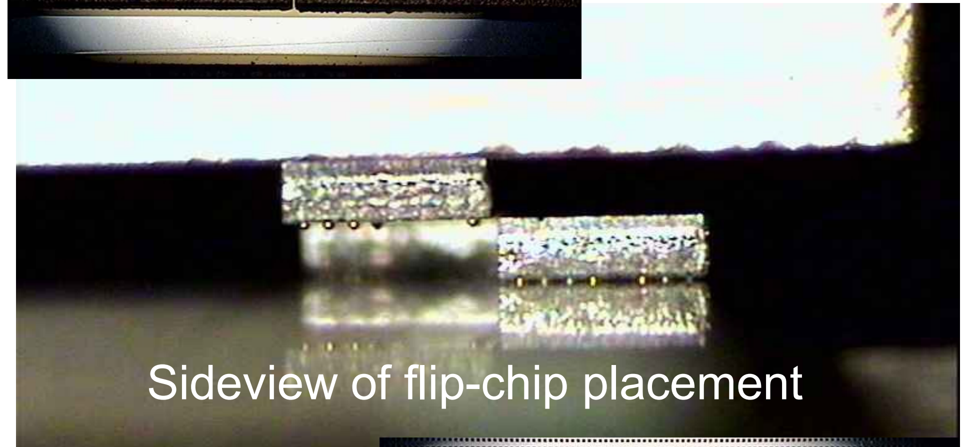
Goldstud Flip-Chip Bonding

Capacitive Coupled Pixel Detector v2



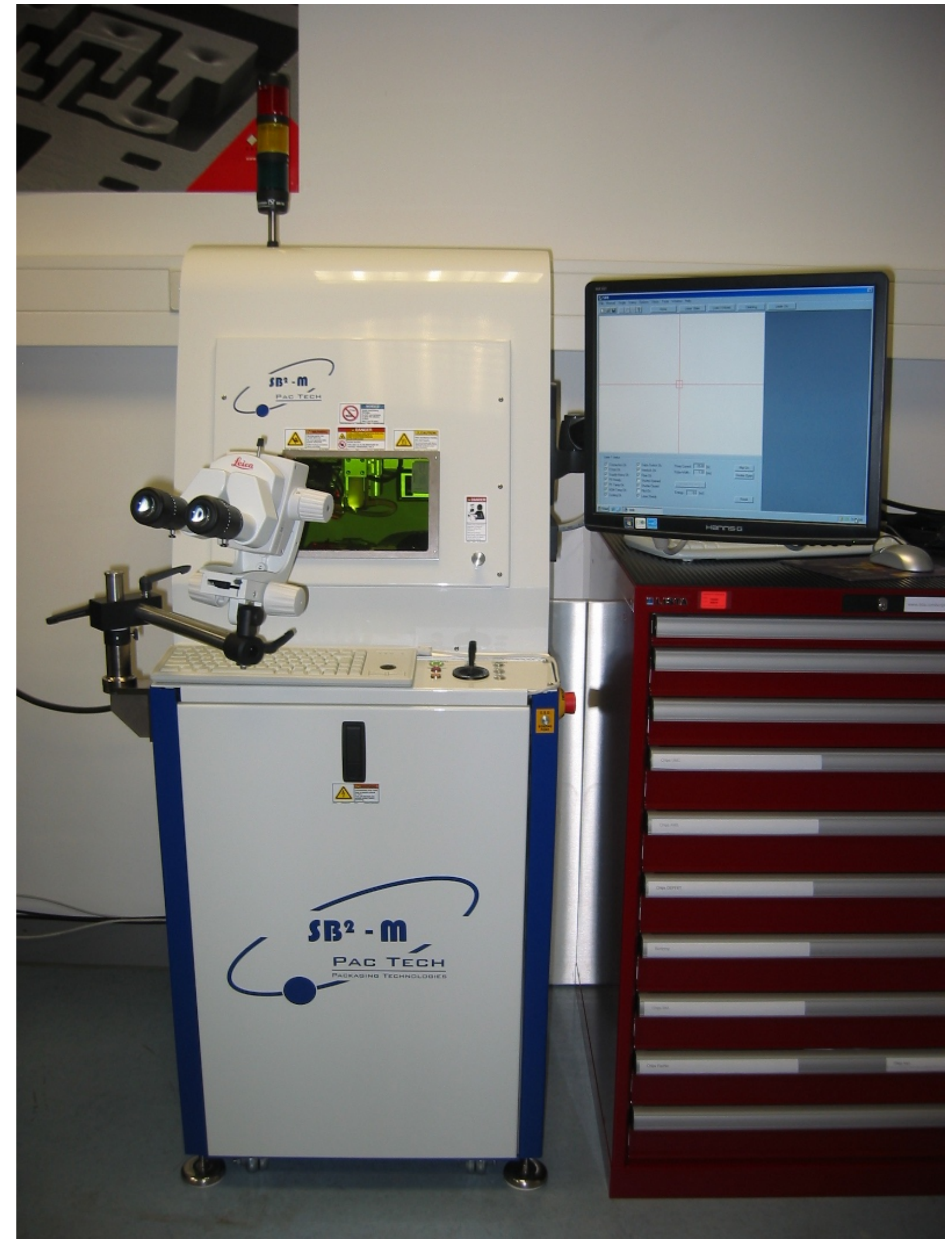






PacTech SB2-M

- Deposit single solder balls
- 60µm solder balls SnAgCu
  - 40µm...760µm possible
  - Max. 5 balls/sec
- Melts ball with 20W IR laser
  - Laser enclosed in housing
  - no laser safety area required
- Low infrastructure requirements
  - pressured air
  - nitrogen



Bond- and Repairhead

Bondhead

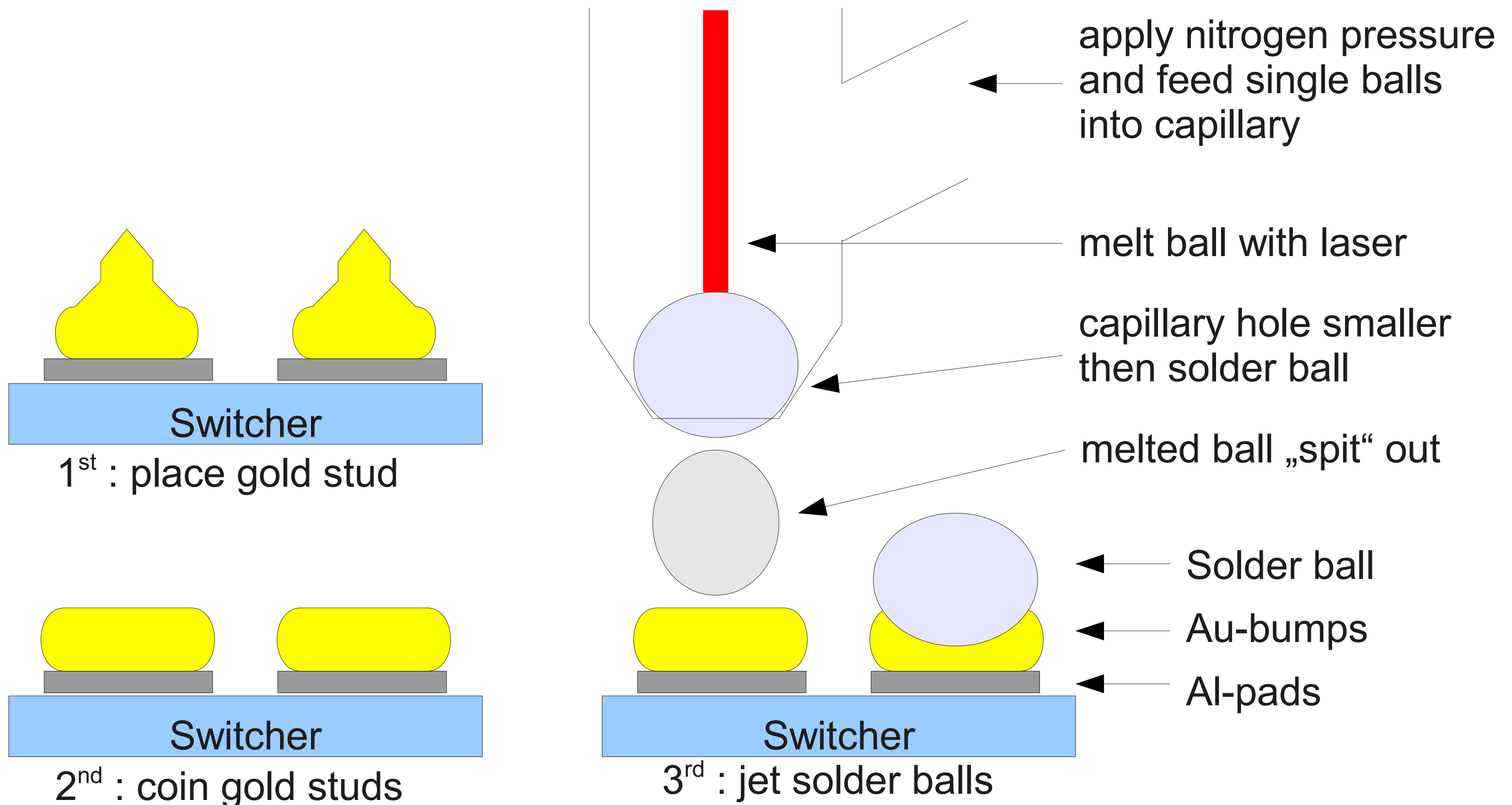
Repairhead

Capillary

Laser safety glass

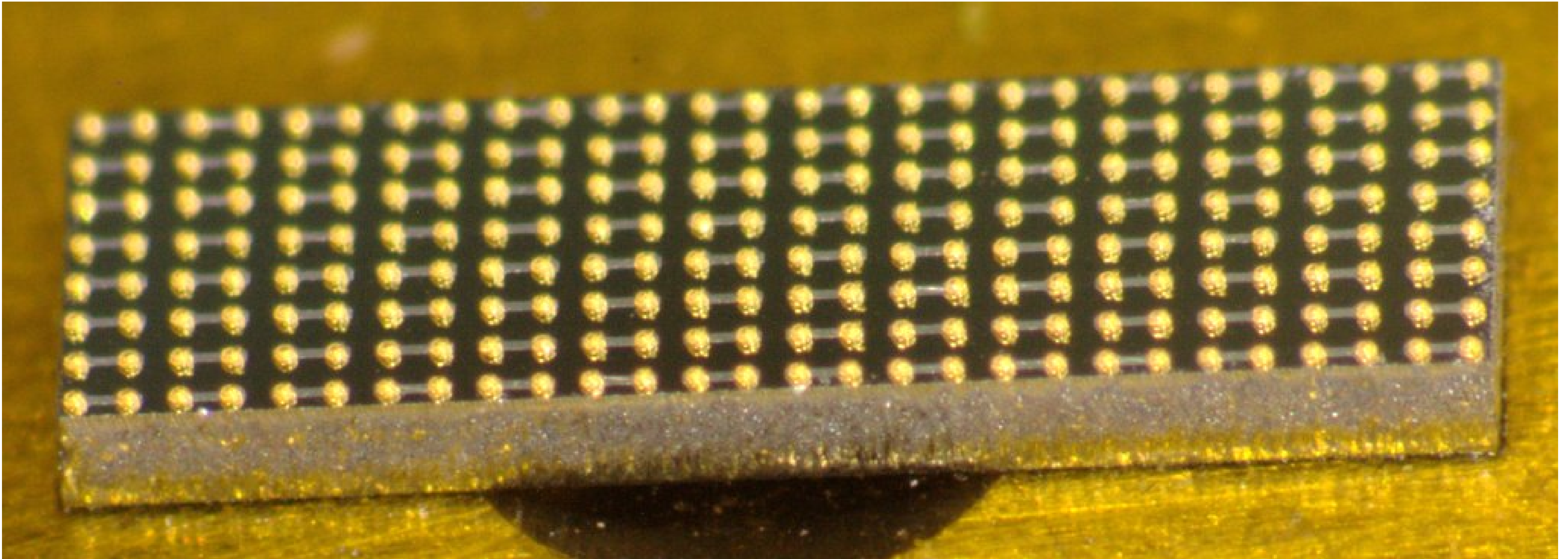
Single Chip Solder Bumping

- Use coined gold studs as an under bump metallization
- Place solder bumps on top using PacTech solder jetting technology

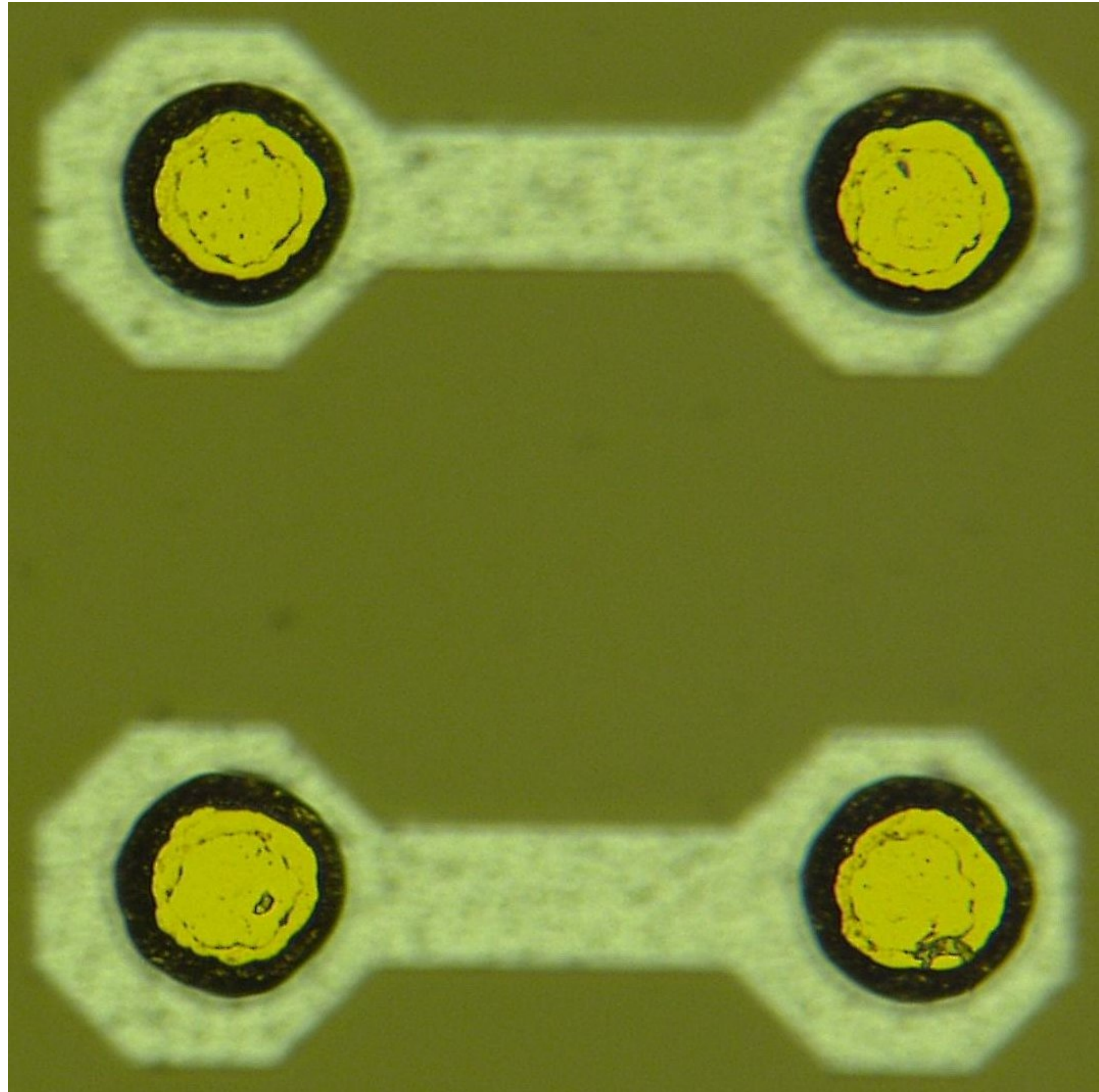


Gold Stud Bumping

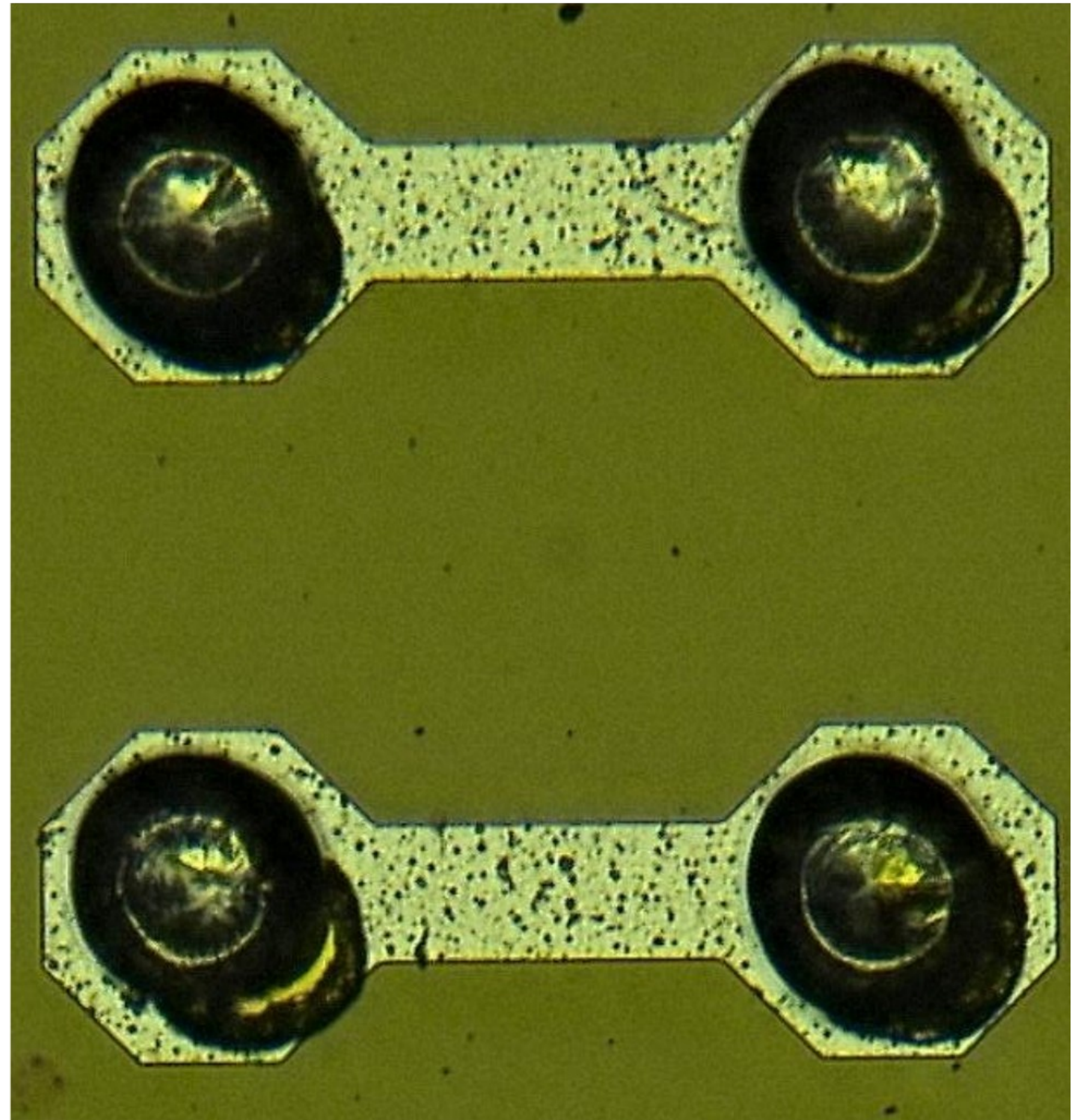
- Place gold studs on chip and substrate
- Coin studs on chip to remove tail on top and create a flat surface
  - using flip-chip machine and big piece of silicon



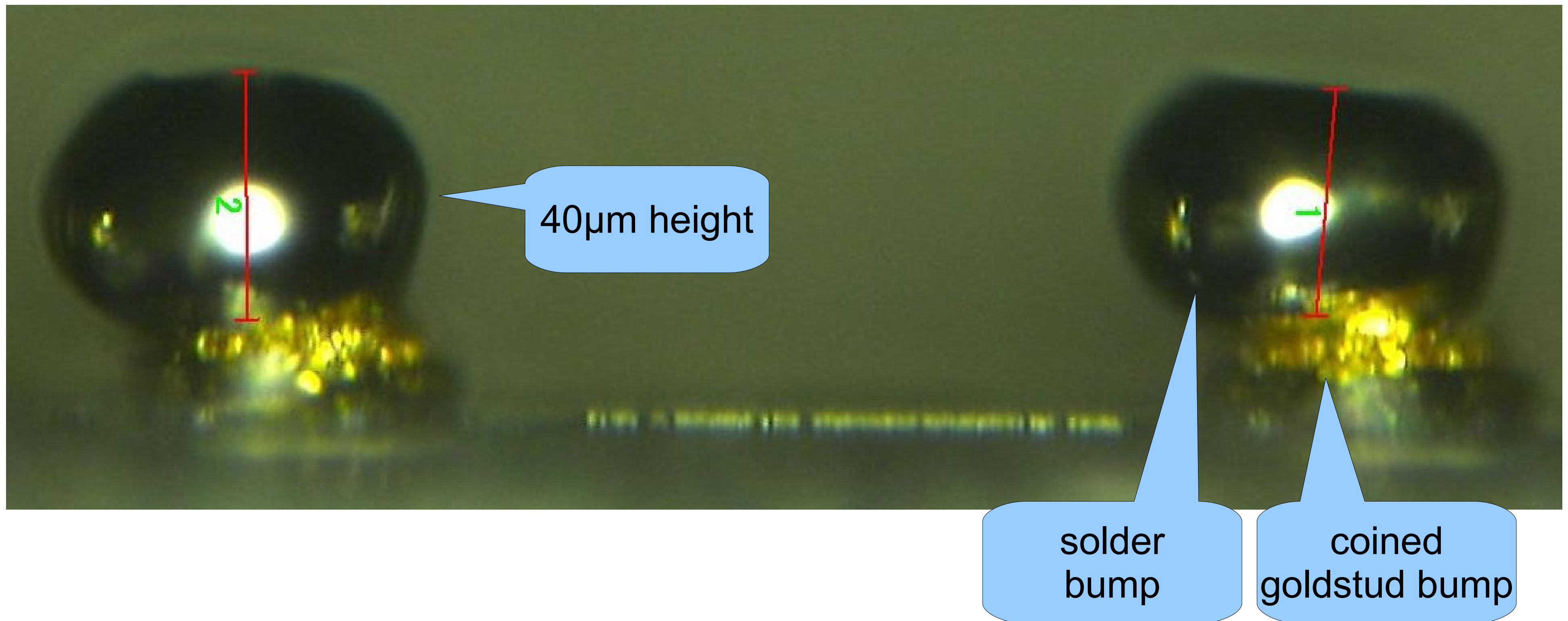
- 58µm bump diameter
- 42µm flat diameter



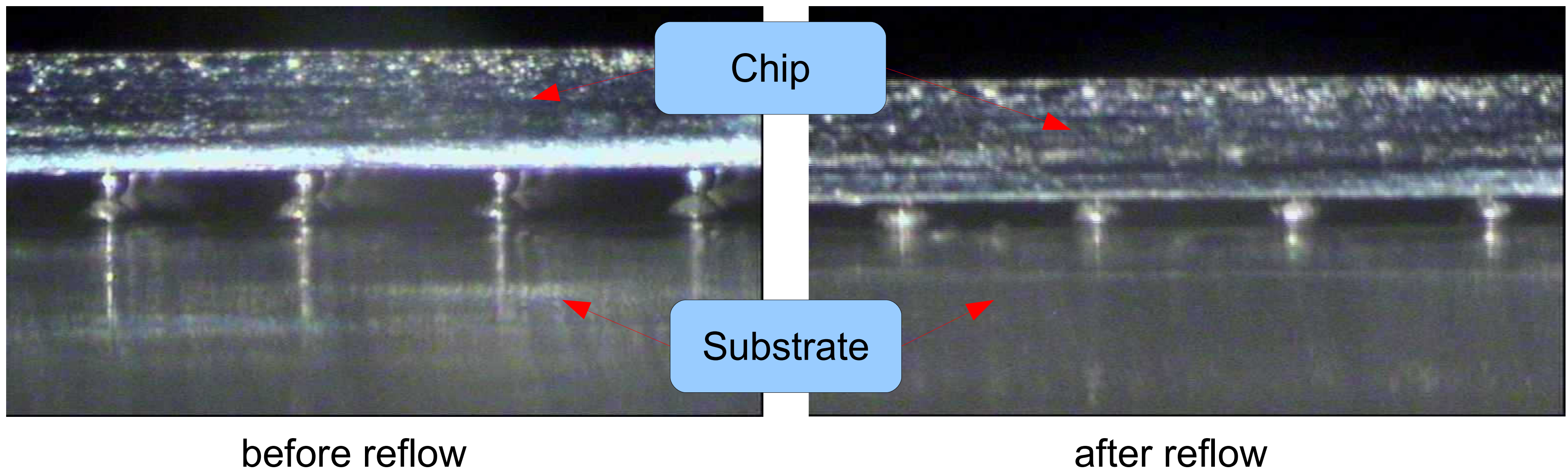
- Ball diameter: 67µm



Solder Ball Side View



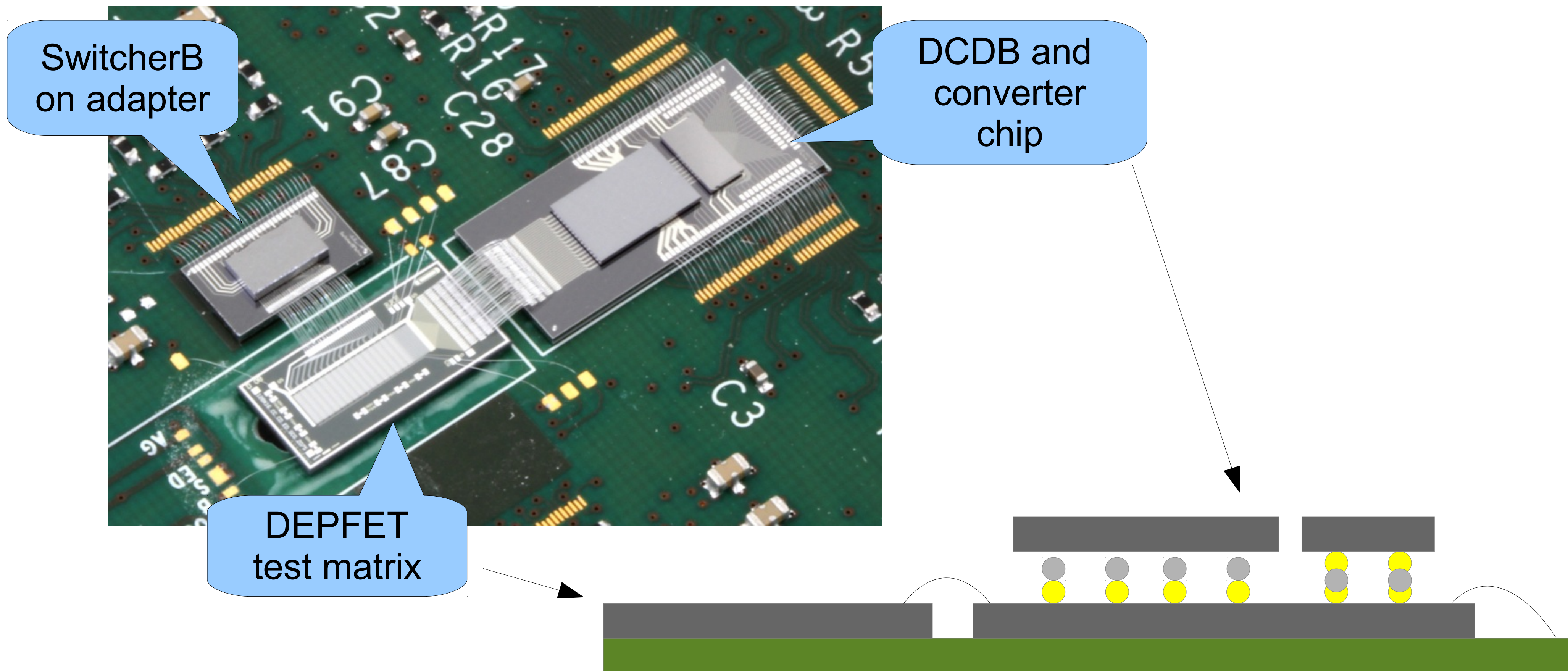
- Soldering in Finetech flip-chip machine
- Flux applied to subtrate
- Nitrogen atmosphere with ramped temperature profile
- Flux cleaning in ultrasonic bath



before reflow　　　after reflow

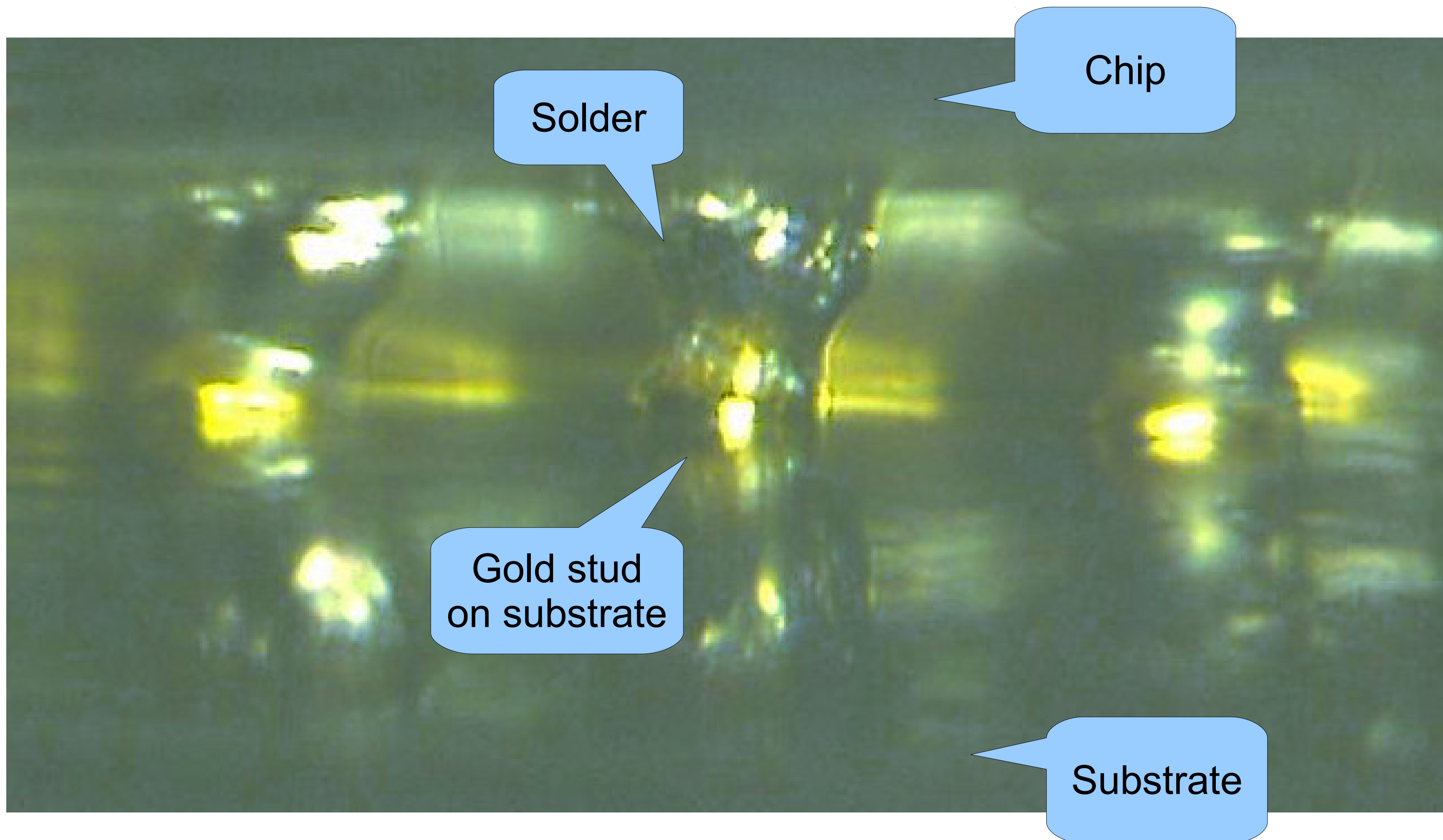
Wire Bond Adapters for DEPFET Test Systems

- Flip-chip only read-out and steering chip
- Wire bond only DEPFET test matrix
- Need wire bond adapters for test systems
  - gold studs as under bump metallization



Flipped Side View

- Solder balls compensate ball placement error



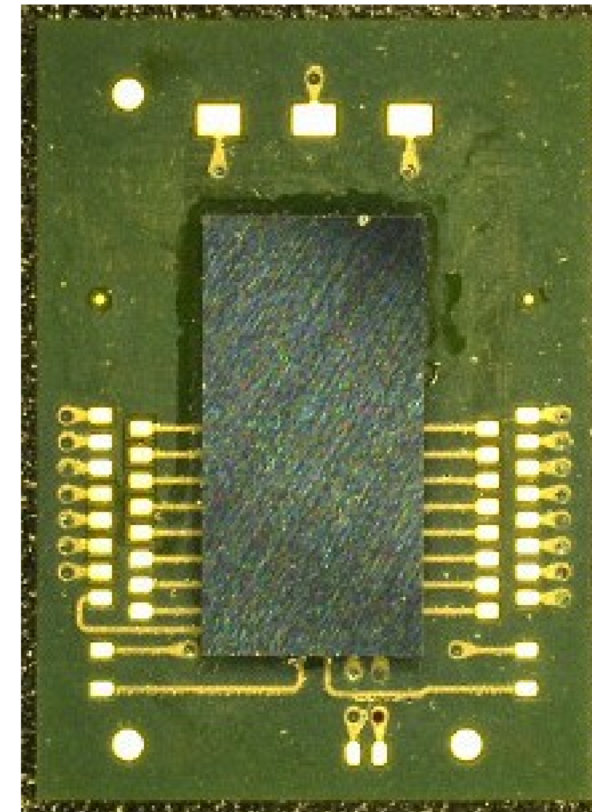
Solder Bumping at XNAP

- X-ray diffraction and imaging with avalanche photodiodes
- Detector is sensitive to pressure
  - solder bumping used for test assemblies

Read-out chip with solder-on-gold

Ceramic or PCB interposer

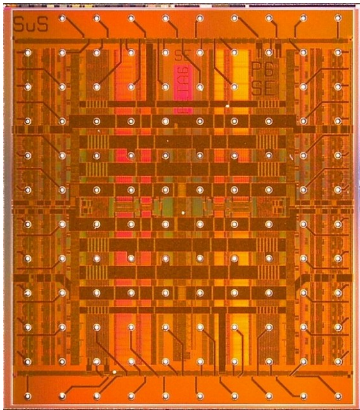
Avalanche photodiode



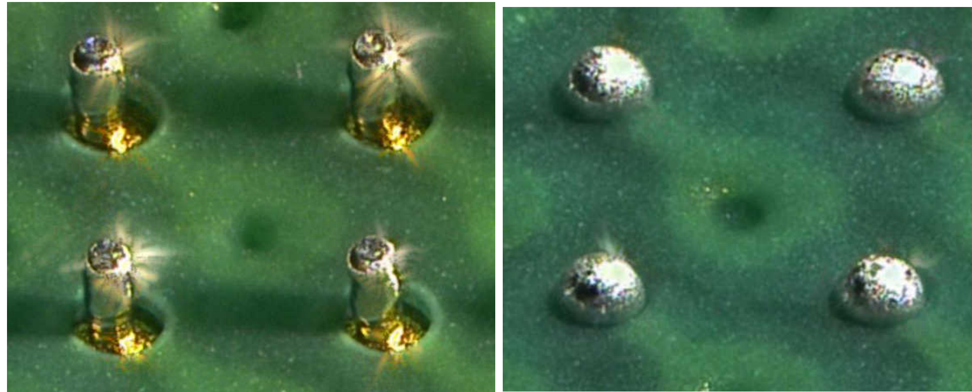
Top view: read-out chip on interposer

Bump Stacking

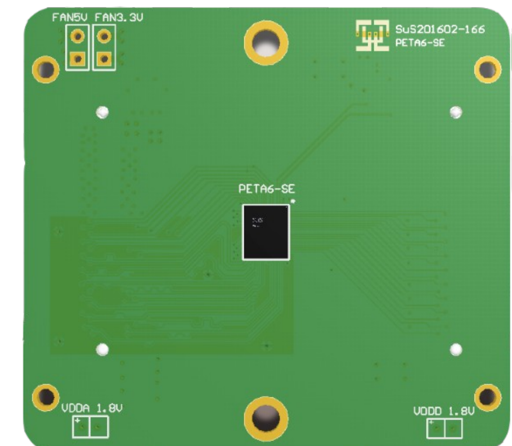
- Stack multiple solder balls to increase solder volume
  - chip-on-board with 100μm balls
  - large pads on PCBs need more solder than 100μm ball provides
  - place balls on PCB and reflow
  - add underfill



5x6mm² PETA6SE ASIC with 100μm balls and 500μm pitch



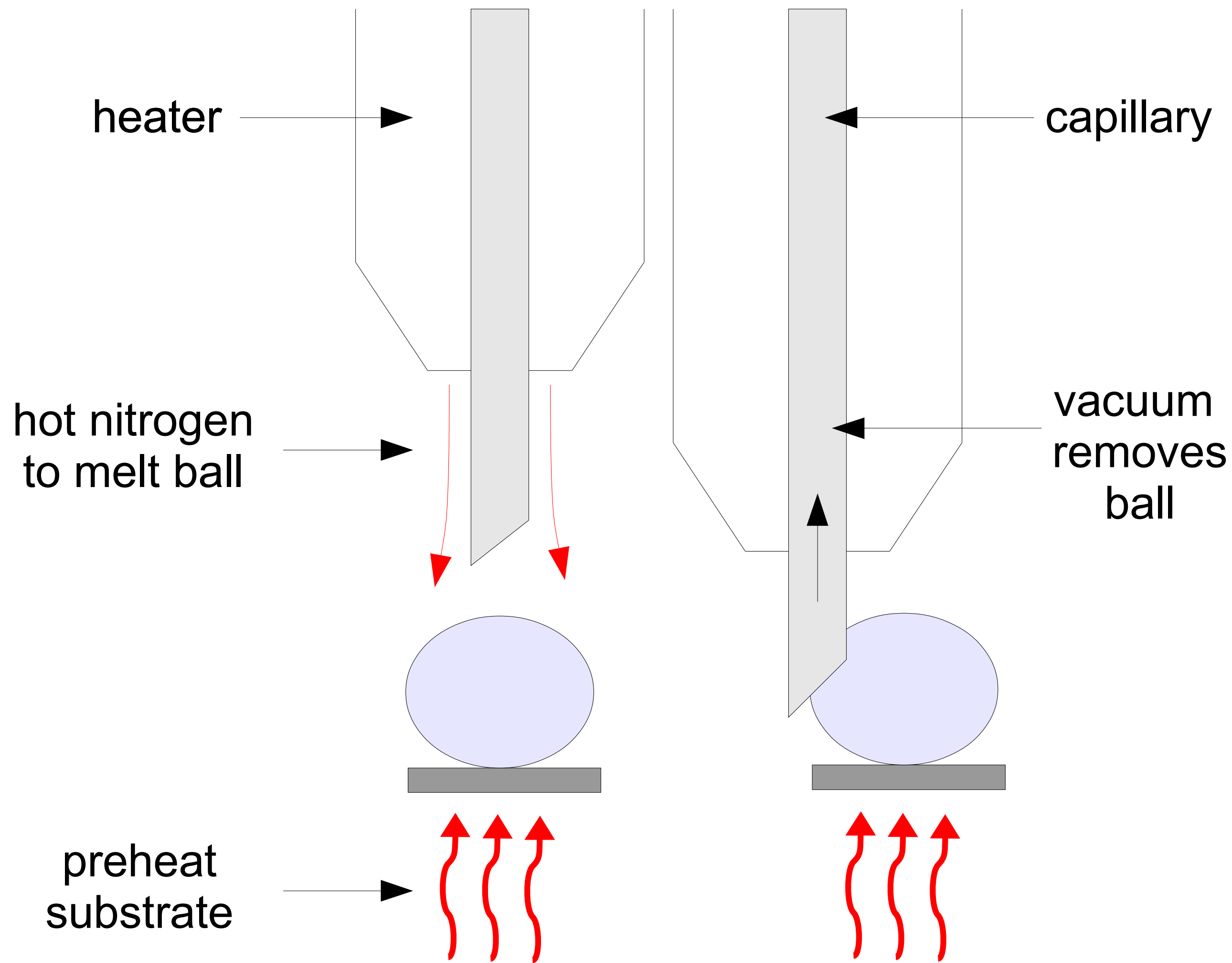
stack of 14 solderballs of 60μm diameter before and after reflow



Chip-on-Board

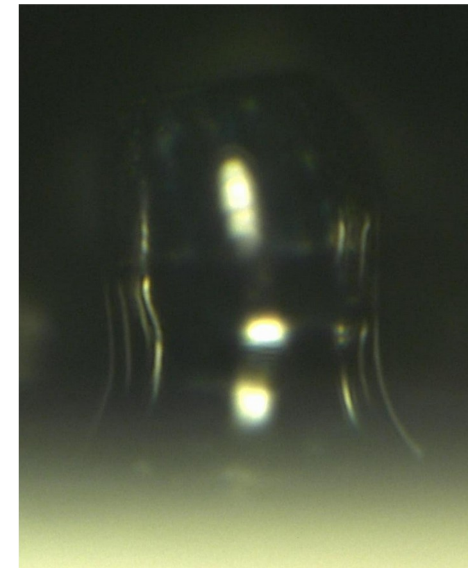
Solder Removal

- Repair head allows selective removal of solder
  - Option for PacTech machine

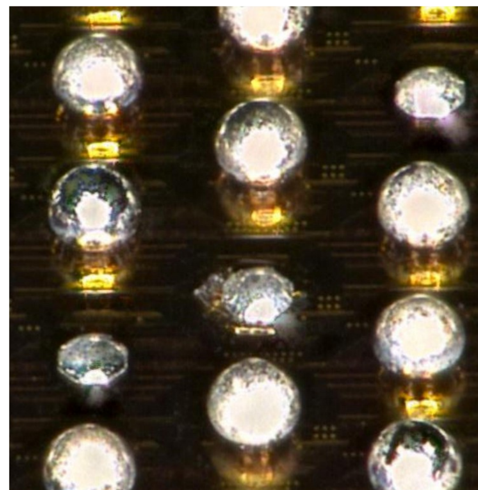


Ball Removal / Reballing

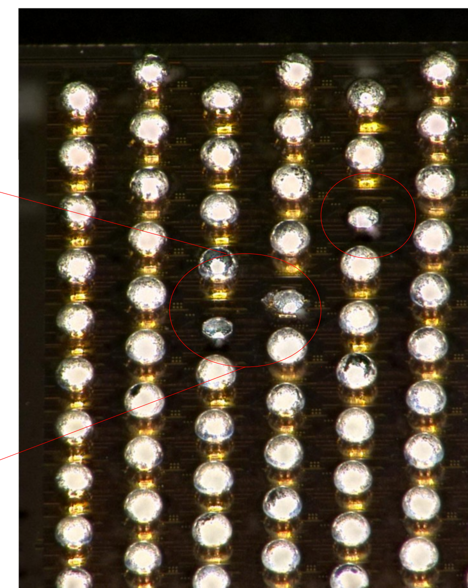
- Reballing of rare chips
  - chips have been desoldered from substrate
  - remaining solder has been removed
  - solder jet multiple 60µm balls to increase final ball size
  - reflow to reshape ball stack
- Removal of single balls
  - disconnect inputs of readout chip from high current pixels
  - selectively remove single balls using repair head
  - reflow to reshape adjacent balls and solder remains



stack of 6 balls before reflow, 128µm diameter after reflow



100µm diameter, 200µm pitch

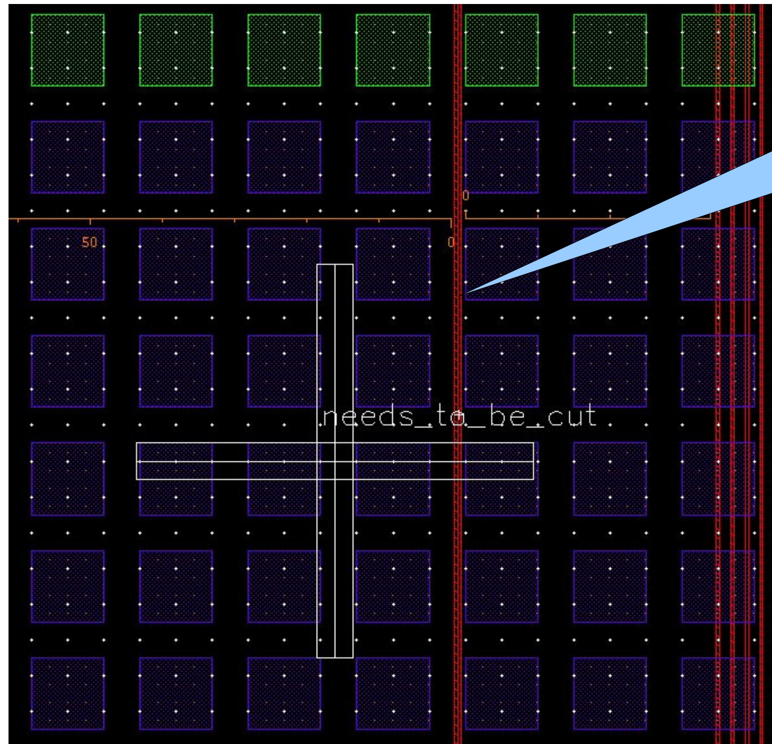


removed single solder bumps

Summary

- Flip-Chip allows highly integrated, mechanically robust multi-chip-modules with good signal integrity
- MPW production with bumping can be troublesome
- Solder baller offers a flexible solution for single chip bumping
- Suitable UBM is required on both sides! Can use gold studs
- Successfully used in Belle-II prototyping (Switcher chips) and for XNAP (APD array prototype)
-

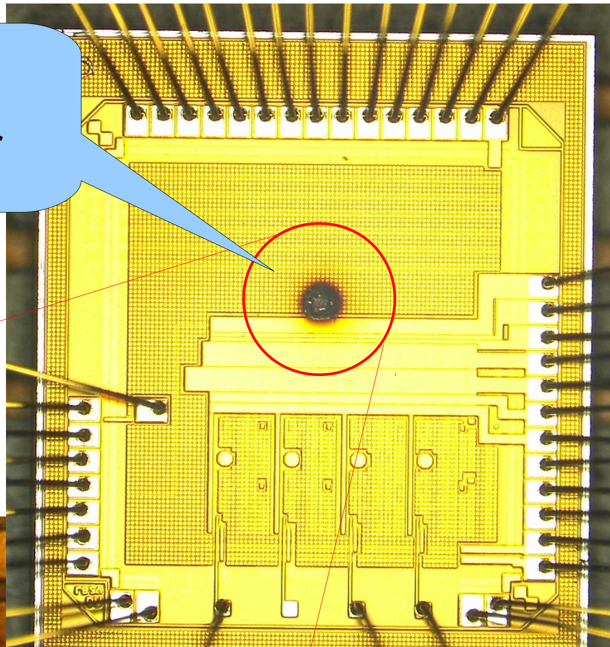
Fun with Lasers

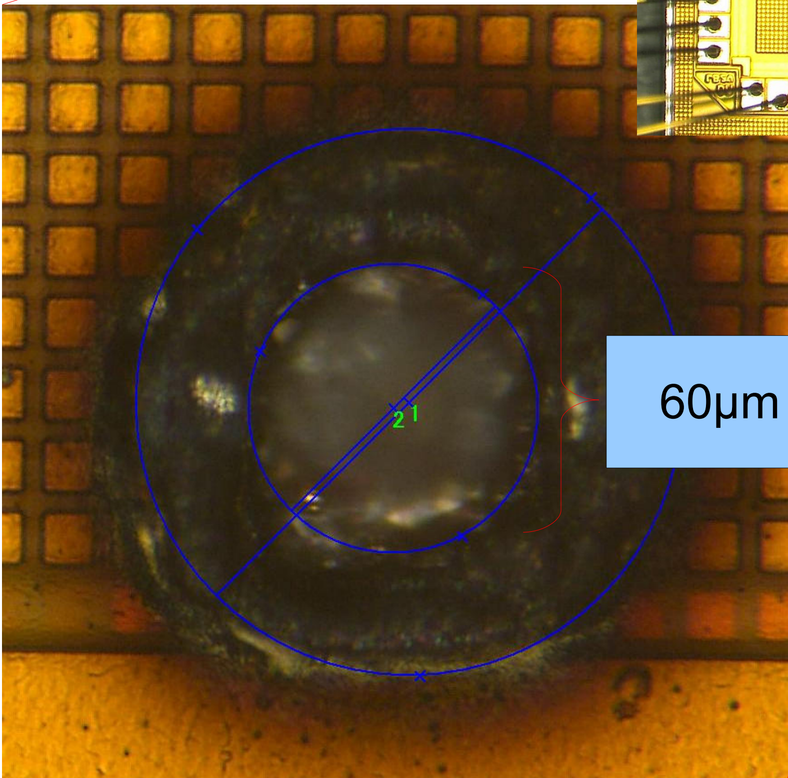


need to cut only this trace ...

35µm

... shoot with laser





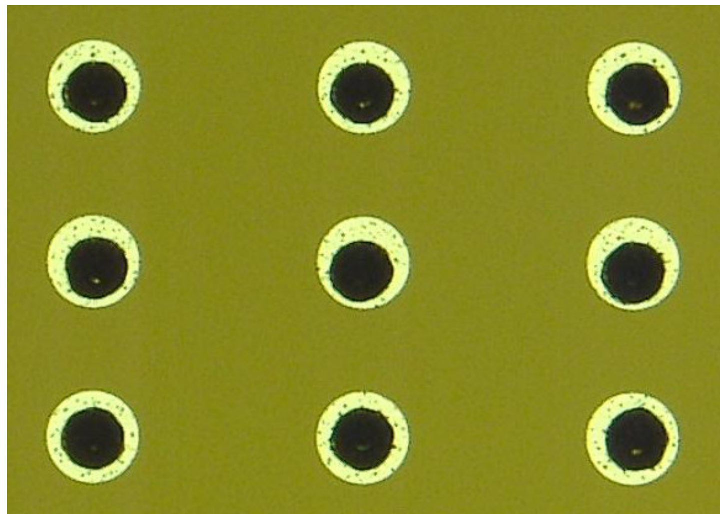
60µm

success :-)

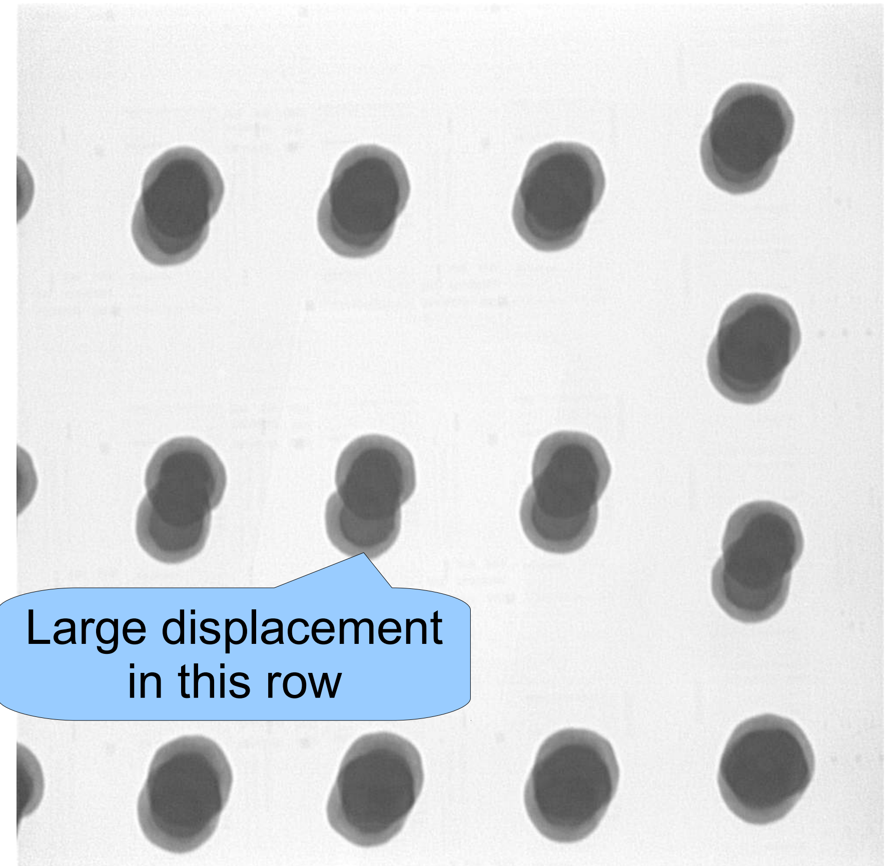
Thank you!

Gold Stud Misalignment

- Gold stud placement error of bonder
  - unconnected bumps



Photograph of gold studs on substrate



X-ray image of flipped assembly