The potential of laser ultrasound for sustainability in metal production and processing

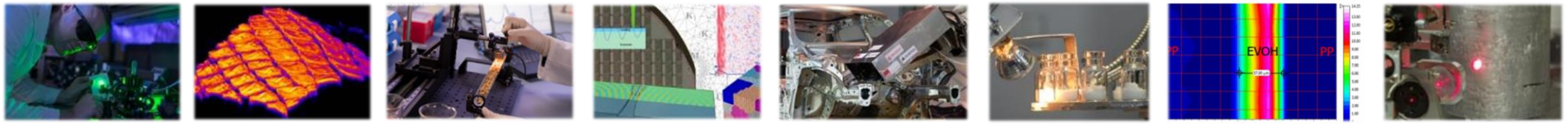
5th International Workshop on Laser-Ultrasound for Metals

5-6 May 2022, Gif-sur-Yvette, France

Dr. Edgar Scherleitner – Area Manager Acoustics

RECENDT
RESEARCH CENTER NON DESTRUCTIVE TESTING

Member of UAR INNOVATION NETWORK

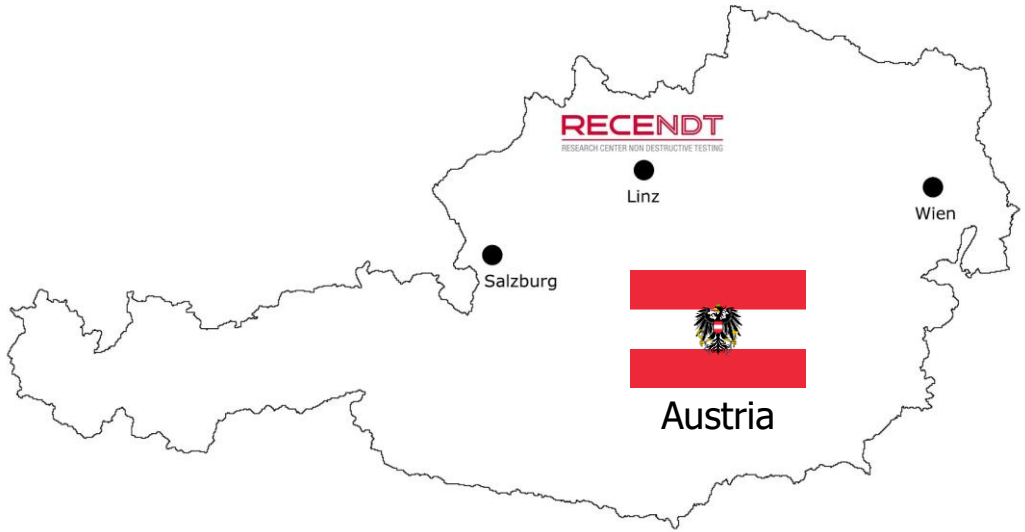


Overview

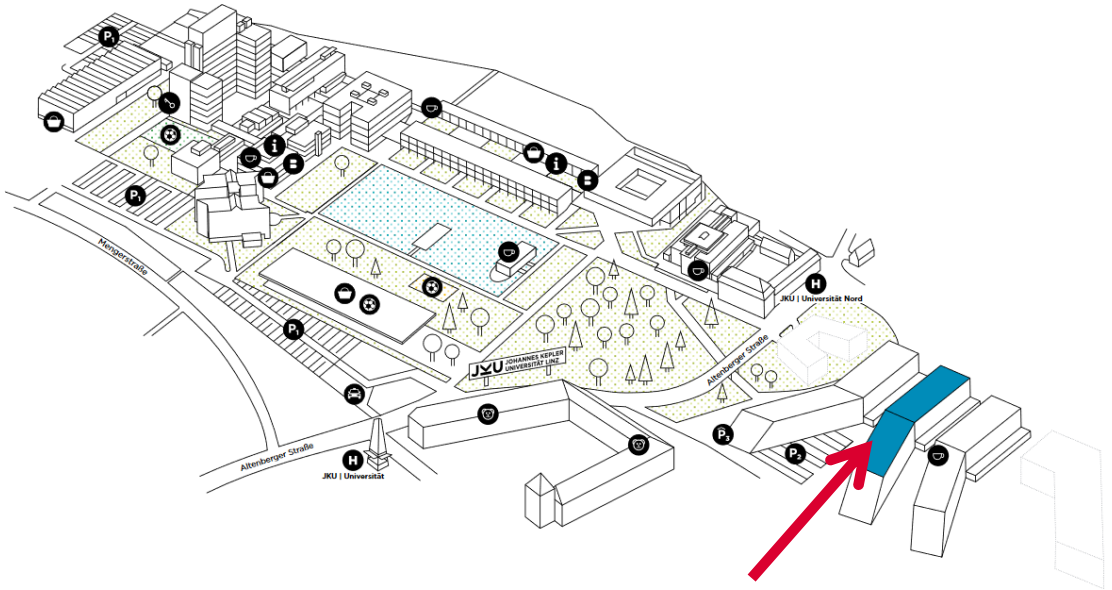
RECENDT
RESEARCH CENTER NON DESTRUCTIVE TESTING

1. Introduction of RECENDT
2. Green deal and arising needs for steel production
3. Contribution of LUS to challenges of steel production
4. Quality assurance in steel processing by LUS

Location of RECENDT



RECENDT: located at JKU
in Science Park 2



SP2, 2. OG

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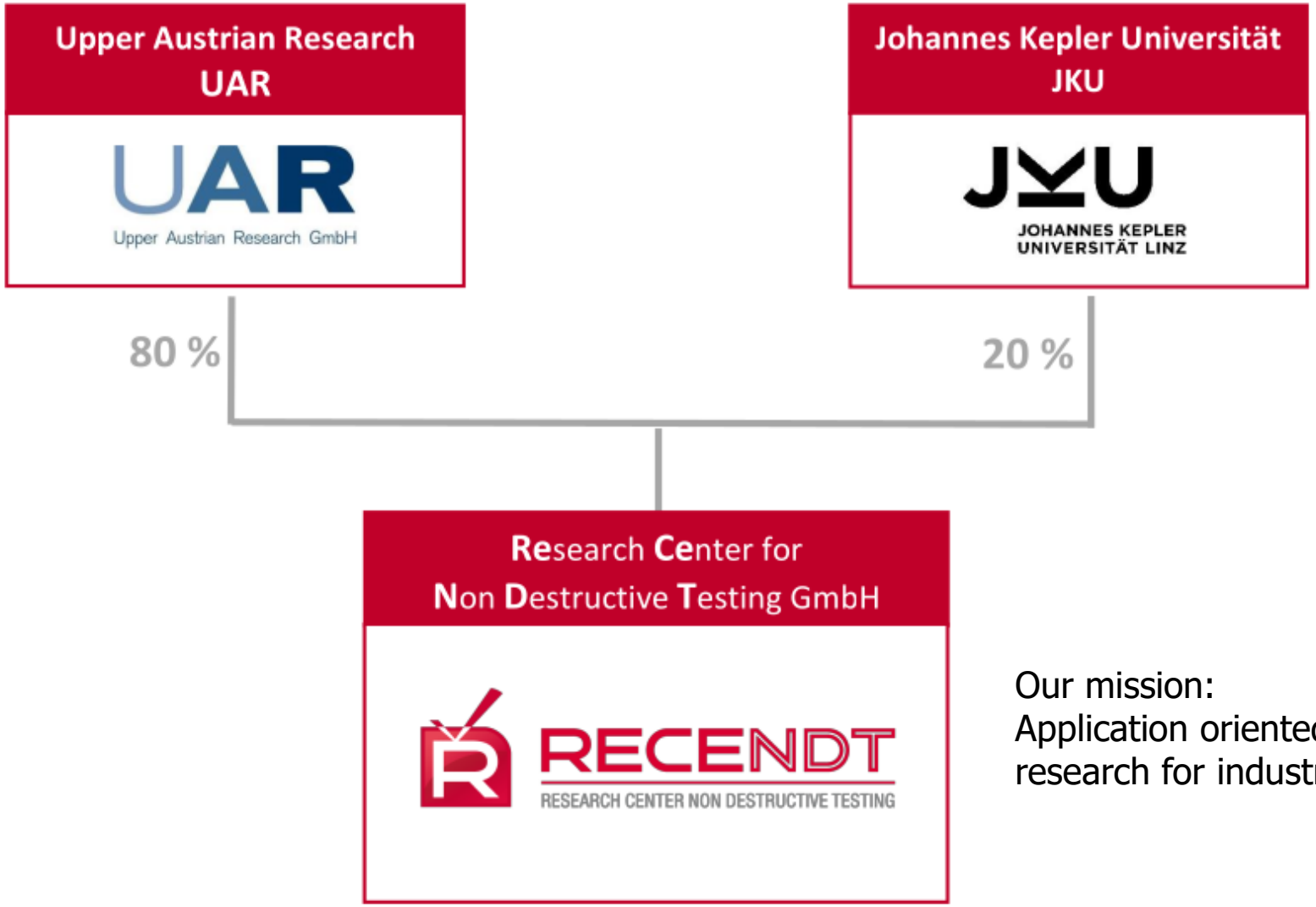
E-Mail: office@recendt.at
Web: https://www.recendt.at

RECENDT: **RE**search **CE**nter for **NDT**



Our mission:
Application oriented (fundamental) research for industry.

Research groups at RECENDT

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Area Acoustics

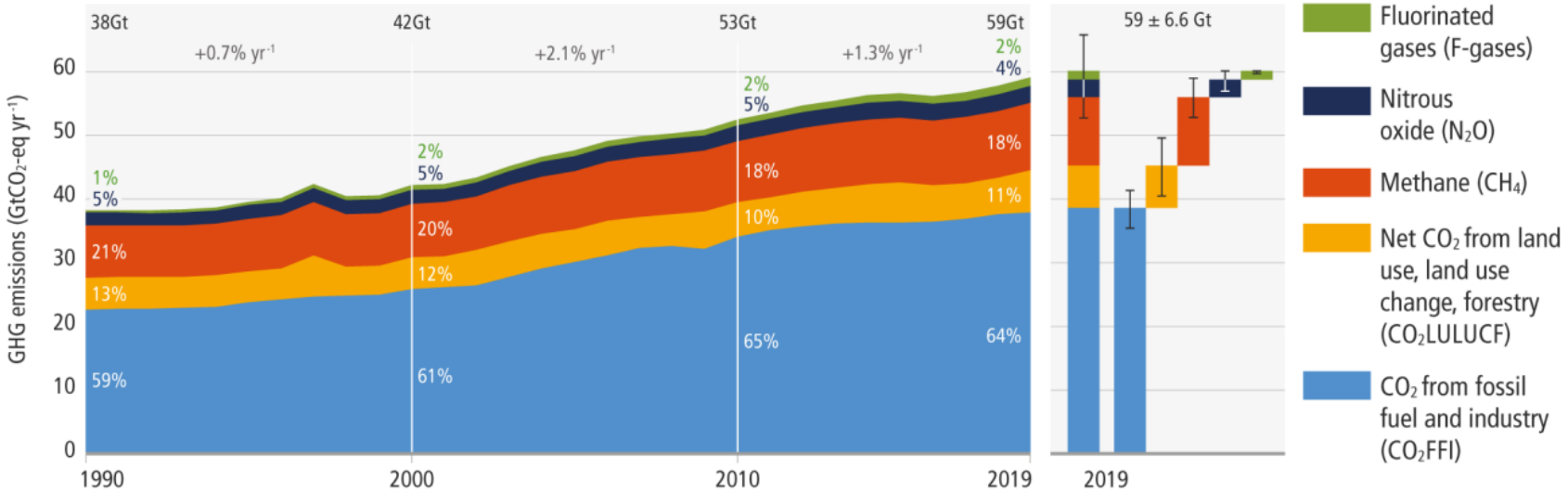
- **Laser Ultrasound (LUS)**
  Laser induced ultrasound for defect detection and material characterization, prototype development, automation, robotics, laser development, piezo ultrasound, acoustic emission
- **Physical and Computational Acoustics (PCA)**
  Investigation of elastic wave phenomena, modelling, simulation, experimental techniques, medical ultrasound, photoacoustic and photothermal reconstruction

Area Optics

- **Infrared- and Raman Spectroscopy (IR)**
  Method for in-line process control and quality assurance like analysis of chemical compositions
- **Terahertz Technology (THz)**
  Technology for penetrating imaging and spectroscopy of non-conductive materials
- **Optical Coherence Tomography (OCT)**
  Technology for high-resolution imaging of non-conductive materials

European Green Deal: climate neutral by 2050!

Global net anthropogenic GHG emissions 1990-2019



<2°C!

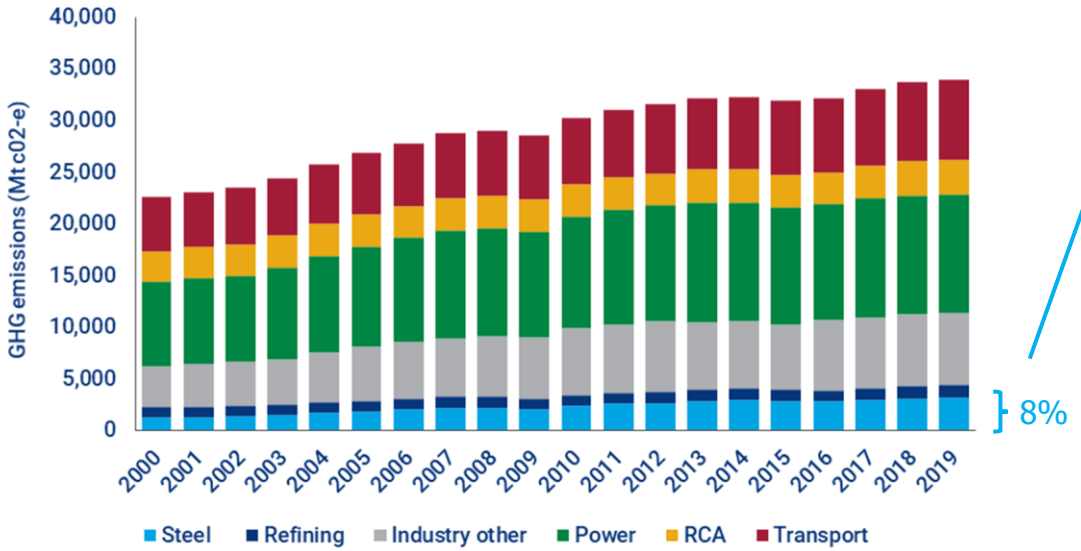
Paris Agreement:

Next step: reduce emissions by at least 55% by 2030 from 1990 levels.

Source: Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) 2022
https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_FullReport.pdf

European Green Deal: climate neutral by 2050!

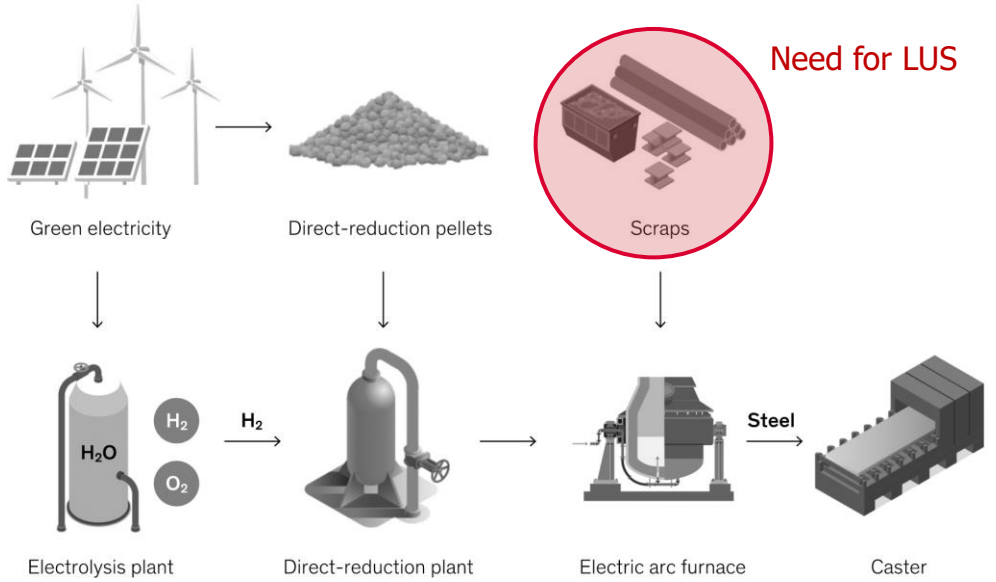
CO_2 emissions share by sectors



Source: Wood Mackenzie

Source: Wood Mackenzie
https://www.woodmac.com/news/opinion/is-green-hydrogen-metallurgical-coals-kryptonite

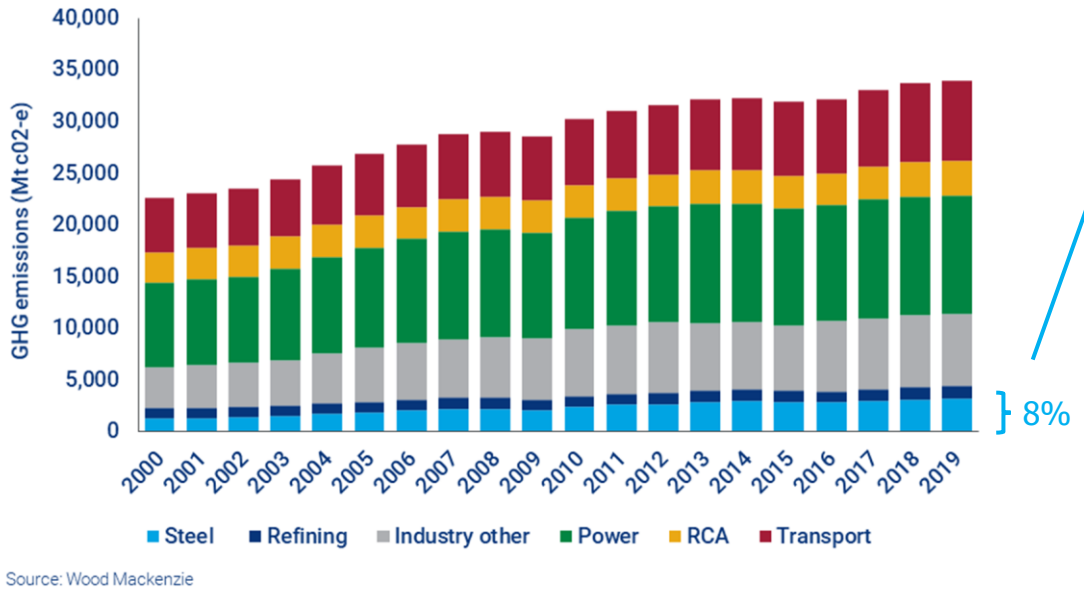
Steel production: H2-based + increased scrap usage



Source: McKinsey
https://www.mckinsey.com/industries/metals-and-mining/our-insights/tackling-the-challenge-of-decarbonizing-steelmaking

European Green Deal: climate neutral by 2050!

CO_2 emissions share by sectors

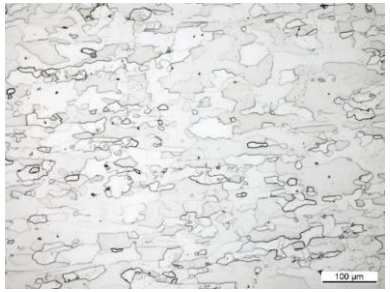


Source: Wood Mackenzie

Steel processing: QA in early process steps

Need for LUS

- Characterization of microstructure, elastic properties
- Detection of defects in materials and joints



Source: Wood Mackenzie
https://www.woodmac.com/news/opinion/is-green-hydrogen-metallurgical-coals-kryptonite

Contribution of LUS to challenges of steel production

Contribution of LUS to challenges of steel production

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Example in Austria:
- 15% (12 Mt) of all CO_2 emissions by one single steel producer - voestalpine

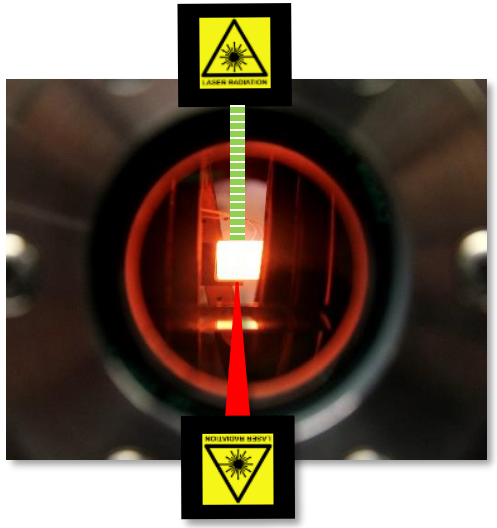
Goals:
- 2030: reduce CO_2 emissions of 30%
- 2050: Climate neutral steel production

Major needs:
- Transformation to H2 usage and more recycled scrap

Challenge by scrap addition:
- Undesirable elements brought in which influence steel properties

Source: voestalpine https://www.facebook.com/voestalpine/

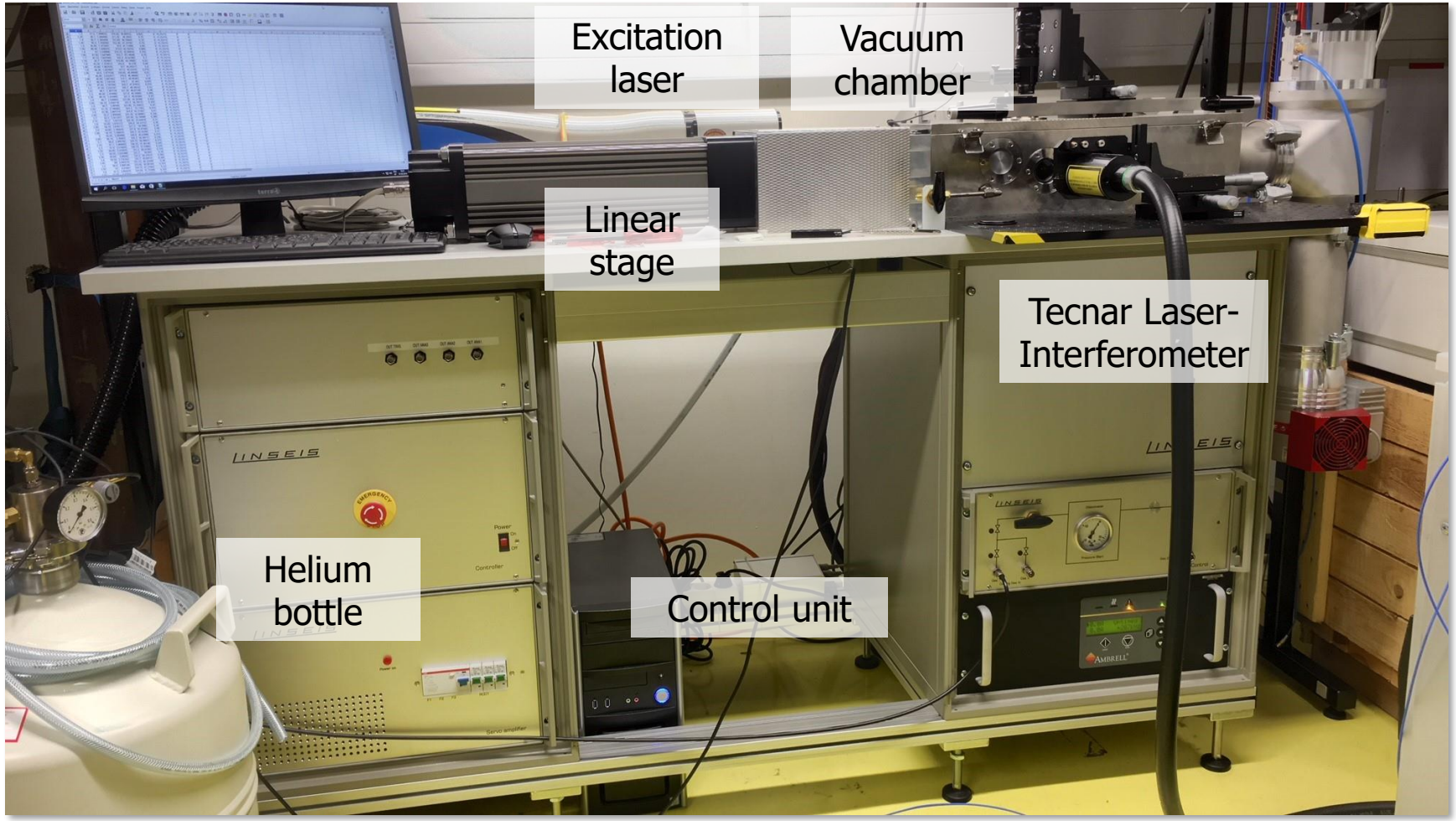
Increasing importance of LUS:
- High-throughput in-situ methods possible
- Correlations between LUS data and
  - phase transformations/fractions
  - grain size distribution/growth
  - texture and recrystallization kinetics



Extend in-situ LUS-methods to accompany the steel production!

LUS to support tuning of thermal treatment cycles

Dilatometer as thermal simulator combined with laser ultrasonic equipment used at RECENDT



Based on LINSEIS DIL/L78 Rita:

- ✓ Flexible system
- ✓ Small footprint
- ✓ Typ. heating rate: ≤2500K/s
- ✓ Deformation force: ≤25kN
- ✓ Deformation rate: ≤125mm/s

LUS to support tuning of thermal treatment cycles

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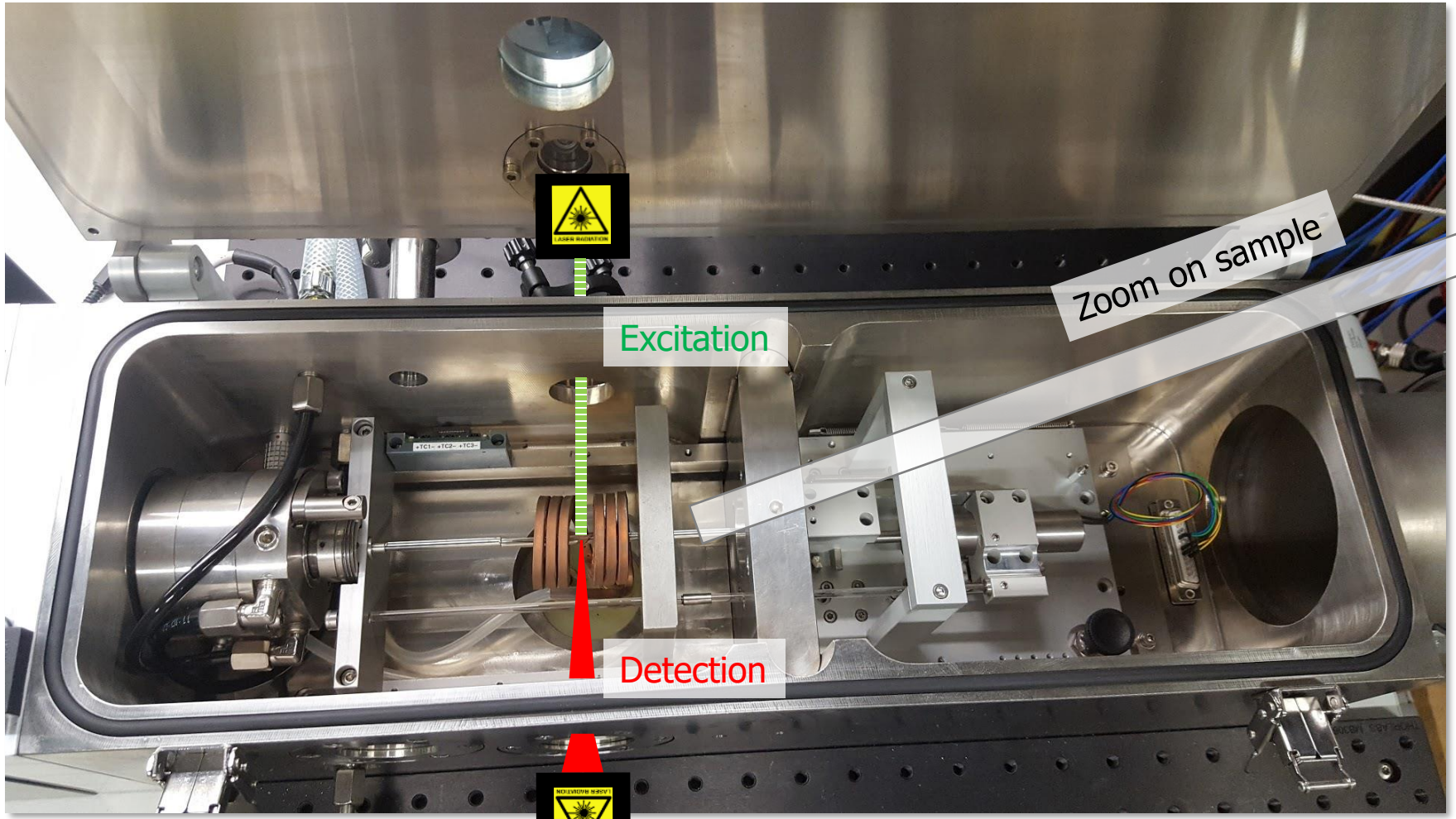
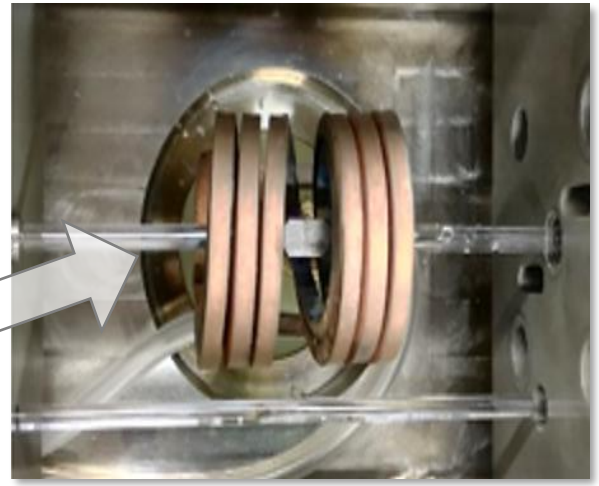
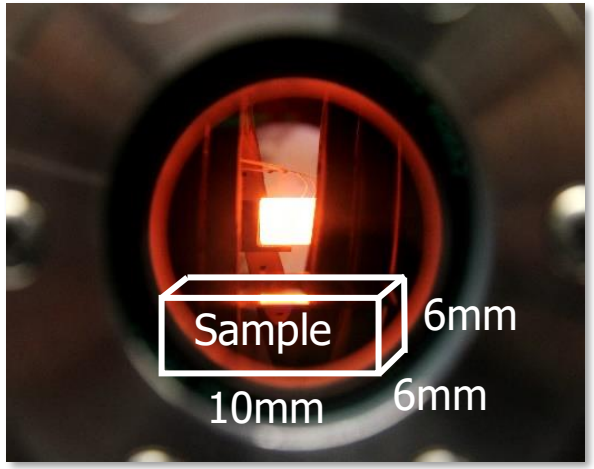
Vacuum chamber with inductive coil providing laser access for cuboid samples



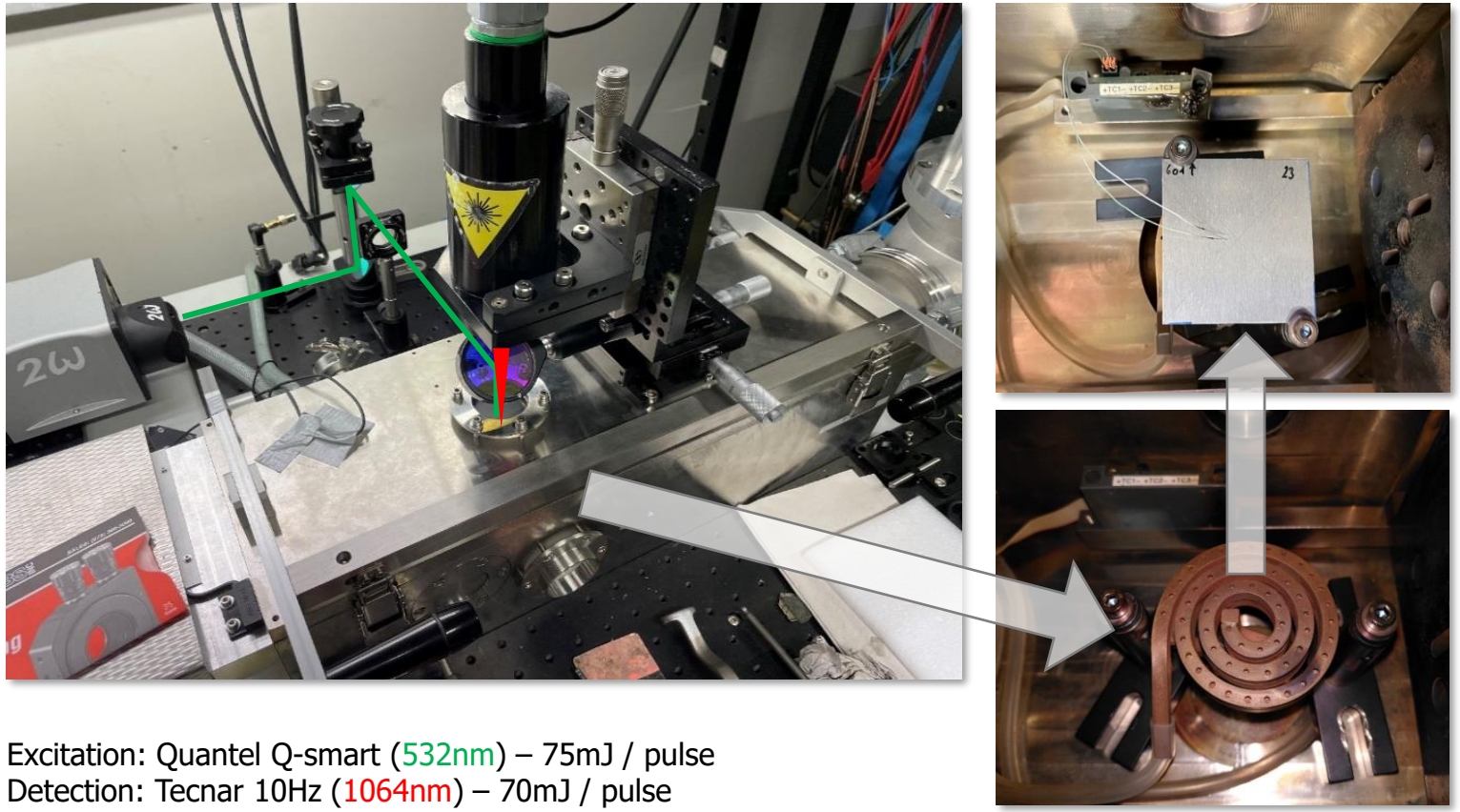




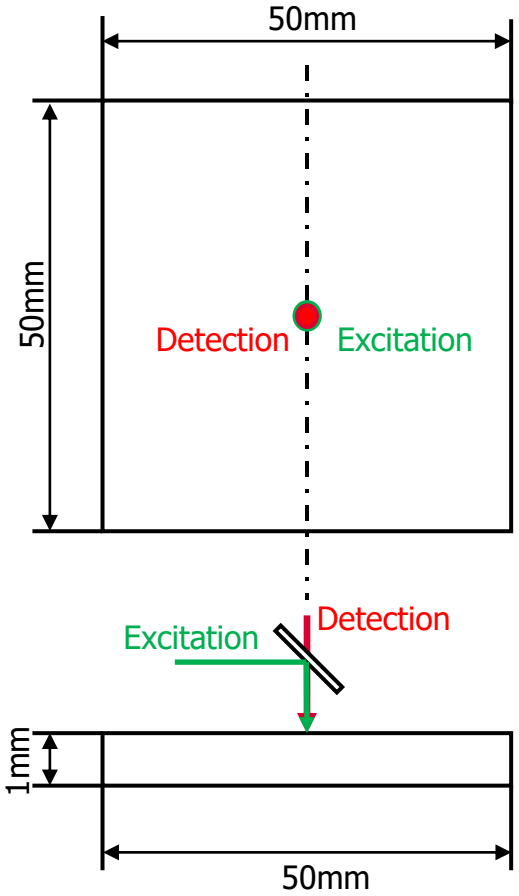
German patent: „Vorrichtung Und Verfahren Zur Bestimmung Elastischer Eigenschaften Und/Oder von Gefügezuständen von Proben." DE102017216714

LUS to support tuning of thermal treatment cycles

Sheet steel samples are heated by flat coil and monitored from top



Excitation: Quantel Q-smart (532nm) – 75mJ / pulse
Detection: Tecnar 10Hz (1064nm) – 70mJ / pulse



Modelling of useful correlations

Of metallurgical interest:

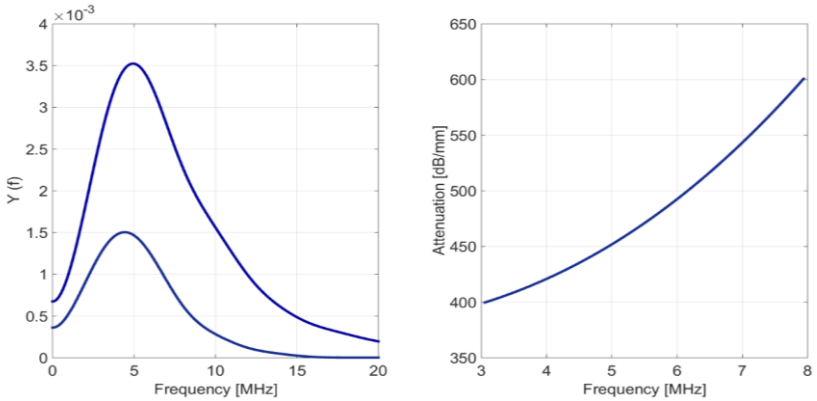
- phase transformations/fractions
- grain size distribution/growth
- recrystallization kinetics

Influence on LUS propagation:

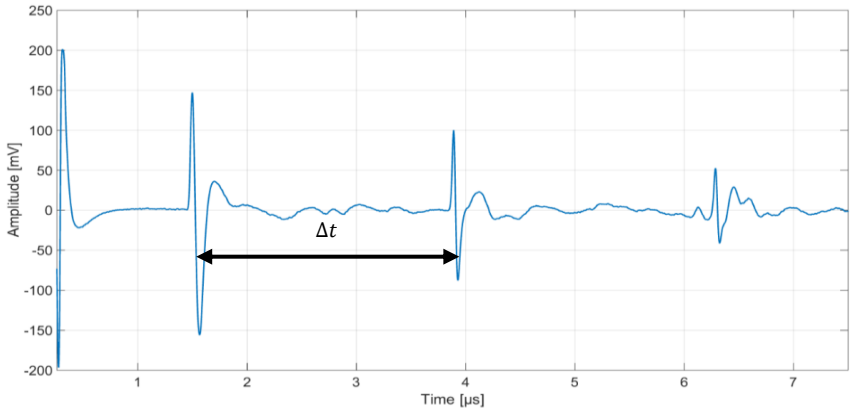
- elastic parameters, density, sample geometry
- grain size distribution
- grain morphology
- crystallographic orientation distribution
- others: precipitations, impurities, defects,…

Models use:

ultrasonic attenuation



speed of sound

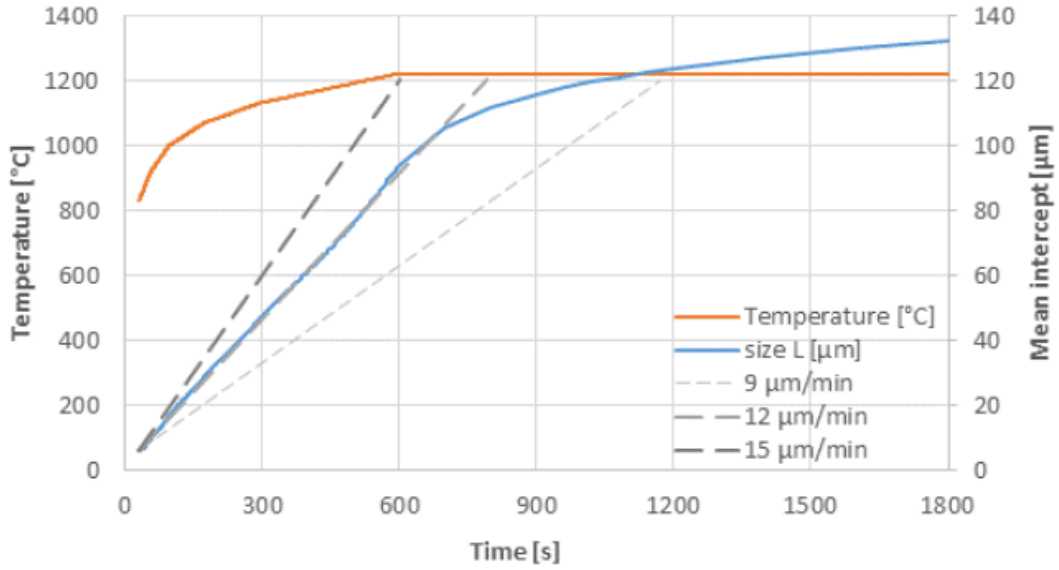


Austenite grain growth

Austenite grain growth

Experiment:

- Plain Carbon Steel 1.1191 (C45, AISI 1045)
- Expected average grain diameter from 5 to 120 µm



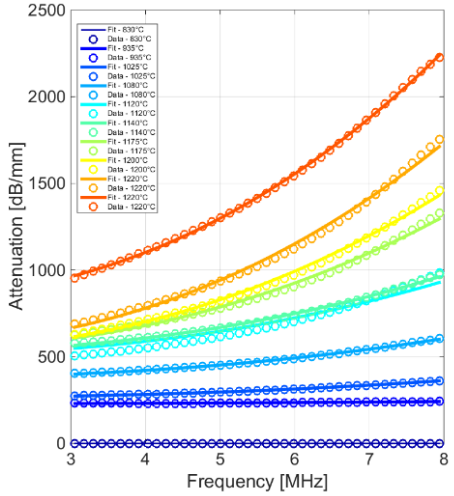
Proceeding:

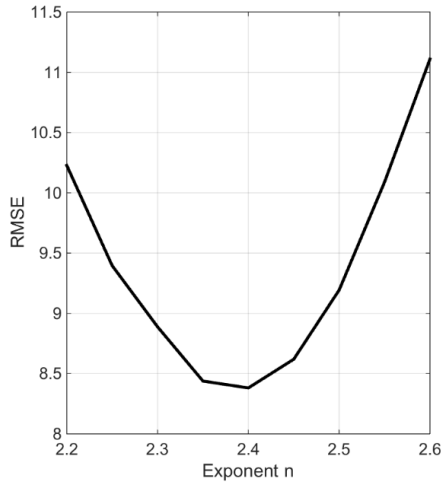
1. $\Delta\alpha' = a + b\, f^n$

Ref: S. Sakar, A. Moreau, M. Militzer, W.J. Poole, Metallurgical and Materials Transactions, 39, 4, pp. 897-907, 2008

2. Guess $n \in [2,4]$
3. Get b from fit of attenuation at calibration points
4. Calculate error of grain size $D_i = \sqrt[n-1]{\frac{b}{c} + D_0^{n-1}}$
5. Go to 2.

Ref: C. Kerschbaummayr, M. Ryzy, B. Reitinger, M. Hettich, J. Džugan, T. Wydra, E. Scherleitner, ASME Proc., QNDE 2021



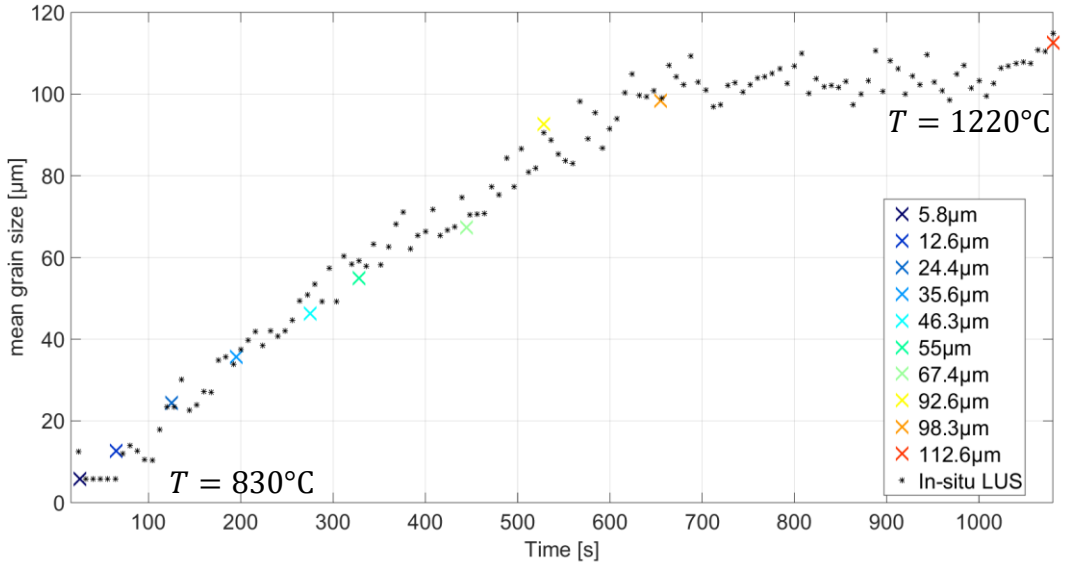


Optimum
$n = 2.34$

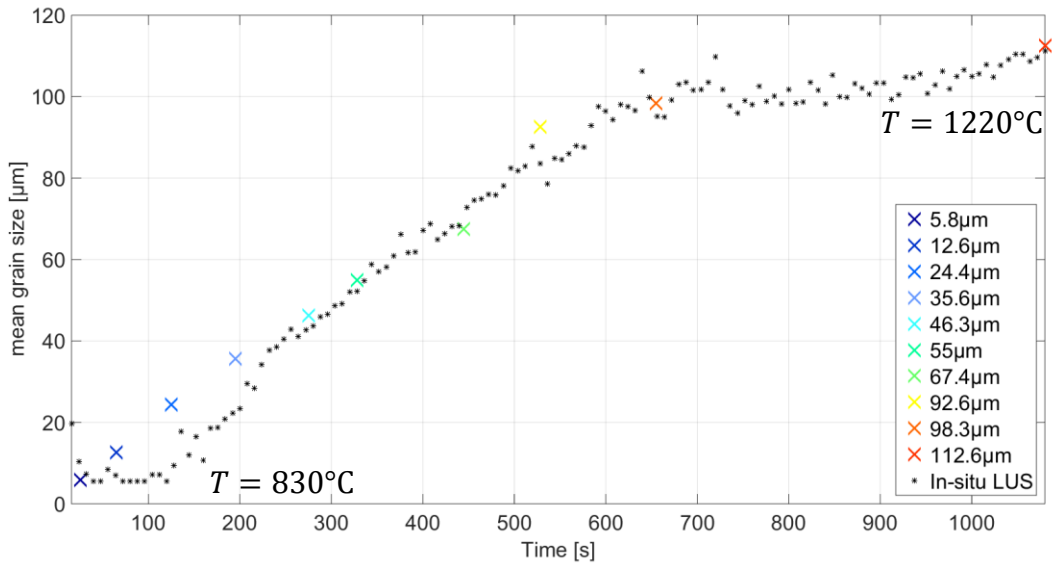
Austenite grain growth

Verification:

Sample Nr. 6

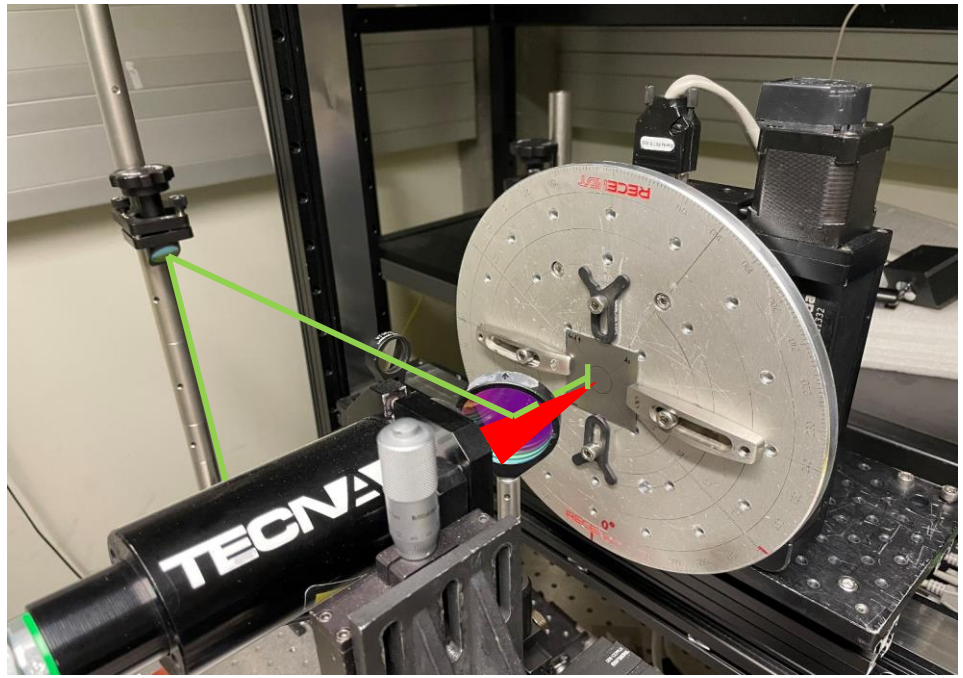


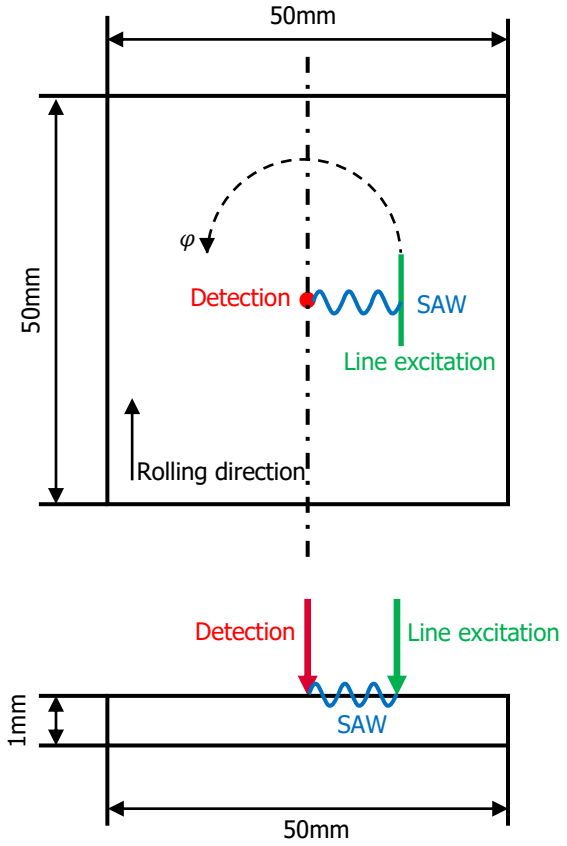
Sample Nr. 7



Recrystallization

Rotational setup (ex-situ):





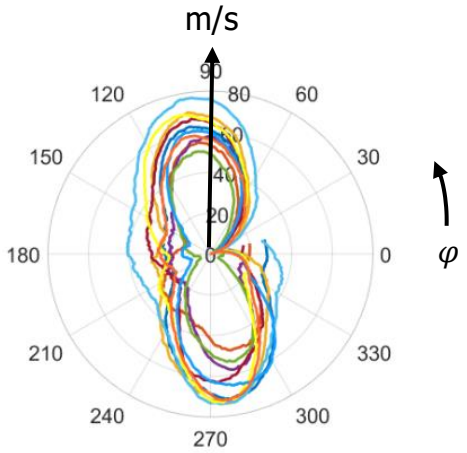
Line excitation for more directed SAW

Anisotropy of cold rolled/annealed sheet steel

Initial condition:

0s

LUS measurements

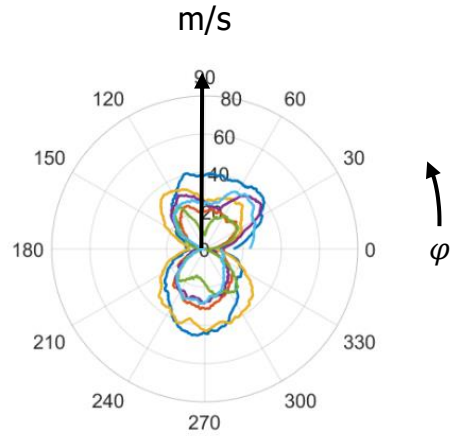


Strong anisotropy

Annealed:

200s

LUS measurements



Reduced anisotropy

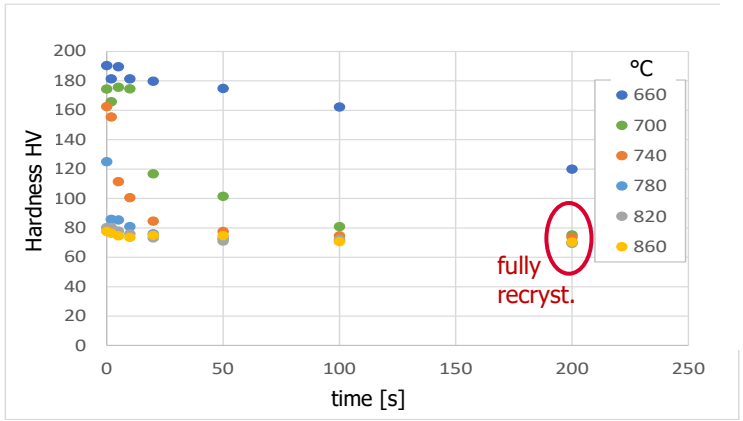
Recrystallization of cold rolled sheet steel

Initial condition / annealed:

0s

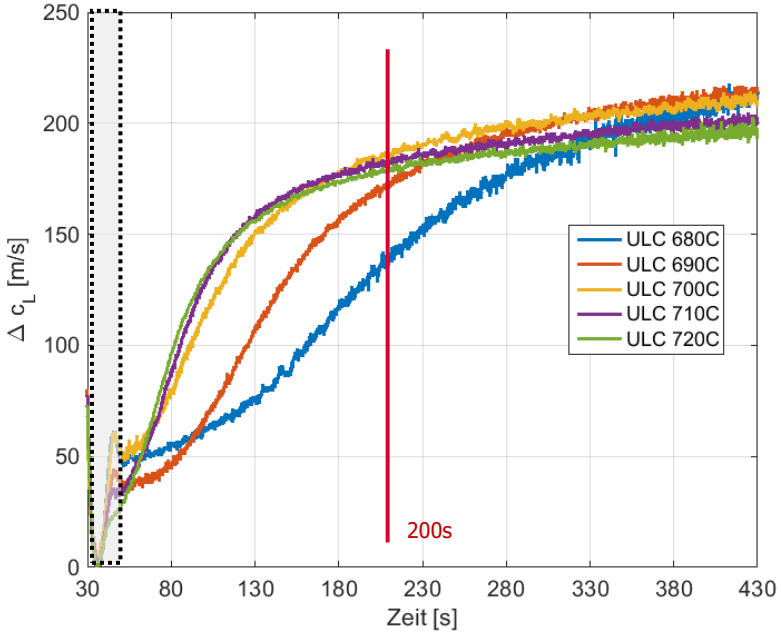
200s

Hardness measurement as reference

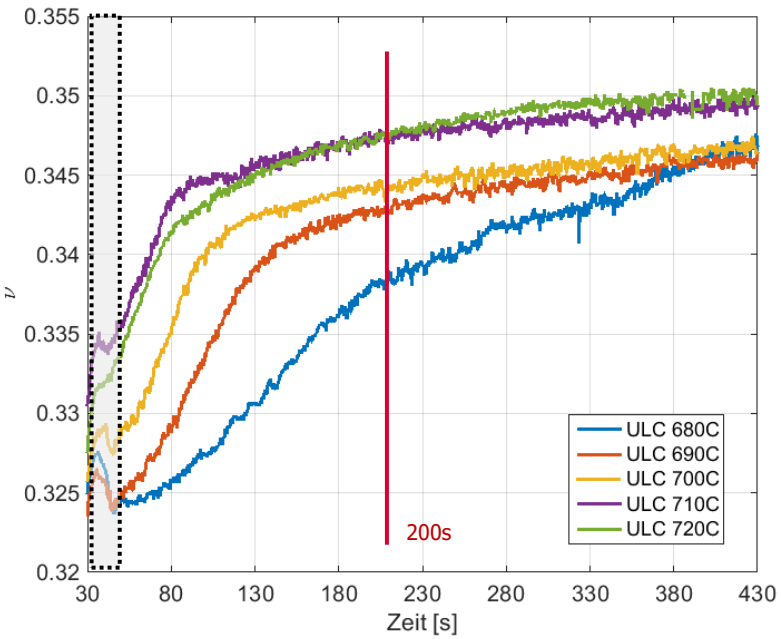


LUS measurements

Longitudinal speed of sound



Estimation of Poisson-Ratio

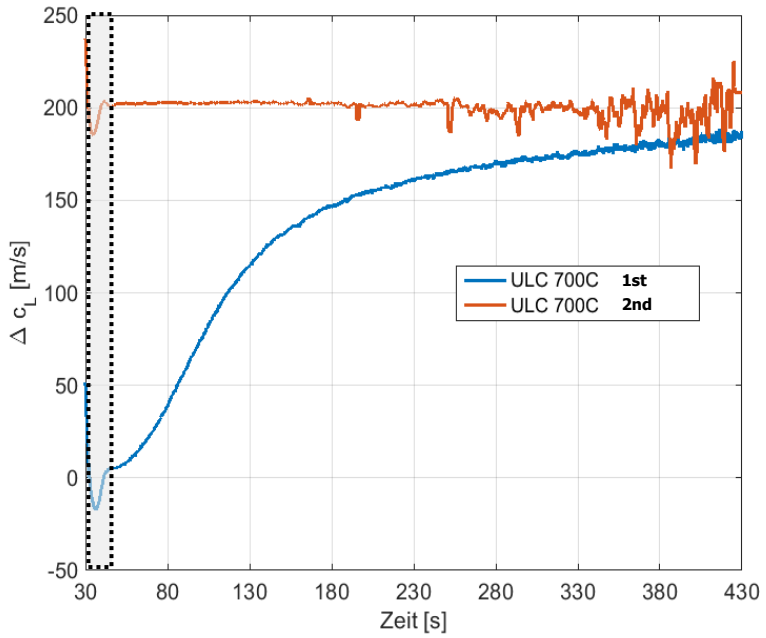


Recrystallization of cold rolled sheet steel

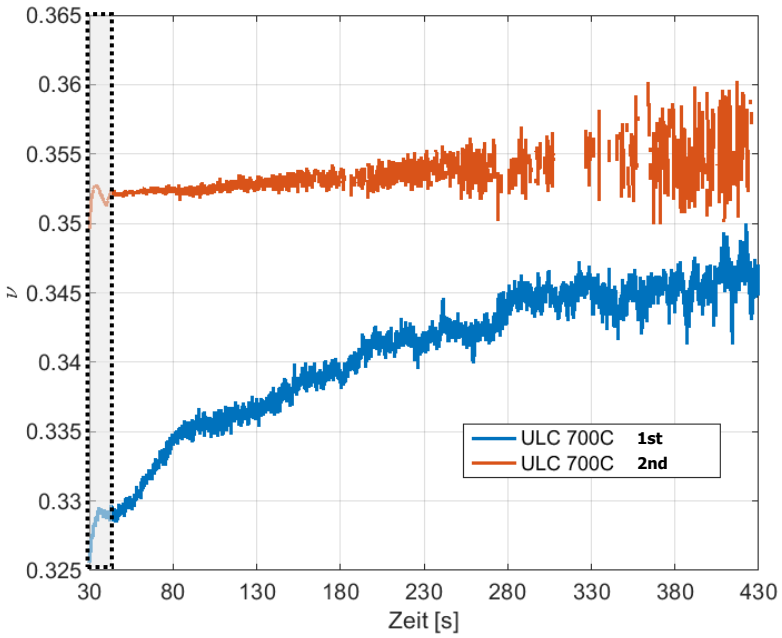
Validity check by comparison of LUS measurement before and after annealing on same sample:

LUS measurements

Relative longitudinal speed of sound



Estimation of Poissonzahl

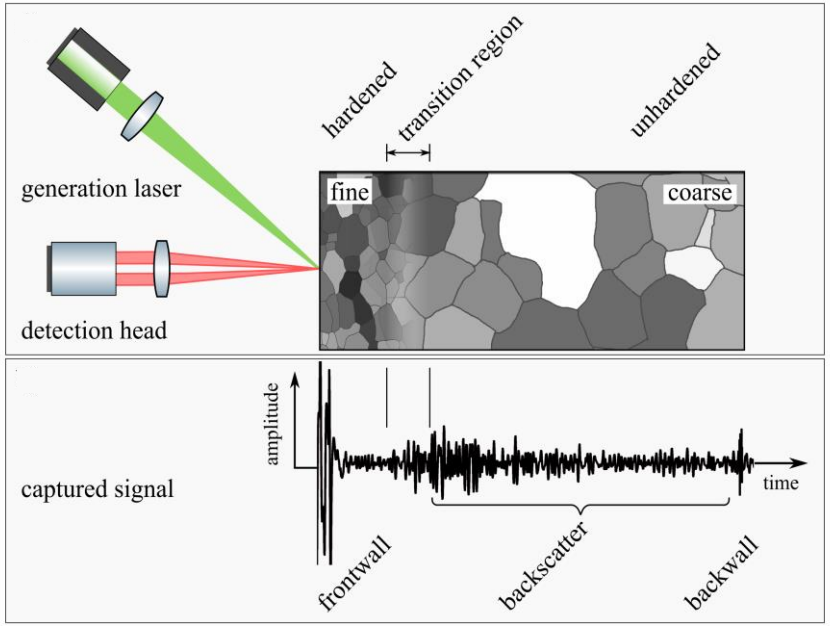


As expected:
2nd run on same sample shows only little change during annealing.

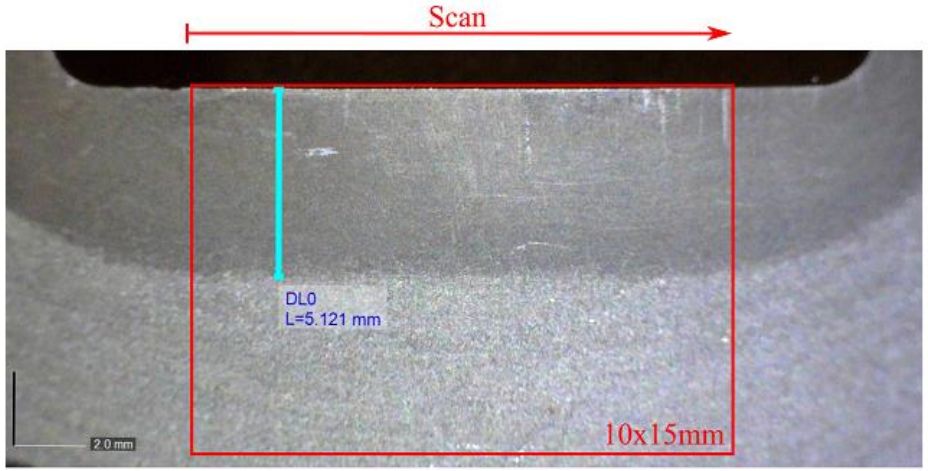
Quality assurance in steel processing by LUS (only small excerpt)

Imaging of hardness penetration depth

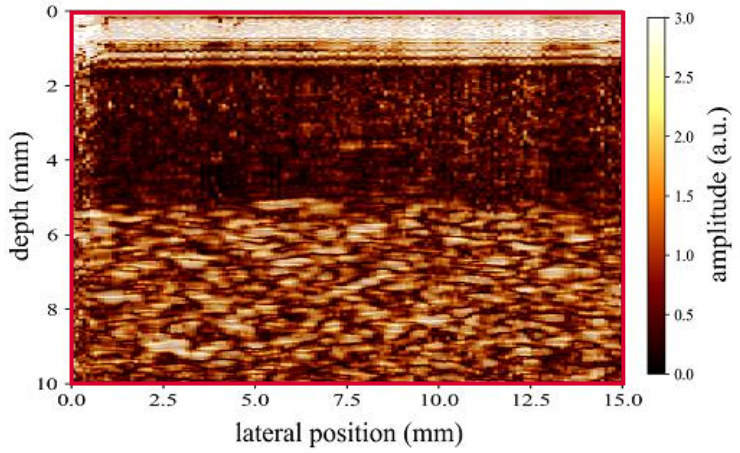
Induction hardened steel parts are scanned by LUS



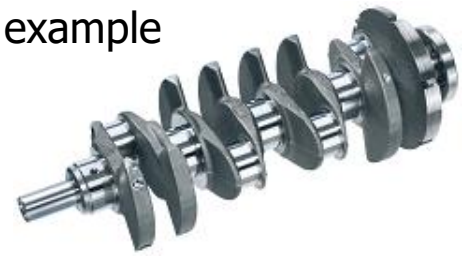
Micrograph:



LUS measurement:



For example



Defect detection in welded joints

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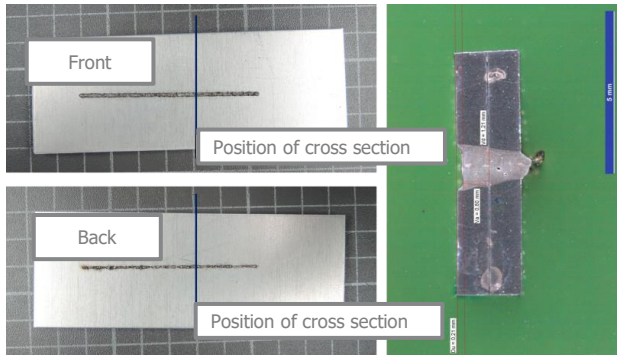
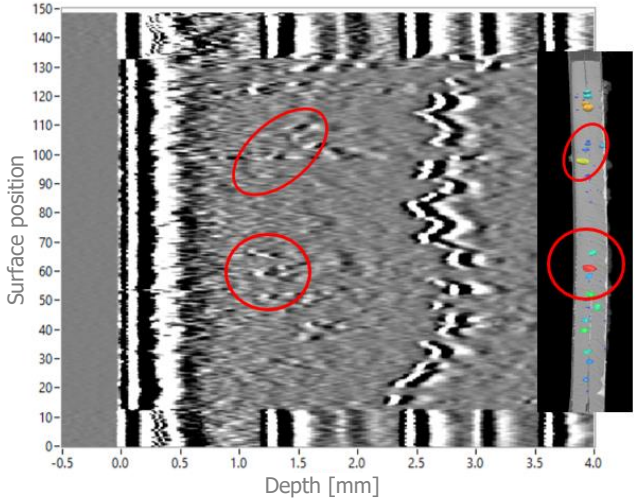
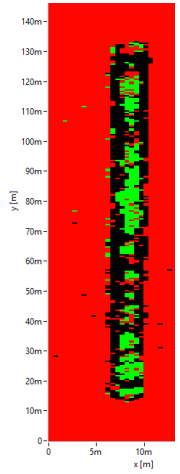
Step weld seams

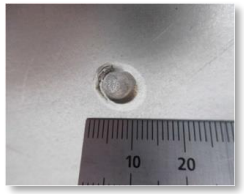


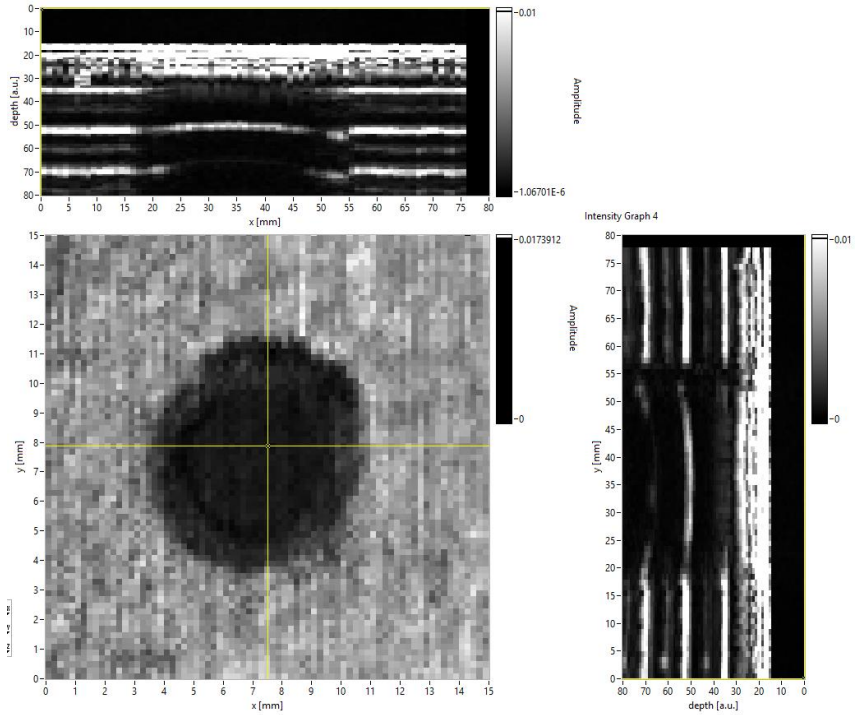




LUS B-scan X-ray scan LUS C-scan

Spot welds



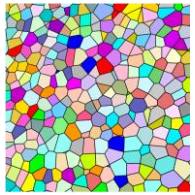


Tomographic display of LUS-scan

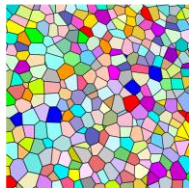
Research of phenomena also by simulations

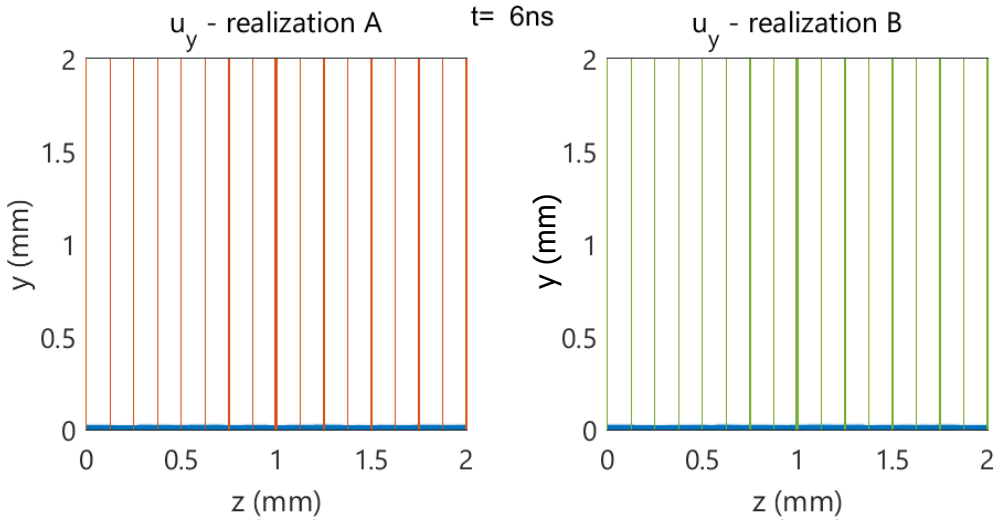
FEM-simulations of SAW grain boundary scattering

Grain boundary scattering



polycrystal

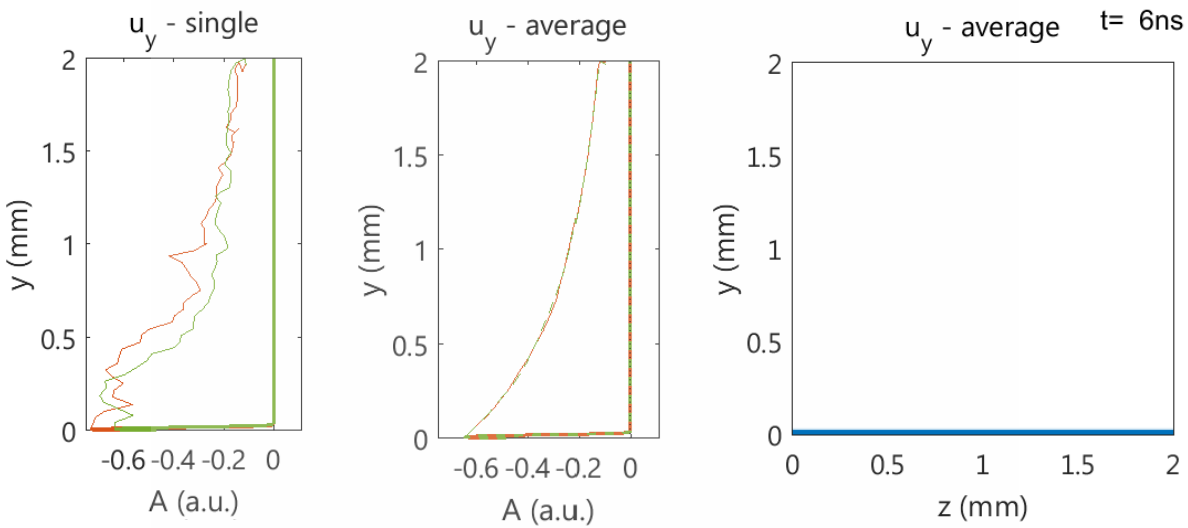




same statistics (e.g. mean grain Ø), different microscopic realizations

Effective attenuation

effective,
homogeneous medium



ballistic wave

'coherent wave'

average in z-direction

Big thanks to you, our scientists, partners and funding sources!

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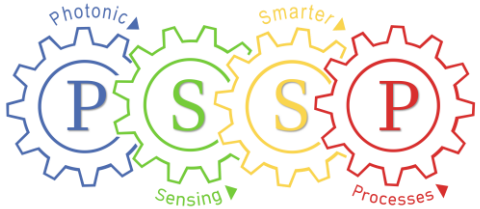
RECENDT´s scientists:

Bernhard Reitinger
Clemens Grünsteidl
Martin Ryzy
Christian Kerschbaummayr
Wolfgang Haderer
Mike Hettich
Georg Watzl

LINSEIS THERMAL ANALYSIS

voestalpine ONE STEP AHEAD.



Financial support was provided by the Austrian research funding association (FFG) under the scope of the COMET programme within the research project "Photonic Sensing for Smarter Processes (PSSP)" (contract number 871974). This programme is promoted by BMK, BMDW, the federal state of Upper Austria and the federal state of Styria, represented by SFG.

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This project is co-financed by research subsidies granted by the government of Upper Austria.

Member of UAR INNOVATION NETWORK

The Research Center for Non Destructive Testing GmbH is member of the UAR Innovation Network and is supported by the strategic economic- and research program "Innovative Upper Austria 2020" of the province of Upper Austria.

We’re looking into it!

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