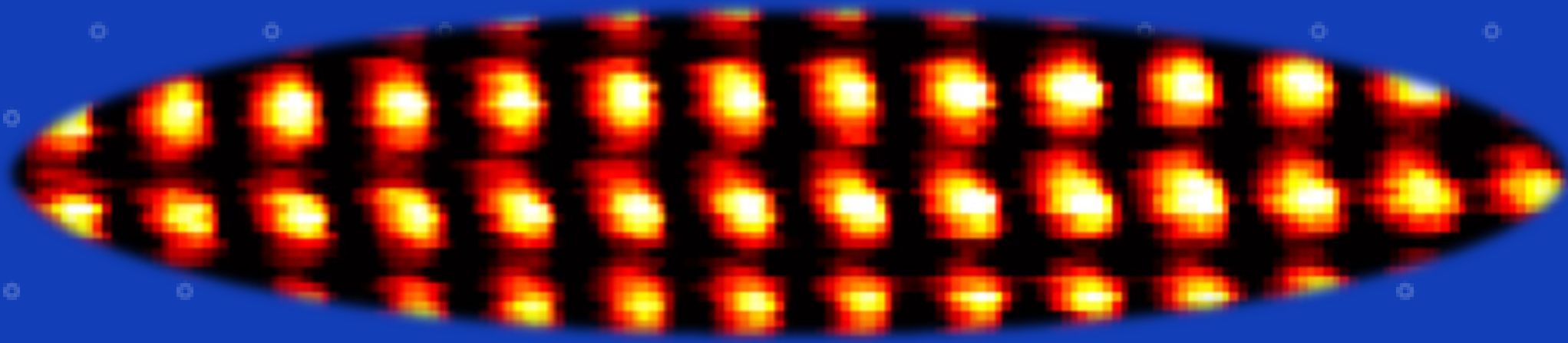
GHz half wavelength contact acoustic microscopy (HaWaCAM)

Benoit Quesson, Paul van Neer, Mehmet Tamer, Kodai Hatakeyama, Maarten van Es, Martijn van Riel, Daniele Piras

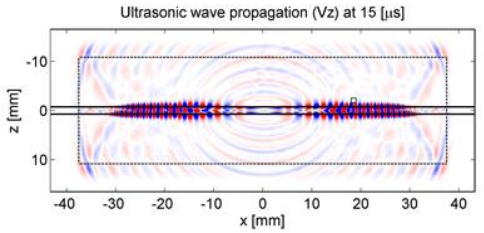


TNO innovation for life

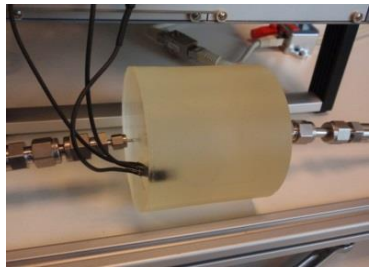
Ultrasonic flowmeter

Innovative ultrasonic flowmeter

- Markets: pharmaceutical, chemical, food, (defense)
- From concept to industrial prototype in 3 years (TRL 1-9)
- Commercialized in 5 years - sales of 1000++ sensors/year;
- Technology diversification to other applications



1st concept



Proof of Concept

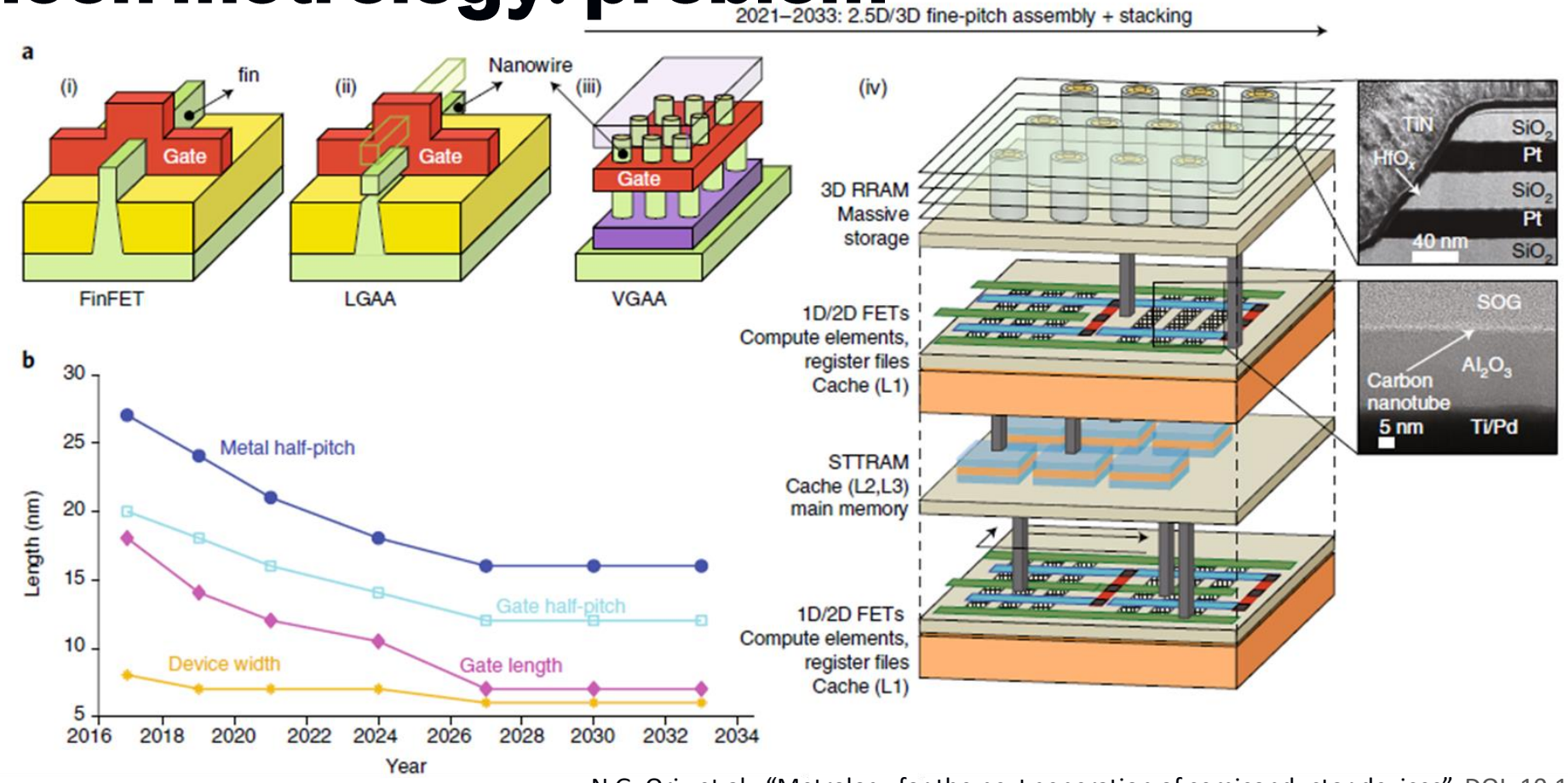
1st BHT Prototype

BHT final Prototype

Commercial product

- Multiple patents on measurement concept
- Role TNO:
  - Short cycle development of sensor
  - Support during product development
  - Product diversification

Semicon metrology: problem



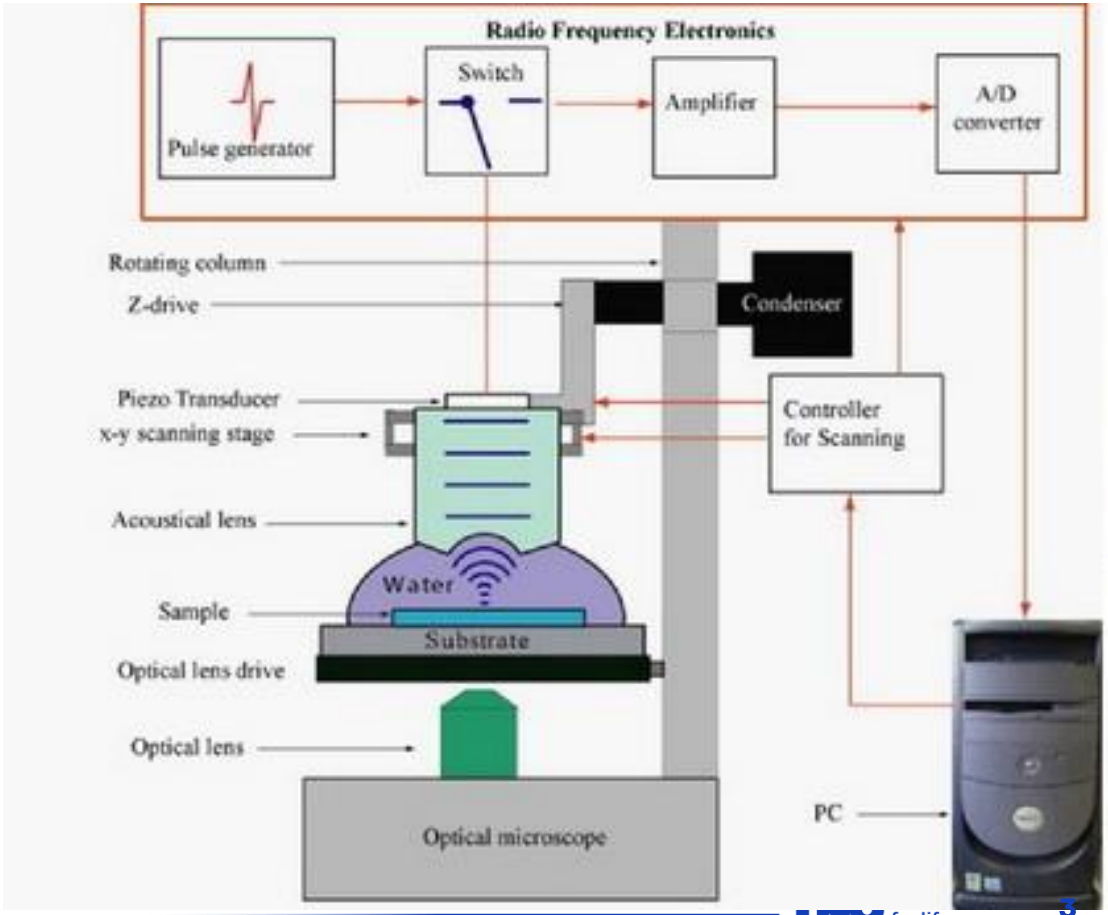
N.G. Orjy et al., "Metrology for the next generation of semiconductor devices", DOI: 10.1038/s41928-018-0150-9

- Industry question:
  - How to fabricate & measure these devices (nanometrology) cost effectively at very high throughput?

Current solutions and their limitations

- Non-destructive inspection workhorse of semicon industry = optics based, limited by
  - Optically opaque layers
  - Detection depth (< O(1 µm)) and resolution (wavelength) of ~0.2 – 1.5 µm
  - Optical resolution is limited by wavelength
- Electron beam: not 3D, destructive
- X-ray: good penetration depth, non-destructive, not limited by optically opaque layers but long measurement time

- Potential alternative modality: acoustic microscopy
- Acoustic microscopy images acoustic impedance differences (stiffness and density)
  - Frequency ~50 MHz to ~1 GHz
  - Resolution (wavelength) > 3 µm (PMMA), > 6 µm (SiO_2)
  - Strongly focused.
  - Requires x,y and z scanning for 3D dataset

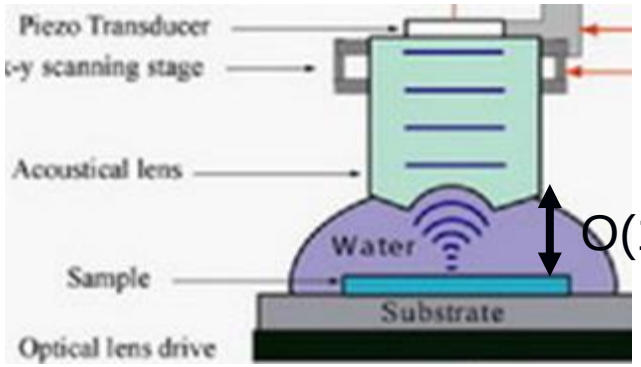


from: Weiss, Lemor et al., IEEE Trans. Ultrason. Ferroelectr. Freq. Contr., 54 2257, 2007.

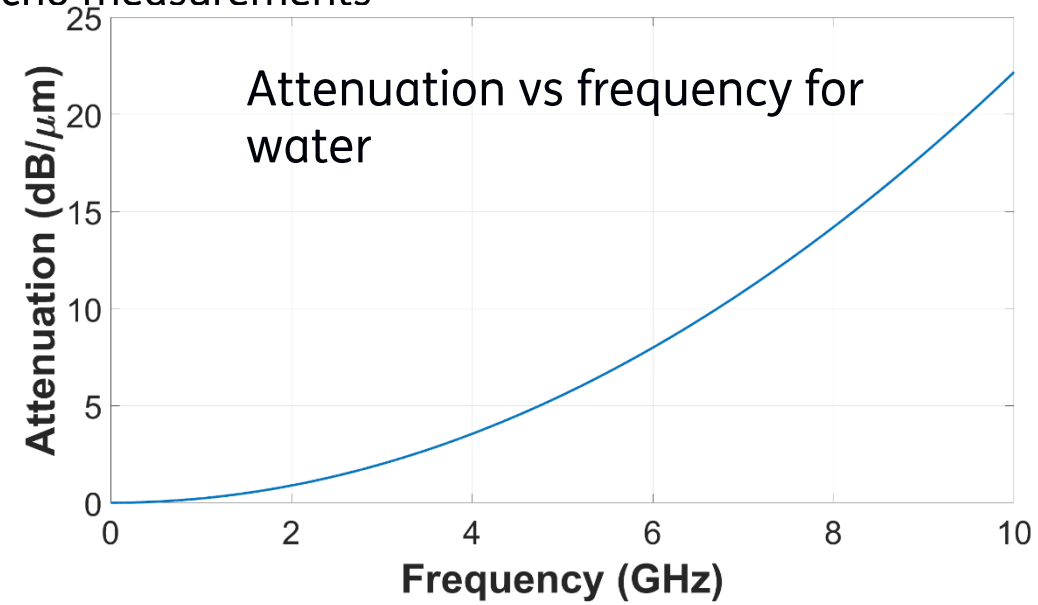
Limits of acoustic microscopy

- Upper frequency limit caused by signal level limitation due to the coupling layer:
  - Coupling layer used to couple acoustical energy from the transducer to the sample
  - Lateral resolution achieved by acoustical lens => long acoustical path in coupling layer => high attenuation
  - attenuation ($\propto f^2$) in the in coupling layer:

    0.22 dB / µm @ 1GHz = already 44 dB loss for pulse-echo measurements



O(100 µm)



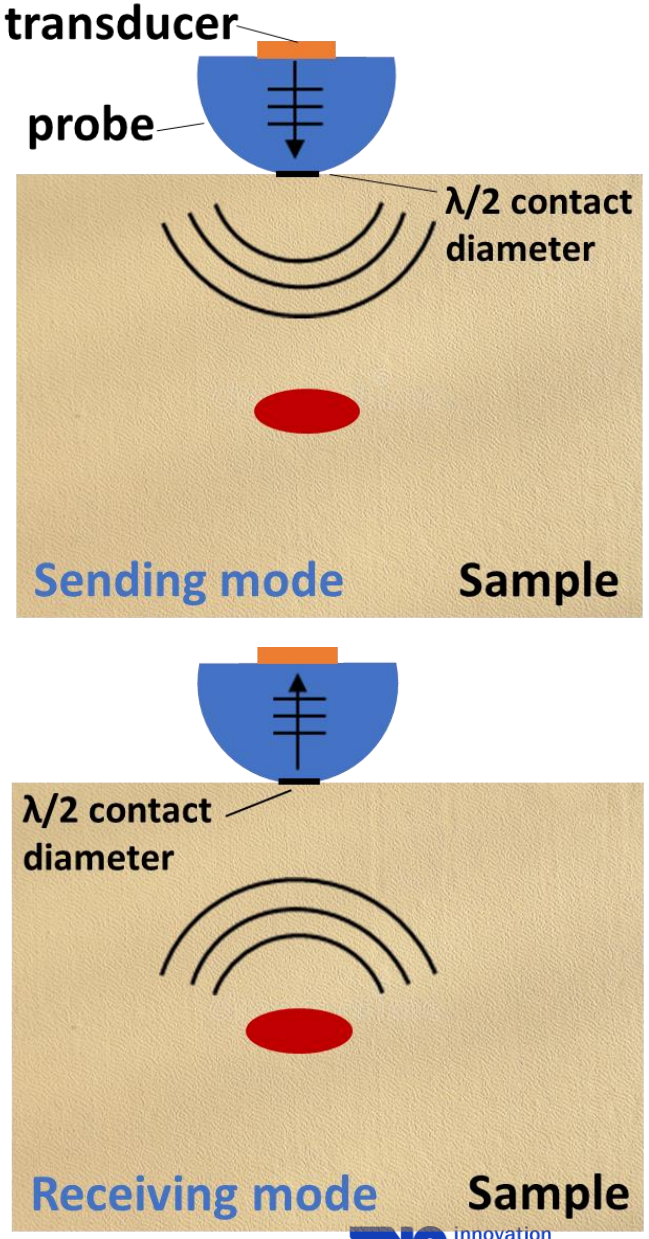
Can we get around the principal frequency limitation by removing the coupling layer?

⇒ Investigate feasibility of Half-Wavelength Contact Acoustic Microscopy (HaWaCAM)

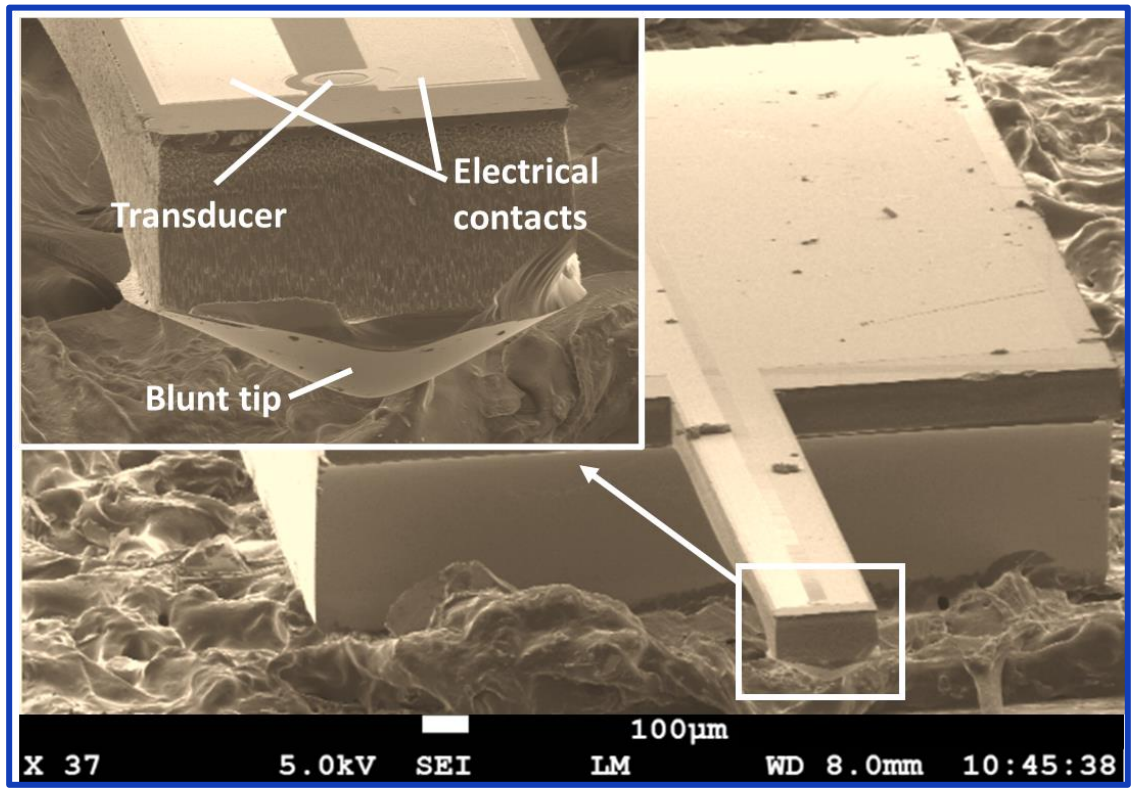
HaWaCAM concept

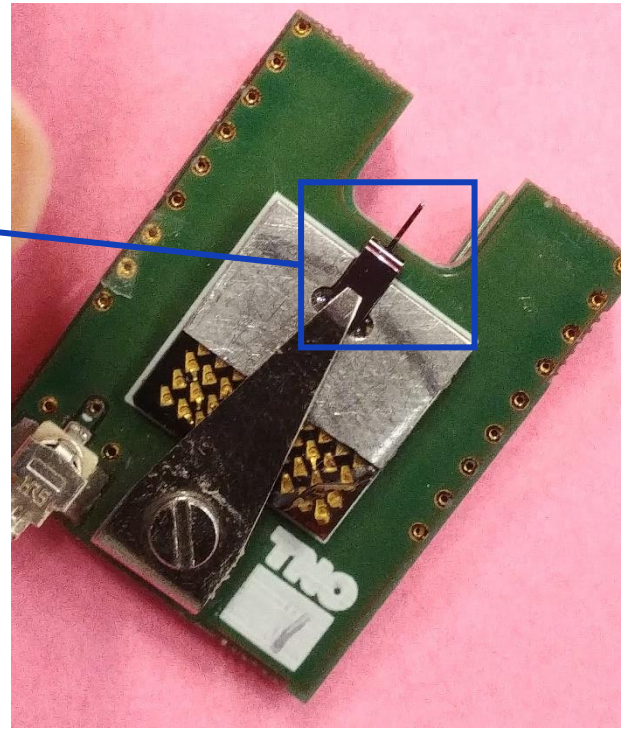
- Half-wavelength contact acoustic microscopy (HaWaCAM)
  - Marries a probe with GHz piezotransducers
  - Image contrast depends on acoustic impedance differences
  - Tip – sample contact diameter ~half wavelength
  - Tip – sample contact: linear

- Characteristics
  - No coupling layer (contact mode)
  - Frequency >>1 GHz → not limited by attenuation in coupling layer
  - Currently implemented: 4 GHz – wavelength 0.75 µm in PMMA, 1.5 µm in SiO_2
  - Penetration O(10's of µm)
  - Non-destructive/nondamaging
  - Ability to image through optically opaque layers



Custom Probe with tip including piezotransducer

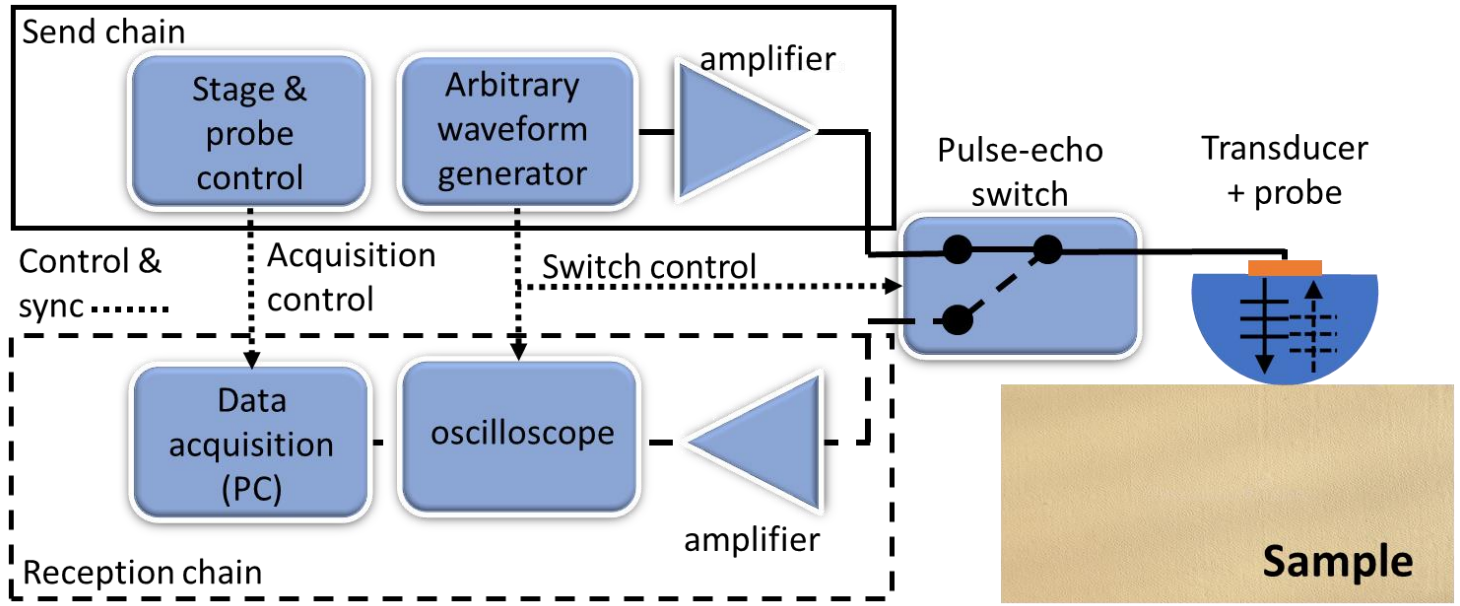




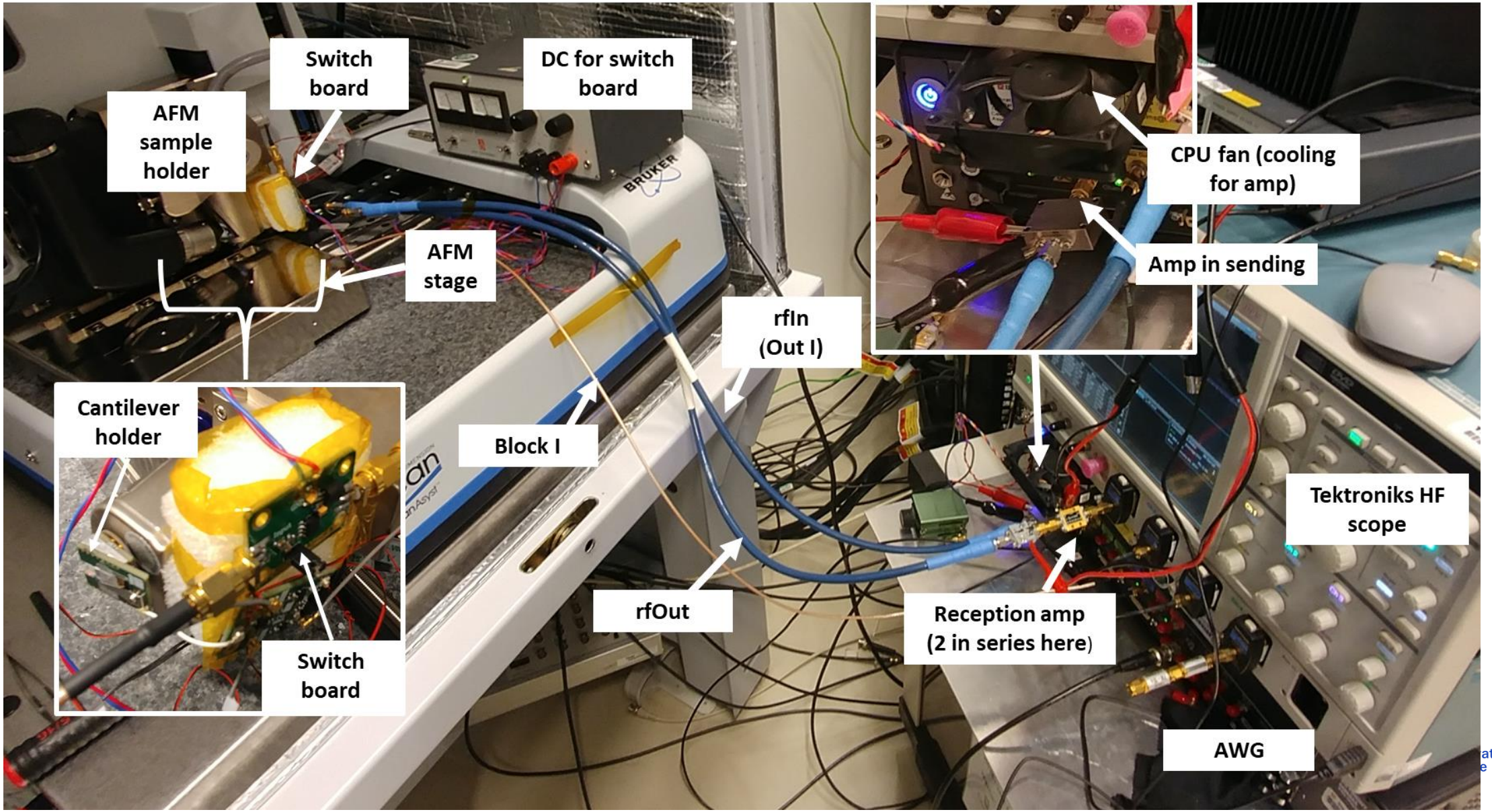
- Piezo resonance frequency ~4 GHz
- Piezo diameter: ~25 µm
- Probe tip height ~100 µm
- Probe tip radius > 10 µm

Experimental setup (1)

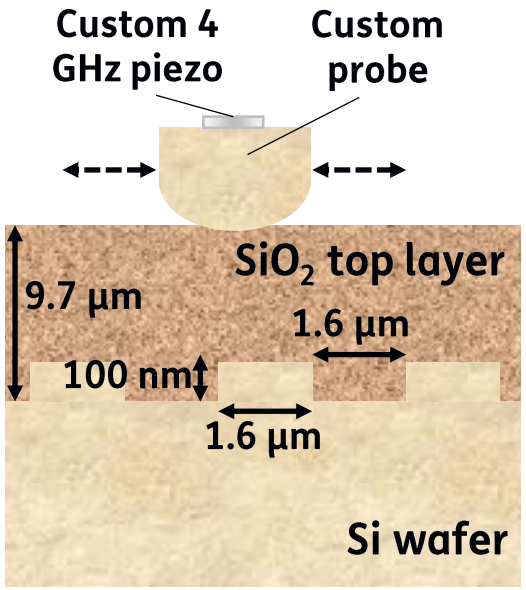
- Excitation signals:
  - Linear chirp
  - 4 GHz center frequency
  - Bandwidth: 4 GHz
  - duration: 5 ns
  - Amplitude: 500 mV
- 400 traces averaged per point
  - Measurement time / point: 0.4 ms
- To position the acoustic probe an atomic force microscope was modified



Experimental setup (2)

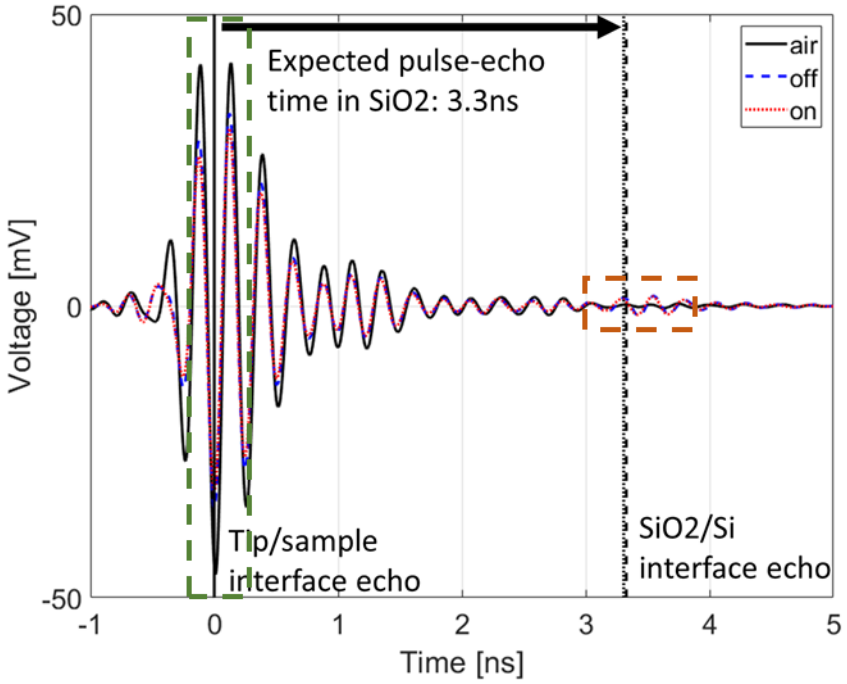


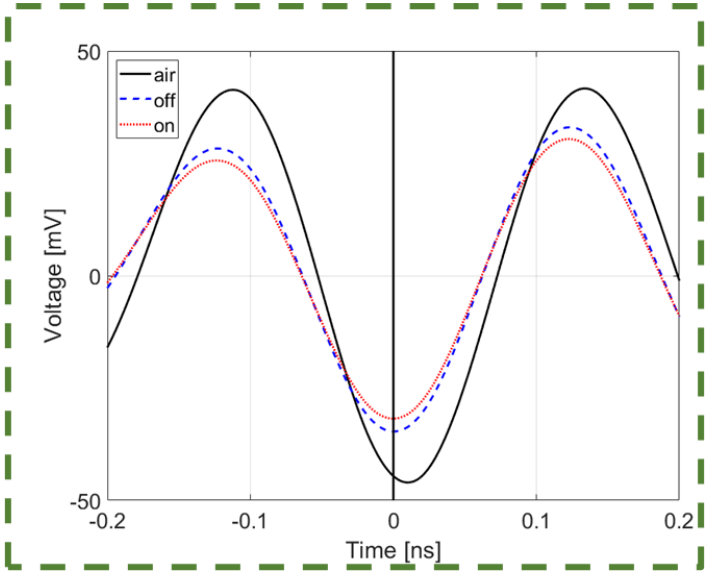
Results (3)

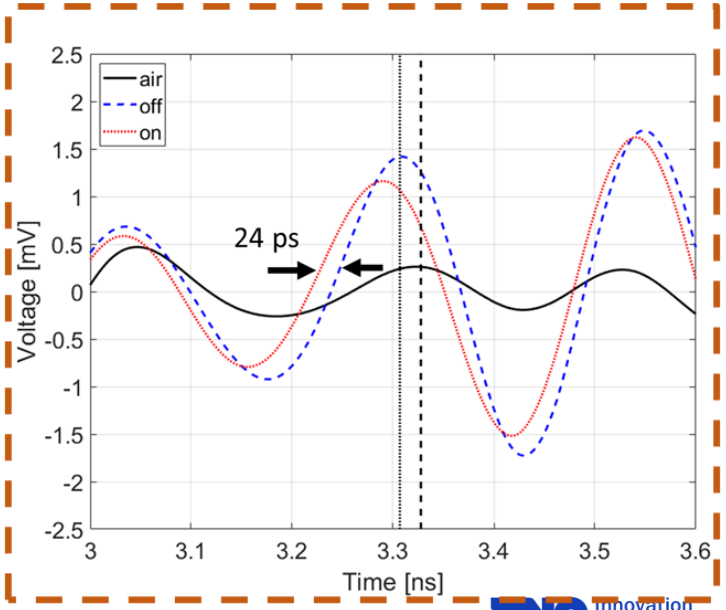


Side view

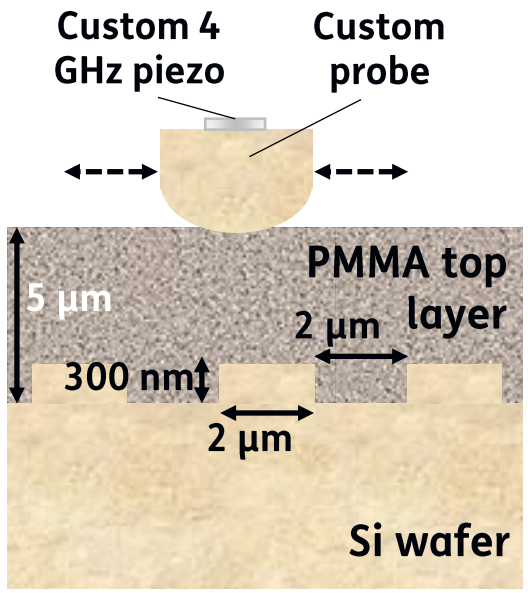
Top view



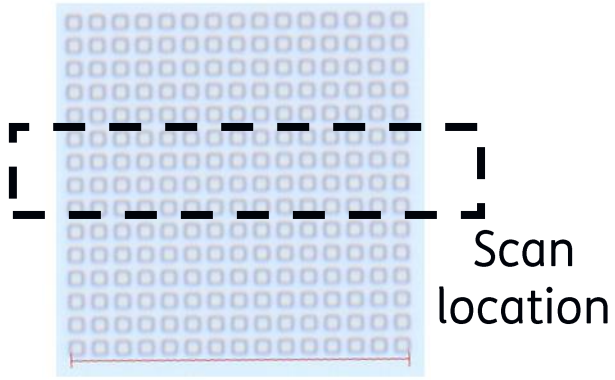




Results (4)



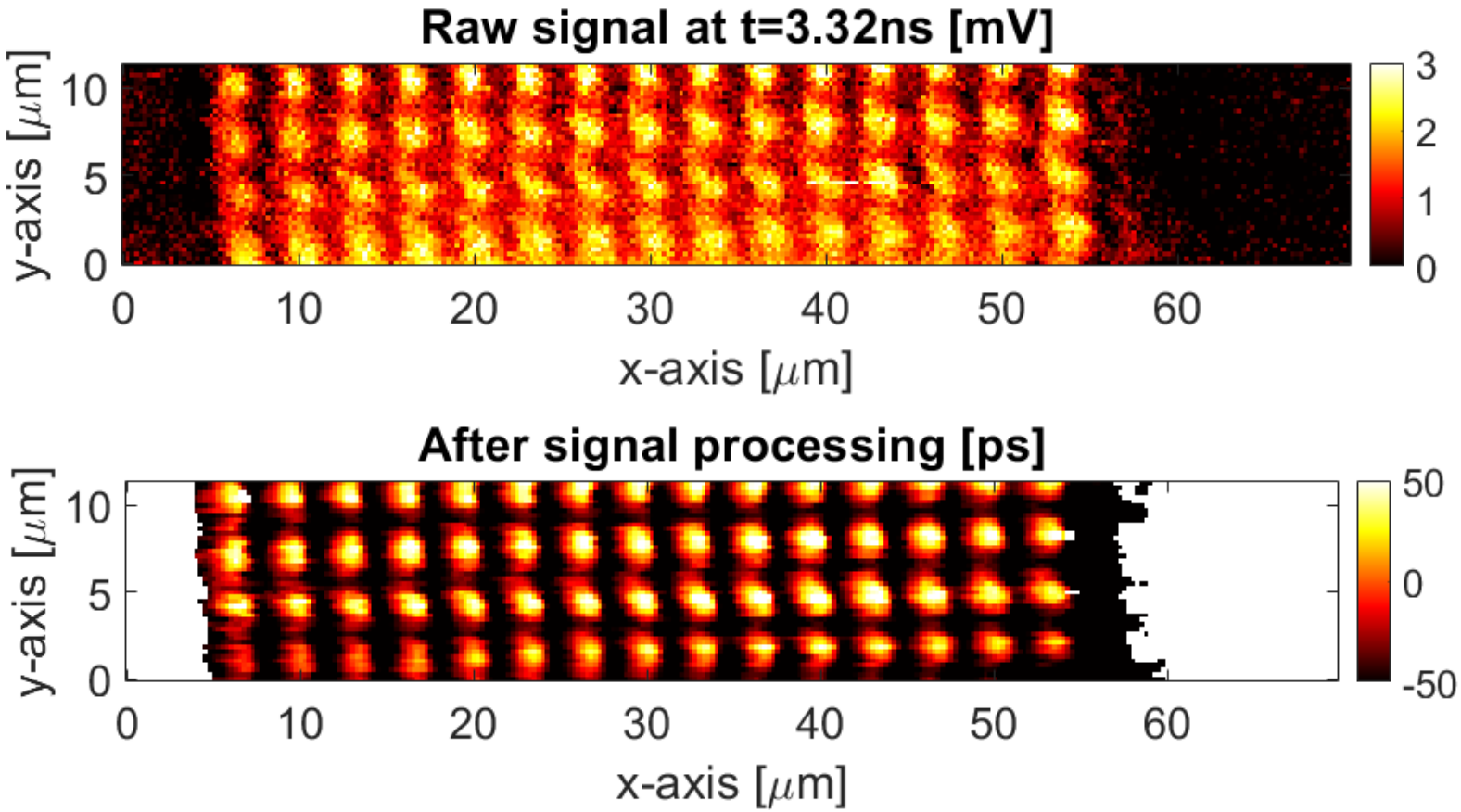
Side view



Scan location

Top view

Raw data:



Conclusion

- Half-Wavelength Contact Acoustic Microscopy (HaWaCAM) is feasible
  - No coupling layer (contact mode) → higher frequencies possible
  - Penetration depth O(10s) of µm

- Good match between experimental and simulation results

- 4 GHz HaWaCAM system designed and built
  - Wavelength 0.75 µm in PMMA, 1.5 µm in SiO_2

- HaWaCAM demonstrated on samples:
  - 1D grating (element height: 100 nm, width: 0,8 µm, pitch: 1,6 µm) buried below 9.7 µm thick SiO_2
  - 2D grating (element height: 300 nm, width: 2 µm, pitch: 4 µm) buried below 5 µm thick PMMA

Way ahead

Within KDT JU Hi-Connects (on going)

Key Digital Technologies Joint Undertaking (KDT JU)

https://www.hiconnects.org/

- ➔ Increase frequency range from 3-5 GHz to 1-20 GHz
- ➔ Increase measurement speed by up to 2 orders of magnitude
- ➔ Plan to measure new samples from partners for both back-end and front-end applications, as support for inspection and metrology

Thank you for your attention

contact: benoit.quesson@tno.nl

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