Capacitive Micromachined Ultrasonic Transducers for Medical and Non-medical Applications

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Fraunhofer

ENAS

Department System Packaging

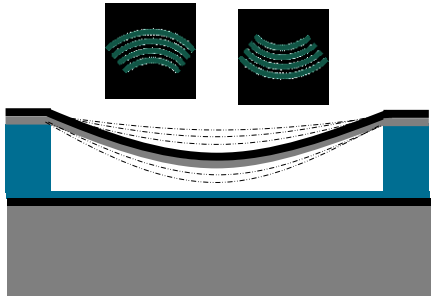
Outline

- Introduction
- Concept
- Fabrication Technologies
- Design Parameters
- Research on CMUT at ENAS

CMUT

Capacitive Micromachined Ultrasound Transducer

- A miniaturized MEMS device for generating and receiving ultrasound waves
- Introduced in 1994 by Stanford
- First in market by Hitachi in 2008



Pros & Cons

- Wide frequency bandwidth
- Batch processing (standard silicon processing)
- Possibility to integrate with the driving electronics
- Various configurations, geometries
- Good acoustic matching
- Miniaturized
- Wide operation temperature range

- High driving voltage
- Cell crosstalk

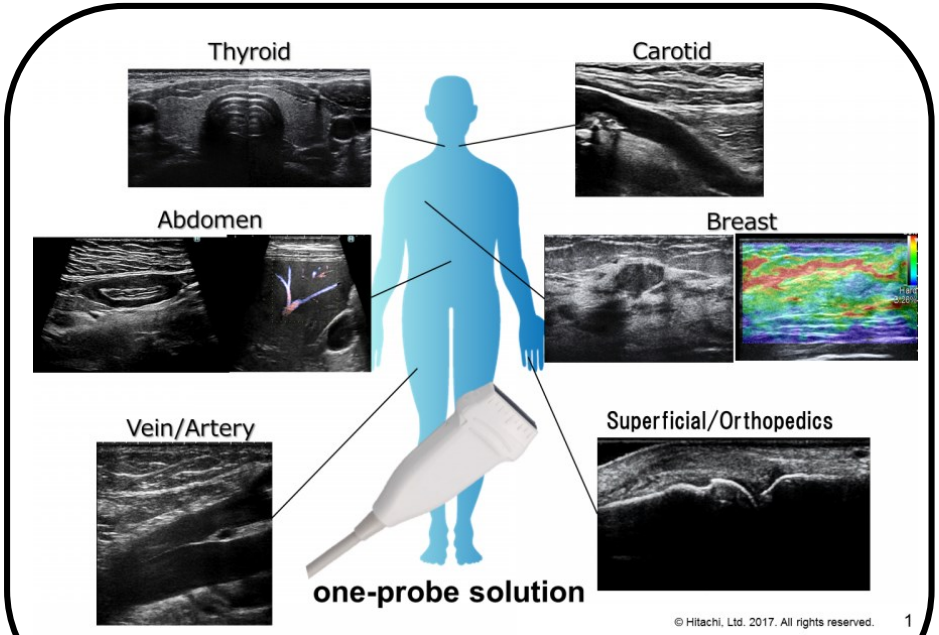
Application

Dominated by medical imaging

- Endoscopy, Probe or Catheter based

Butterfly Network

- First handheld CMUT probe
- Battery operated
- Connected to smartphone



Multi-tasking 4G CMUT linear matrix probe by **Hitachi**

High frequency probes by **Kolo**

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Application

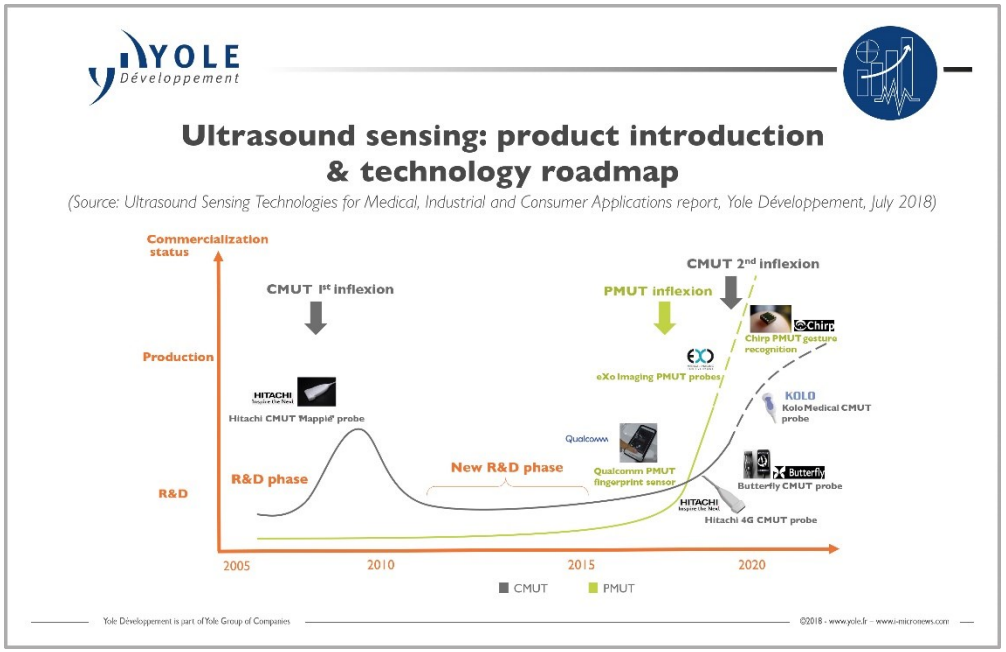
Other applications

- Medical therapy
- Photoacoustic imaging
- Gas flow sensors
- Acoustic actuator / manipulator
- Non destructive testing

Market and the players

Market

- CMUT market is rapidly expanding.
- Medical imaging remains the main applications.



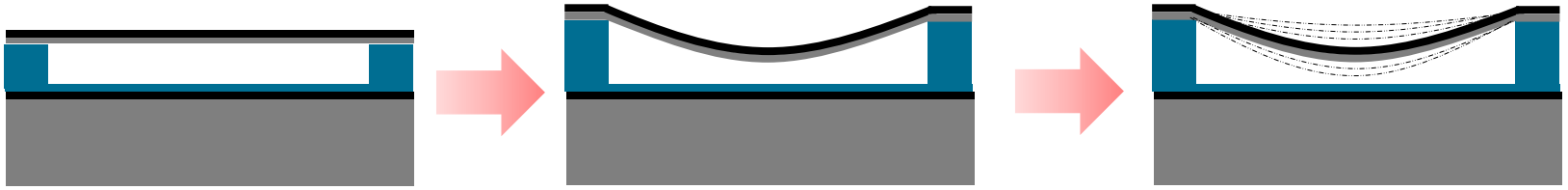
MUT market status (Yole Development, July 2018)

Players

- Research
  - Stanford University, University of Roma Tre, Fraunhofer, Imec, ...
- Industry
  - Hitachi, Butterfly Network, Philips, Kolo, Vermon

Concept

CMUT → a MEMS-based parallel-plate-capacitor with one plate fixed and the other movable



CMUT

DC biased

Membrane is in a static operating point.

AC coupled

Membrane vibrates around its static operating point.

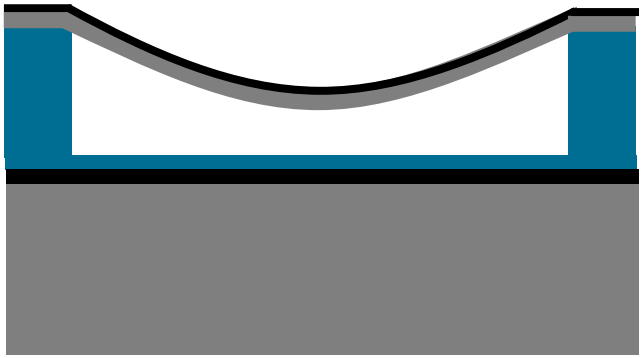
Usually a CMUT probe / device consists of an array of CMUT cells

Key components of a CMUT

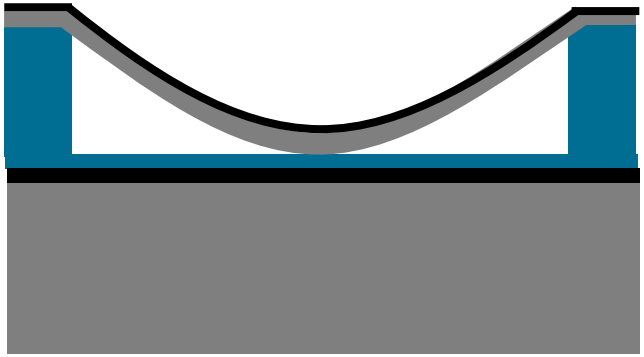
- ❑ **Membrane (size and material)**
- ❑ **Single or multi layer**
- ❑ **Gap between the two plates / electrodes**

Concept

Recently introduced mode of operation



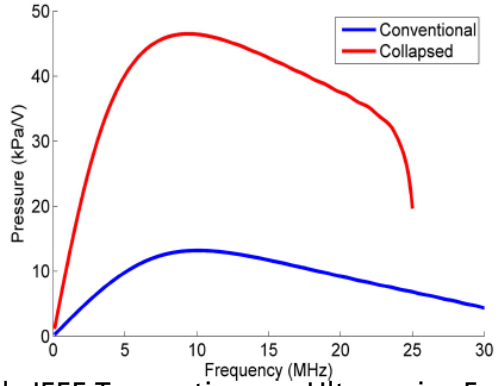
Conventional Mode



Collapse Mode

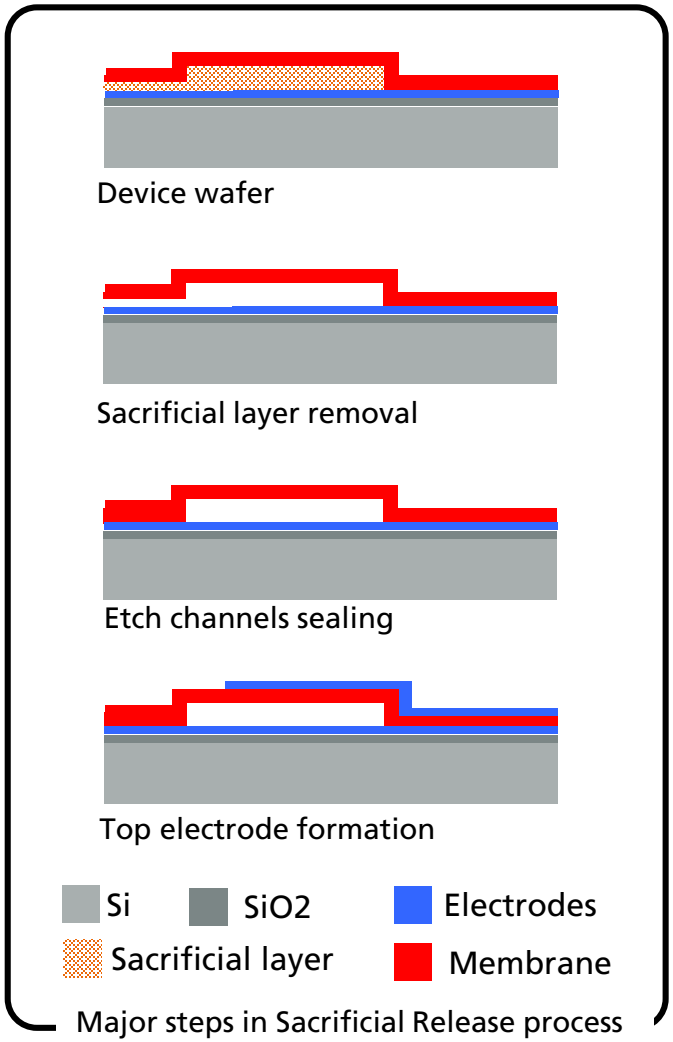
Collapse vs. conventional

- ❑ Enhanced receive / transmit efficiency (sensitivity)
- ❑ Higher output pressure

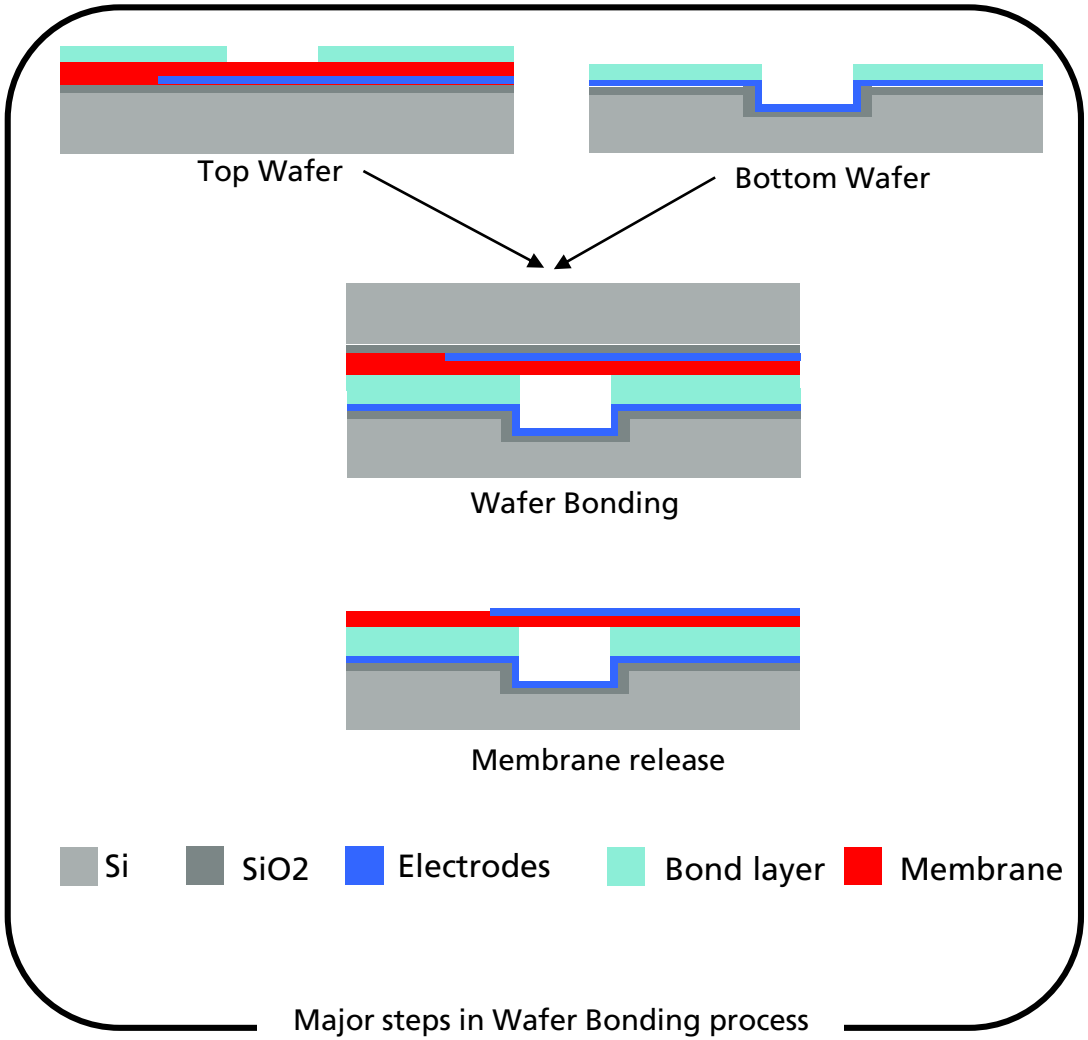


K. K. Park, et al,, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 60, no. 6, pp. 1245-1255, June 2013.

Fabrication technologies



Major steps in Sacrificial Release process



Major steps in Wafer Bonding process

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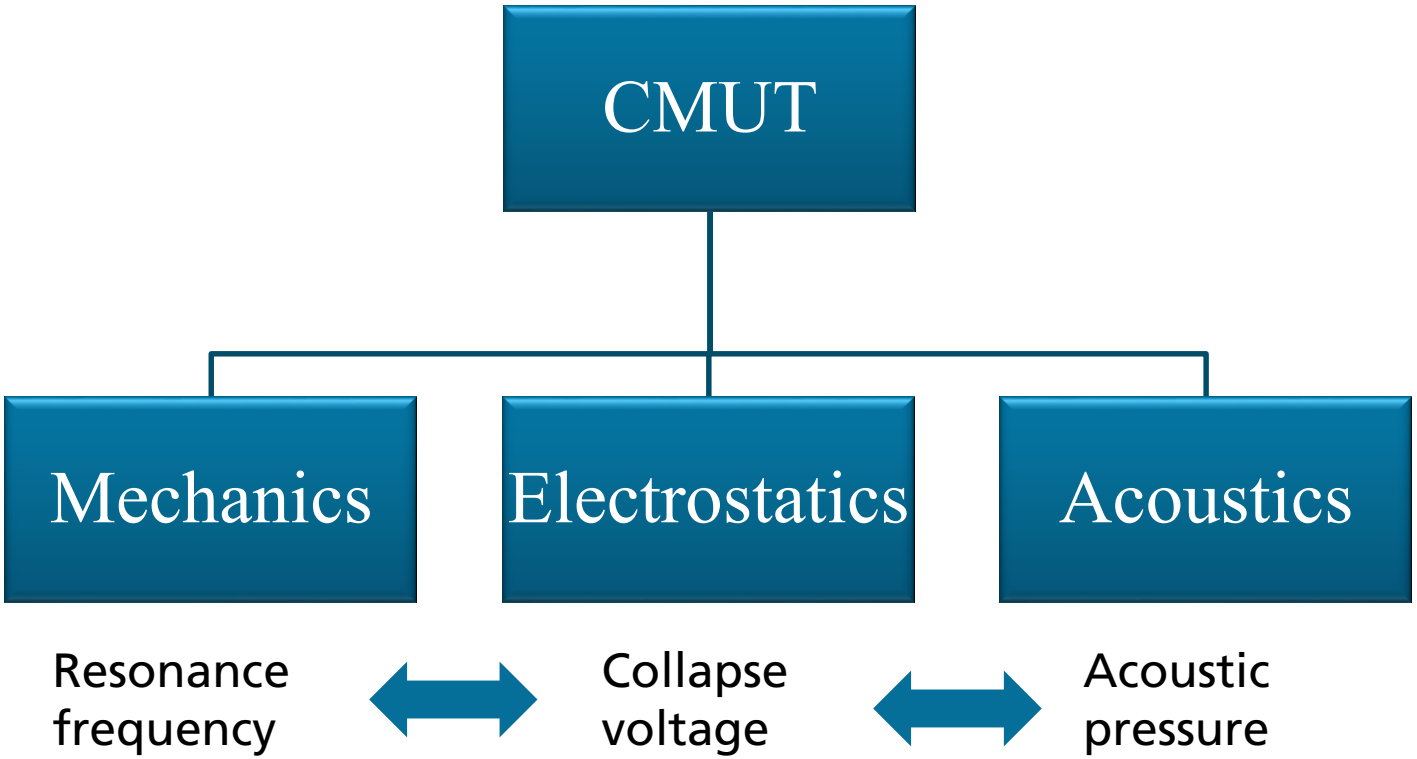
Design parameters

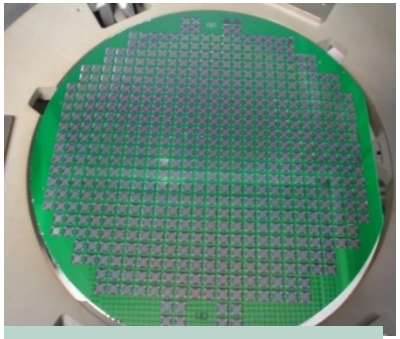
... a complex multiphysics system



Finite element analysis (FEA) tools are used to calculate device parameters.

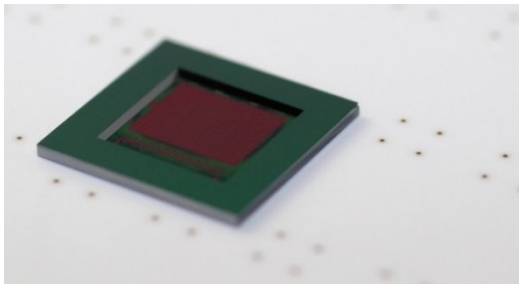
Research on CMUT at ENAS

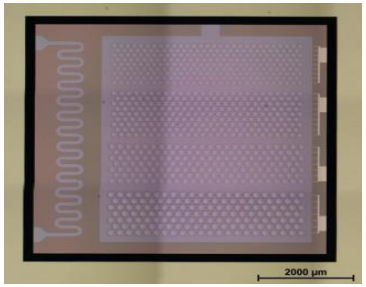
Design, Technology Development, Fabrication and Characterization



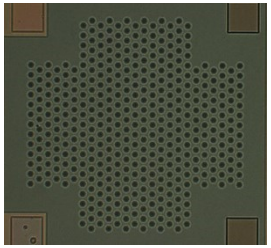
CMUT wafer prior to dicing

CMUT assembled on ¼ “ capsule or characterization



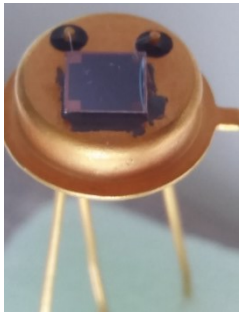


Multifunction sensor with ultrasonic transducer for air applications
High temperature stable component for applications up to 300 ° C



Microscope image of a fabricated CMUT

CMUT on test PCB



CMUT on TO package

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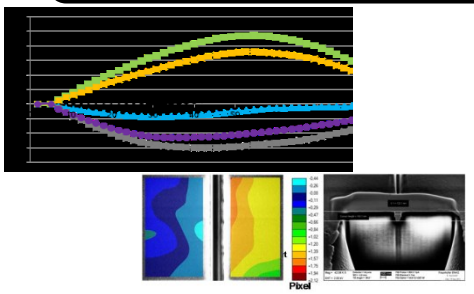
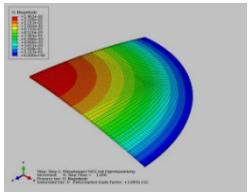
Research on CMUT at ENAS

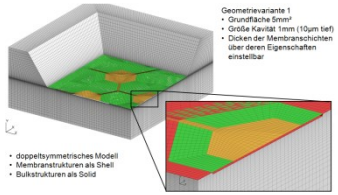
Development flow

Material selection



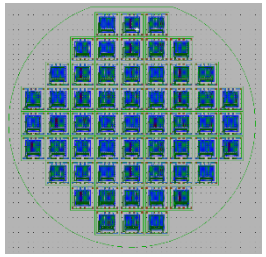
Simulation

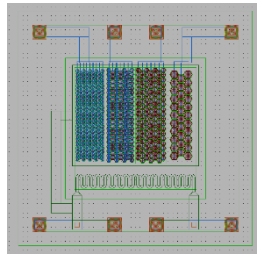




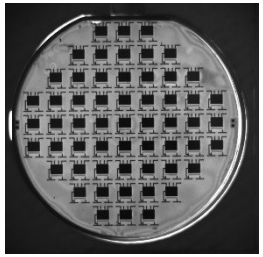
Extract device geometry

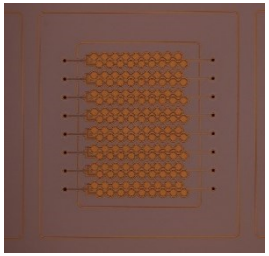
Layout & Mask design



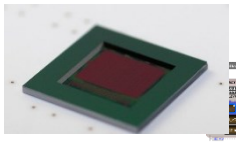


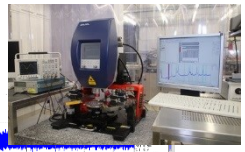
Fabrication

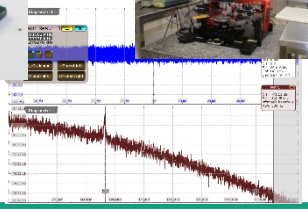




Assembly, packaging and characterization







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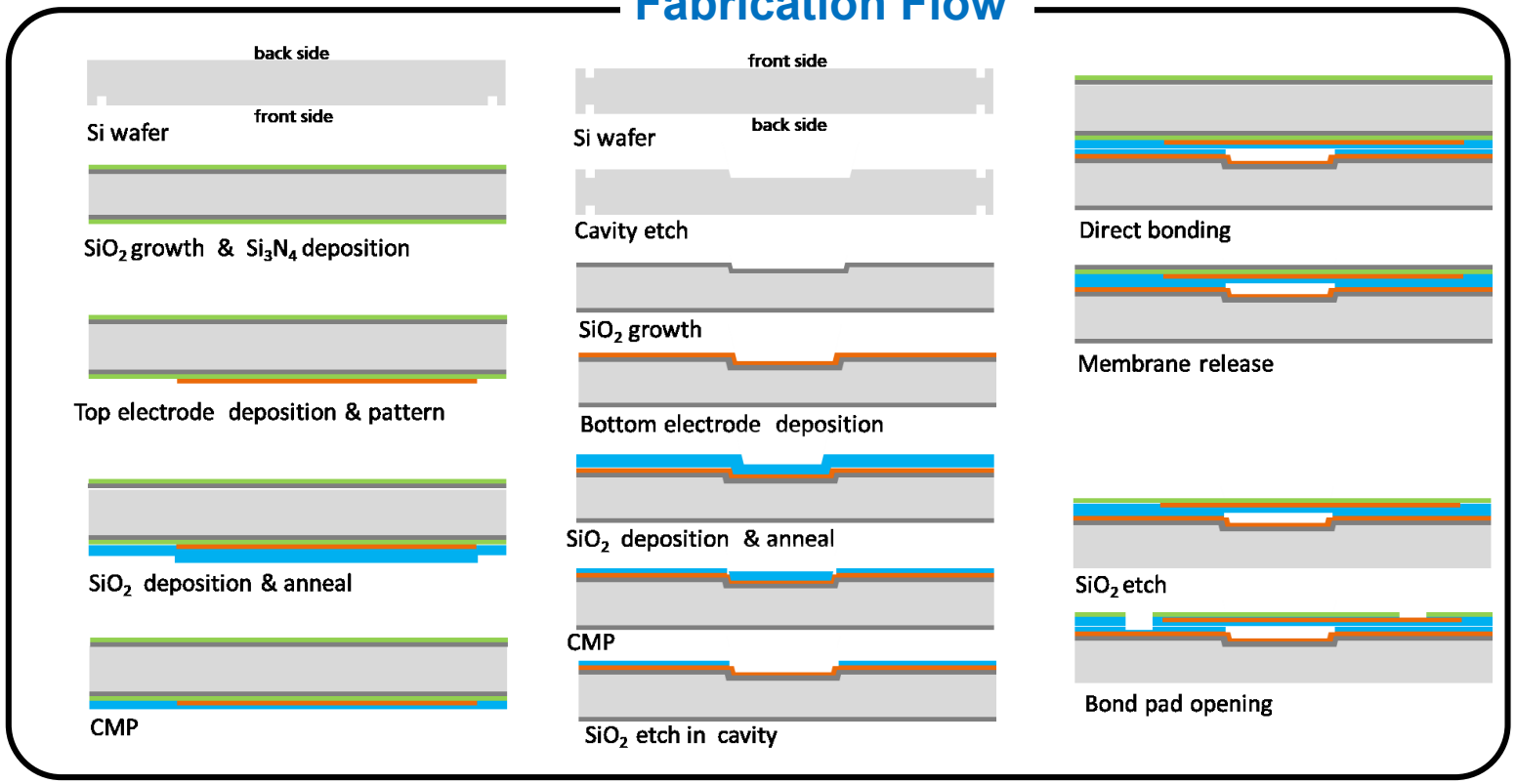
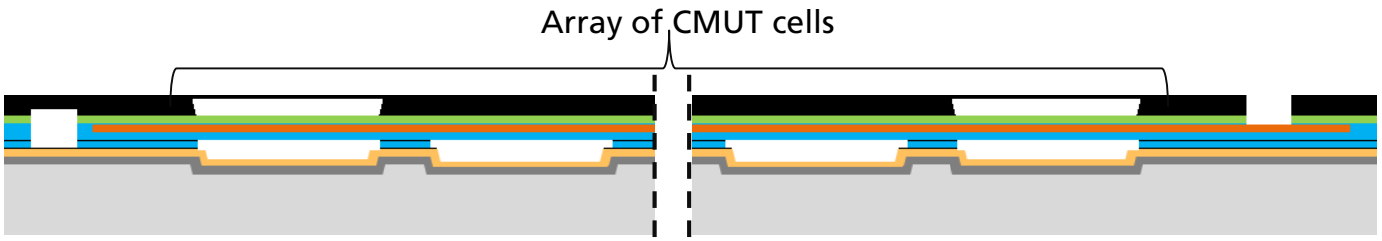
Research on CMUT at ENAS

Fabrication Flow





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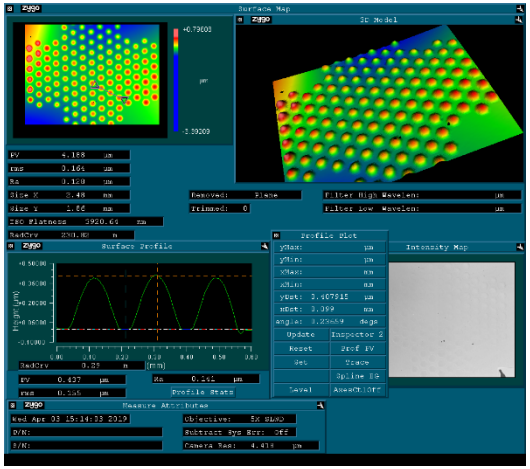
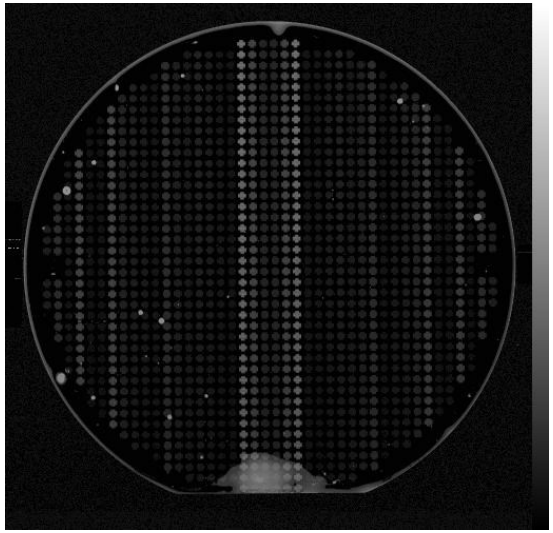
Performance characterization

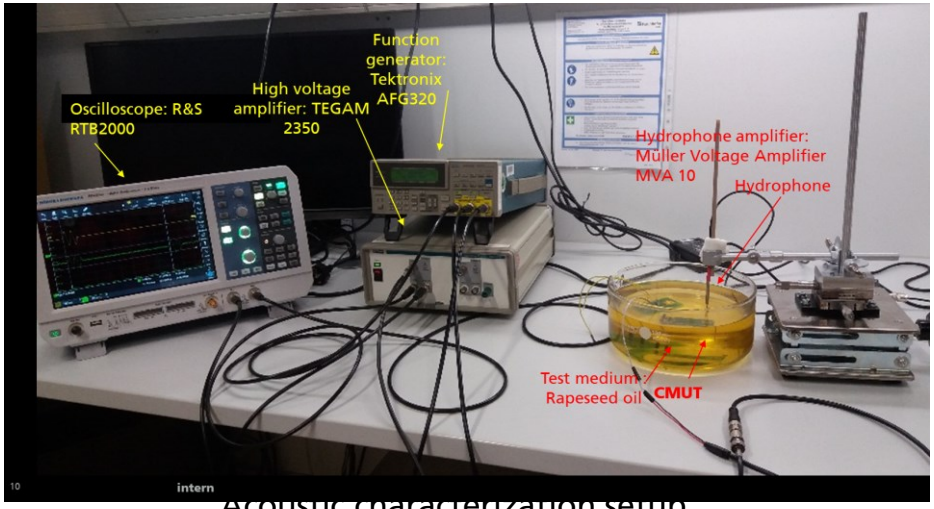
- Wafer / Device level characterization (SAM, WLI, LDV,…)
- Electrical characterization
- Acoustic characterization (with hydrophone)



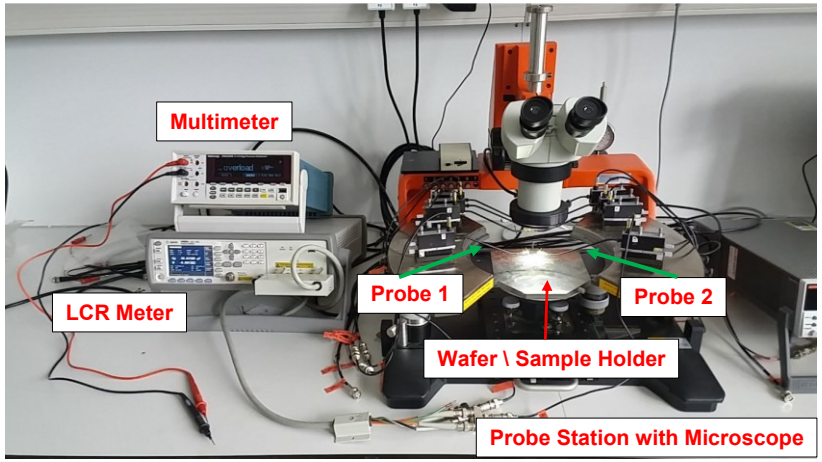
While light interferometry of CMUT membranes



Scanning acoustic microscopy (SAM) image of a bonded wafer pair



Acoustic characterization setup



Electrical characterization setup

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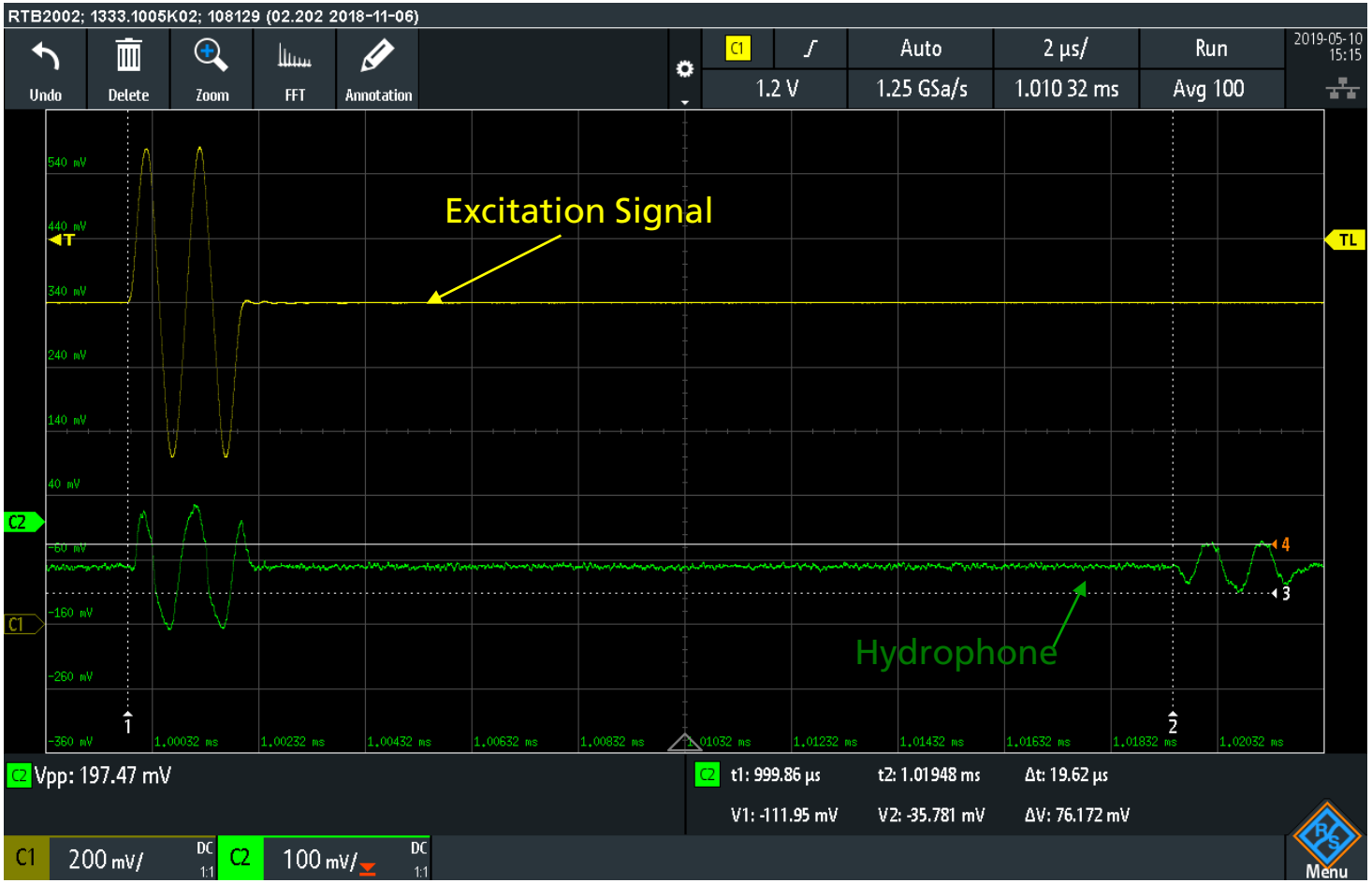
Performance characterization



Example of acoustic pressure characterization at distance of ca. 28 mm from the source (CMUT)

Ongoing work

- Device design for different specifications (applications)
- Comprehensive and coupled FEA modeling
- Receive / transmit characterization
- FEA verifications

Acknowledgements

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- Fraunhofer Society
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Thank you!