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Innovation Services

MEMS & Micro Devices

CMUT and PMUT: New Technology Platform for Medical Ultrasound

Rob van Schaijk

November 2018

MUT introduction

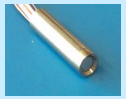
Medical ultra-sound imaging

Probes and transducers

Linear array
- Sound waves in straight line
- Rectangular image
- Often high frequency vascular probes

Curvilinear array
- Wider footprint
- Lower frequency for abdominal imaging

Phased array
- Electronically steered beam
- Small array for e.g. cardiac imaging



Endoscopic and intravascular
- Full panoramic view
- Doppler for blood flow dynamics
- IVUS operates in high frequency range

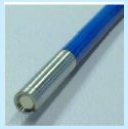
Systems

Cart based systems

Portable

Hand-held

Endoscopic and intravascular



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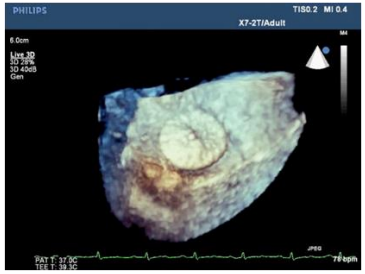
Medical ultra-sound imaging application range

	Diagnostic Applications			Interventional Applications		
Probe						
Application	General imaging	HIFU	Superficial / High resolution	Minimal invasive	Catheter, TEE, ICE, IVUS	
Frequency	1-5 MHz	4-8 MHz	3-9 MHz	5-10 MHz	10-15 MHz	20-40 MHz

Low frequency	Mid frequency	High frequency
		

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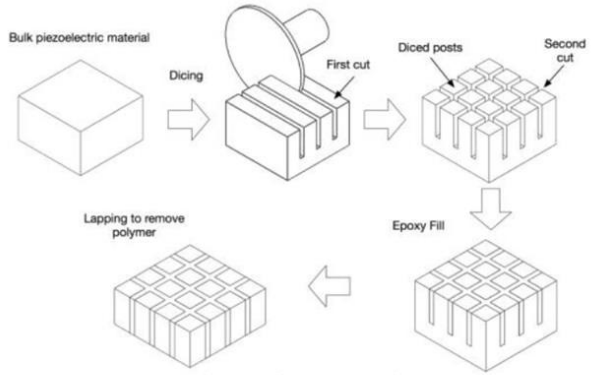
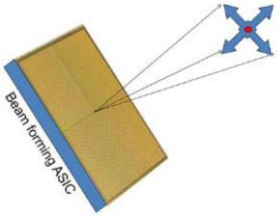
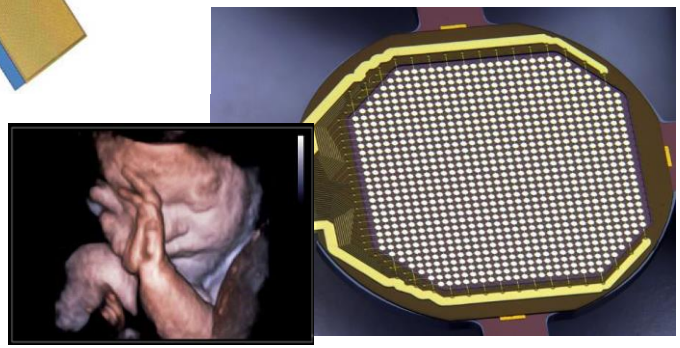
Bulk piezo versus MUT

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



Sawing of piezo material;
Source: Jet Propulsion Laboratory, California Institute of Technology





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

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CMUT versus PMUT

	Ceramic Piezo	CMUT	PMUT
Pros	• Proven technology	• Integration with electronics (on top of ASIC) → 3D imaging • High bandwidth and resolution • Suited for high frequency (catheters)	• Integration with electronics (flip-chip on ASIC) → 3D imaging • No bias voltage needed • Low frequency range (>40kHz)
Cons	• Labor intensive and expensive • Miniaturization • High frequencies	• High bias voltage (~100V) • Only for high frequencies (> 1MHz)	• Challenging material (deposition, properties, lead,..)

Both CMUT and PMUT are promising new technologies for US medical imaging (1MHz-40MHz)

- PMUT better in lower frequency range
  - Products in < 1MHz range (gesture detection, fingerprint sensor,..)
- CMUT better suited for higher frequency range
  - Advantage in catheters

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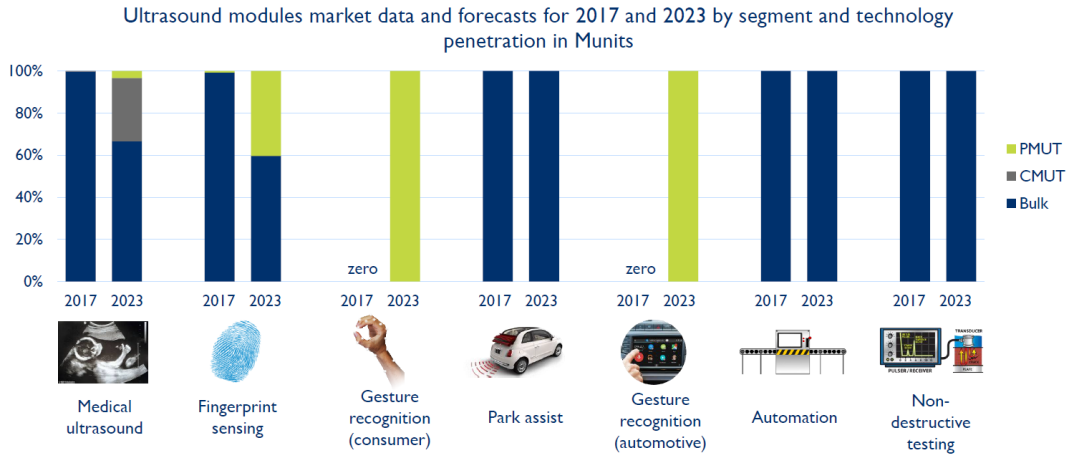
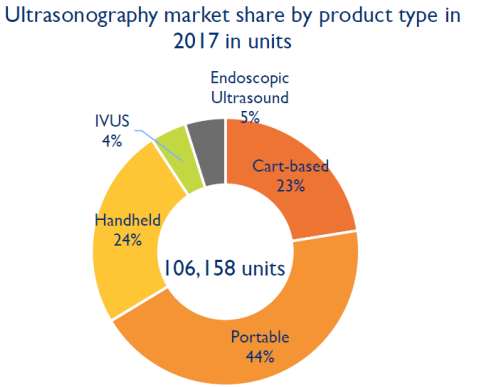
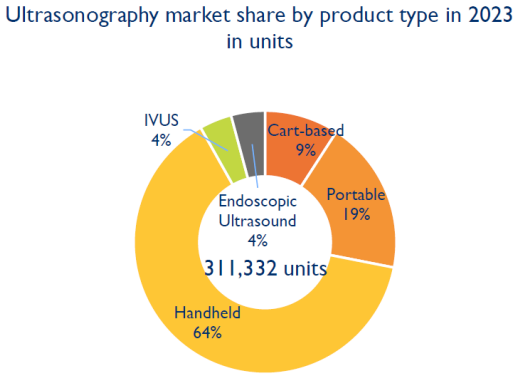
Market data and forecast

According to Yole 2018 (*)

- PMUT will be mainly used in fingerprint sensing and gesture detection
- CMUT will be mainly used in medical ultrasound imaging
- Strong growth expected for handheld imaging device → strong focus on cost







(*) YOLE Développement *Ultrasound Sensing Technologies for Medical, Industrial, and Consumer Applications; Yole report 2018*

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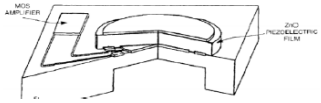
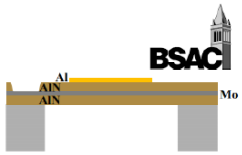
PMUT history

PMUT origins linked to thin-film deposition techniques



First development made on PMUT by Honeywell

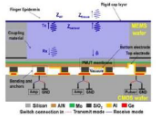


AlN based PMUT, S. Shelton et al.; Source: Berkeley University

1980 — 2000 — 2010 — 2018

Research	*Foundry*	*US module*
• Leti • VTT • Berkeley • Imec	• STMicroelectronics • Silex • Global Foundries • Fujifilm Dimatex	• ?

TDK InvenSense



UltraPrint PMUT technology

Qualcomm

Fingerprint module

Gesture recognition sensor

MEDICAL IMAGING FOR EVERYONE

YOLE Développement *Ultrasound Sensing Technologies for Medical, Industrial, and Consumer Applications; Yole report 2018*

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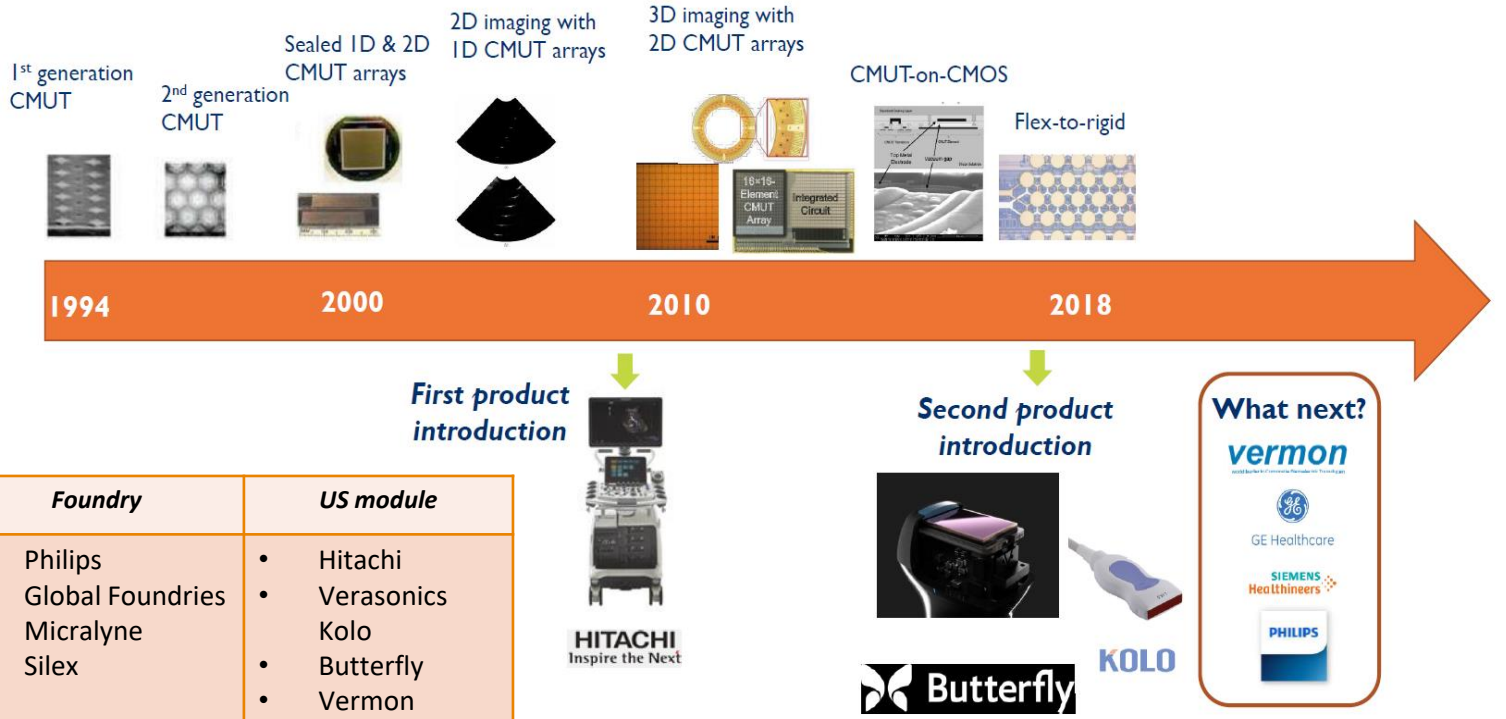
CMUT history



Research	*Foundry*	*US module*
• Stanford • Fraunhofer • VTT • Leti • Imec	• Philips • Global Foundries • Micralyne • Silex	• Hitachi • Verasonics Kolo • Butterfly • Vermon

YOLE Développement *Ultrasound Sensing Technologies for Medical, Industrial, and Consumer Applications; Yole report 2018*

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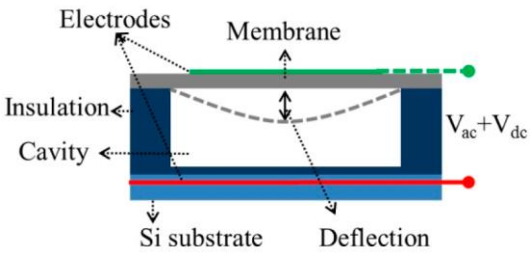
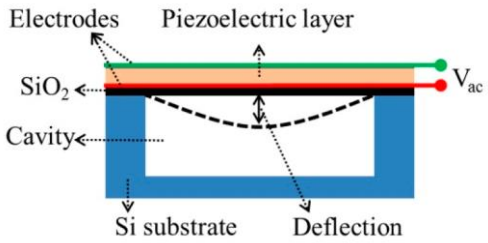
Image: Yongqiang Qiu et al., Sensors 2015, 15(4), pg. 8020-8041





MEMS US transducers

CMUT

Low Temp. Sacrificial layer

- Possible on CMOS ASIC (low temp.)
- Uniformity issue and stress in layer stack

High Temp. Wafer bonding

- Uniform, but needs flat and smooth wafers
- High temperature process not compatible with CMOS

PMUT

Low Temp. PVD sputtering

- Sputtering is mature and fast (expensive equipment)
- Possible on CMOS ASIC (low temp.)
- Often: (Sc doped) AlN

High Temp. CSD Sol-gel

- Cost effective
- Most common PZT
- Lower throughput
- Uniformity issue
- Not common in semiconductor industry

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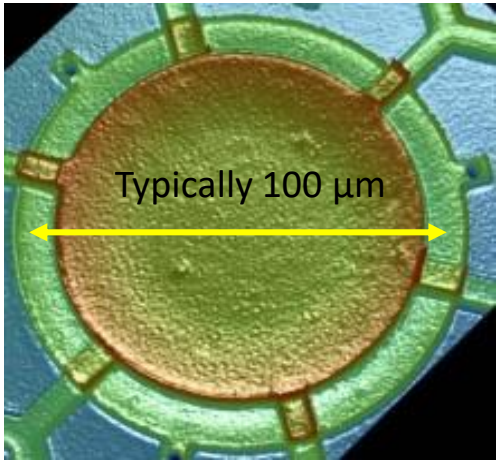
CMUT technology platform

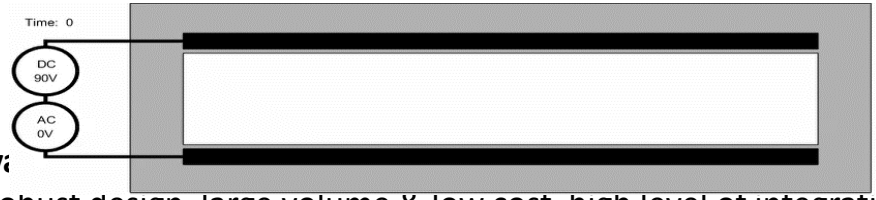
CMUT

Capacitive Micromachined Ultrasound Transducer

A replacement for piezo-based ultrasound in the medical domain

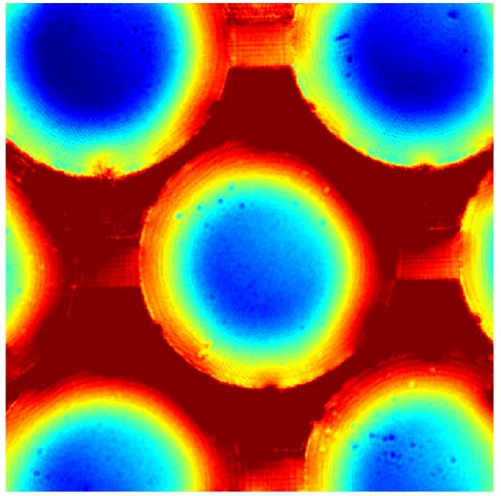
- CMUT is fabricated by IC technology
- Parallel plate capacitor on membrane
- Transmits and receives ultrasound at 1 - 50MHz
- Collapse mode: the membrane touches the cavity bottom
- An RF-voltage makes the membrane vibrate





Adva

- Robust design, large volume & low cost, high level of integration
- Miniaturization & high frequency, lead free for disposable applications



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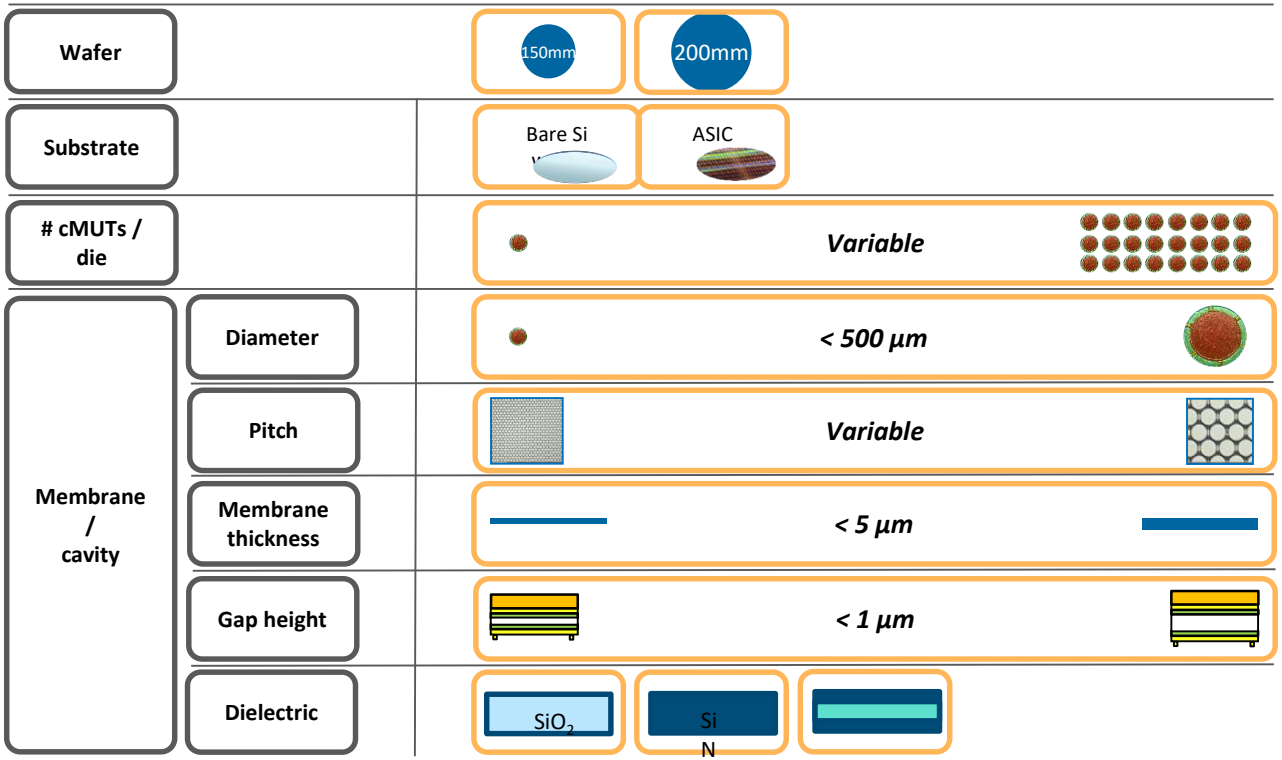
CMUT modular technology platform

CMUT in general offers a lot of **design freedom**



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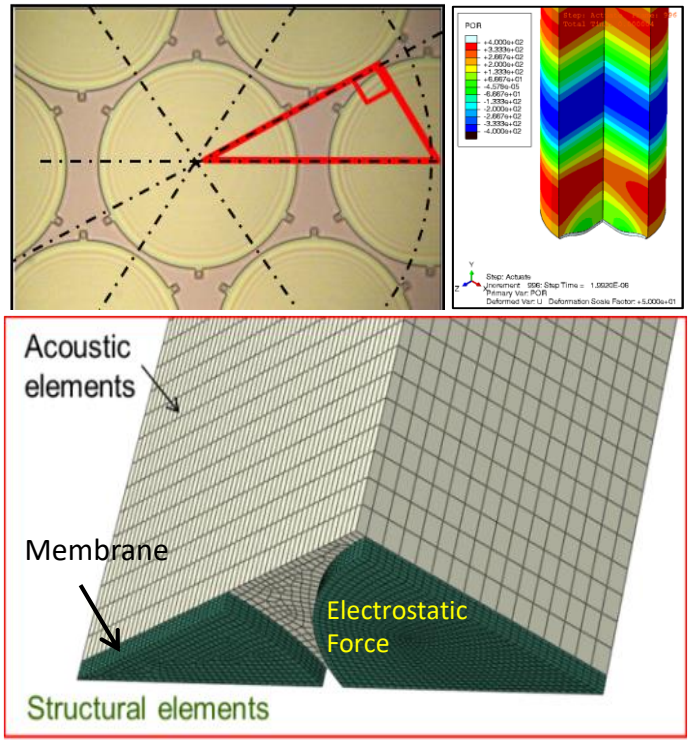
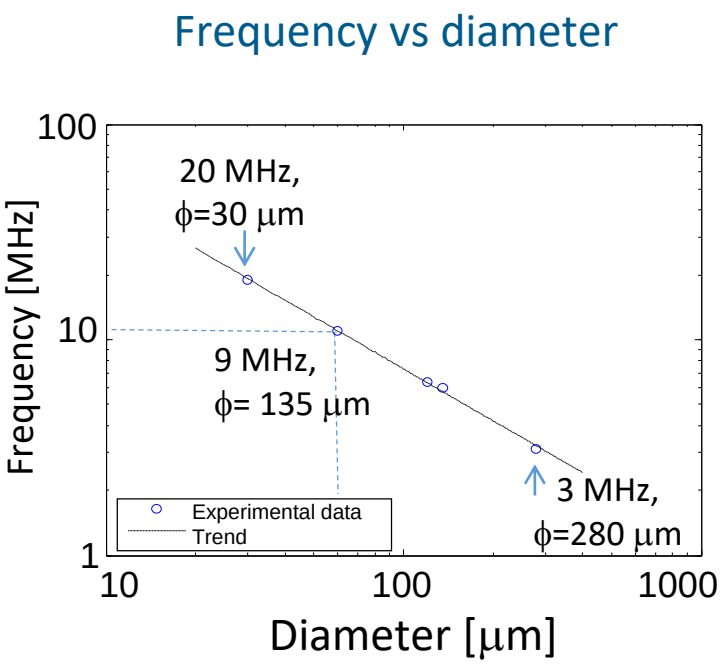
CMUT design





- FEM and analytical model
- Validated for a wide range of frequencies

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Top view of a CMUT – on - ASIC

Cross section

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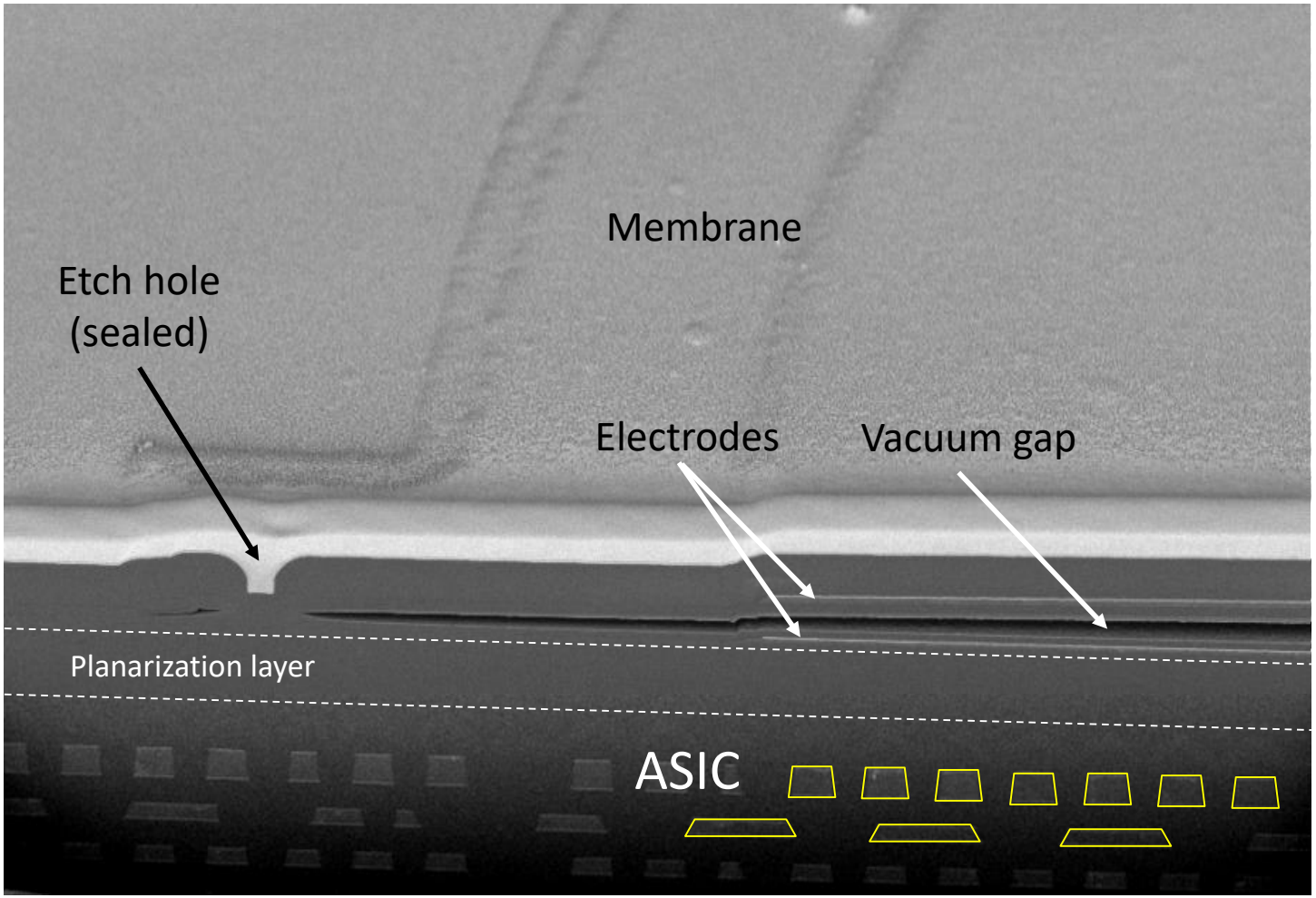
Membrane
Etch hole
(sealed)
Electrodes
Vacuum gap
Planarization layer
ASIC

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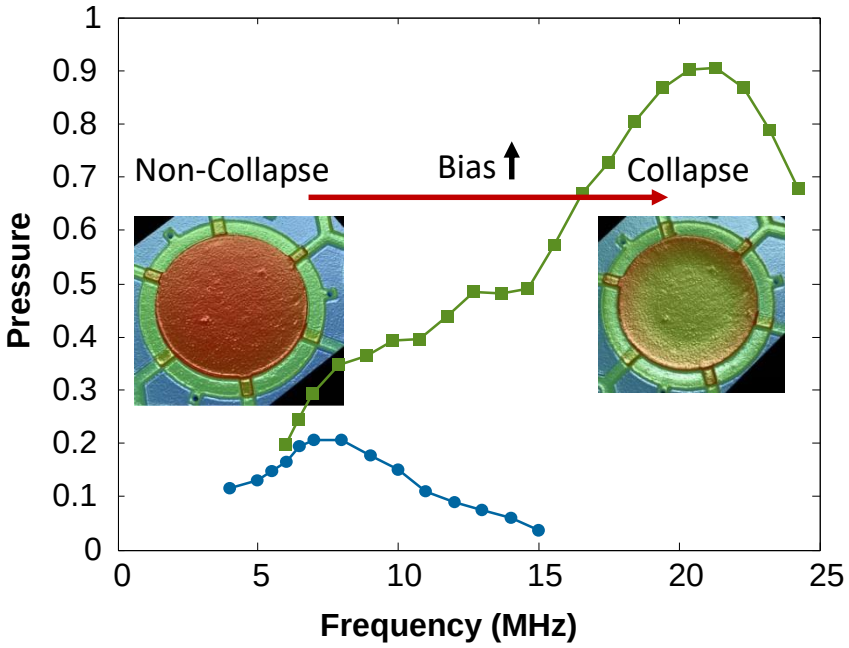
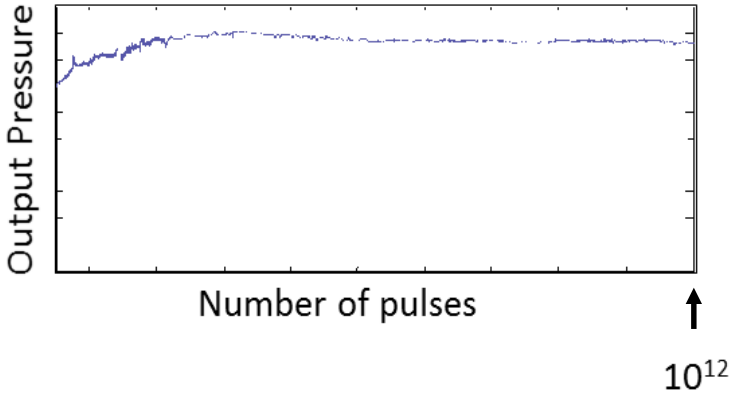
Collapse mode operation



Advantages:

✓ High performance



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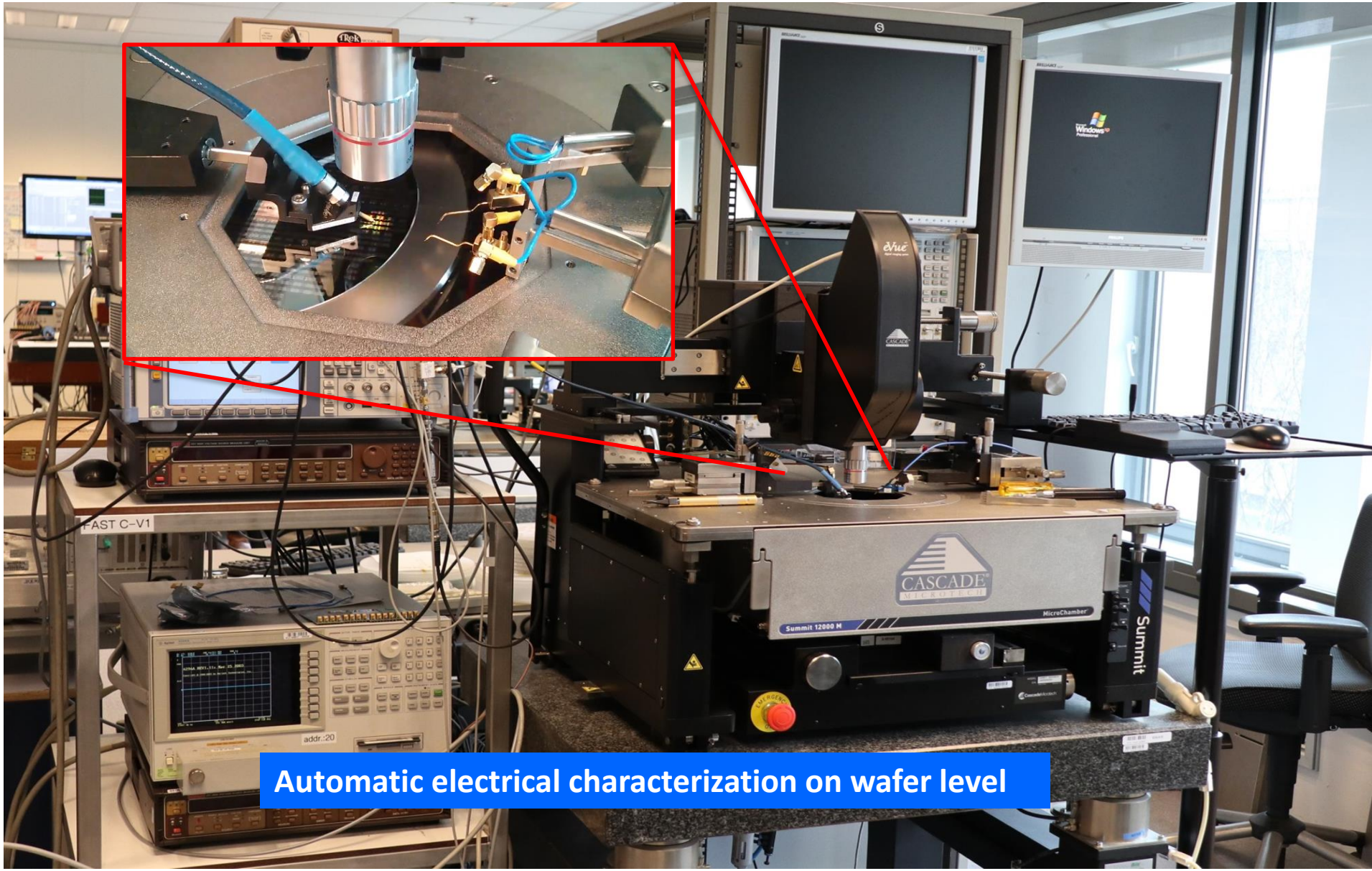

Automatic electrical characterization on wafer level

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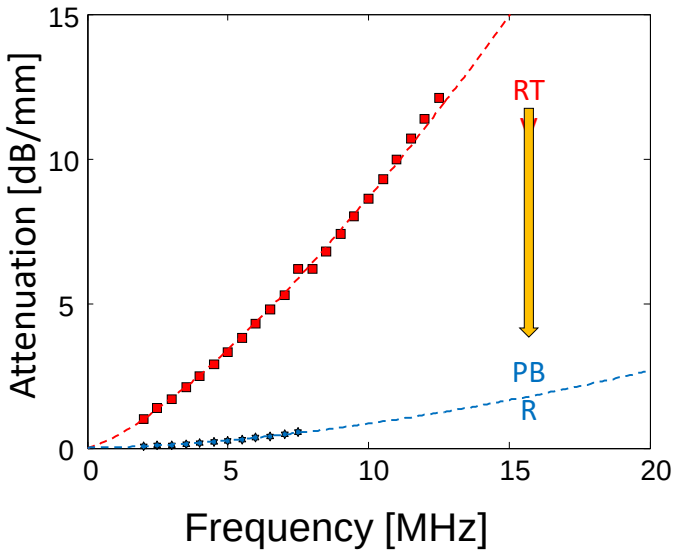
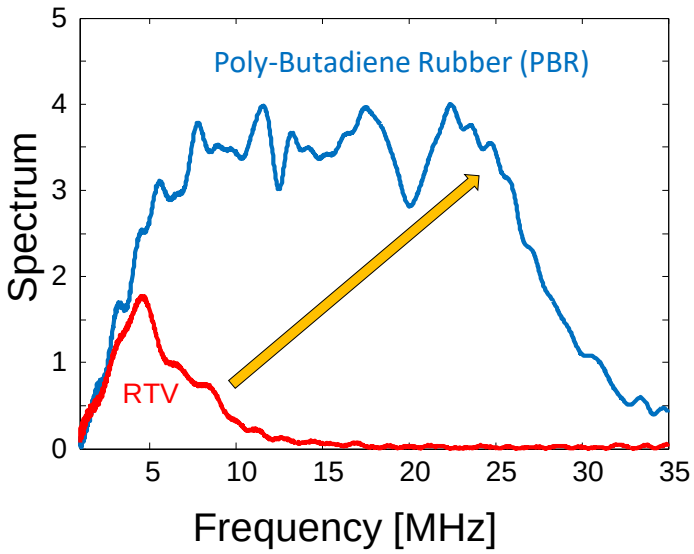
Packaging: acoustic interface

Key to output characteristic: pressure and bandwidth





- CMUT requires a dedicated window, optimized for its application.
- FEM - optimization on attenuation, impedance and mechanical properties

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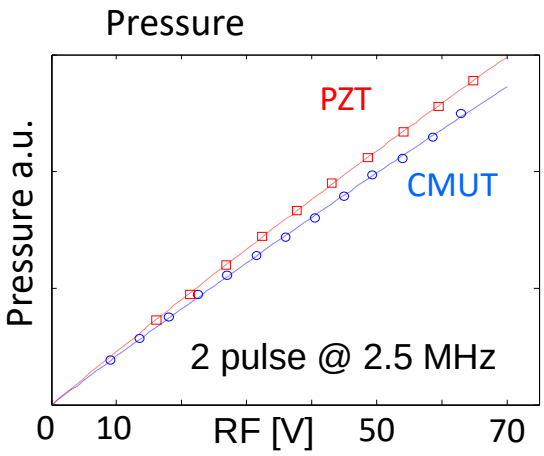
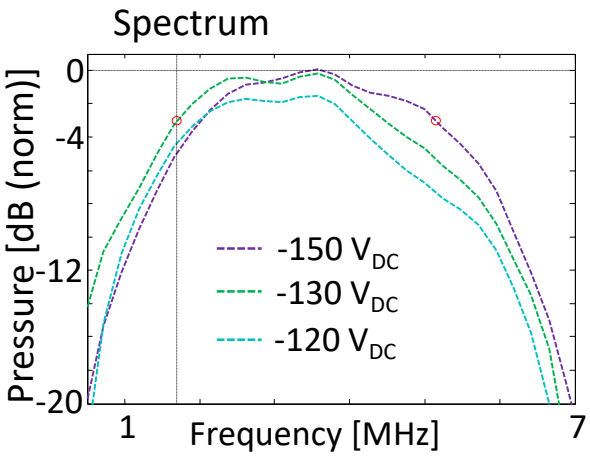
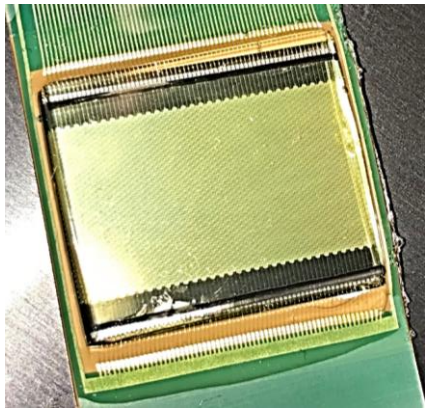
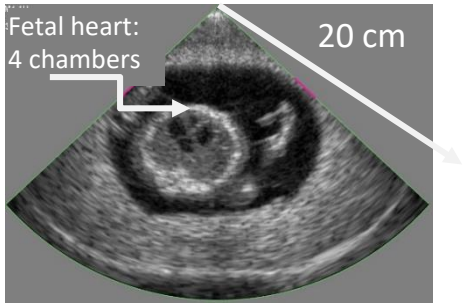
Low frequency example: CMUT imaging probe

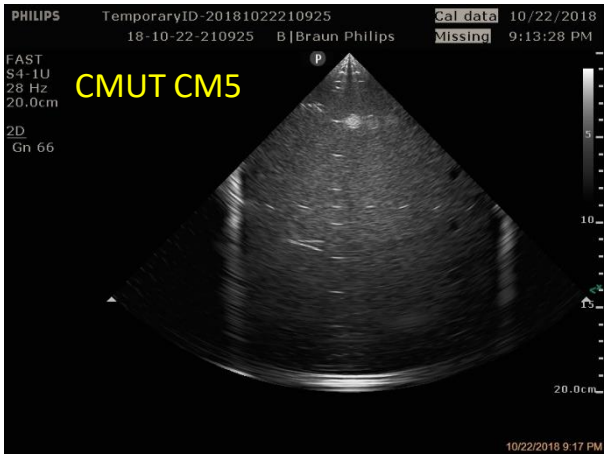


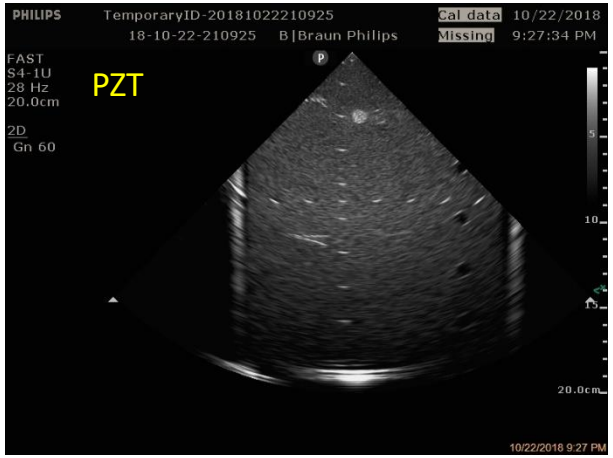






- fetal imaging, 24 weeks phantom
- 20 cm penetration





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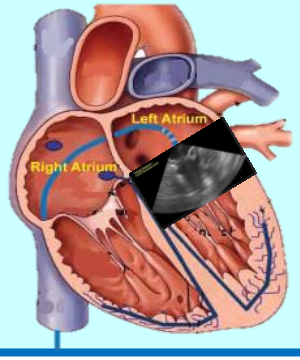
Collapse mode: frequency agility

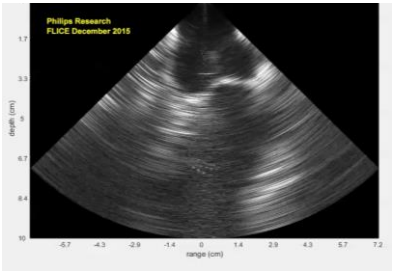
Example: cMUT based Forward Looking Inter Cardiac Echo (FLICE)

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

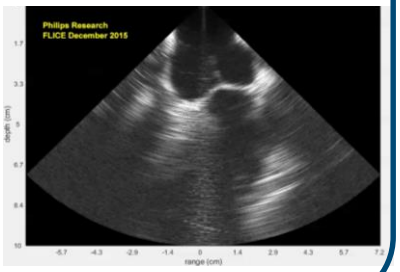
2x2 mm aperture →



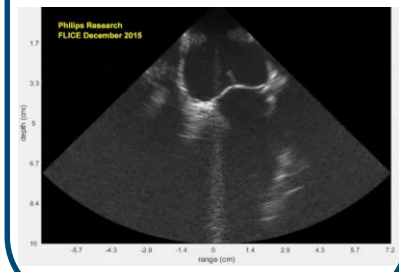
Penetration mode
Bias low → 6MHz



General mode
Bias nominal → 10MHz



Resolution mode
Bias high → 14MHz



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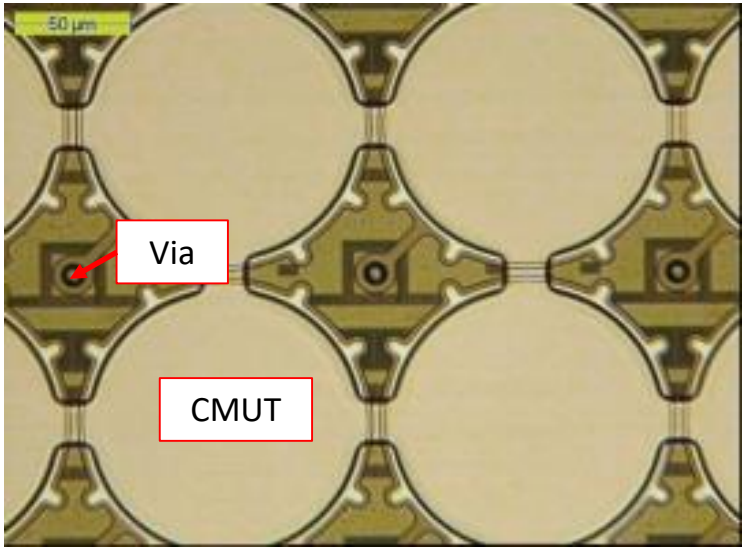
Live 3D ultrasound image



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

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Miniaturization challenge: smart catheters

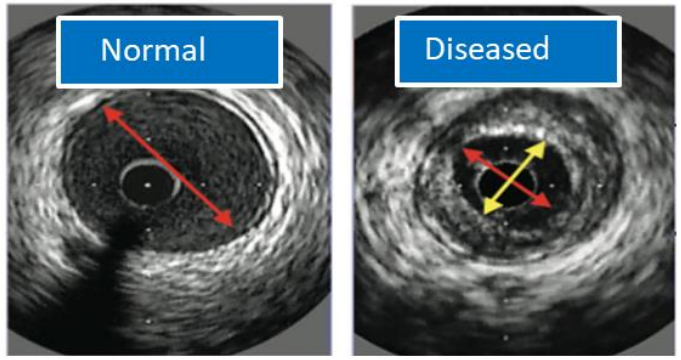
Approximately 10% of the western population will at some moment in their life be treated in a cath lab

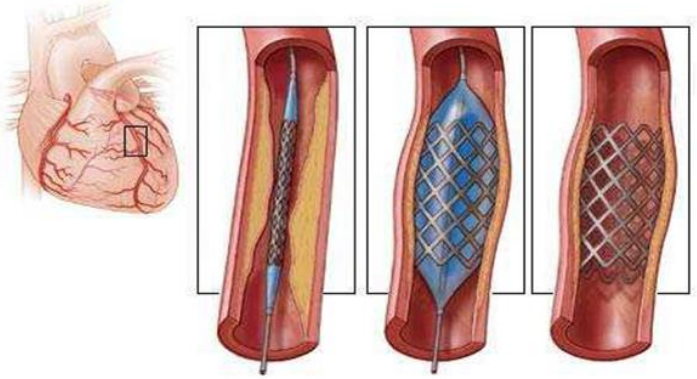
Our vision:

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

Simplifying complex procedures to

IVUS for stent sizing & deployment verification





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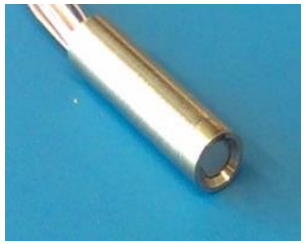
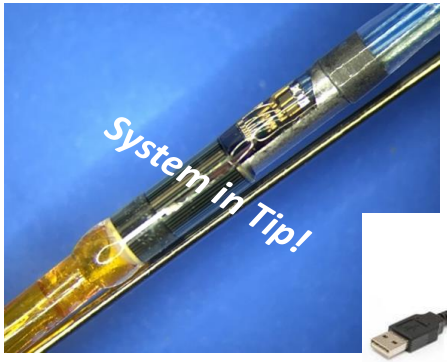
Smart catheters

Todays 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

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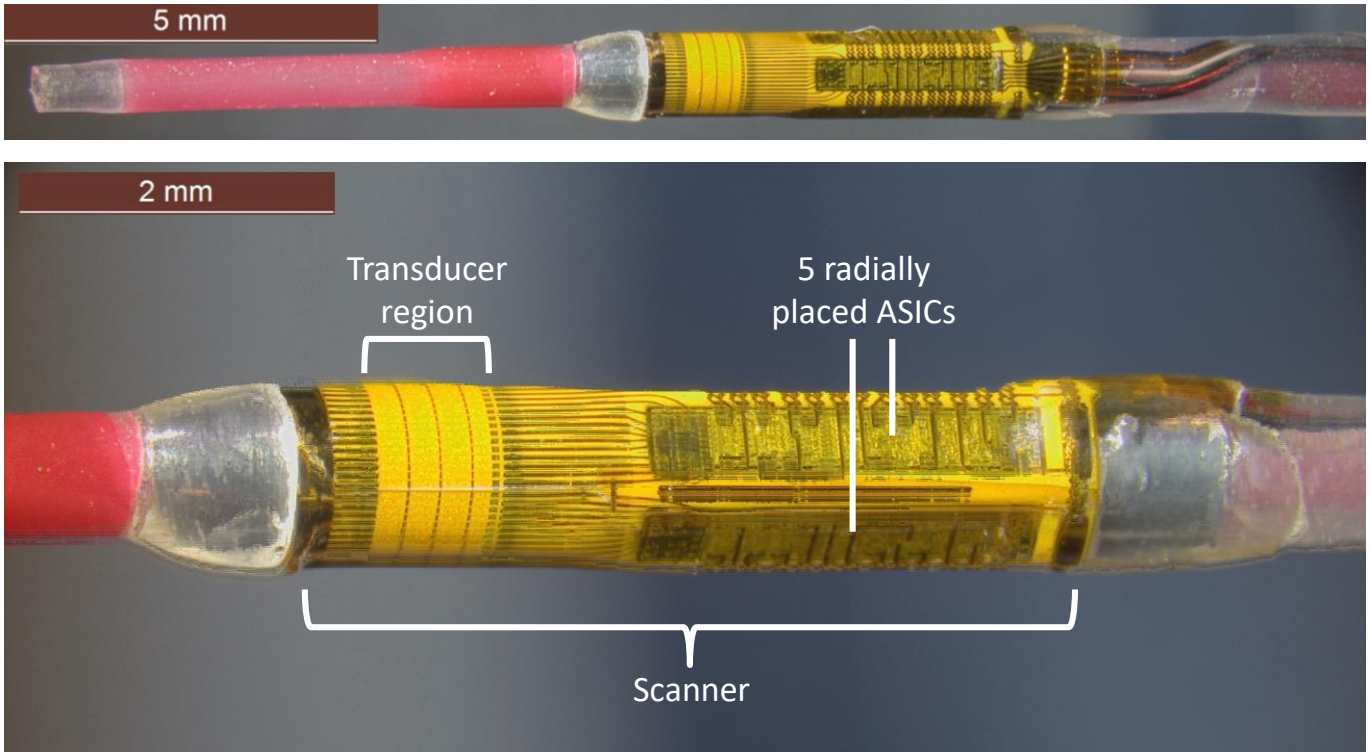
State-of-art: Volcano Eagle Eye IVUS catheter

Ø 1.2 mm catheter, 64 piezo elements around circumference



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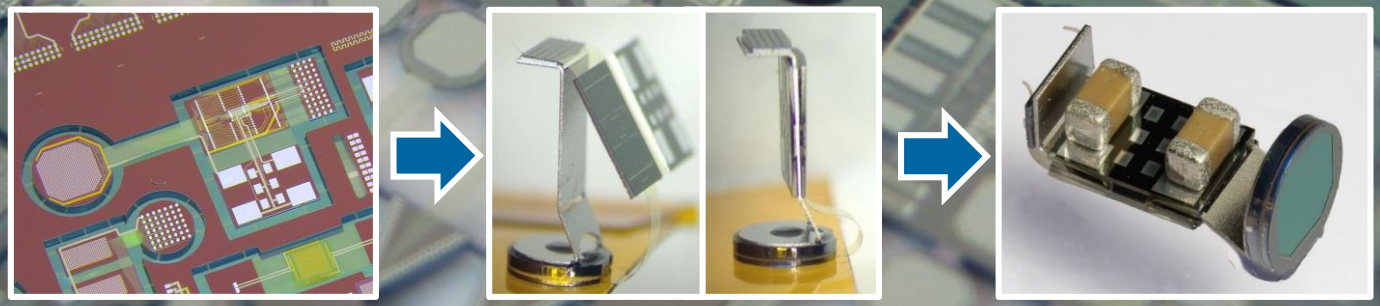
Flex-to-Rigid (F2R) interconnect platform

Interconnect built into device:

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



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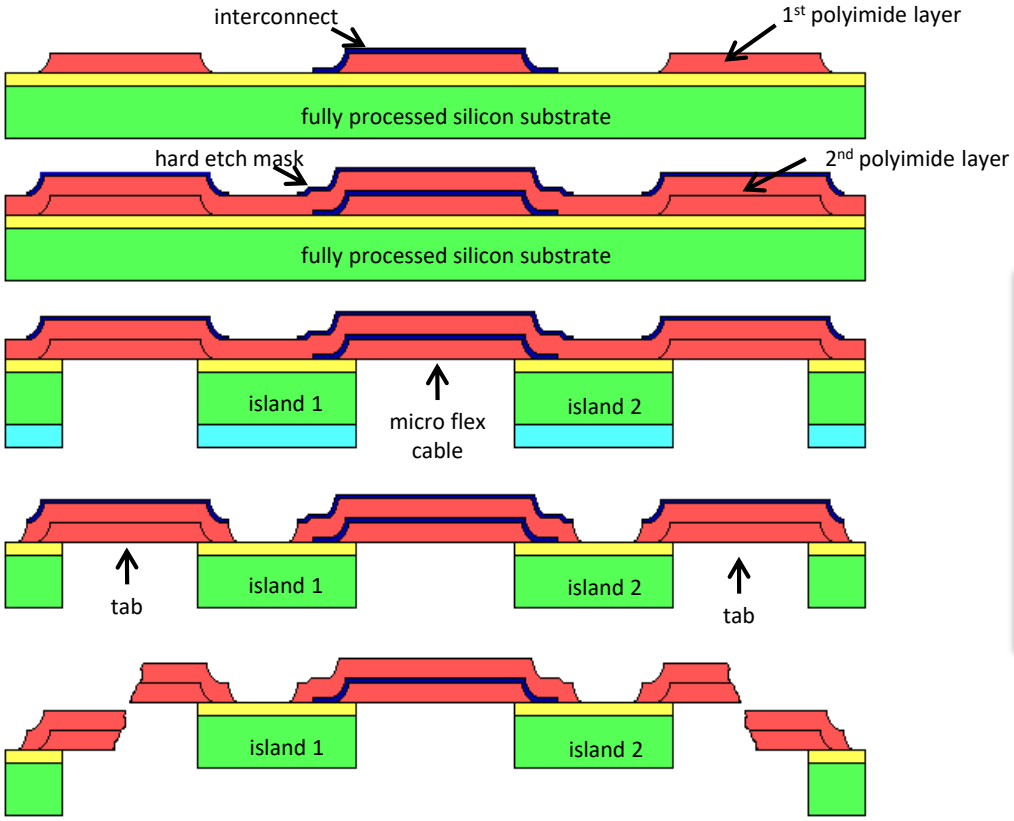
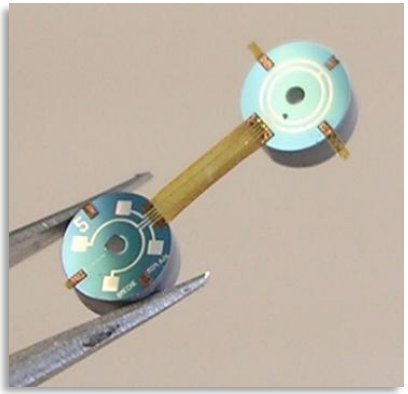
Standard Si process flows: Schematic F2R process flow





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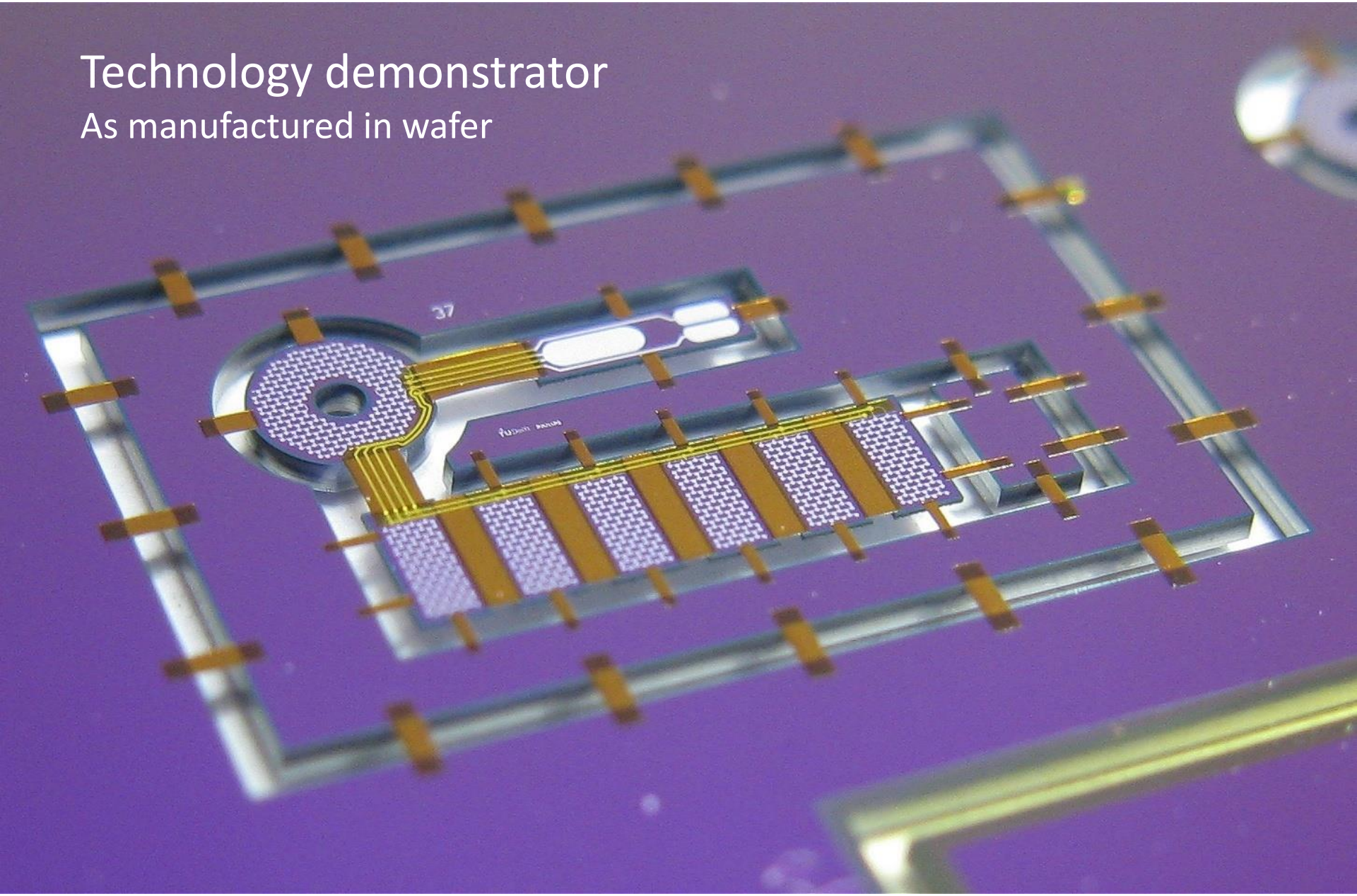
Technology demonstrator

As manufactured in wafer



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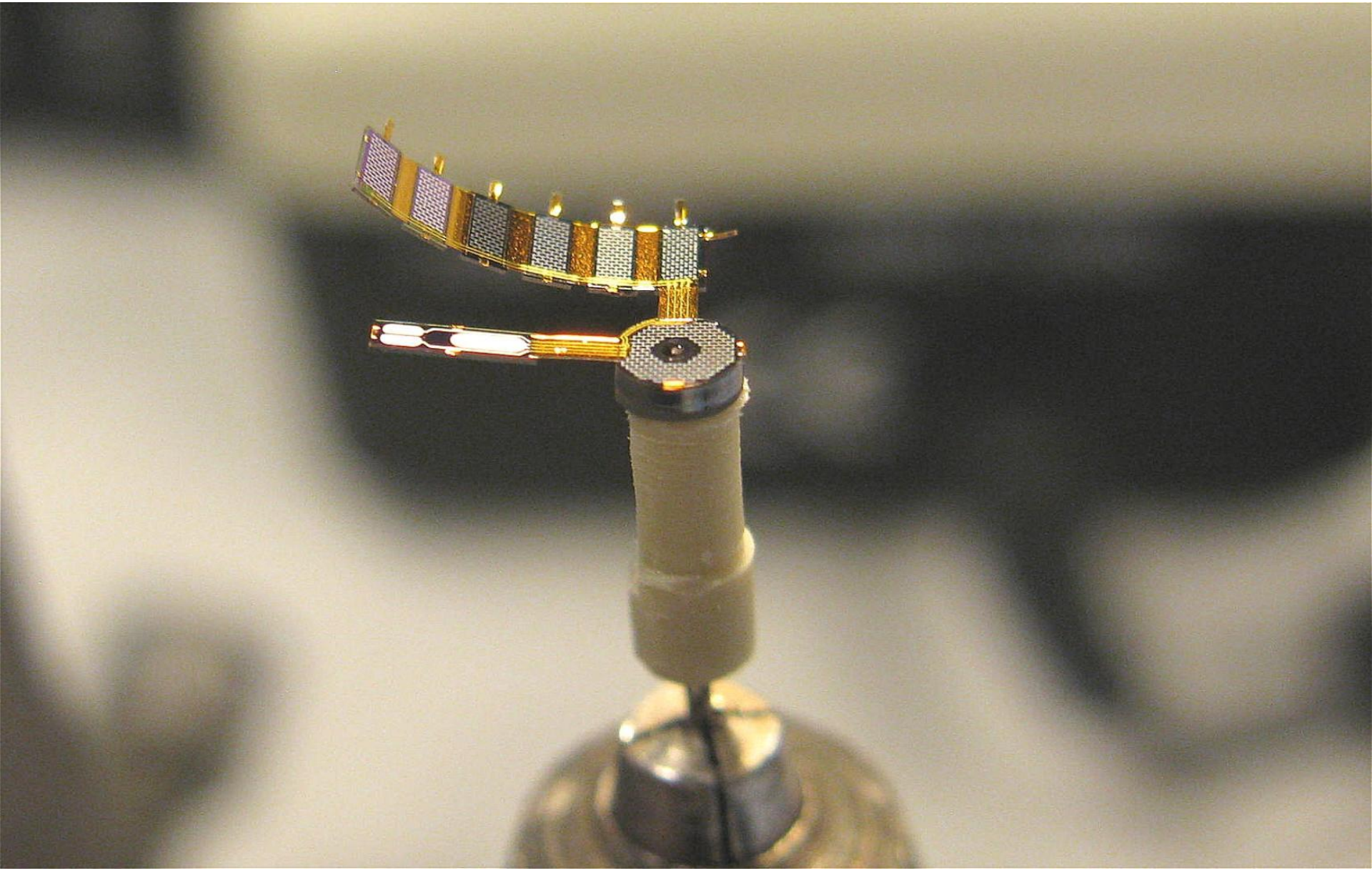

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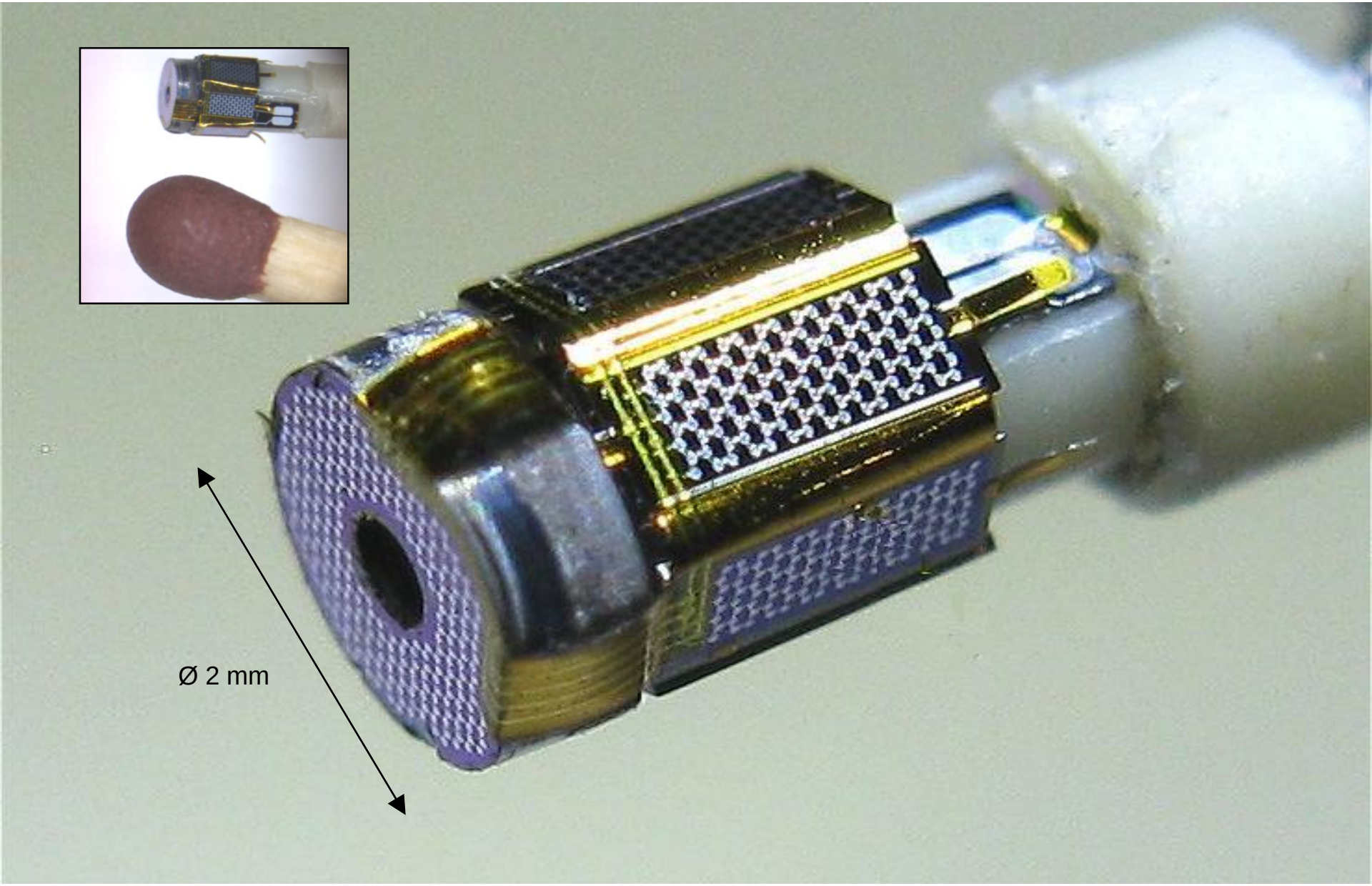

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To evaluate CMUT performance and develop CMUT applications

Contact: Paul.Bekkers@Philips.com

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Thank you!

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