Anwendungen von Laserultraschall als zerstörungs- und kontaktfreie Methode in der Dünnschichtcharakterisierung

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EFDS Workshop Linz: Dünnschichtcharakterisierung, 10-11 November 2025

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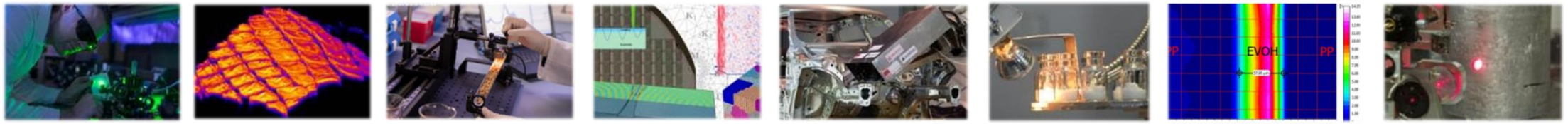
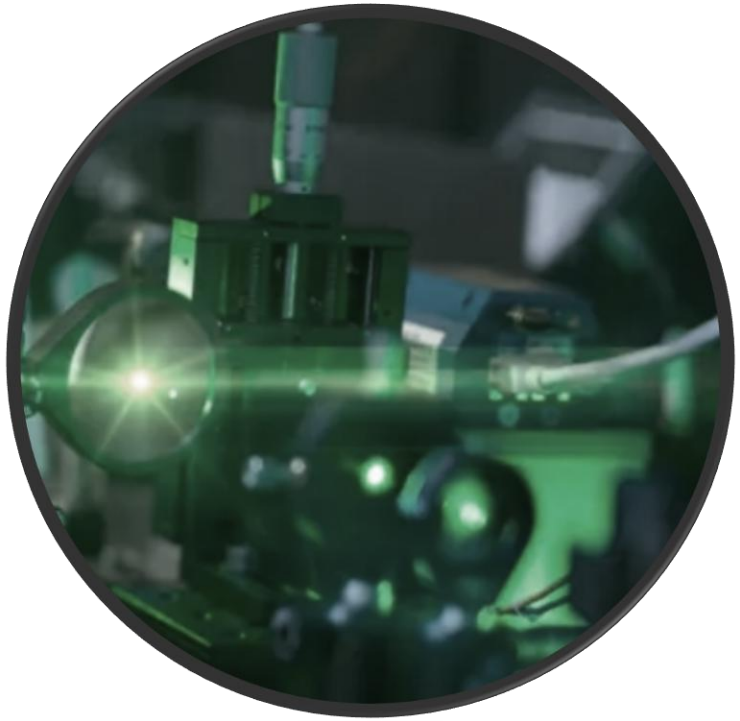


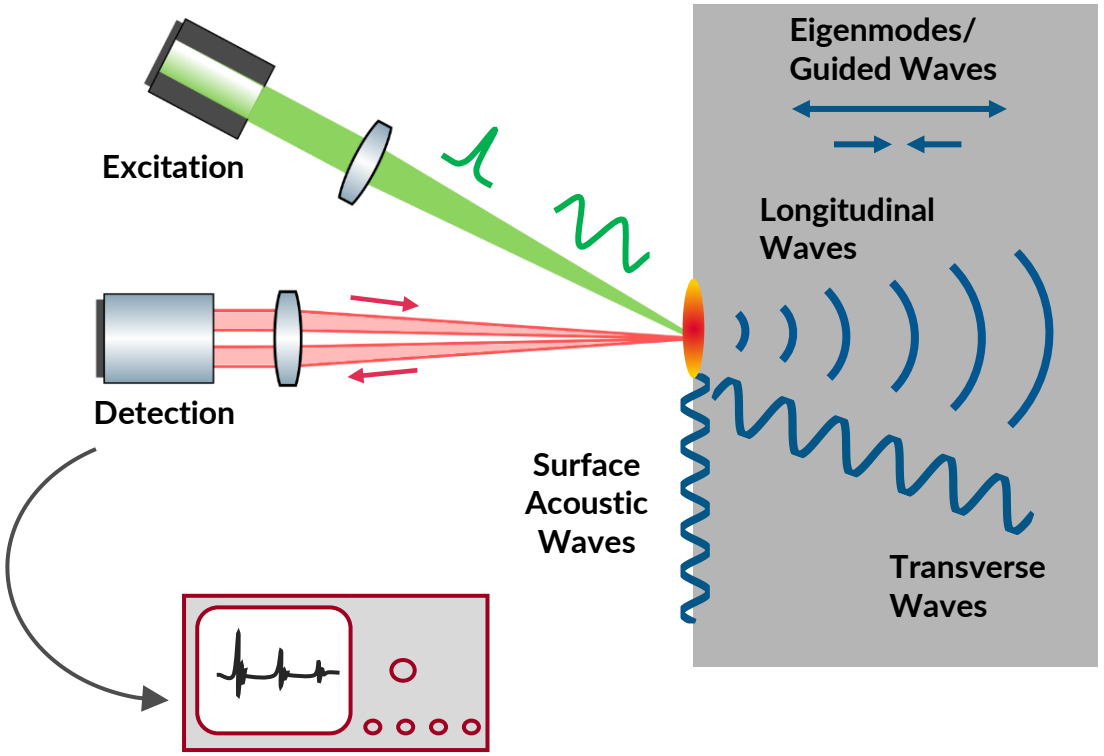
Laser Ultrasonics

One concept - many applications



Laser Ultrasonics – Working Principle

All optical excitation and readout of acoustic dynamics



Main steps in LUS methodology

- Absorption of laser irradiation
- Excitation of ultrasound/acoustic dynamics
- Acoustic interaction with sample or device
- Optical readout with second laser
- Interpretation of results / modelling

Basic Concepts

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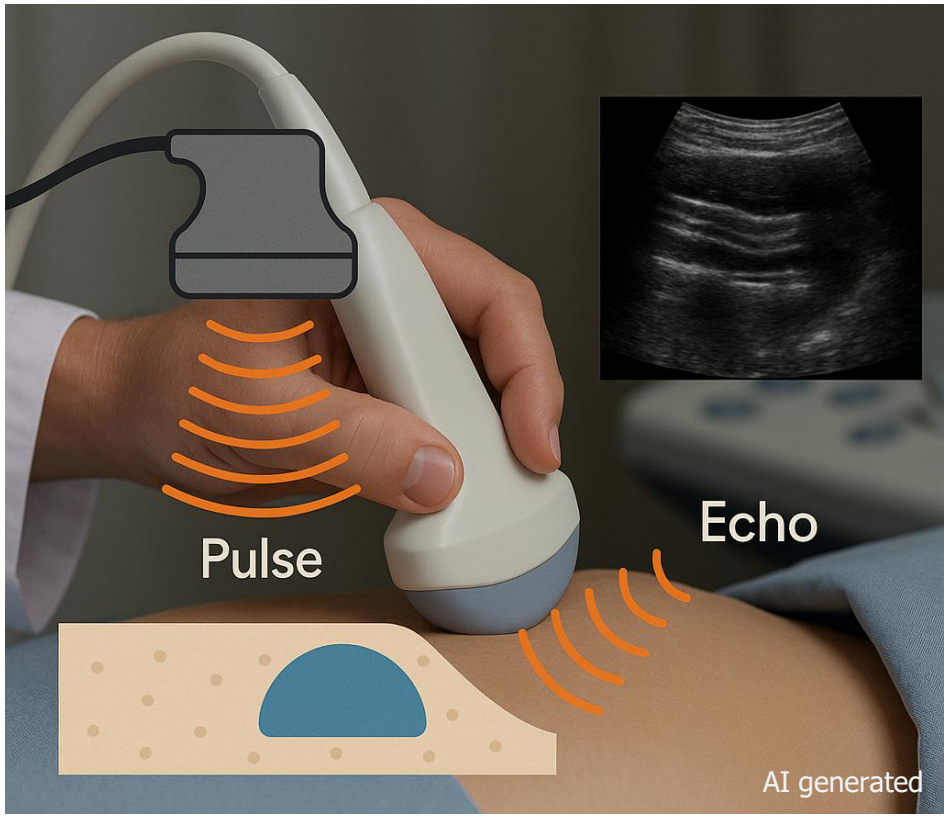
Resonances/Guided Waves

Clapper → Laser excitation

Pulse-Echo



Meters
Tens of centimeters

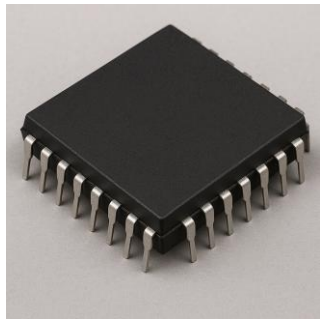
Centimeters
Millimeters

Micrometers
Nanometers

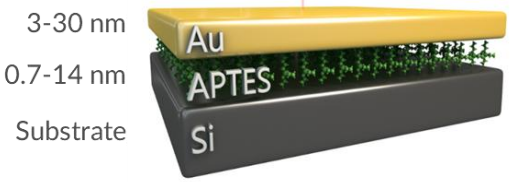
Laser ultrasonics covers a broad frequency range

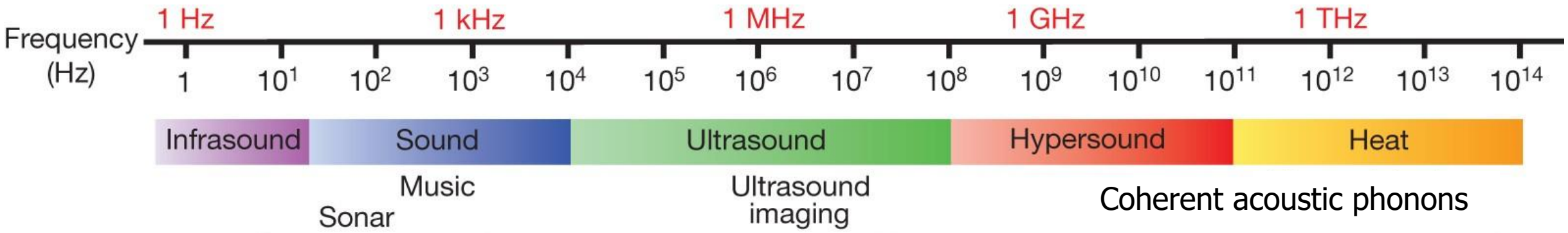
Steel industry

Packaging
Welding
Wafer-Bonding
Microstructure



Thin films/Multilayers
Micro-/Nanostructures

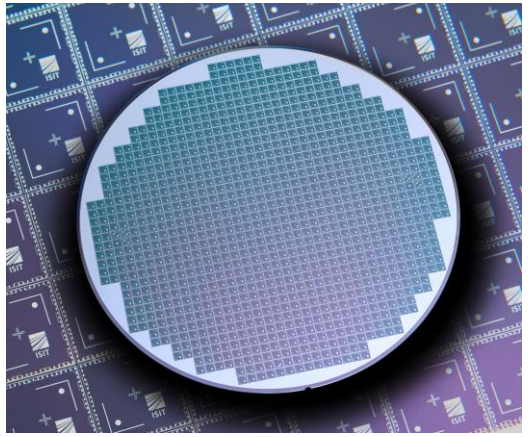




Adapted from: Maldovan, M. Sound and heat revolutions in phononics. *Nature* **503**, 209–217 (2013). https://doi.org/10.1038/nature12608

Laser Ultrasonics - Features

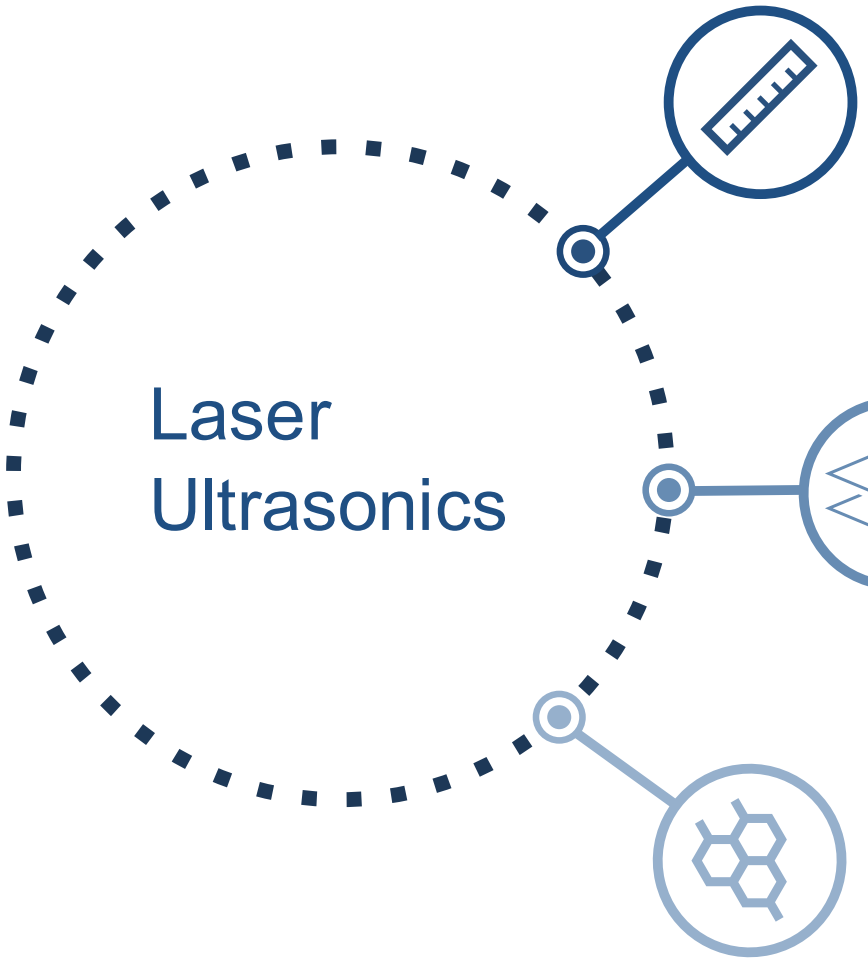
- All-optical excitation and detection
- Non-contact
- Non-destructive



Source: https://www.isit.fraunhofer.de/de/mikro-fertigungsverfahren/module-services/testwafer-substrate/silizium-wafer.html

- Lateral resolution sub-µm possible
- Axial resolution down to single nm

- In-situ/Inline capability
- Harsh environments



Structural/Elastic Characterization

Elastic/ Viscoelastic Properties
Adhesion
Acoustic Damping
Doping Profiles
Layer Thickness/ Periodicity
Internal/Residual Stresses
...

Defect Detection

Delamination
Voids
Cracks
...

Materials/Systems

Metals
Semiconductors
Polymers
Oxides
Shape Memory Alloys
Makro- Nanosystems
Thin films

Multilayers

Superlattices
(E.g. Bragg Mirrors)

Thin Film Metrology

Examples

Nuclear Fusion Target Inspection

Nuclear Fusion Target Inspection I

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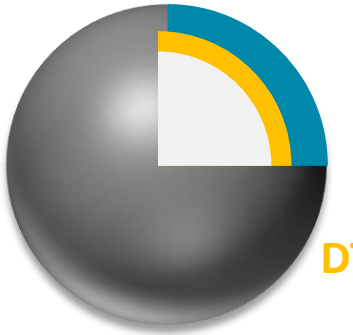
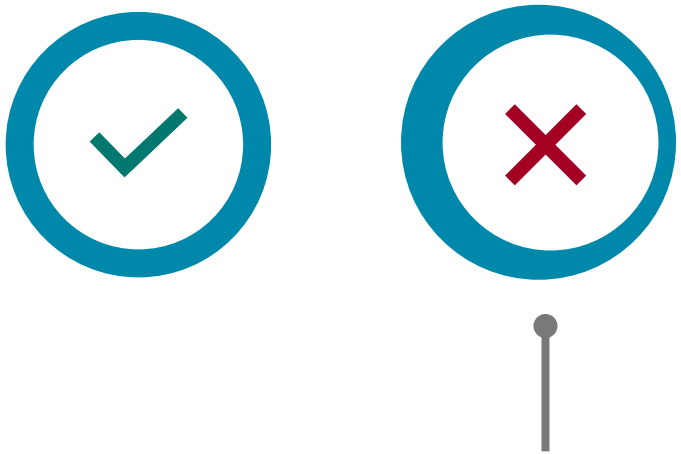
Inertial Confinement Fusion Target



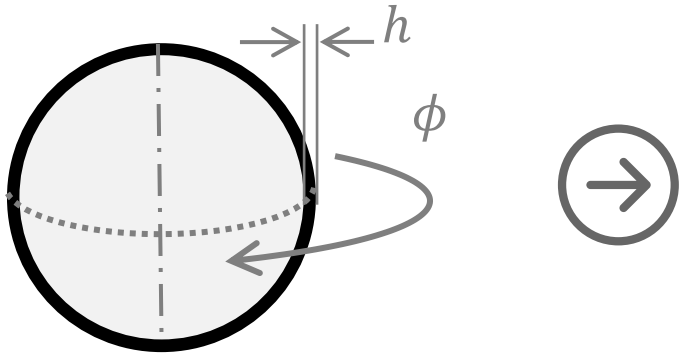
GENERAL ATOMICS

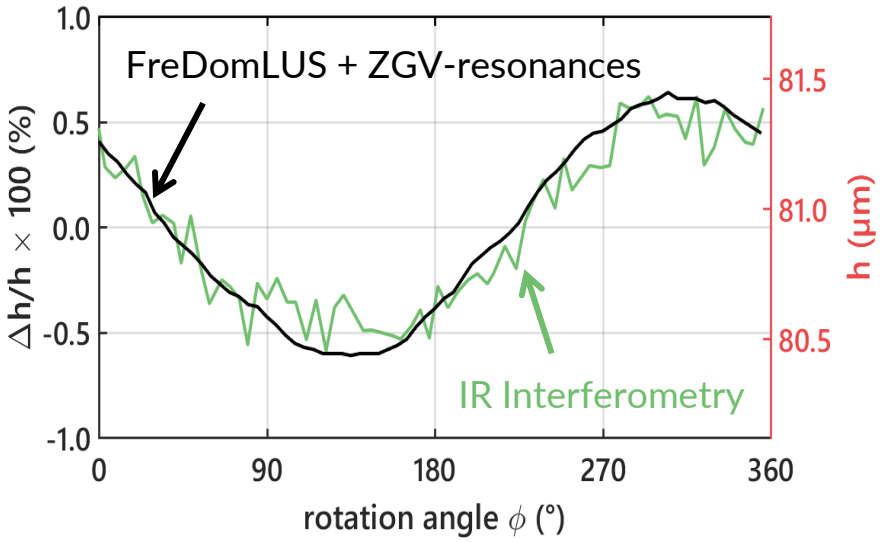
ISSUE
Non-uniform shell thickness
Optical testing not possible



Inefficient or no nuclear fusion

SOLUTION: Zero-Group Velocity Modes as local thickness measurement





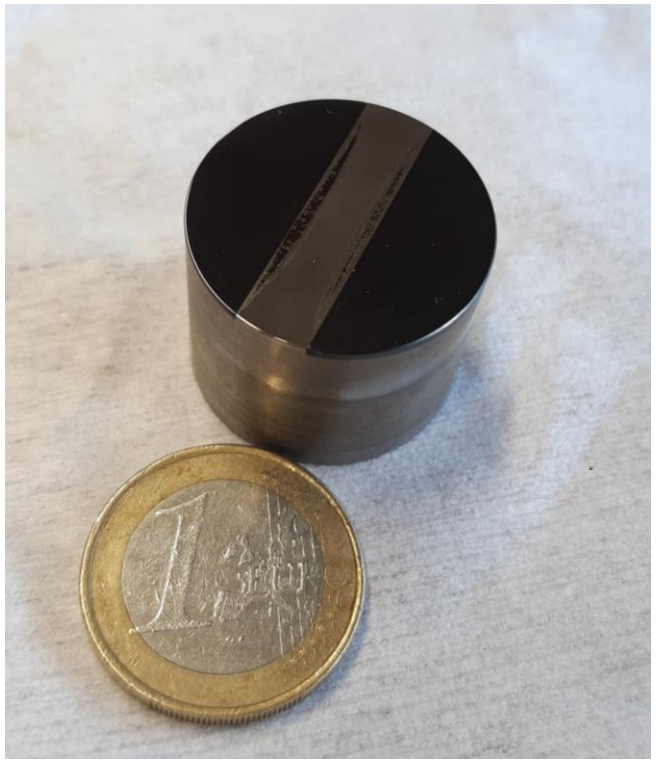
Currently integration into test devices

Austrian press articles

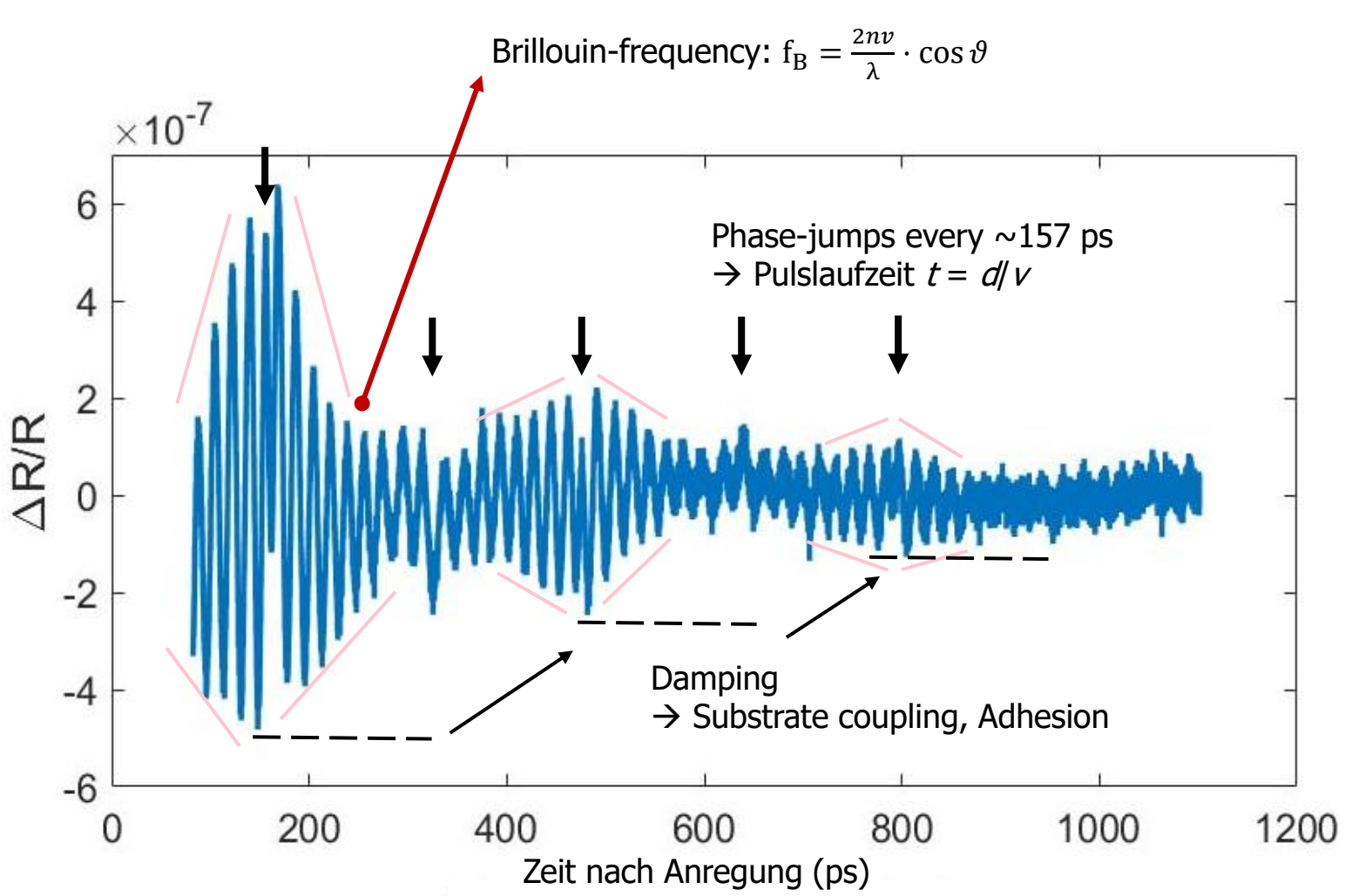
Yan, Guqi et.al.
Journal of Physics: Conference Series , Vol. 2966, No. 1, online 31.03.2025 (7th Int. Symposium on Laser Ultrasonics and Advanced Sensing (LU2024), Oct. 2024, Nanjing, China), IOP Publishing, DOI: 10.1088/1742-6596/2966/1/012007

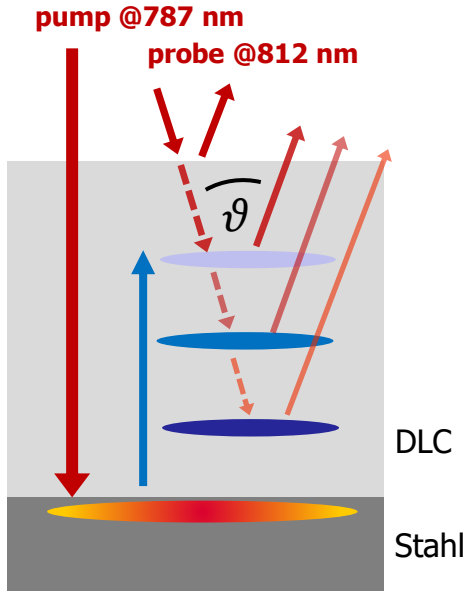
Micronlayers and 3D-structures

Diamond Like Carbon



Signal and Interpretation: Ultrafast Opto-Acoustics

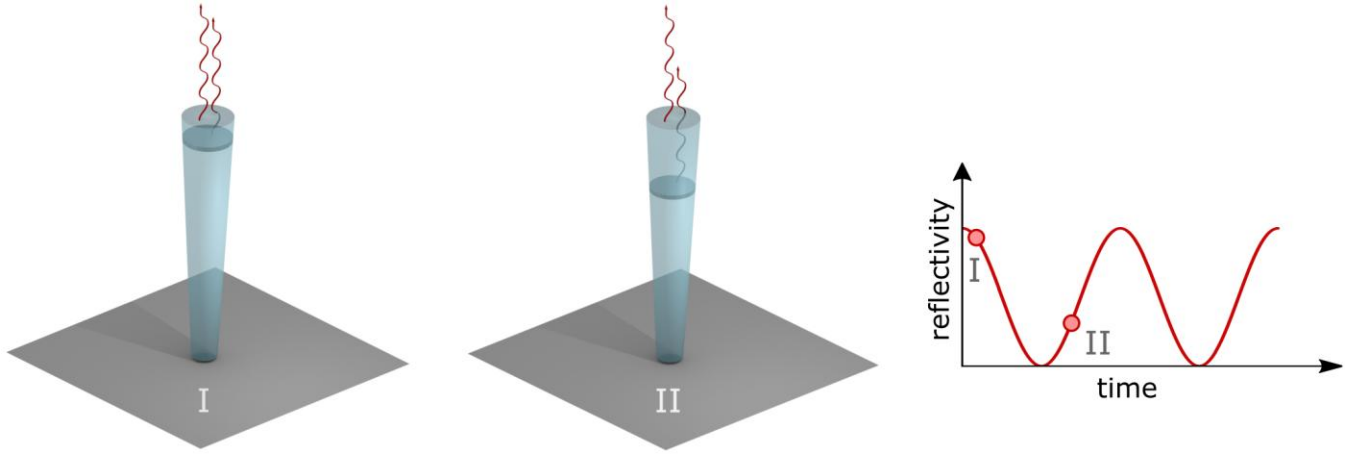


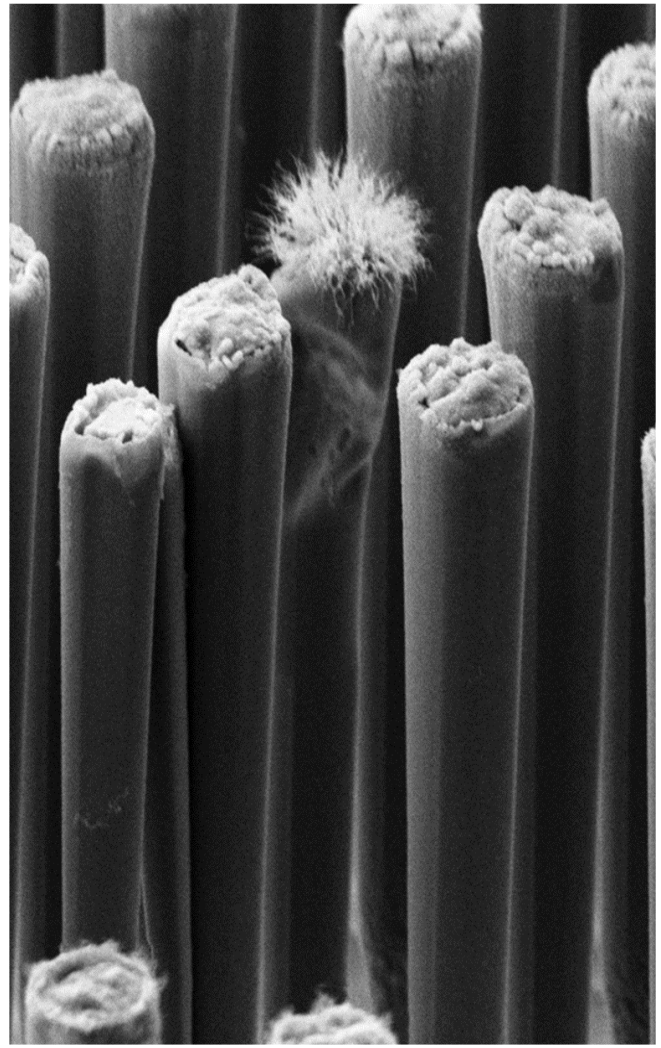


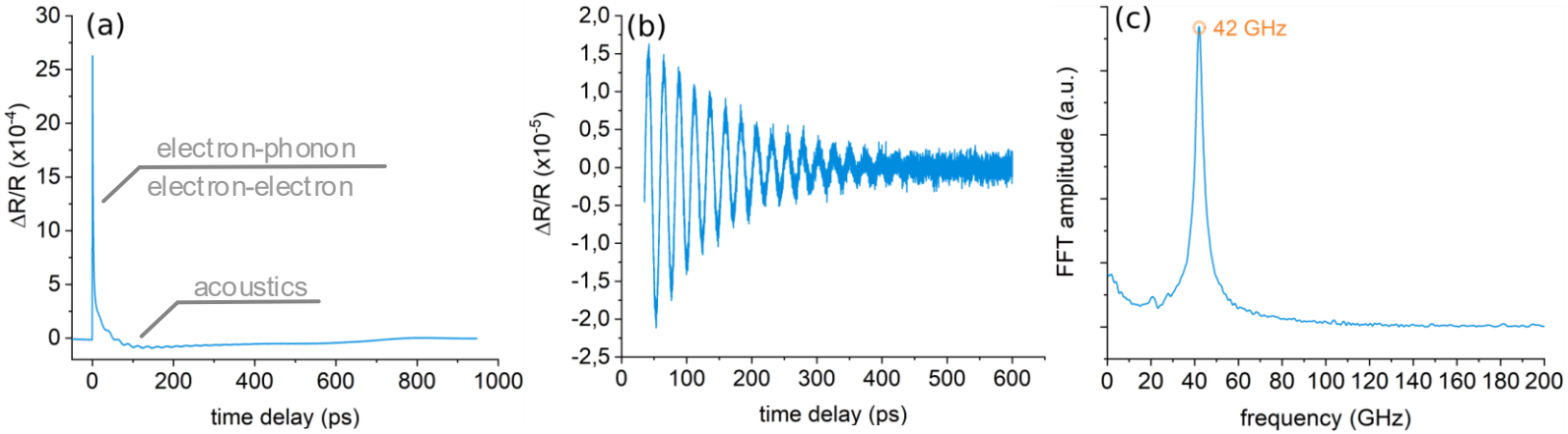
Time-resolved Brillouin scattering

- Optical absorption and pulse generation in steel substrate
- Phase jumps in signal when pulse traverses interface or surface
- Interface sensitivity through acoustic reflection coefficient

Looking into Micromechanical Resonators

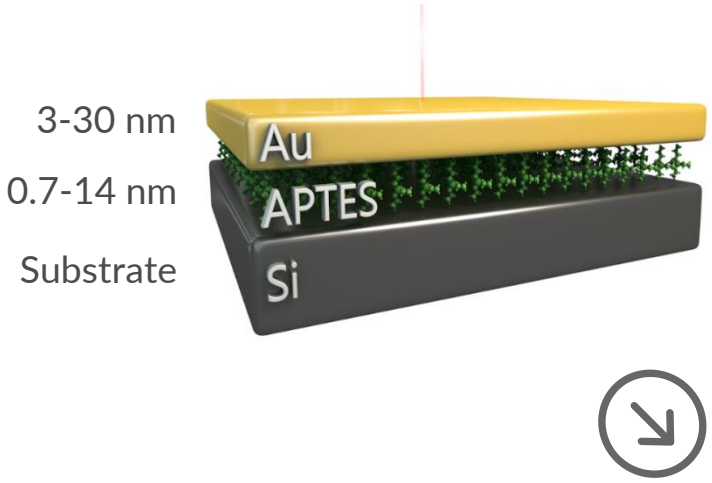




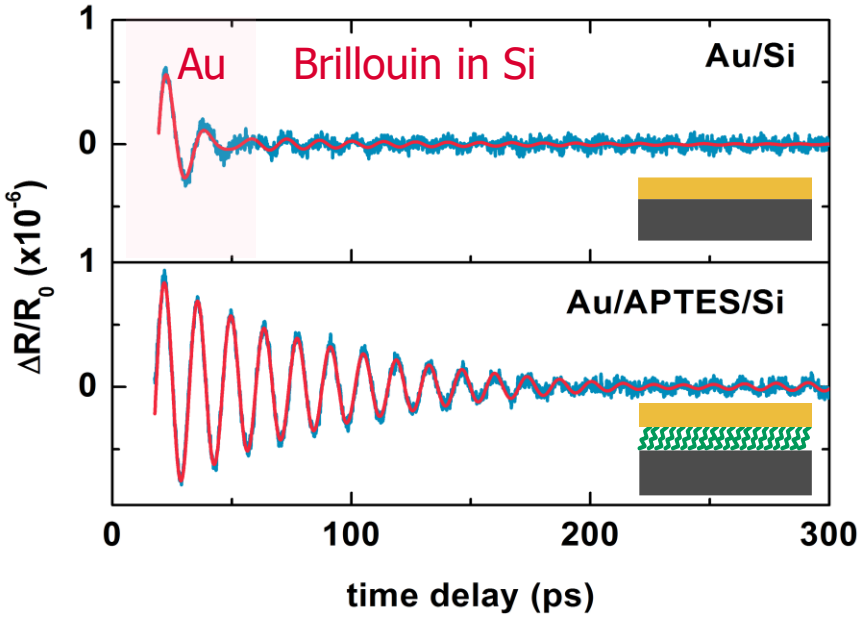


Detected signal on pillar → Acoustic component → Frequency spectrum

Nanolayers

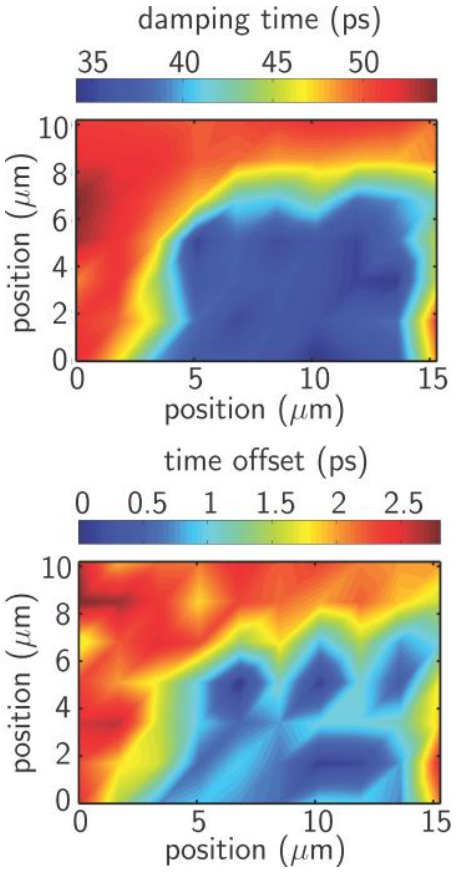


Acoustic Eigenmodes and Lifetime



Structuring the APTES layer

Subsurface Imaging



M. Hettich et al., *Appl. Phys. Lett.* **98**, 261908 (2011)

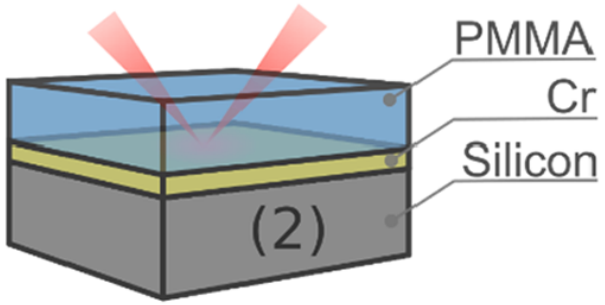
M. Hettich et al., *Appl. Phys. Lett.* **101**, 191606 (2012)

M. Hettich et al., *Scientific Reports* **6**, 33471 (2016)

Ultrathin Polymers – Thickness and Glass Transition

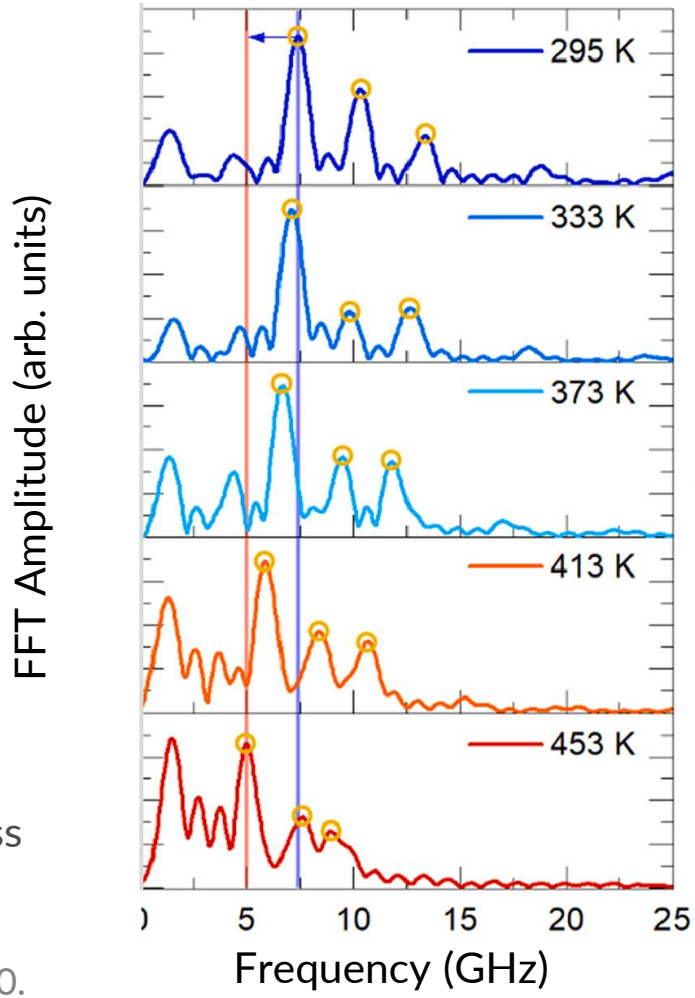
Source: https://external-content.duckduckgo.com/iu/?u=https%3A%2F%2Fruggedstandard.com%2Fwp-content%2Fuploads%2F2018%2F11%2Fmid-shot-man-charming-smile-ironing-how-to-iron-a-dress-shirt-ss-FEATURE-.jpg&f=1&nofb=1&ipt=36aaf72d47a8646fe7efea1dacd3e1a023c552e6bd29ce4c1738df64b68930cb

Ultrathin Polymers – Thickness and Glass Transition

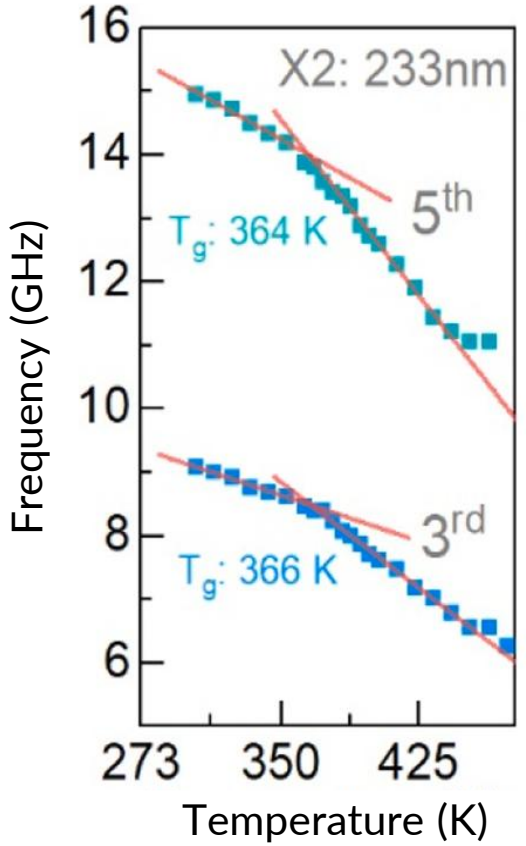


PMMA-
Eigenmodes

Temperature
Dependence



Glass-Transition



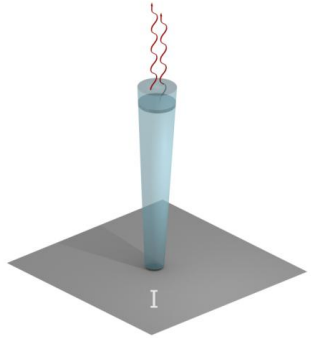
Glass-transition-temperature and thickness measurement in 30-500nm PMMA films

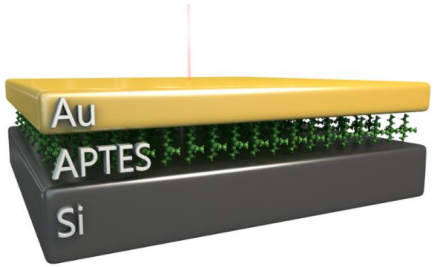
Brick, Delia, et al., *Ultrasonics* **119** (2022): 106630.

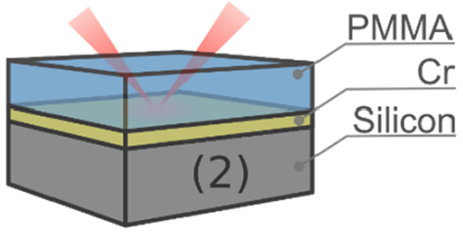
Take Home Message

Laser Ultrasonics - Picosecond Ultrasonics

- A powerful tool for non-destructive and non-contact metrology of thin films, nano- und microstructures, nanoparticles
- Subsurface information accessible with optical lateral resolution down to the sub-µm regime and nm- axial resolution
- Interface sensitive, Adhesion, Film thickness, Doping
- Can in principle be applied during film growth (not demonstrated yet)







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Questions?