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Innovation Services

CMUT: a versatile ultrasonic platform developed by Philips

Rob van Schaijk
MEMS & Micro Devices
06-06-2019



PENTA cluster number E!9911



Integral part of innovation organization of Philips



*Effective January 1, 2019, the reporting segment Diagnosis & Treatment comprises two clusters: Precision Diagnosis and Image-Guided Therapy.

PHILIPS

Innovation
Services

A short introduction



~1,000
experts



**10,000 m²
infrastructure**

test & prototyping
facilities, cleanrooms, labs



**NPS
>50%**
Customer satisfaction
of 4.5/5

Certified for



Simple mission:
to accelerate
your innovation

Our **key areas** of **expertise**



**Medical devices
& equipment**



High-precision equipment



**Connected digital products
& systems**



**MEMS devices
& micro-assembly**



**Manufacturing processes
& systems**



**Design for reliability
solutions**



Industry consulting



Environment & safety



MEMS & Micro Devices

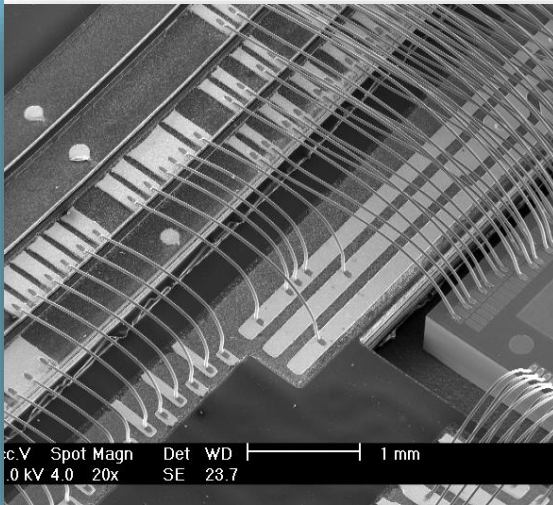
Development and manufacturing at Philips Innovation Services

High Tech Campus



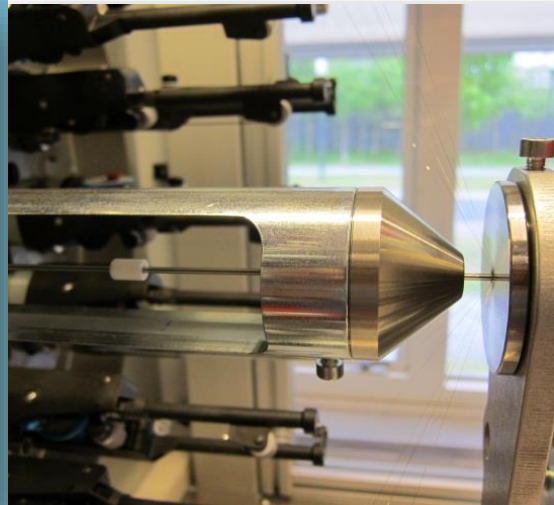
MEMS Foundry
Micro-fabrication
2650 m2 Clean room
ISO13485 certified

Greenhouse (Strijp)



Micro-assembly
die/board/system level
2500 m2
ISO13485 certified

High Tech Campus



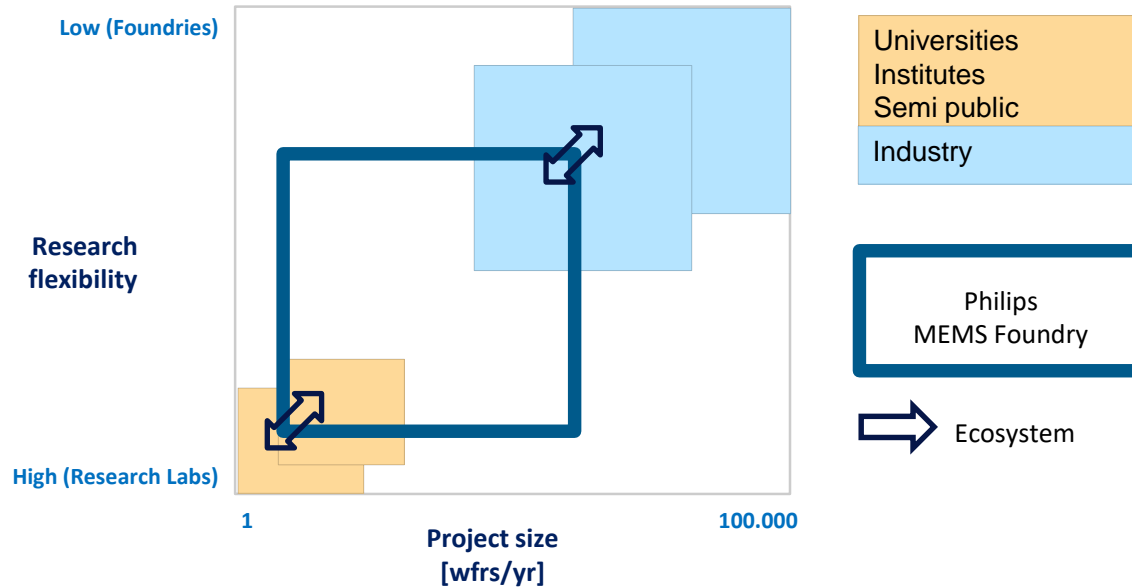
Process Development Micro Devices
Smart catheters, in- and on-body devices
Workshop, 300 m2
ISO13485 certified



Our position in the market

Filling and bridging the gap

Filling: many MEMS applications stay below 5 wafers/year
Bridging: transfer to larger foundries for much higher volumes





CMUT: Capacitive Micro-machined Ultrasound Transducer

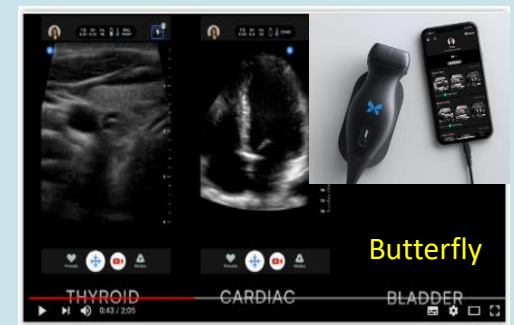
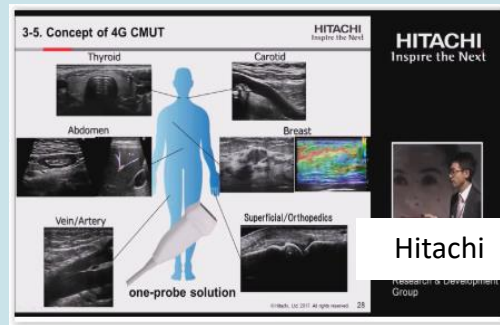
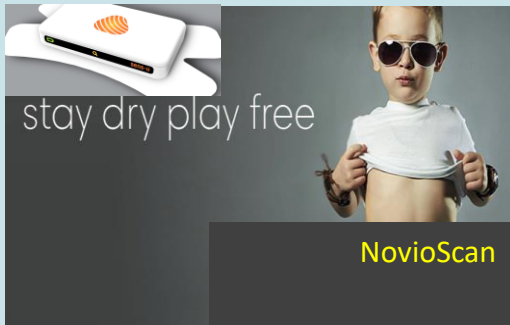
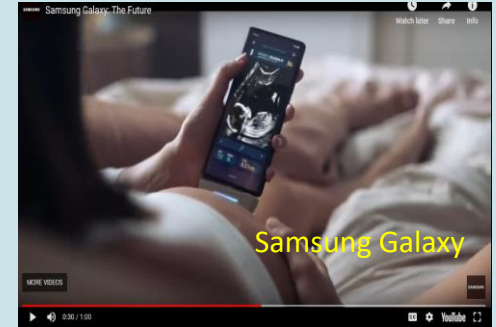
Medical ultrasound application range



Handheld and wearable ultrasound



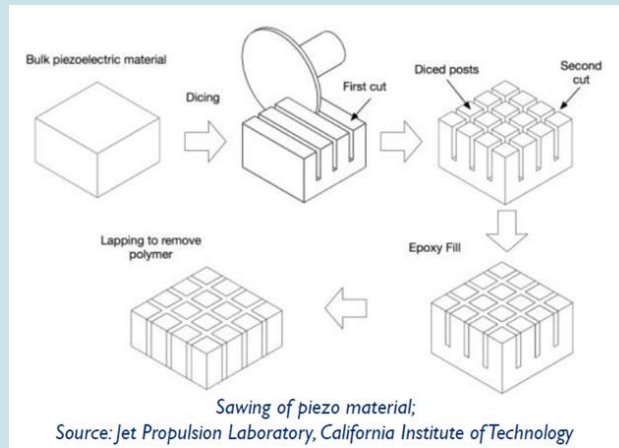
Keywords: Consumer Ultrasound, High volume, Pregnancy, Bladder, Medical and non-medical applications



Bulk piezo versus MUT

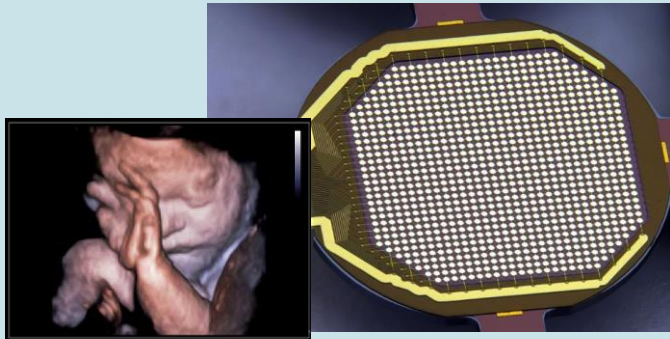
Todays ultrasound imaging:

- Based on piezo-ceramics
- Difficult to manufacture
- No volume production
- Labor intensive → expensive
- Reserved for professional use



The MEMS US revolution:

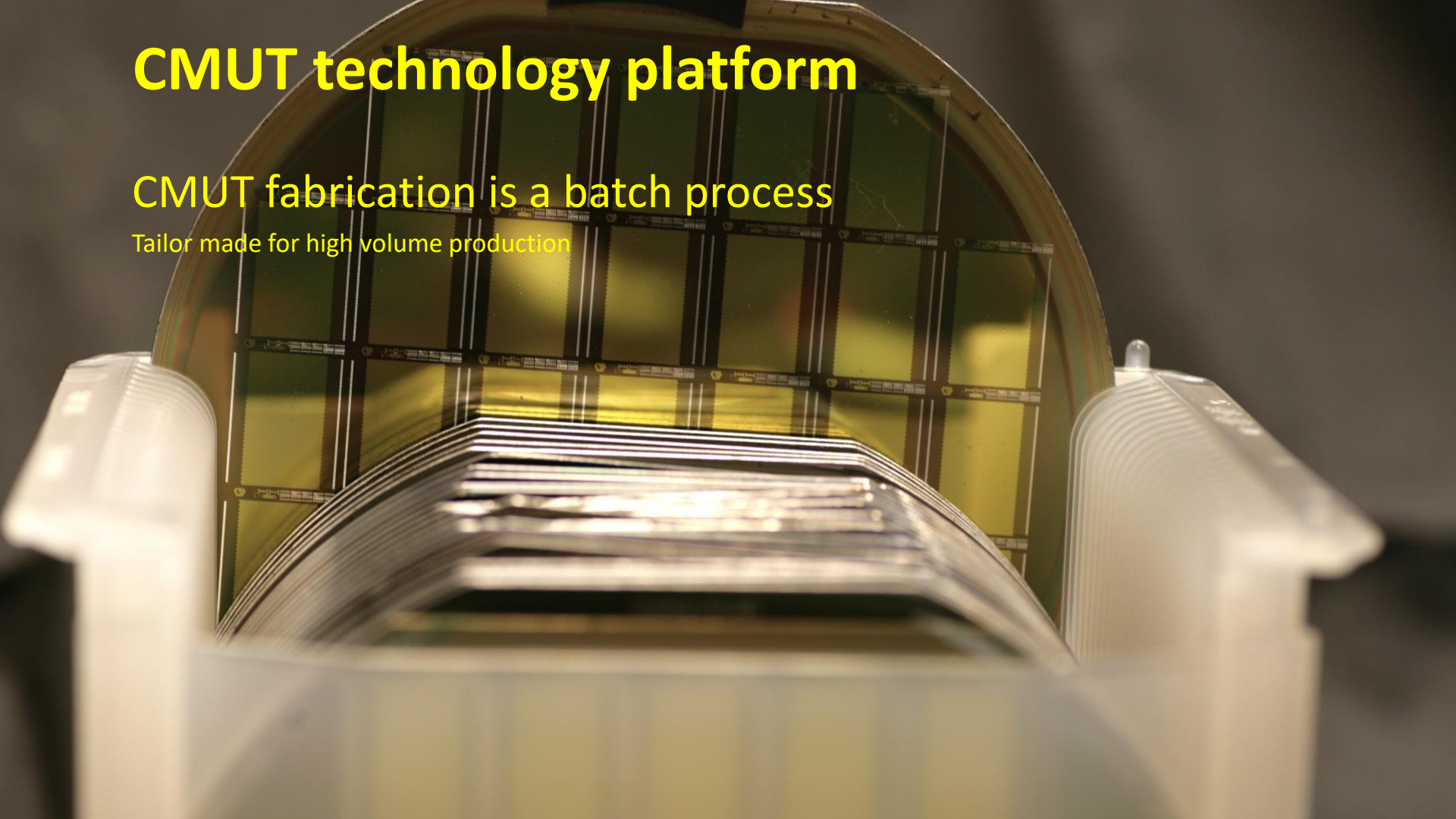
- High volume production
- Eliminate (manual) assembly
- Low-cost platform → multiple applications
- Miniaturization → catheters
- Higher frequencies
- 3D imaging compatible
- Enter consumer market



CMUT technology platform

CMUT fabrication is a batch process

Tailor made for high volume production



CMUT

Capacitive Micromachined Ultrasound Transducer

A replacement for piezo-based ultrasound in the medical domain

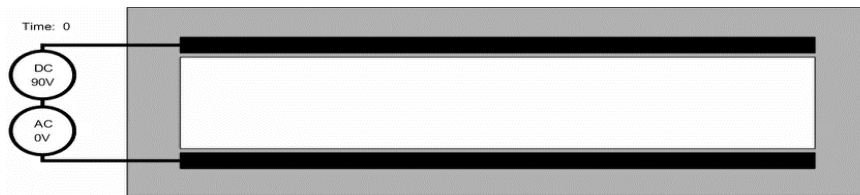
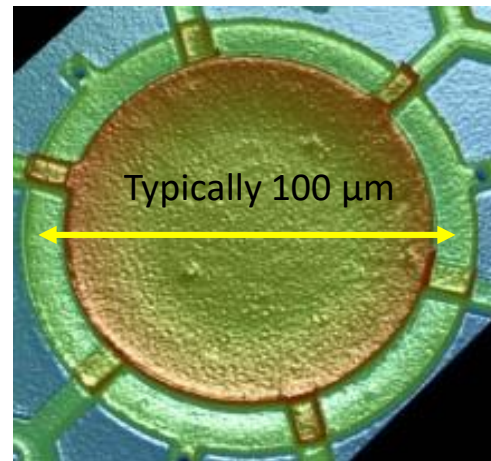
CMUT is fabricated by IC technology

Parallel plate capacitor on membrane

Transmits and receives ultrasound at 1 - 50MHz

Collapse mode: the membrane touches the cavity bottom

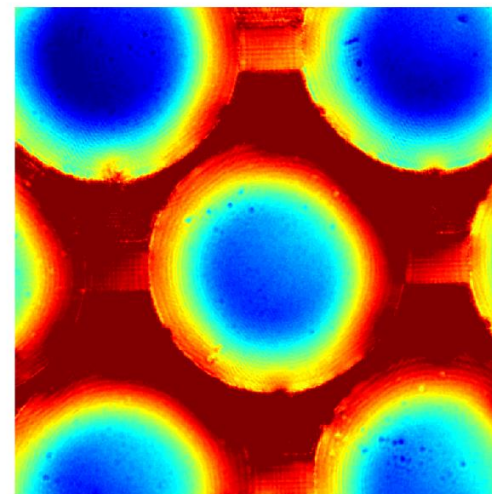
An RF-voltage makes the membrane vibrate



Advantages:

Robust design, large volume & low cost, high level of integration

Miniaturization & high frequency, lead free for disposable applications

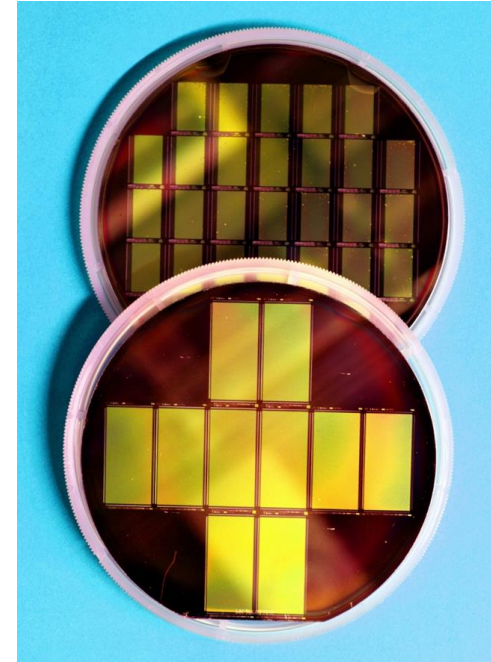


CMUT modular technology platform

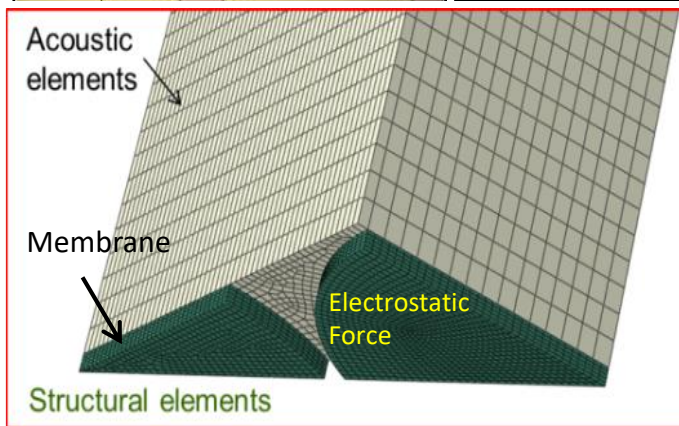
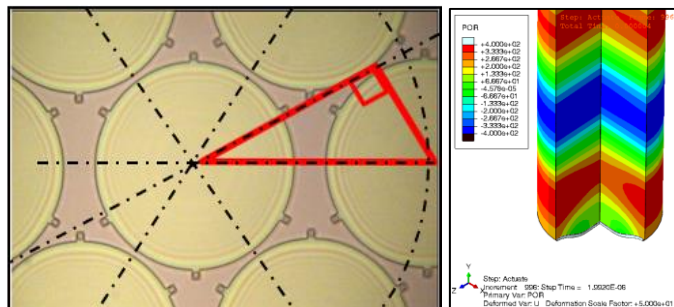


CMUT offers a lot of **design freedom**

Wafer		150mm 200mm
Substrate		Bare Si ASIC
# cMUTs / die		Variable
Membrane / cavity	Diameter	< 500 μm
	Pitch	Variable
	Membrane thickness	< 5 μm
	Gap height	< 1 μm
	Dielectric	SiO ₂ SiN



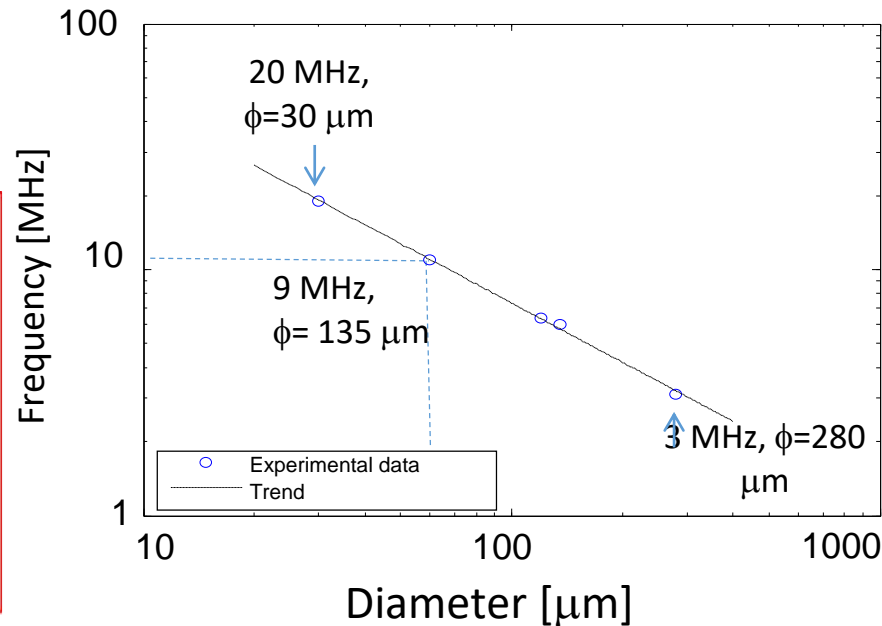
CMUT design



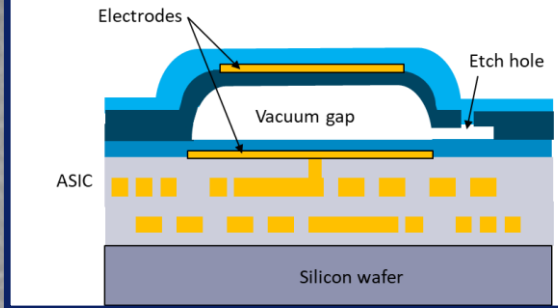
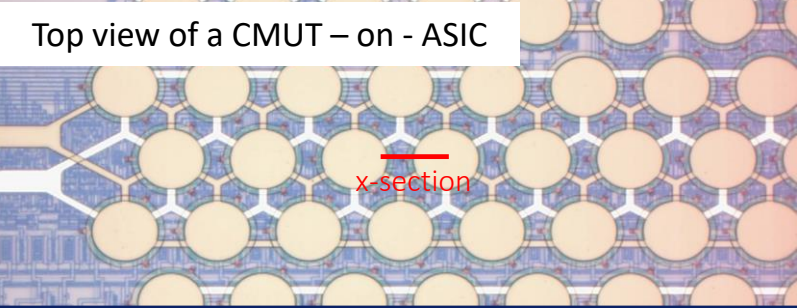
FEM and analytical model

Validated for a wide range of frequencies

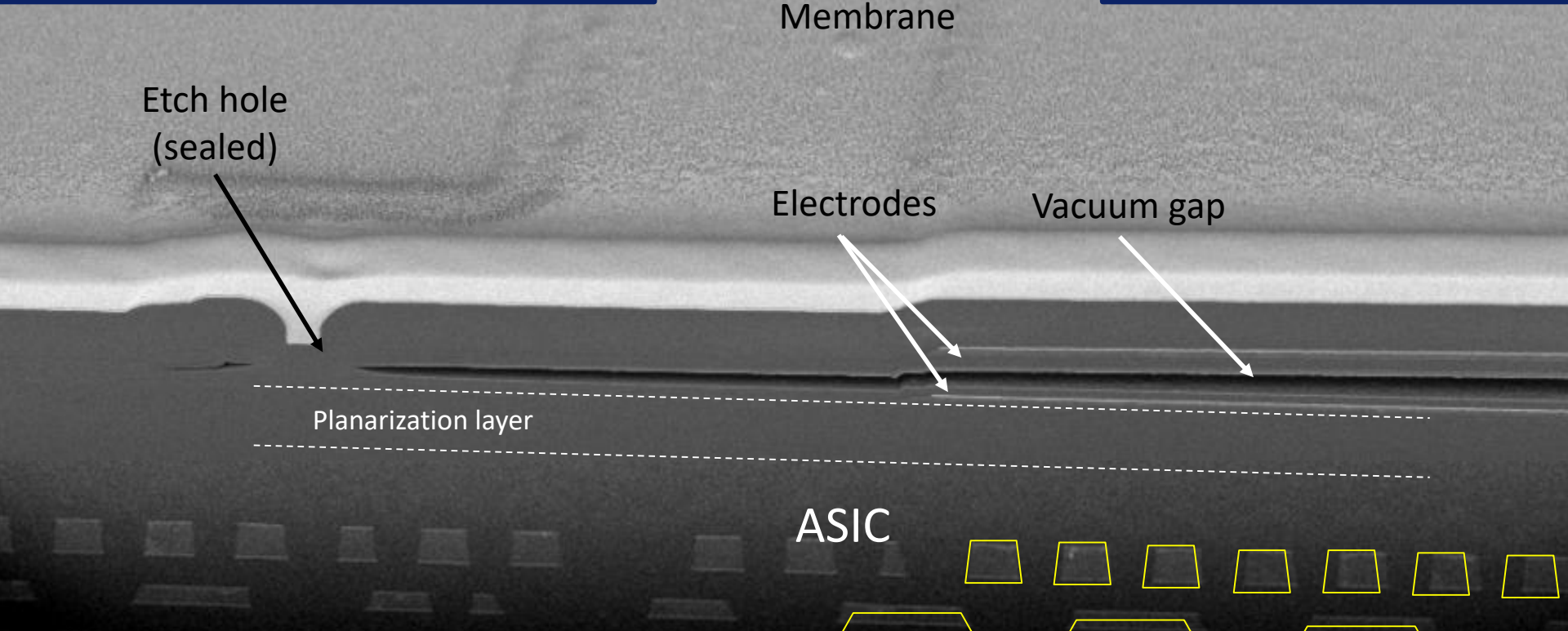
Frequency vs diameter



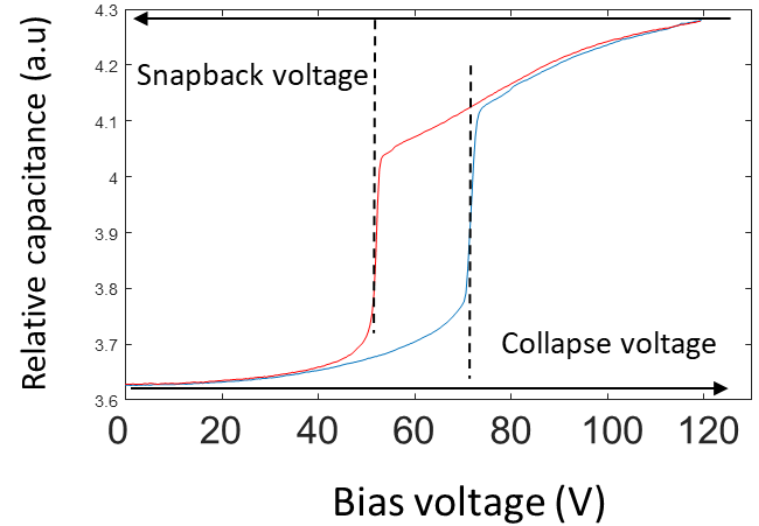
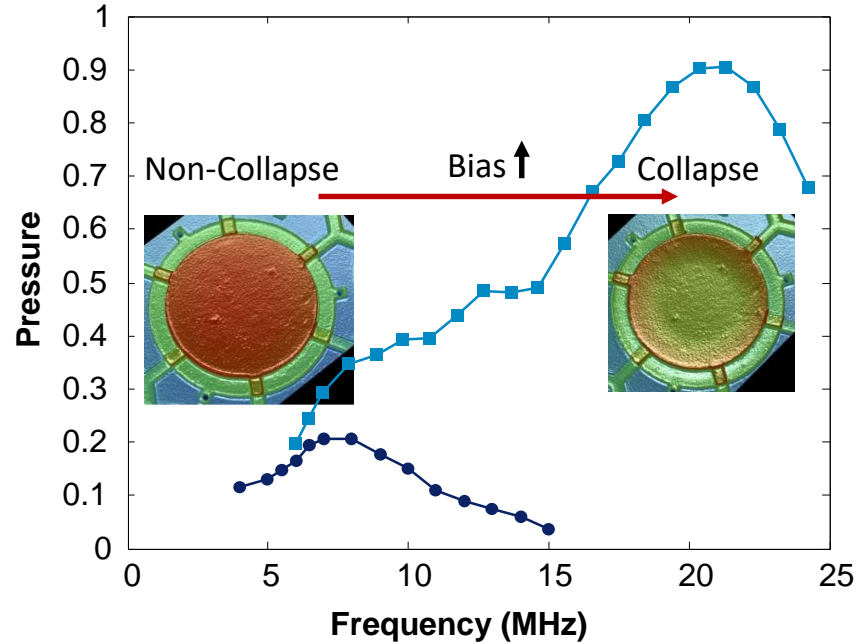
Top view of a CMUT – on - ASIC



Membrane



Collapse mode operation

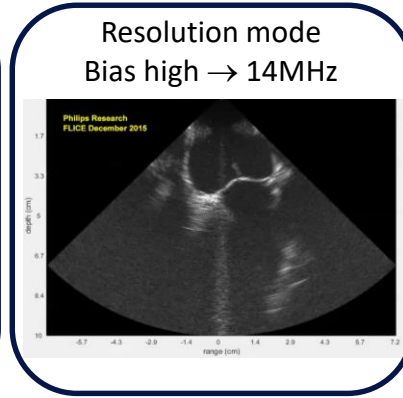
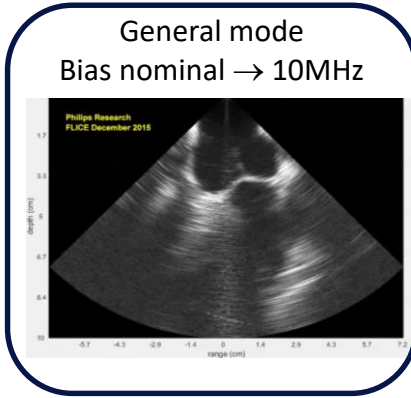
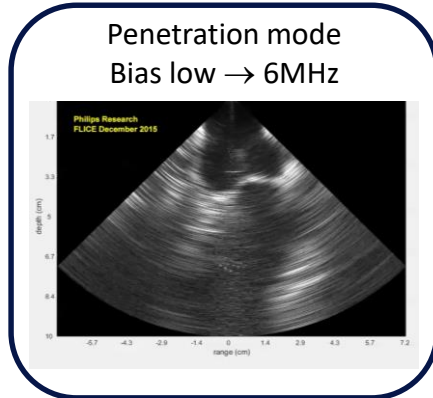
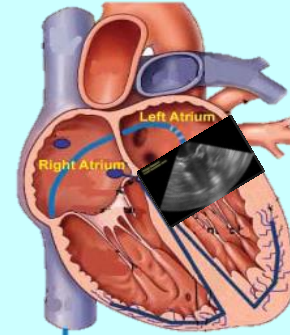
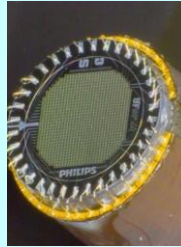
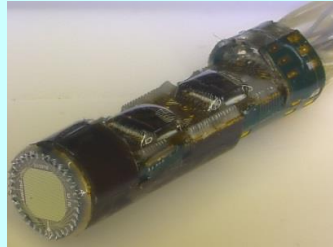


Collapse mode: frequency agility

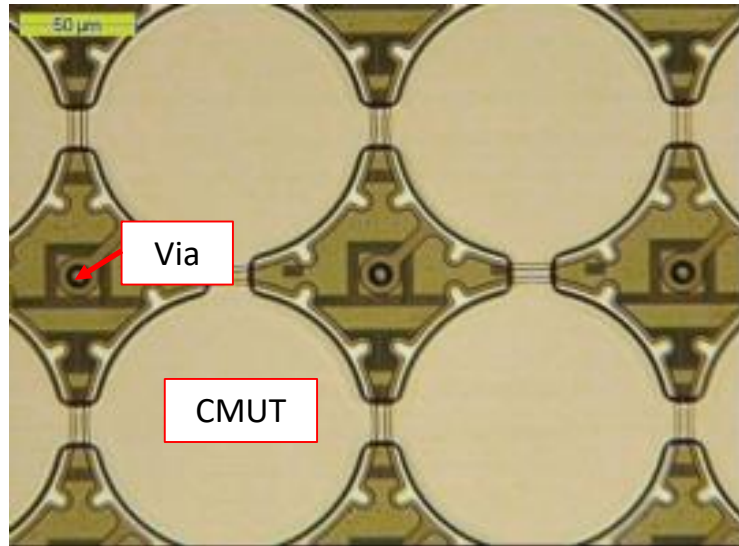
Example: cMUT based Forward Looking Inter Cardiac Echo (FLICE)

- Image from inside the hart (aortic valve)
- cMUT frequency tuning 6 \rightarrow 14 MHz enables zooming

2x2 mm
aperture \rightarrow

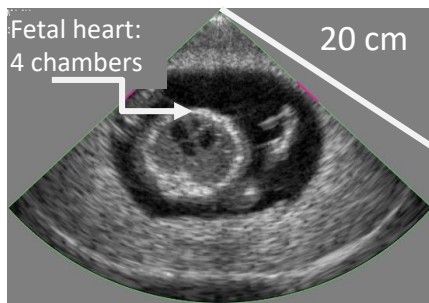
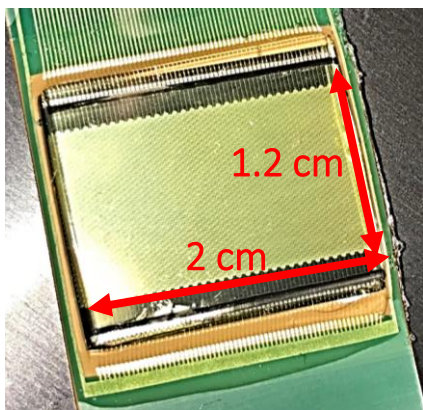
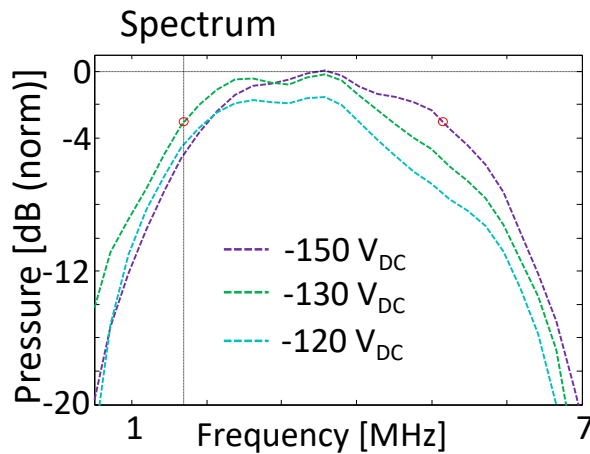
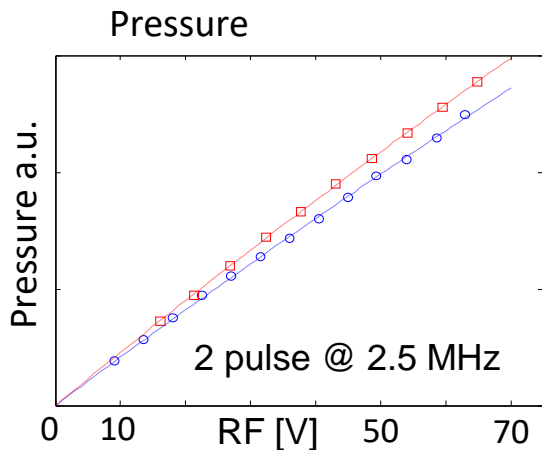


3D U/S – Towards general complete solution

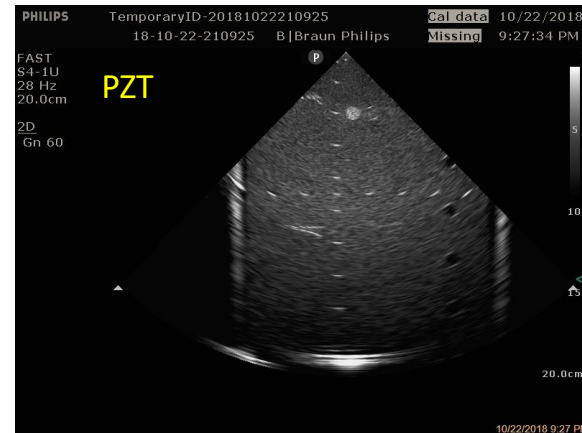
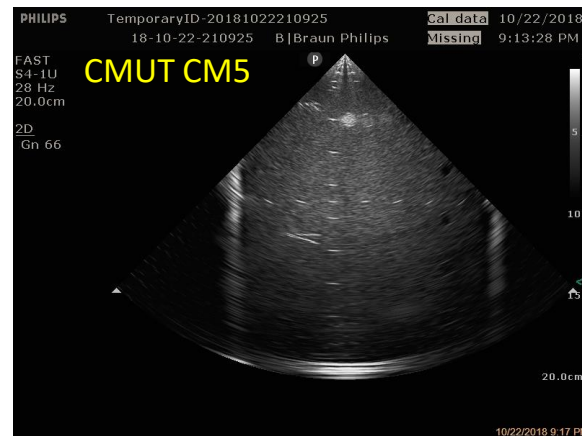


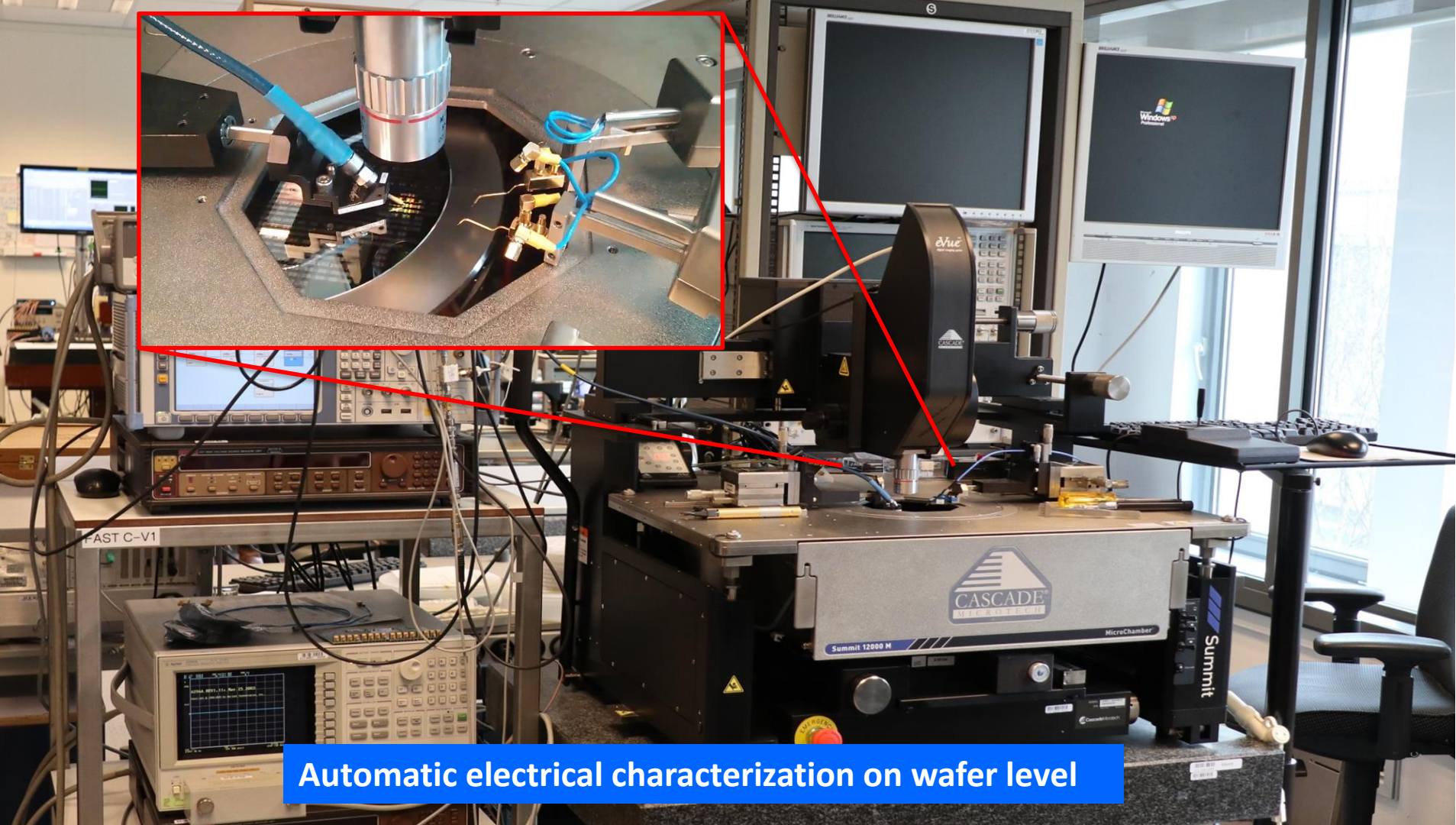
- Monolithically integrated CMUT-on-ASIC
- Test array 6x6 mm with 2000 individual elements
- Each element = one membrane

Low frequency example: CMUT imaging probe



- fetal imaging, 24 weeks phantom
- 20 cm penetration

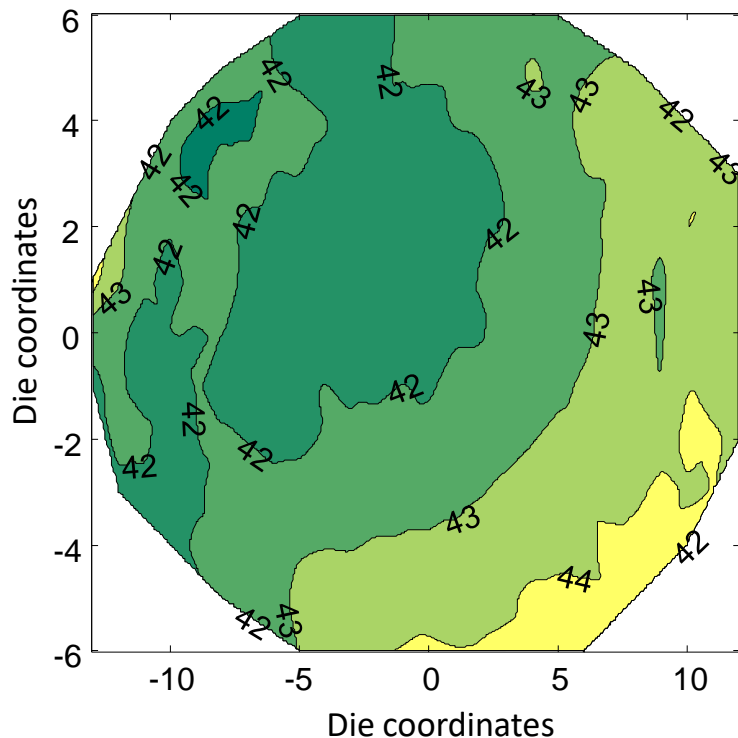




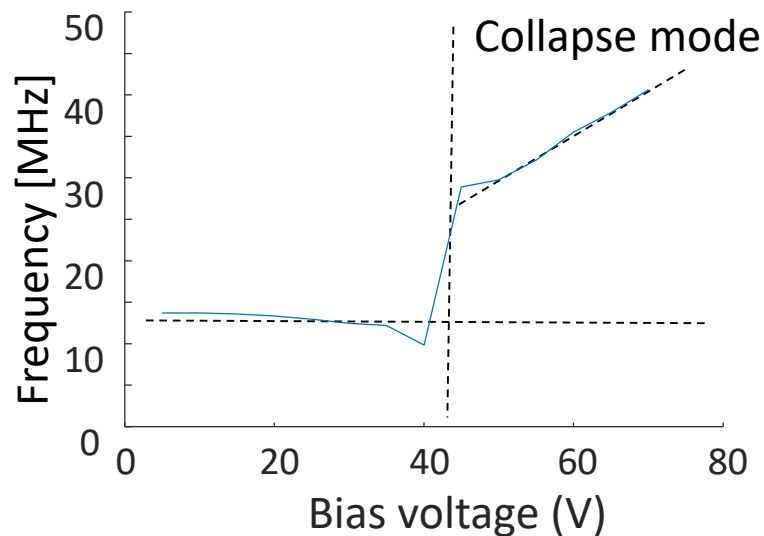
Automatic electrical characterization on wafer level

Wafer level electrical characterization

Wafer map of collapse voltage



- Capacitance
- Resonance frequency
- Element uniformity
- Frequency tuneability & linearity
- Model verification (FEM & analytical)



Fast CV/impedance measurements

- Fast CV measurements → development @ Salland Engineering
- Hardware:
 - Fixed probe card for 64 elements
 - HV amplifier and capacitance meter
 - Based on charge amplifier and lock-in amplifier

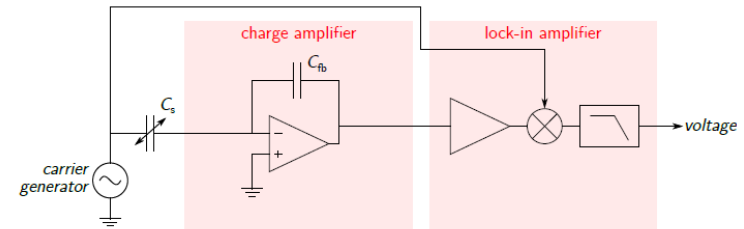
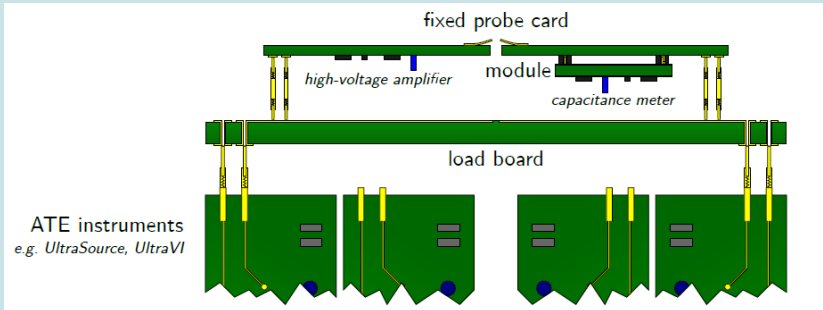
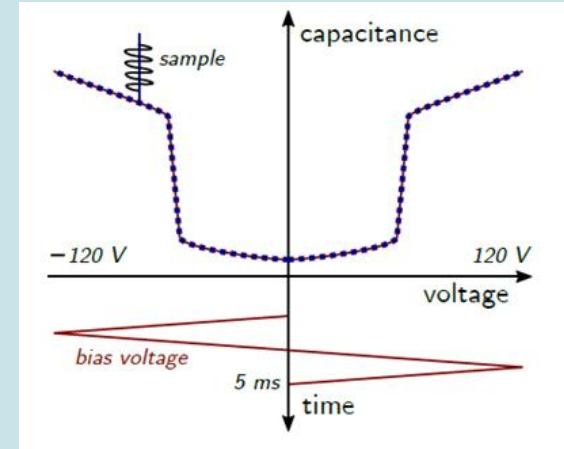
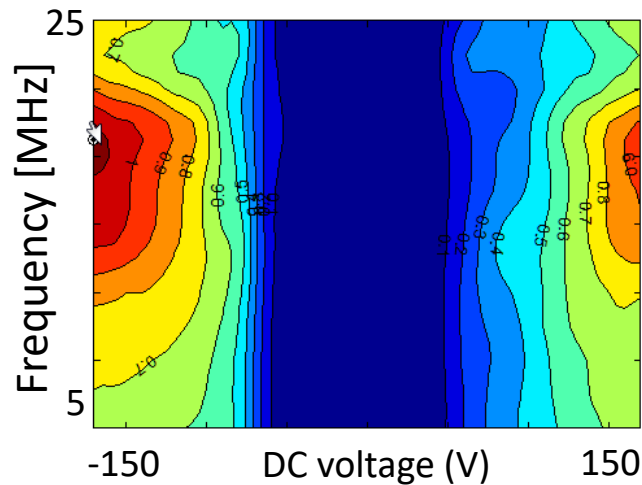
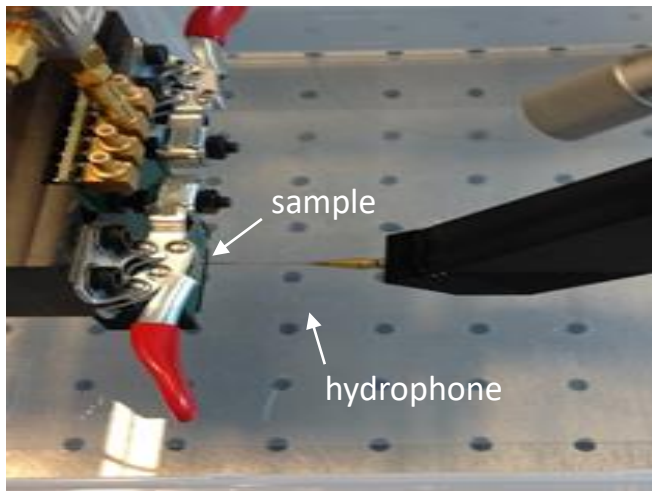


Figure 2: Capacitance measurement using charge amplification and lock-in amplification.

Test sample characterization: CMUT pressure map



Automated acoustic testing:

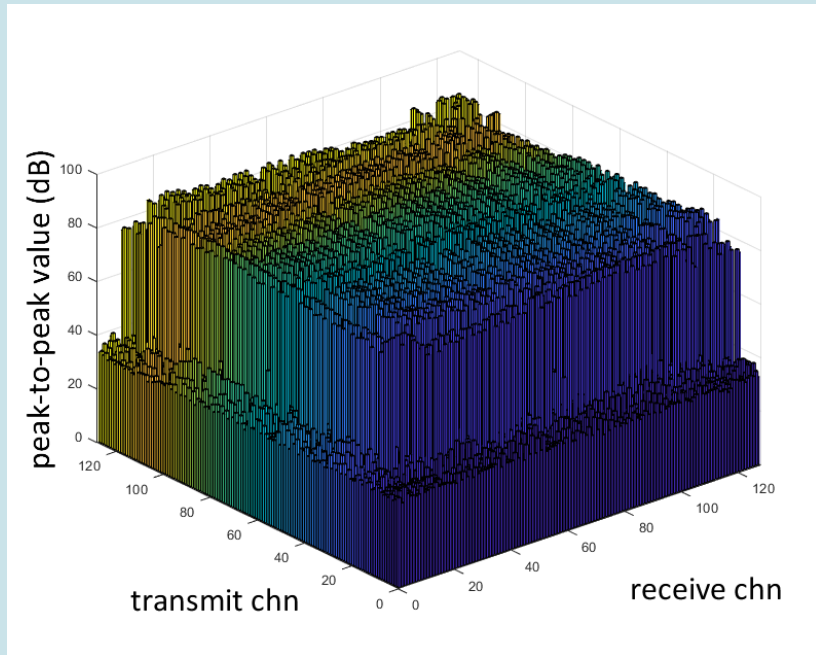
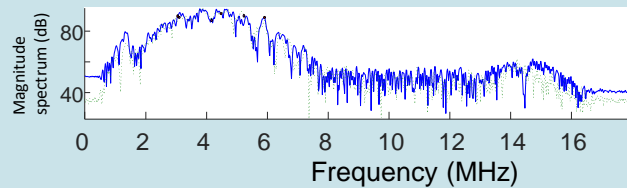
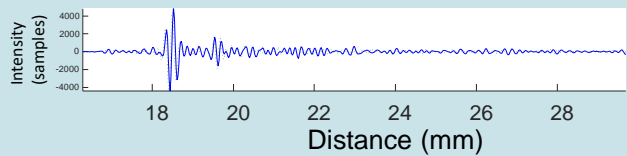
Signal recording for a range of frequencies,

DC voltage,

pulse voltages

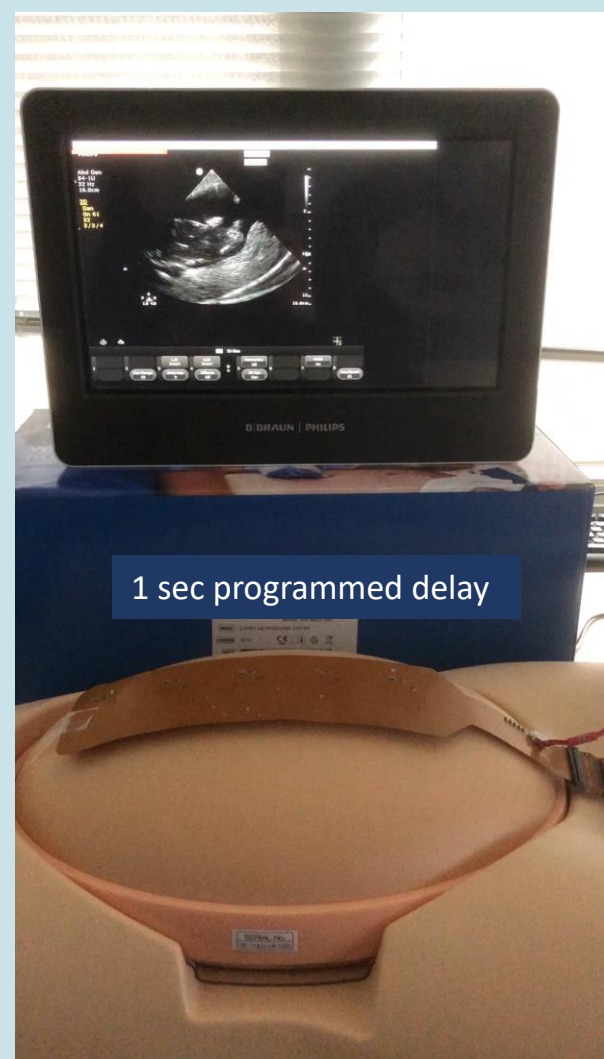
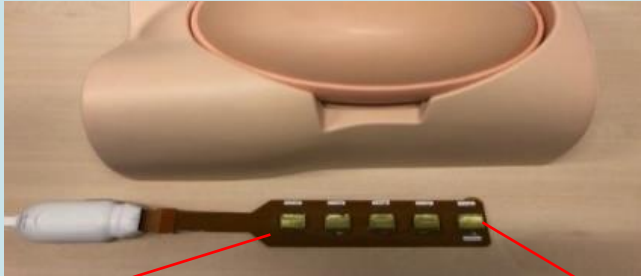
Transducer level testing

Channel check on Transducer array using Verasonic system



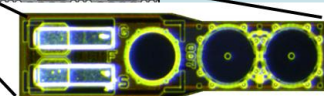
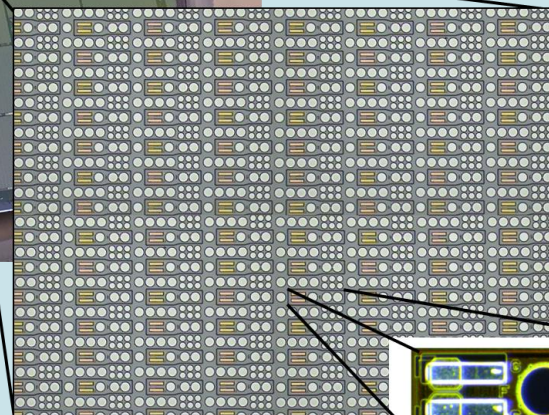
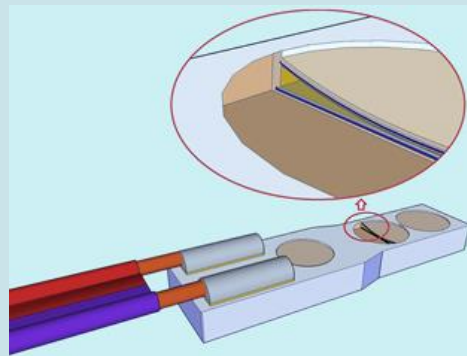
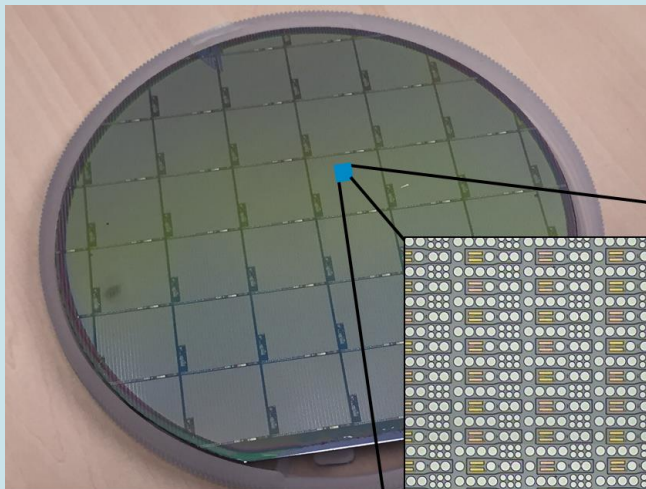
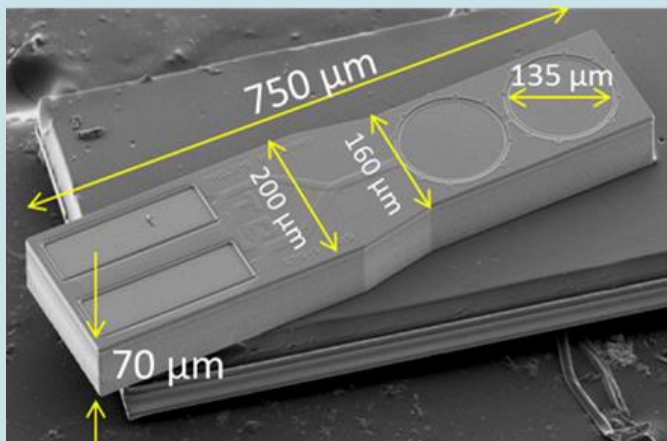
Very large view demonstrator

5 transducers in parallel on flex → switch between transducer via DC bias



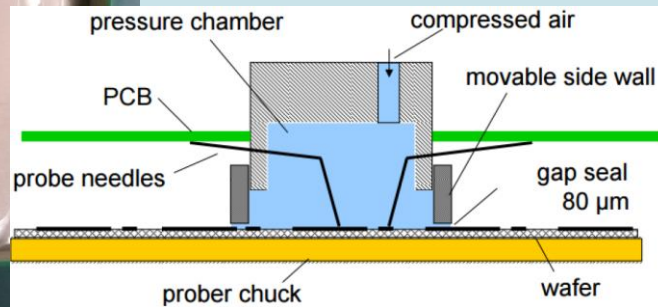
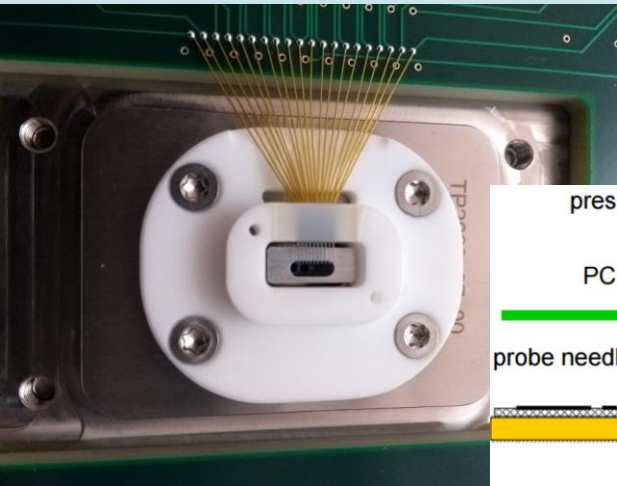
Monolithic integrated – Capacitive pressure sensor

- Digital: Pressure to Frequency
- 2-wire solutions
- Low drift, Low temperature dependence
- High pressure sensitivity
- Robust: high burst pressure
- **34000 devices on 150mm wafer**

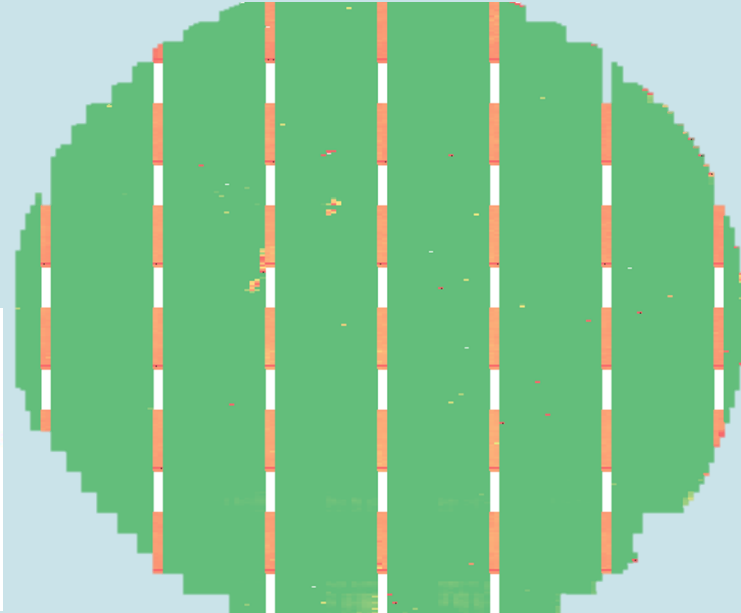


Wafer level test @ Salland

- Automatic pressure sensitivity measurement with cantilever probe card (Teradyne ATE)
- Filtering of mal-functioning sensors and delivery of known-good devices in gel-pack
- Multiple site fixed probe card: 10 sites
- Test time per die: ~400ms
- Yield > 90%



Wafer map of pressure sensitivity



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Thank you for your attention!

Questions?



innovation  you



**Smart
Body
Patches**



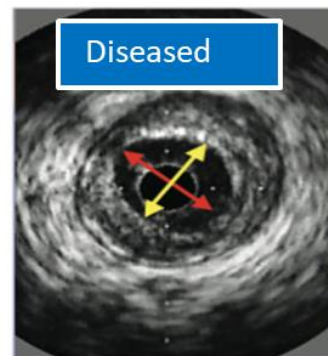
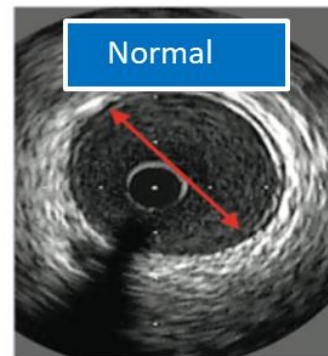
PENTA cluster number E!9911

Miniaturization challenge:
smart catheters

Approximately 10% of the western population will at some moment in their life be treated in a cath lab



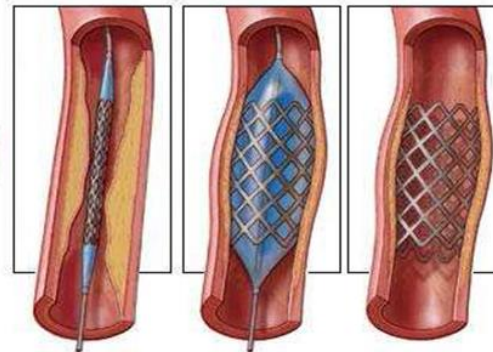
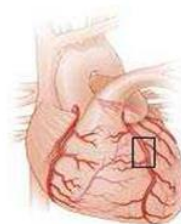
IVUS for stent sizing & deployment verification



Our vision:

- **Seamlessly integrated systems** that make in **cost-effective**
- Creating a unique, uncluttered, **radiation free**
- Clinical specialists that become **your partner** innovation to life, **enable new therapies**

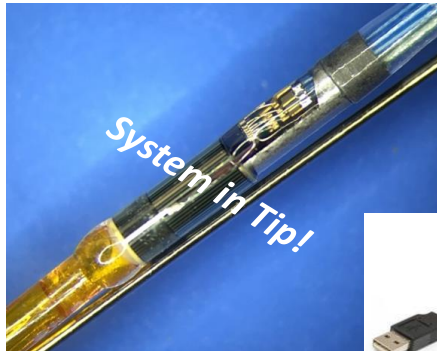
Simplifying complex procedures



Smart catheters

Today's Ultrasound transducers:

- Obsolete technology
- Analog instruments (expensive)
- Many expensive (coaxial) wires
- Point solutions
- Not integrated in the Cath Lab

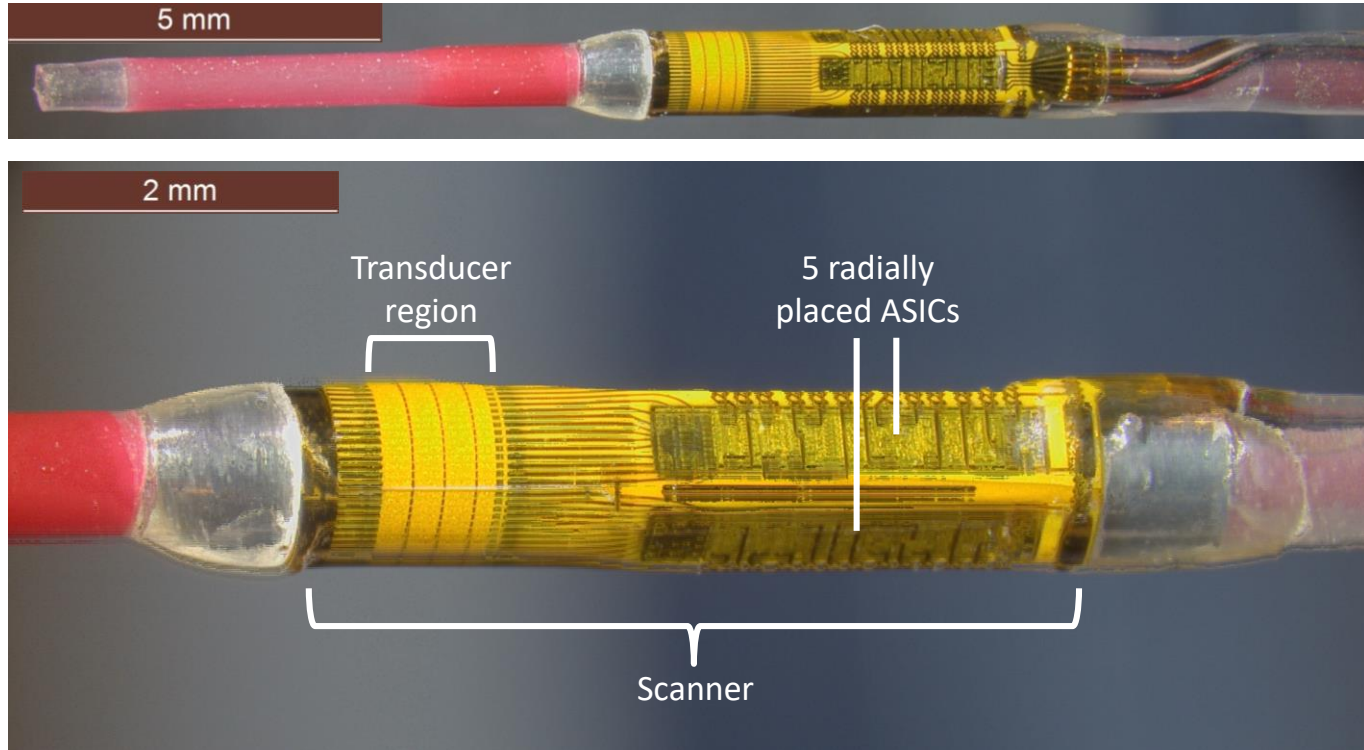


Next generation smart catheter:

- State of the art technology
- in-tip AD conversion
- Open MEMS technology platforms
- MUT with flex-to-rigid (F2R) interconnect
- High speed serial interface
- Standardized connector (e.g. USB type)
- Fully integrated in Cath Lab infrastructure

State-of-art: Volcano Eagle Eye IVUS catheter

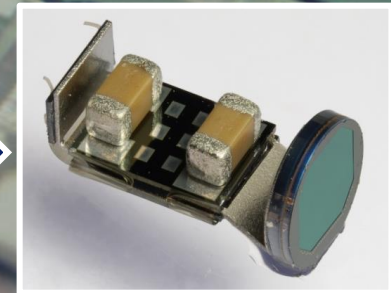
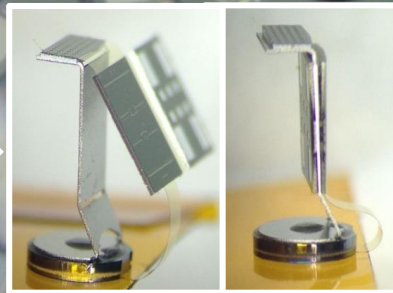
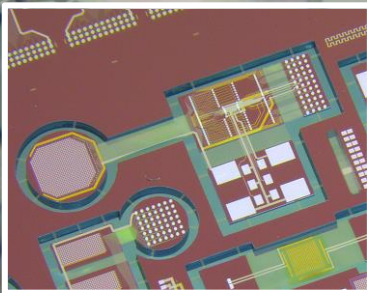
Ø 1.2 mm catheter, 64 piezo elements around circumference



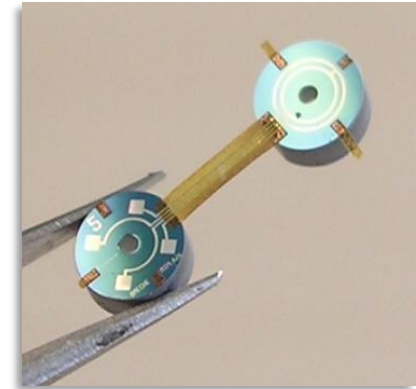
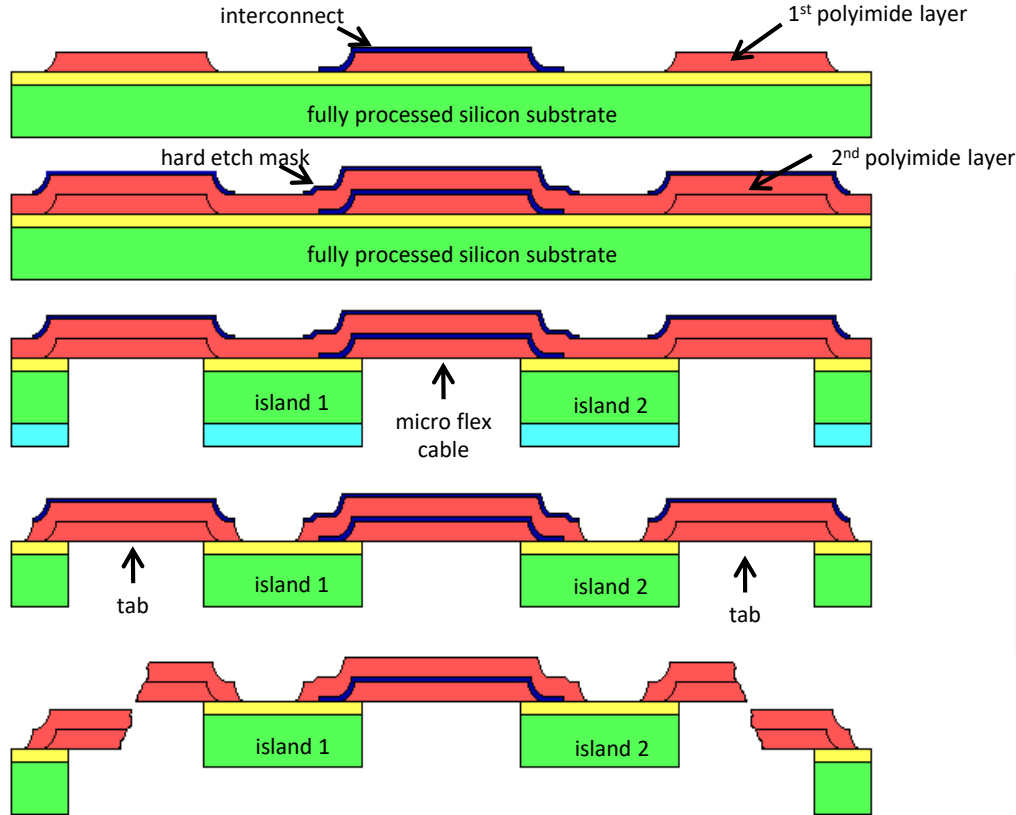
Flex-to-Rigid (F2R) interconnect platform

Interconnect built into device:

- Seamless cMUT-interconnect integration
- Simplifies interventional device manufacturing
- Enables advanced functionality

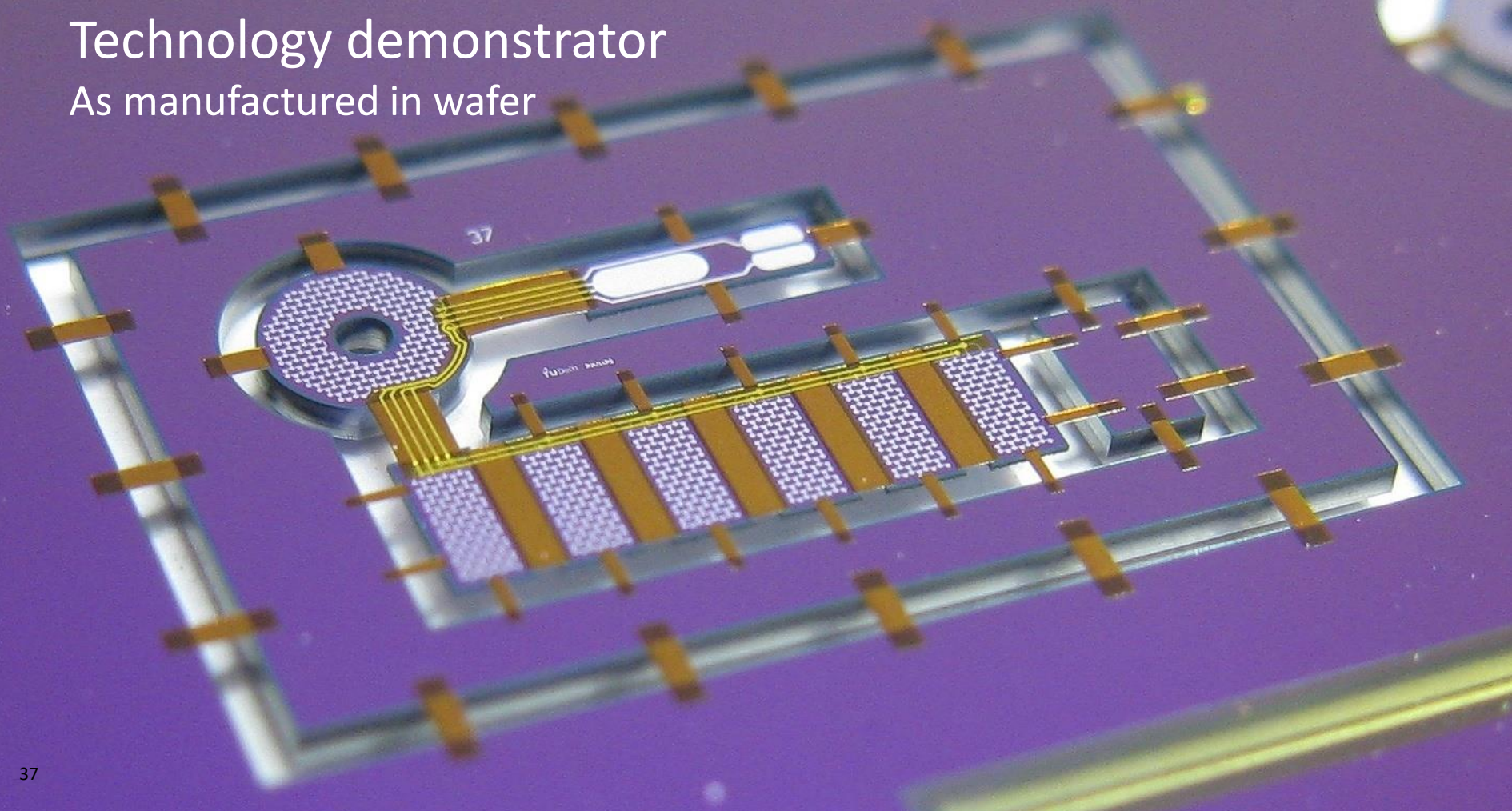


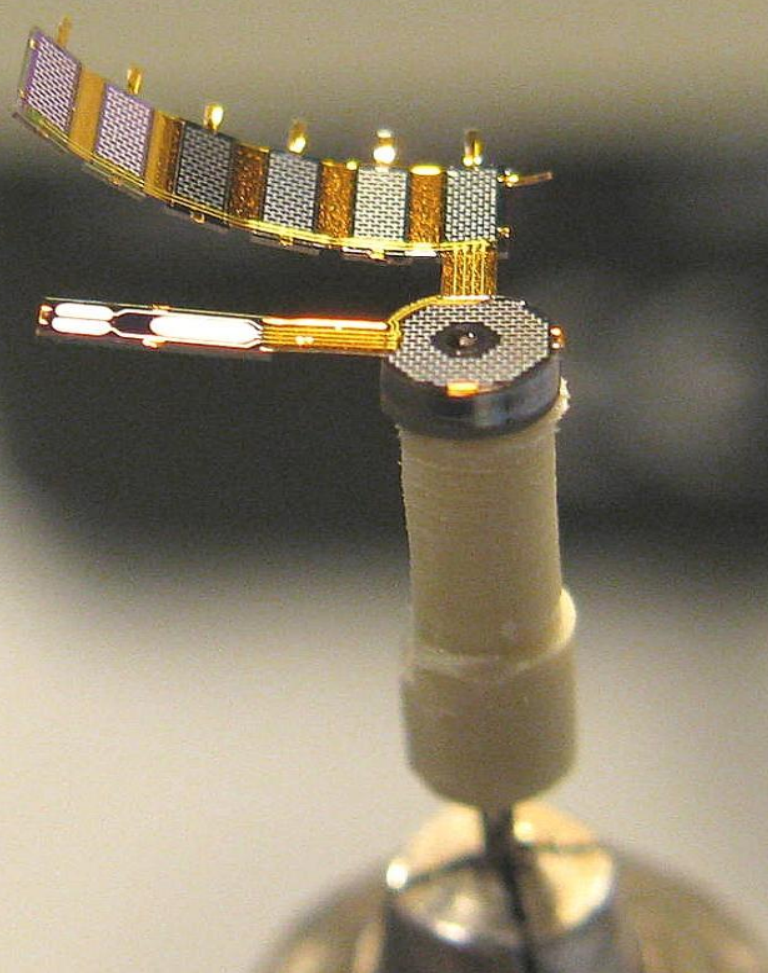
Standard Si process flows: Schematic F2R process flow

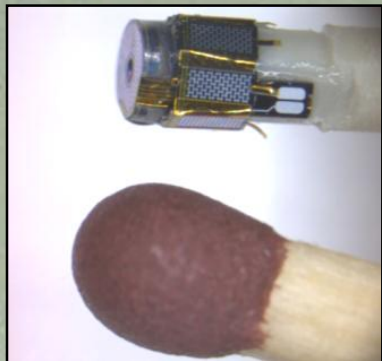


Technology demonstrator

As manufactured in wafer







Ø 2 mm

