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matériaux microélectronique acoustique nanotechnologies

Characterization of porous metal backing for high-temperature ultrasonic transducers

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Outline

Introduction

Porous Materials

Characterization at room temperature

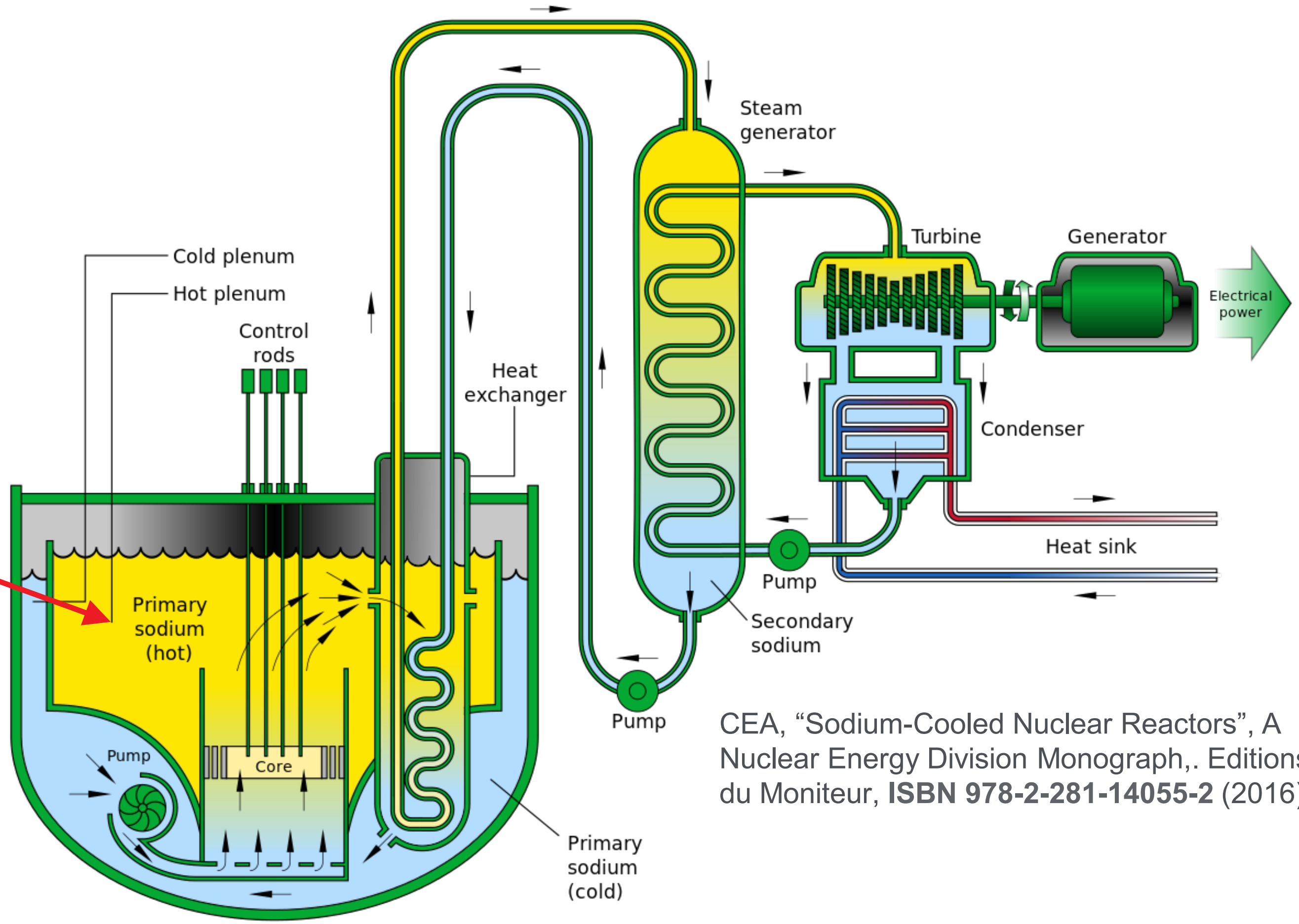
Characterization in temperature

Transducer simulations

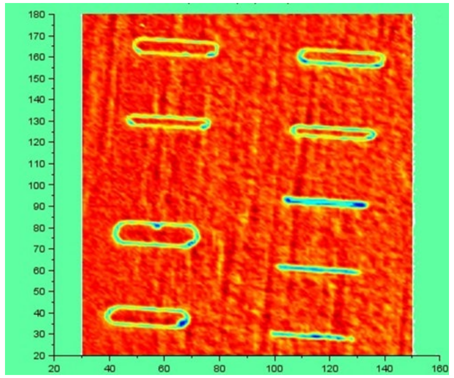
Conclusion

Development of the new nuclear plant generation

- Fast neutron reactor
- Improvement of the Uranium/plutonium NRJ efficiency
- Need to control and inspect in and out structures
- Harsh environment
  - ✓ High-temperature constraint >585°C
  - ✓ Radiation environment (γ photons, neutrons)
  - ✓ Permanent immersion in sodium
  - ✓ Corrosion



CEA, "Sodium-Cooled Nuclear Reactors", A Nuclear Energy Division Monograph,. Editions du Moniteur, **ISBN 978-2-281-14055-2** (2016)



Acoustic imaging in sodium 200°C

Develop HT US techniques for inspection

(telemetry and acoustic imaging)

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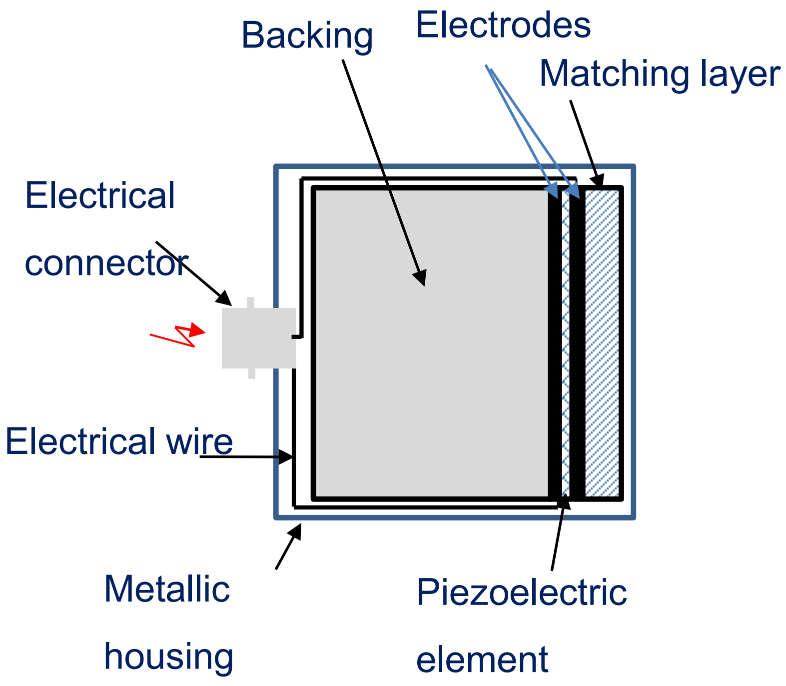
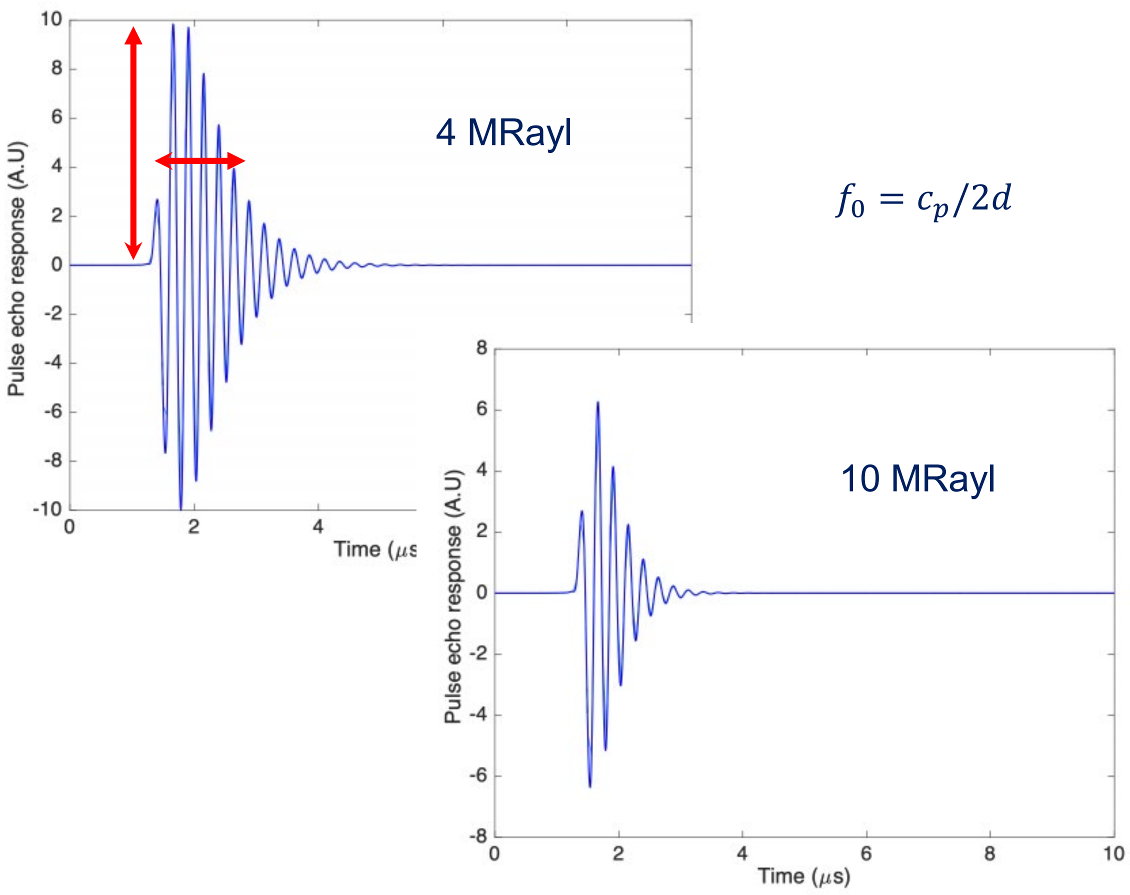
Conventional transducer



Simulated pulse echo response of a 4 MHz piezoelectric transducer based on a PZ27 ceramic (Ferroperm) radiating in water



$f_0 = c_p/2d$

Role of backing:

- Damp the vibration of the piezoelectric crystal
- Attenuate the US waves

Effect on the sensitivity axial resolution

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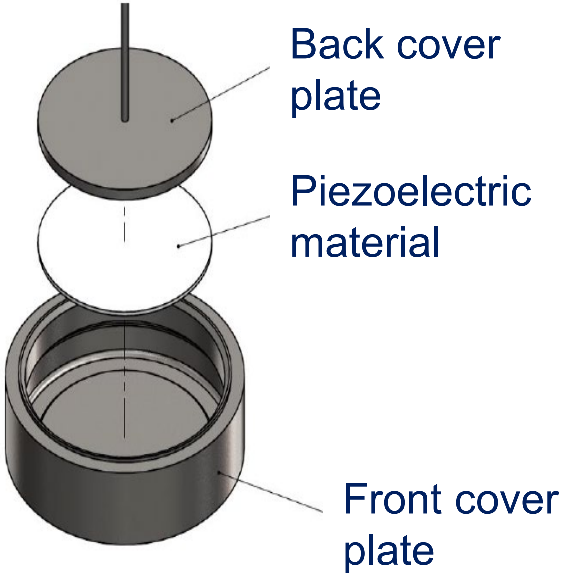
High temperature transducers $LiNb0_3$ based

$LiNb0_3$: $T_c \geq 1200°C$

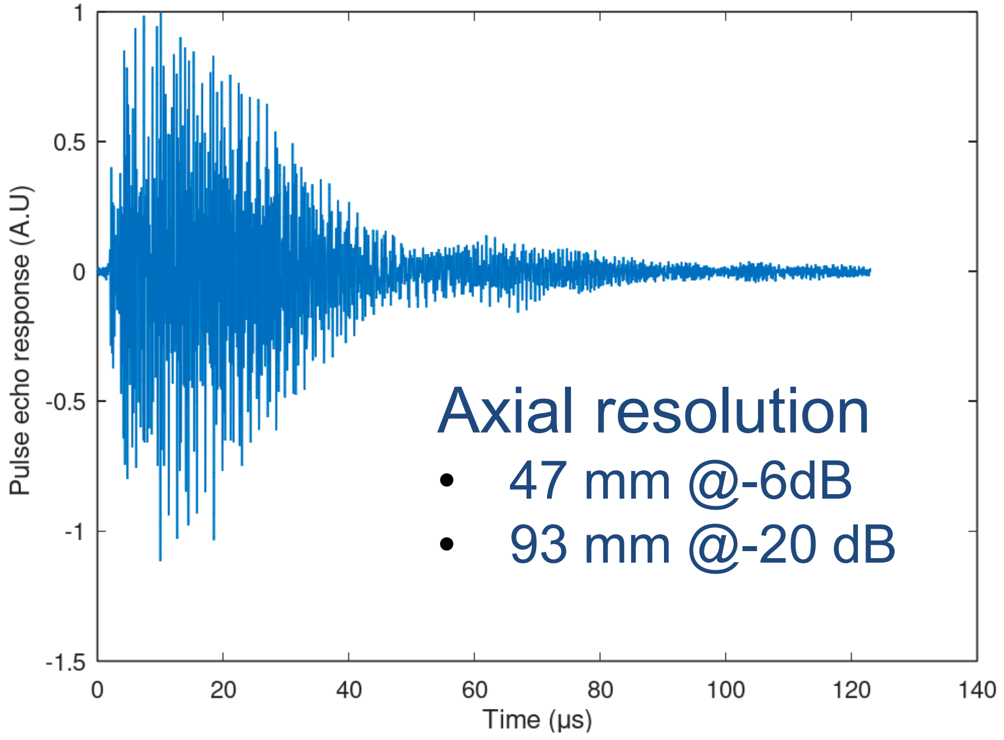
Front layer / rear layer	
Thickness (mm)	1.2 / 2

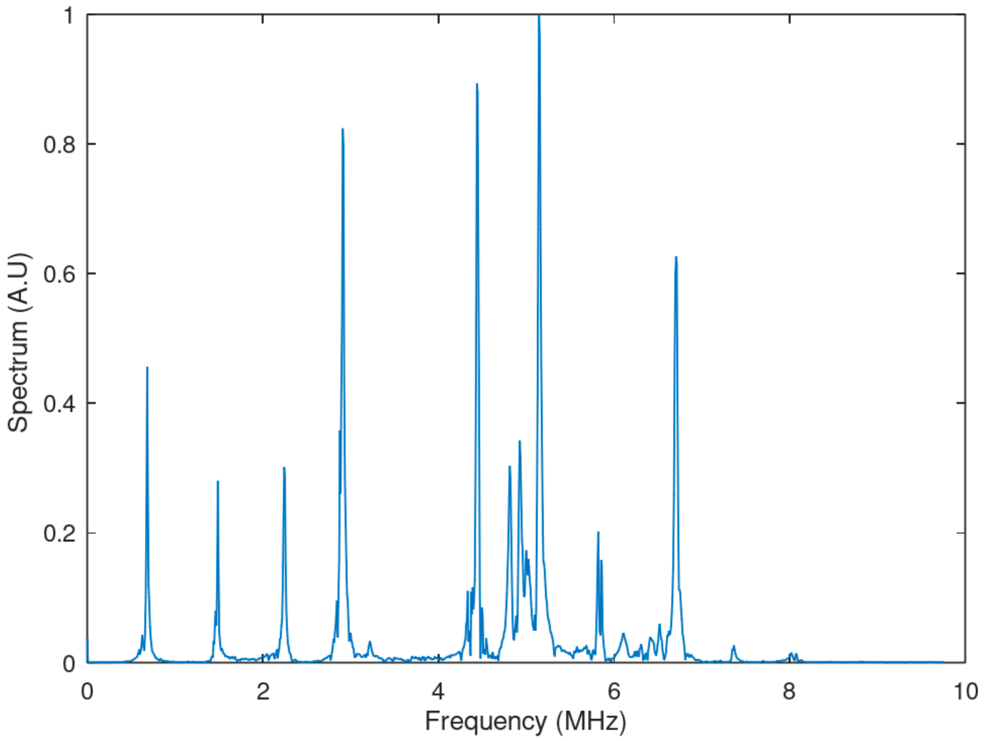


High-temperature ultrasonic transducer
Diameter 40 mm

High temperature transducers LiNb03 based

Pulse echo and frequency response in water





$f_p = 4.6\ MHz$! Center freq of LiNbO3
$f_0 = 0.7\ MHz$ for the transducer (coupled resonators)

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Are porous metal suitable to be used as a backing for High Temperature applications?

- High attenuation coefficient
- Acoustic impedance
- Physical and mechanical
- The coefficient of thermal expansion (CTE).

- **Porous metals**
- Electric properties
- Transducer assembly (brazing capability)

Porous stainless steel (Amespore)

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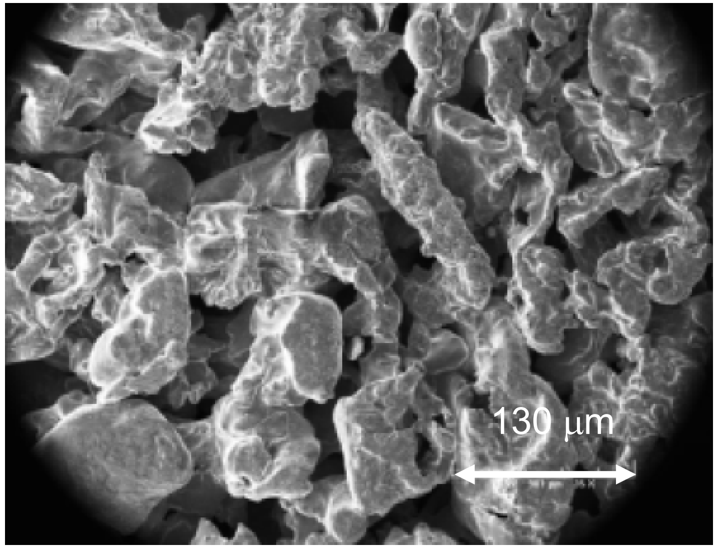
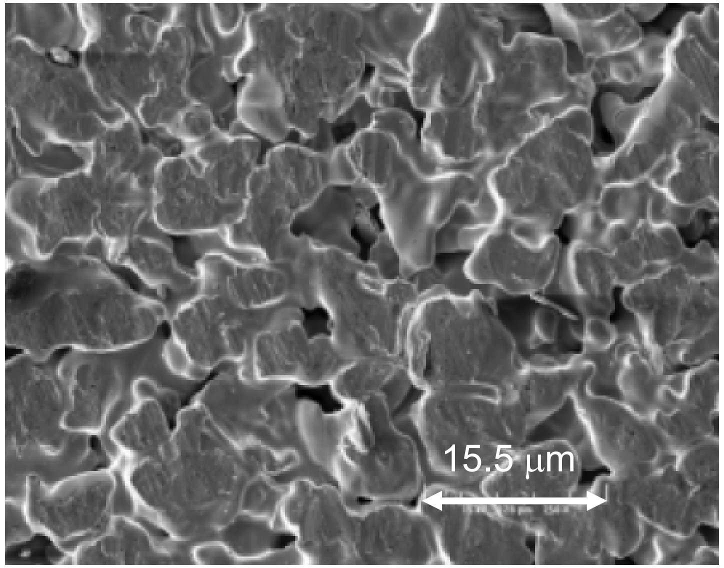
Porous stainless steel (SS 316L)

Material	Nominal thickness (mm)	Measured Thickness (mm)	Nominal density (kg.m^{-3})	Measured density (kg.m^{-3})	Nominal porosity (%)	Measured porosity (%)	Nominal Pore size (µm)
SSU02-10	10	9.98	5900 - 6300	6059	21 - 26	25.20	1.7
SSU05-10	10	10.30	5000 - 5600	5073	32 - 37	36.91	7.6
SSU10-10	10	10.13	4700 - 5100	5268	36 - 41	34.97	10.9
SSU15-10	10	9.92	4600 - 5000	4526	37 - 42	44.12	13.5
SSU25-10	10	9.88	4400 - 4800	4444	39 - 44	45.14	26.5
SSU40-10	10	10.34	4000 - 4400	3828	44 - 49	52.75	39.0
SSU60-05	5	5.05	3600 - 4000	3811	49 - 54	52.95	59.5
SSU60-10	10	9.89	3600 - 4000	3856	49 - 54	52.04	59.5



SSU40-10 52% porosity



SSU02-10 25% porosity

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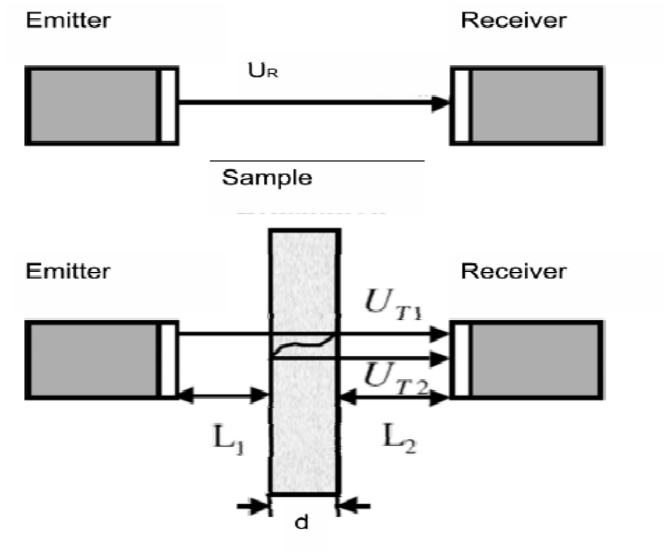
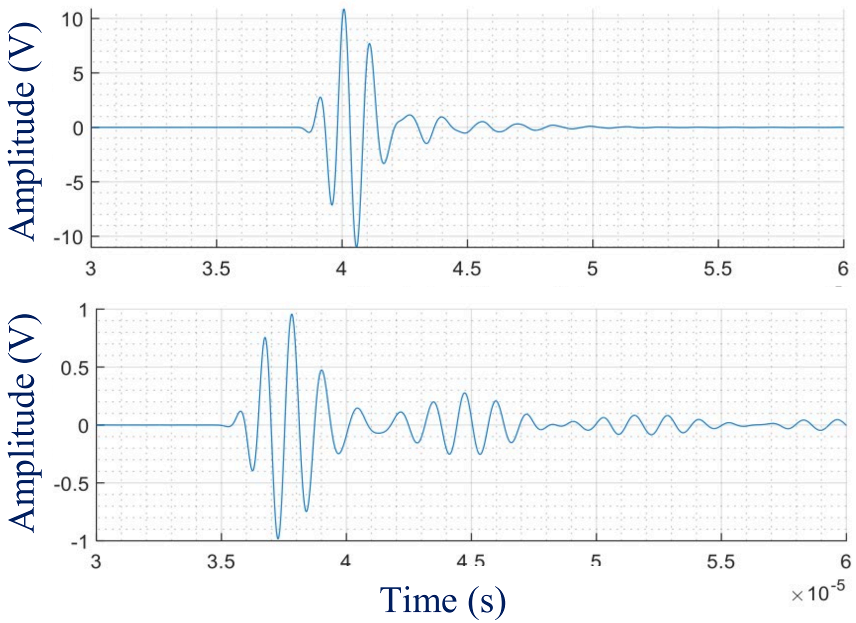
Insertion substitution method





$$\Delta t = t_1 - t = d\left(\frac{1}{c} - \frac{1}{c_w}\right) \Rightarrow c$$

$$\alpha = -20log\left(\frac{\bar{U}_{T1}(f)}{T.U_R(f)}\right) * \frac{1}{d}$$

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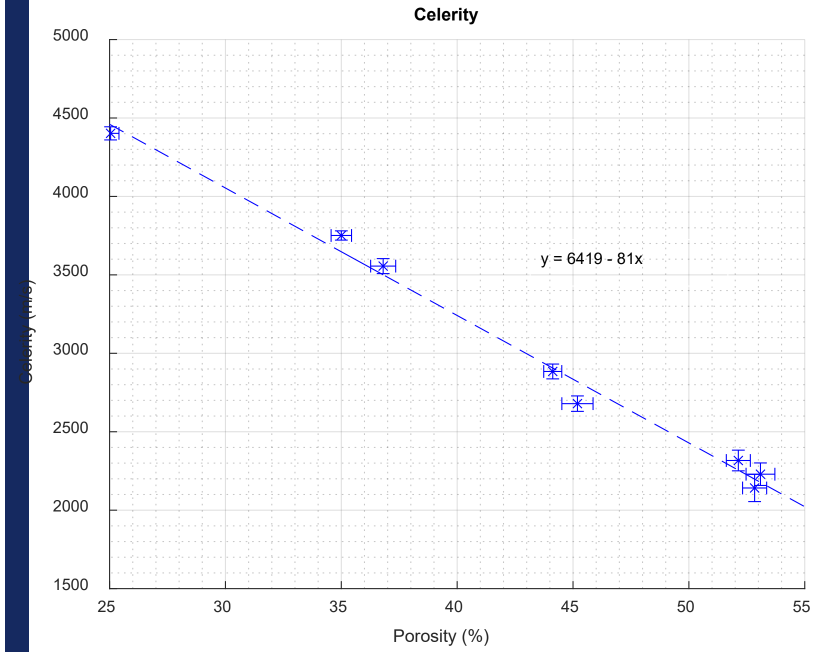
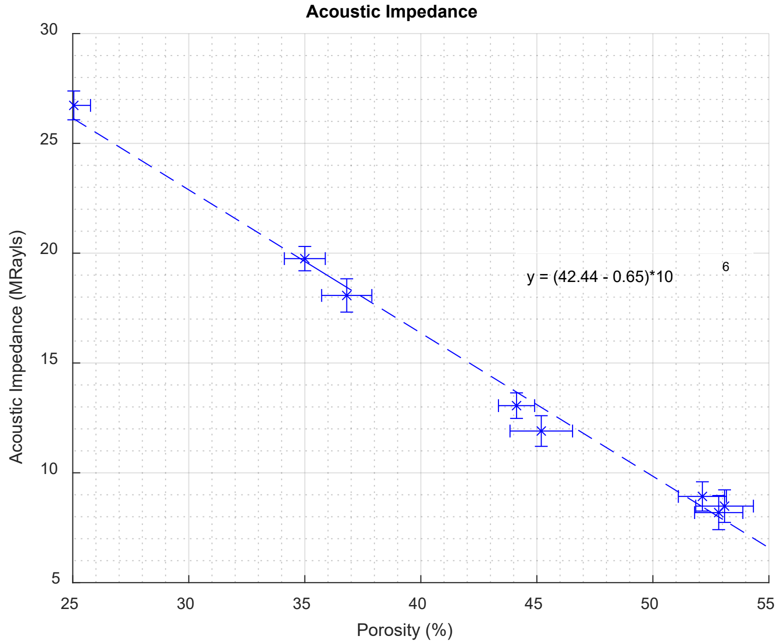
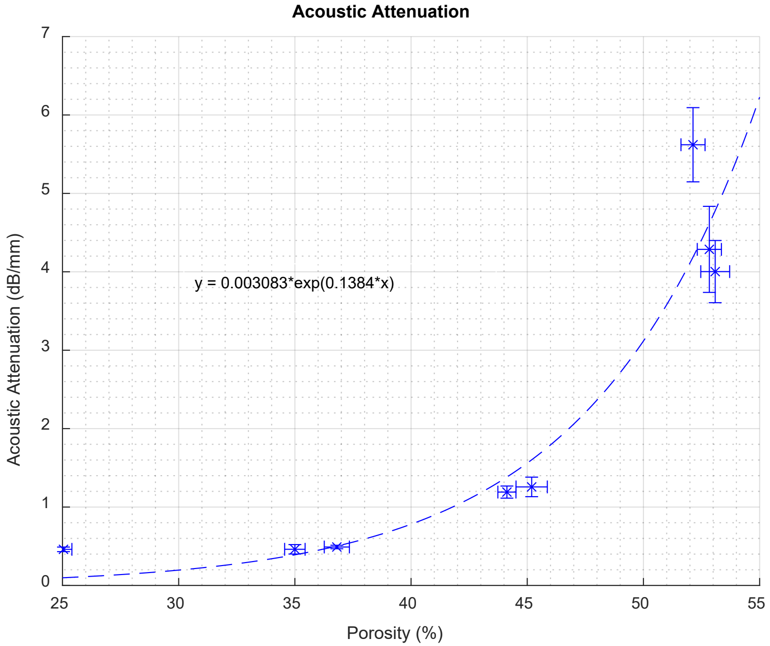
Results and discussion







Linear dependence of the variation of the celerity and the acoustic impedance as a function of the porosity.
High attenuation of 1.1 $dB.mm^{-1}$ at 1MHz a porosity of 45 %.
=> A backing thickness of 20 mm leads to an attenuation of 40 dB at 1 MHz, which is largely sufficient for developing imaging systems

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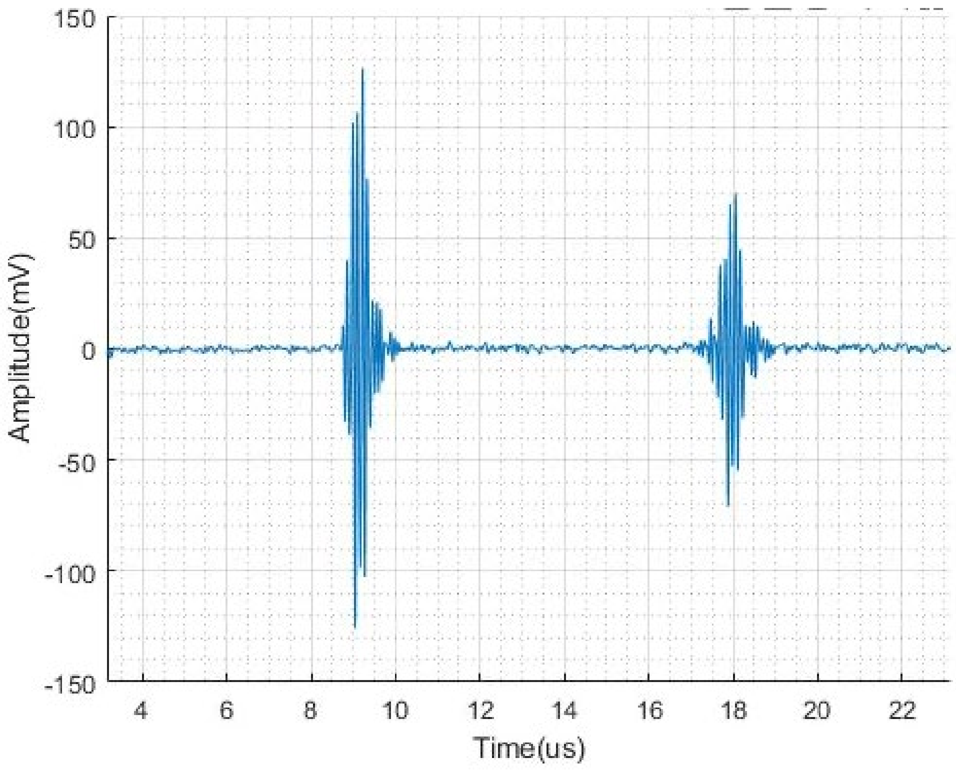
Transducer characteristics

Tra,sducer	Center frequency	2.5 MHz
	Diameter	10 mm
Delay line	Material	Ferritic steel
	Length	25 mm
Temperature	range	Amb.-500°C



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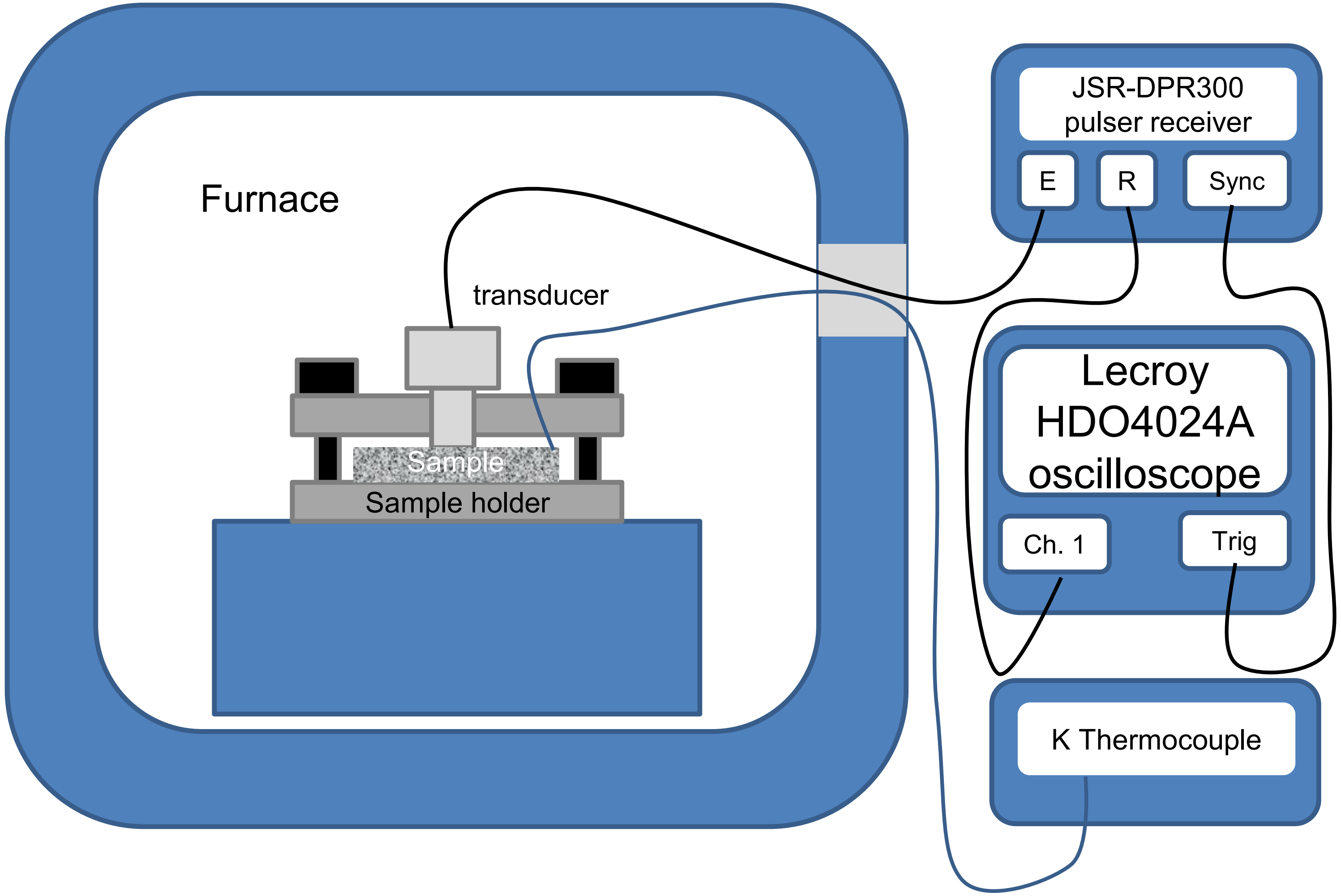
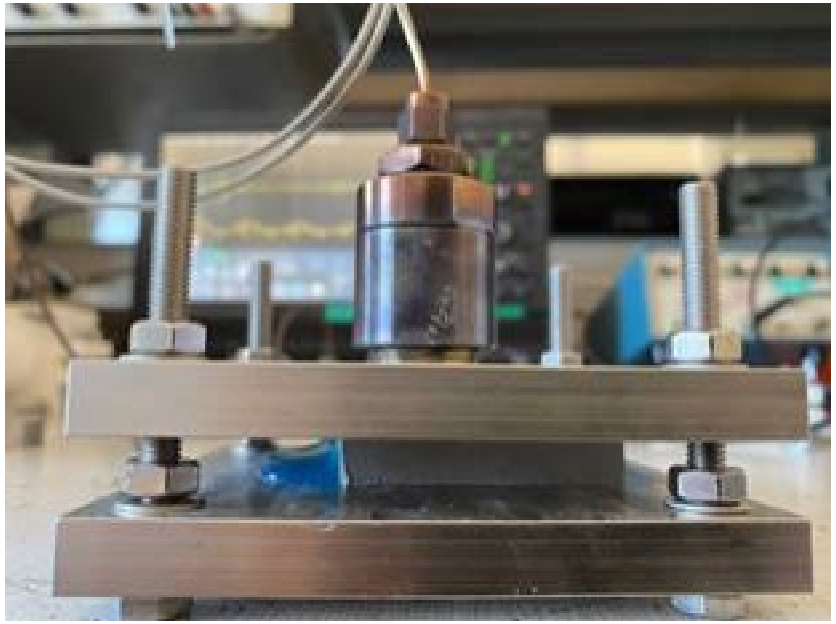
Characterization in temperature

Experimental set-up



Sample Holder



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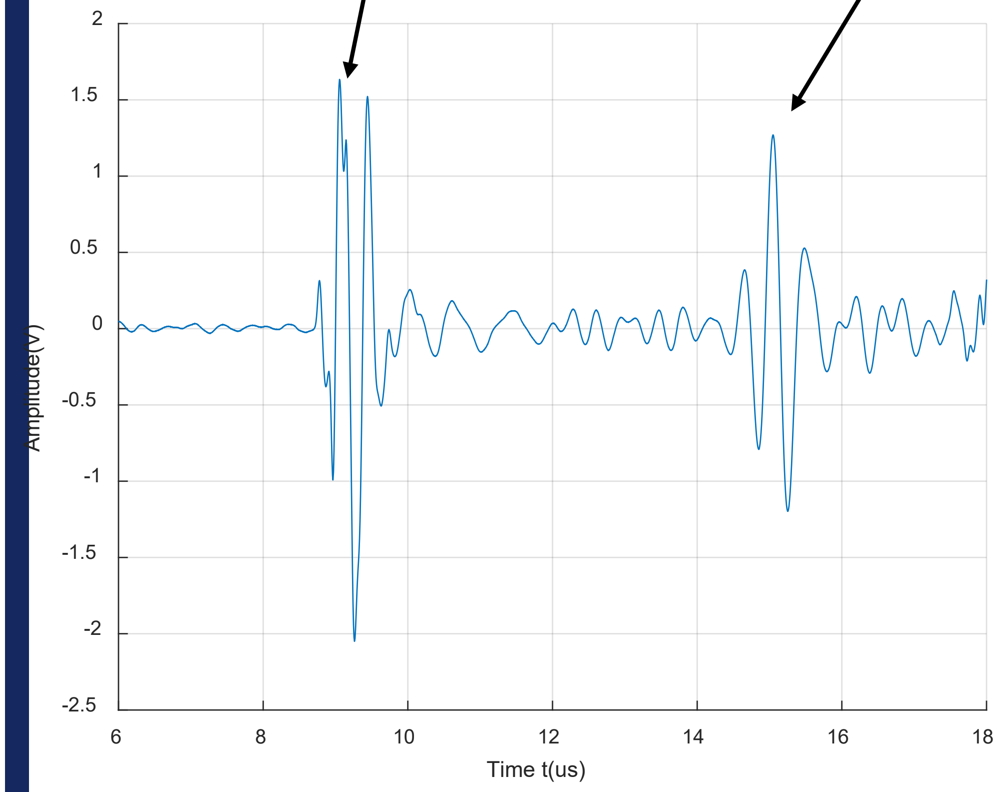
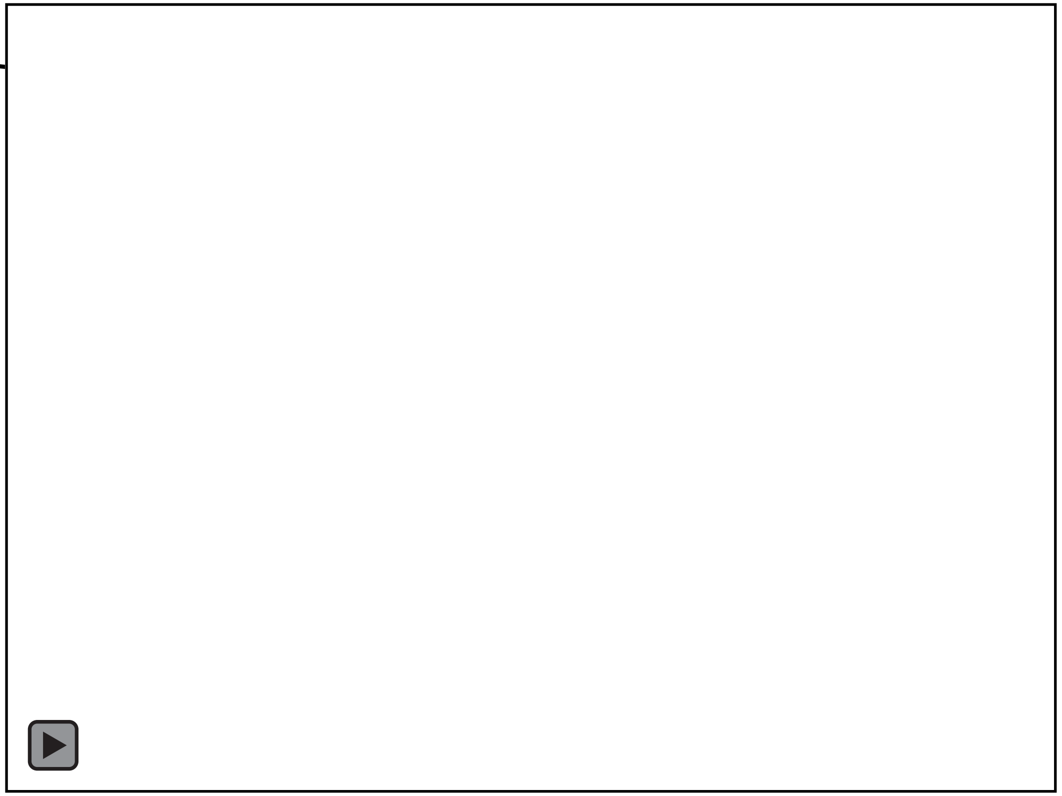
Signal received

Round trip echo in the delay line

Round trip echo in the sample





SSU10-10- Porosity 35% - 200^{0}C - 2MHz

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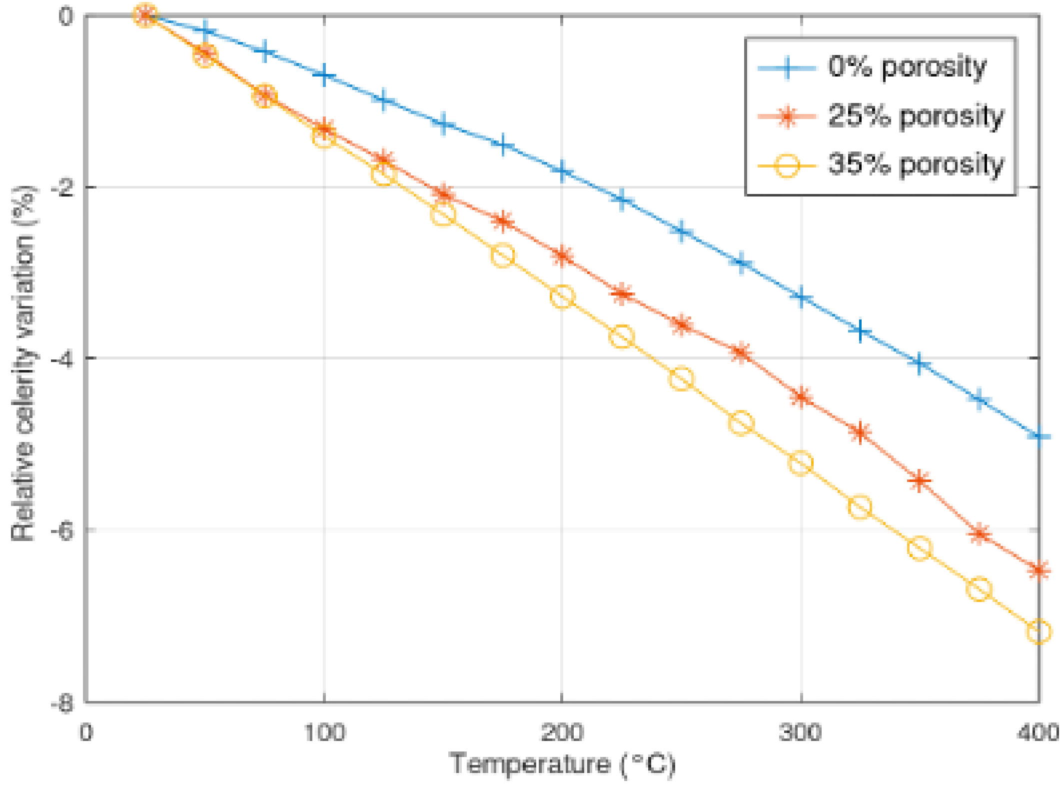
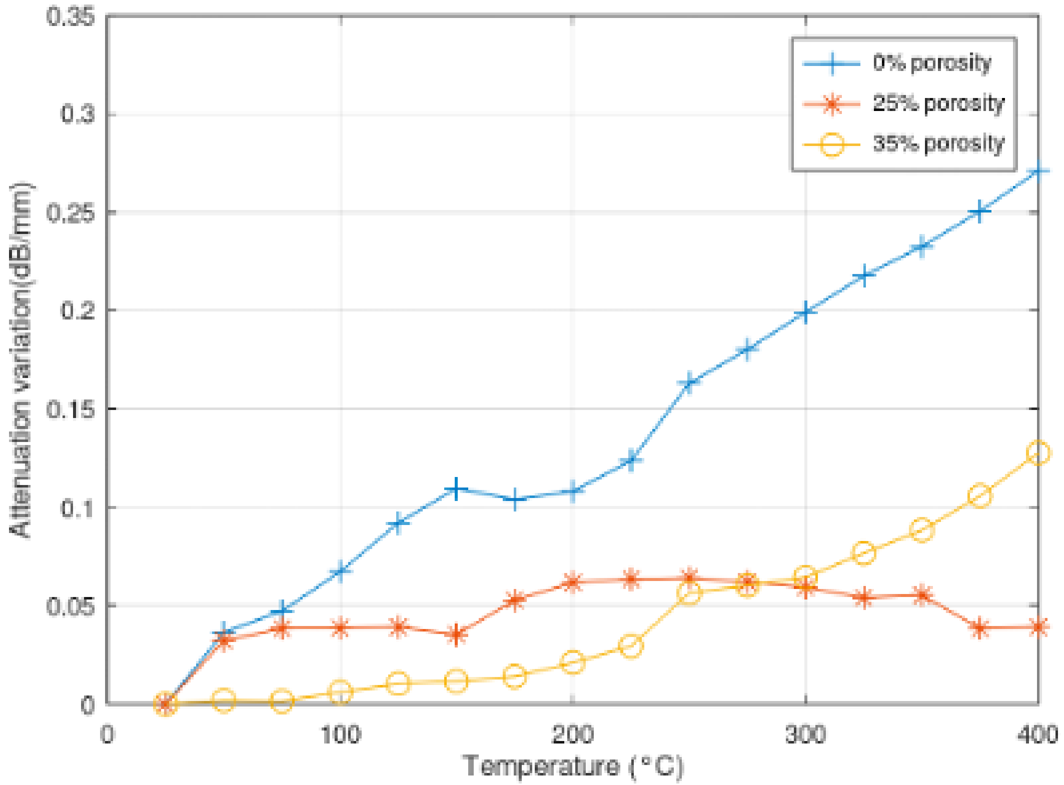
Results

Relative celerity variation



Attenuation variation



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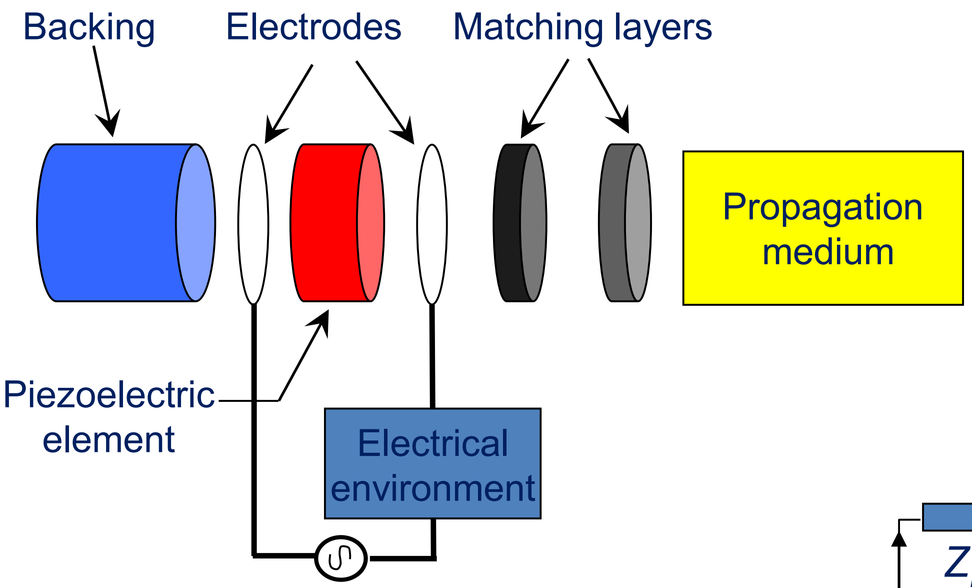
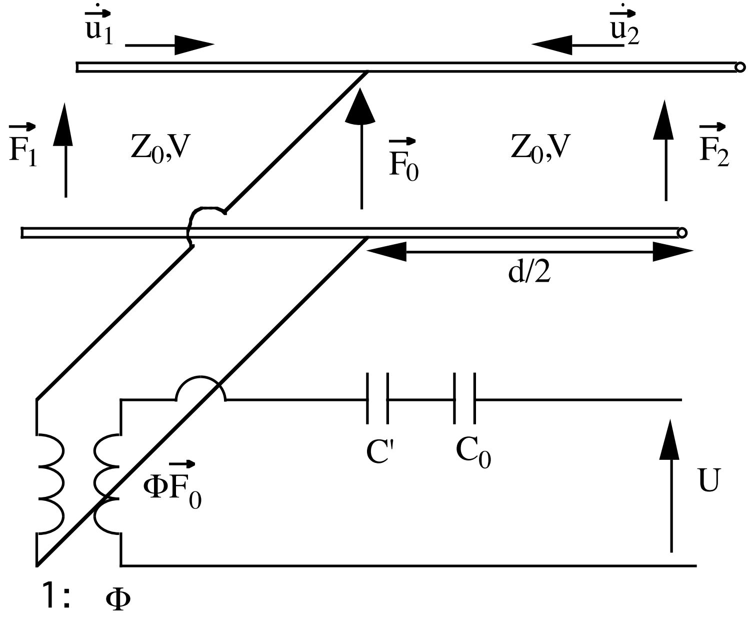
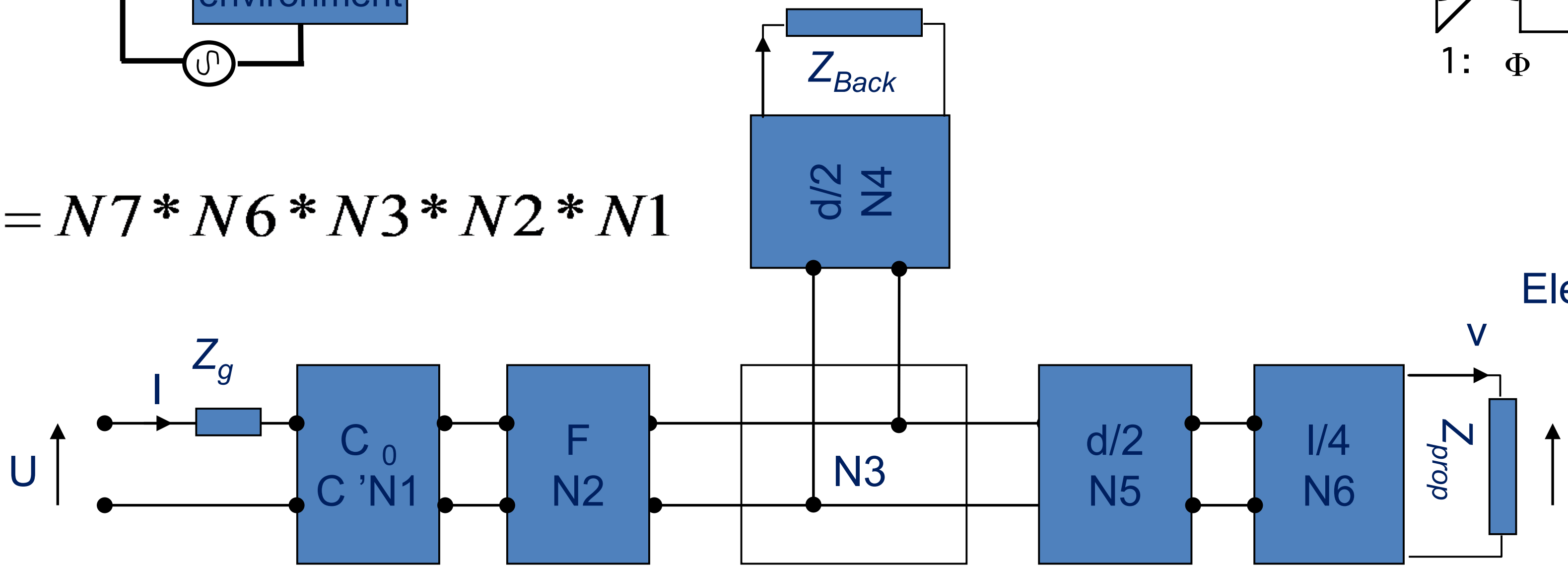
KLM Model

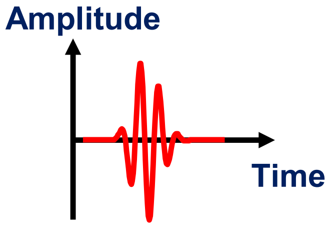




$$N_{tot} = N7 * N6 * N3 * N2 * N1$$



Electroacoustic response



Simulations of the reference transducer

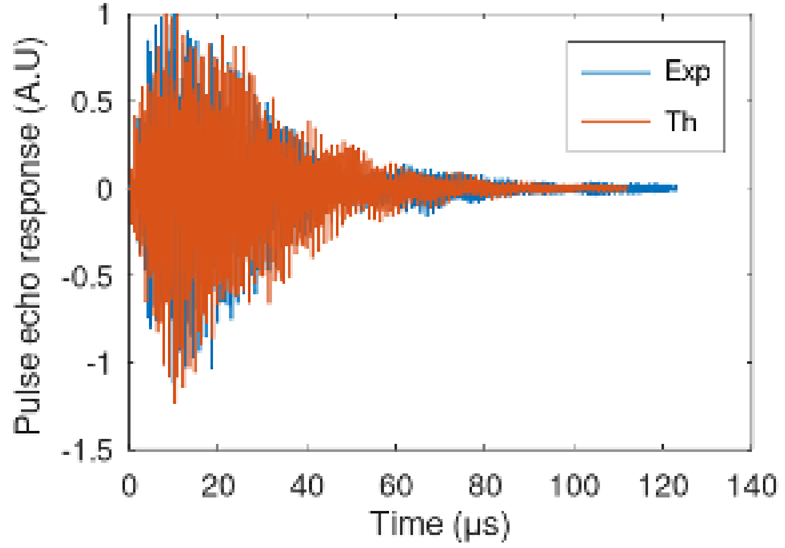
Cristal	$LiNbO_3$ Z-cut	Front layer / rear layer	
Diameter (mm)	40	Thickness (mm)	1.2 / 2
Thickness (mm)	0.78	Velocity ($m.s^{-1}$)	5740
Density ($kg.m^{-3}$)	4650	Loss tangent	0.001
Velocity ($m.s^{-1}$)	7140	Acoustic impedance (MRayl)	46.2
Acoustic impedance (MRayls)	33.2		
Relative dielectric constant	29.16	Propagation medium (water)	
Coupling coefficient	0.17	Acoustic impedance (MRayl)	1.5

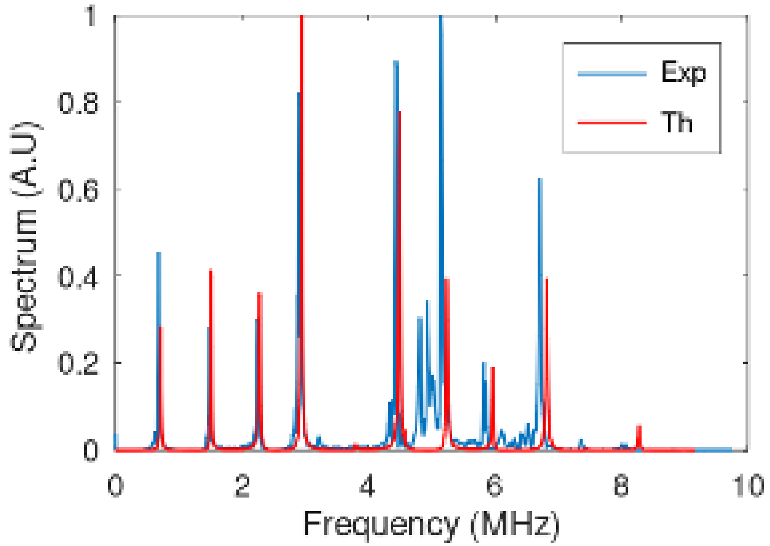
Sensitivity (Th)

- -12 dB

Axial resolution

- 47 mm @-6dB
- 93 mm @-20 dB





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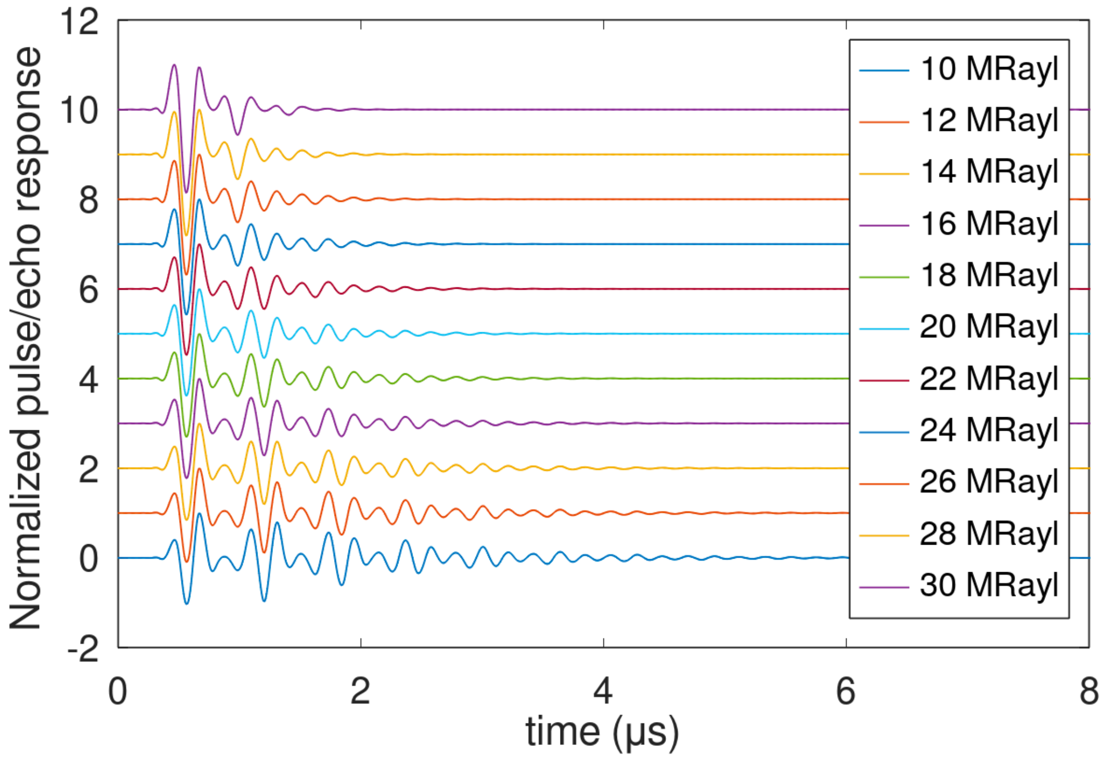
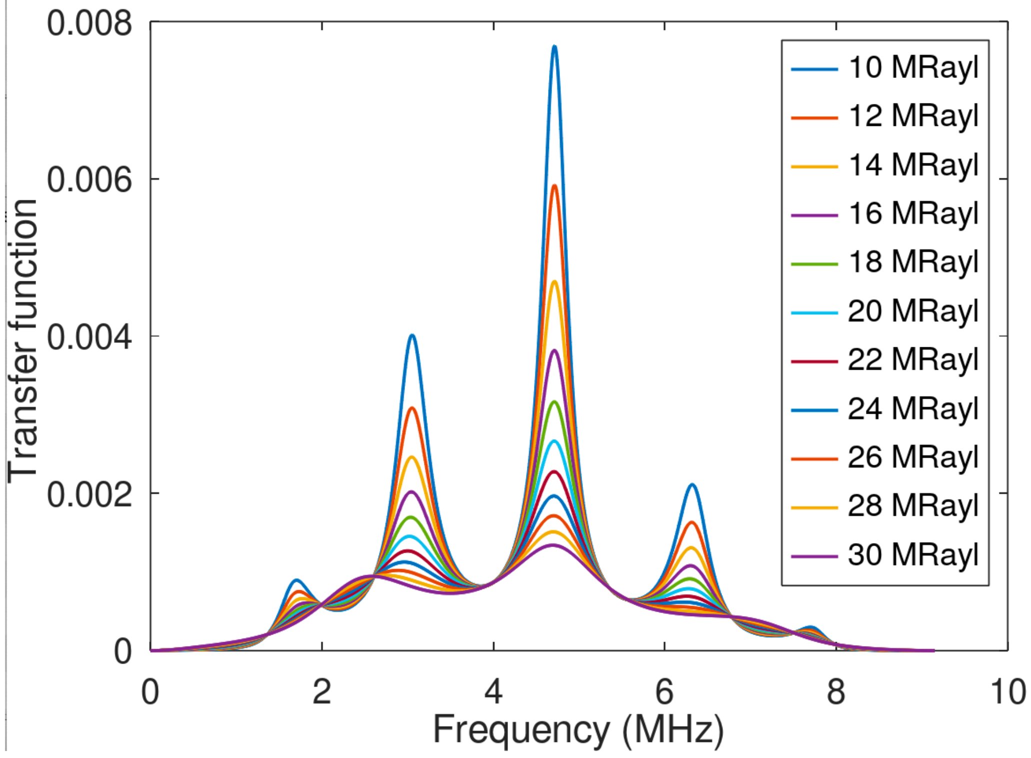
Influence of the backing impedance on the electroacoustic response





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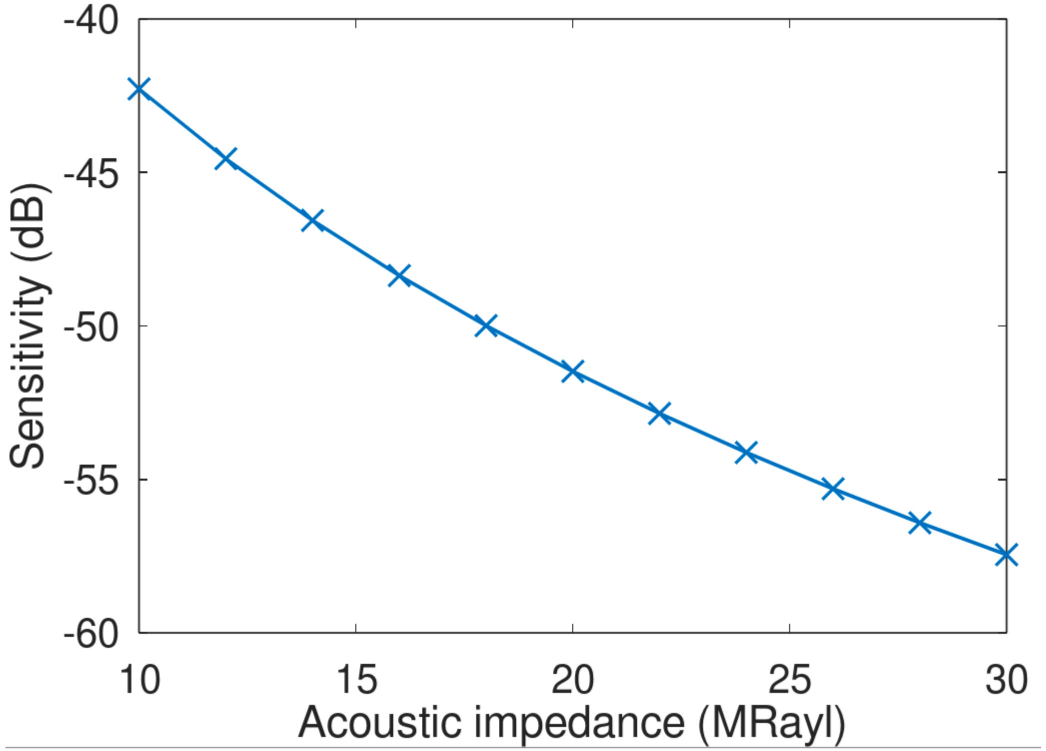

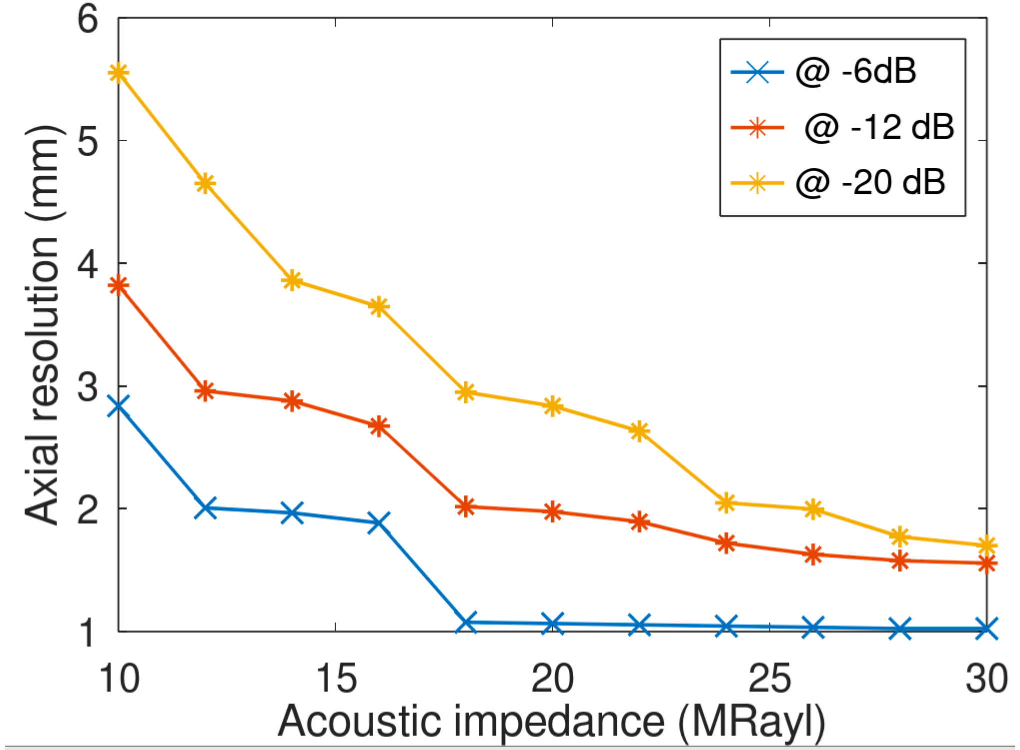

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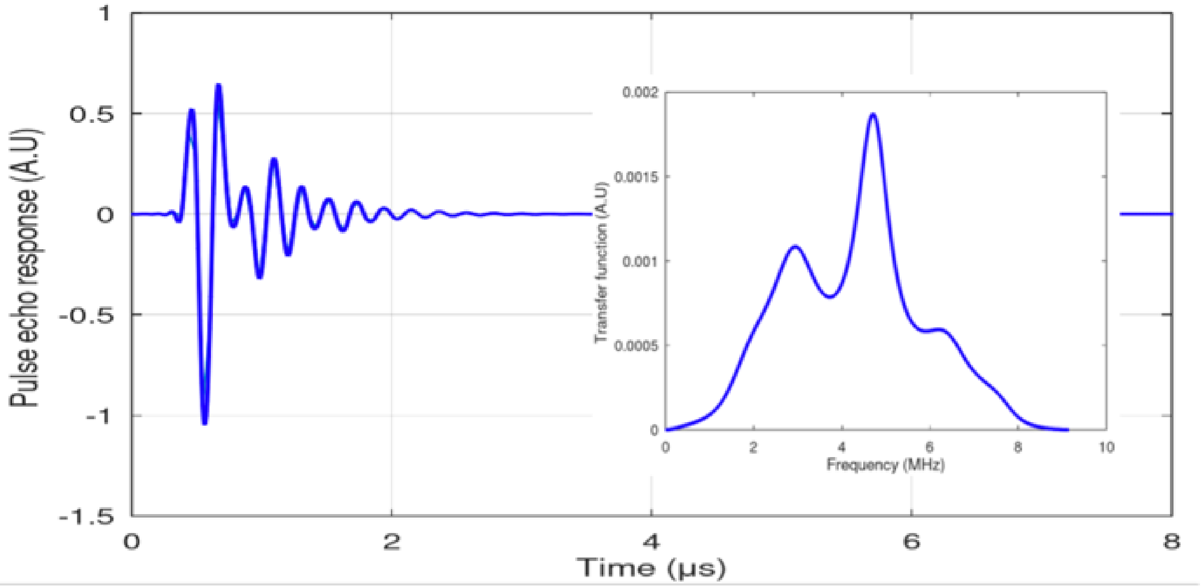
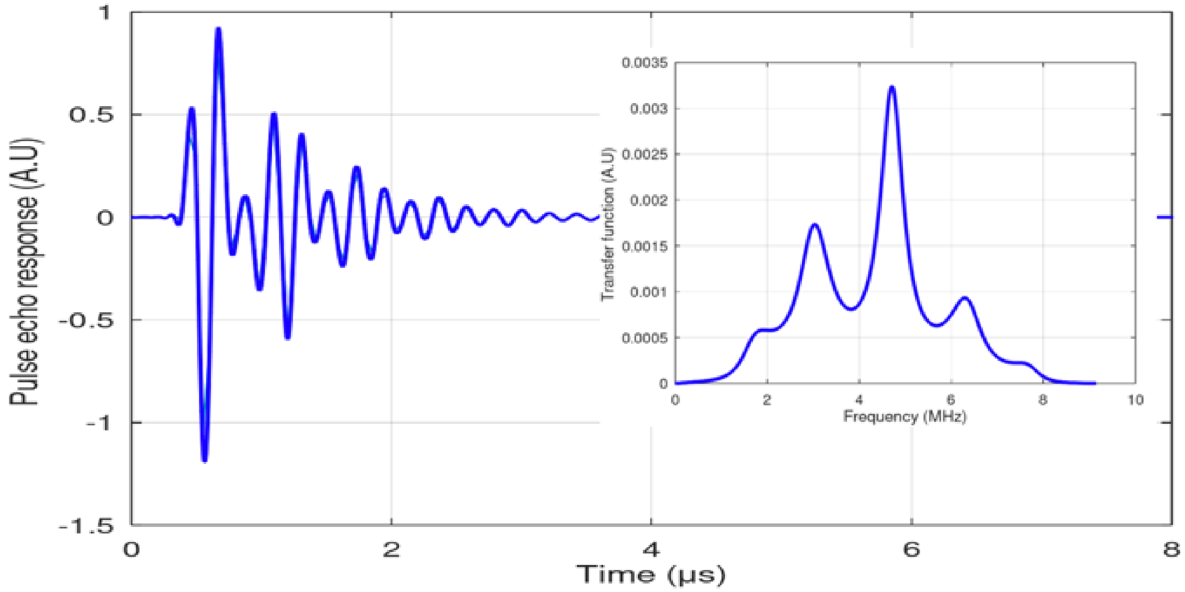
Simulation of the pulse-echo and frequency response of a LiNbO3-based transducer

25 % of porosity



35 % of porosity



Sensitivity	-54.6 dB
Axial resolution	1 mm at -6 dB
	2 mm at -20 dB

Sensitivity	-49.8 dB
Axial resolution	1 mm at -6 dB
	3 mm at -20 dB

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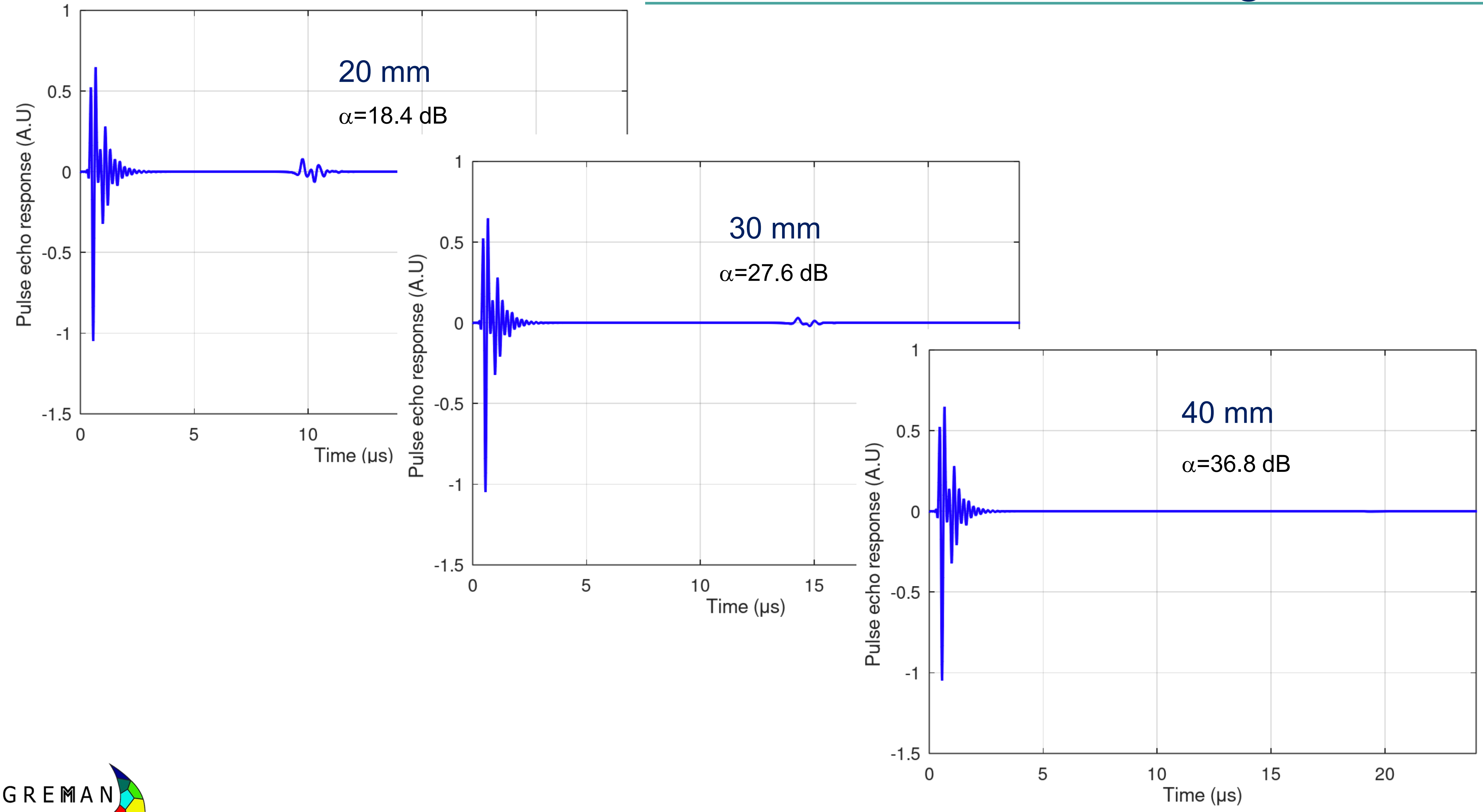
Influence of the backing thickness



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Conclusion

HT ultrasonic transducer

- imaging of defects
- improving the axial resolution

Porous metals are good candidates.

- compatible material with high-temperature
- conducting material that allows direct electric contact on the rear face

Characterization at room temperature: porosity 25% to 52 %.

- Celerity ranges from 4500 (25 %) m/s to 2200 m/s (52 %)
- Attenuation ranges from 0.46 dB/mm to 5 dB/mm

Characterization as a function of temperature: porosity of 25% to 35 %.

- Celerity variation decreases by 5% $\Delta T=375°C$
- No attenuation variations are observed

Simulations of a HT transducer with such a backing

Strong improvement of the axial resolution

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Perspectives

Up to now: Experimental approach

Now :

- Modeling of the acoustic parameters as a function of the porosity level and pore size
- Design and Fabrication of a new high-temperature ultrasonic transducer
- Comparison Th/exp
- Conduct tests in temperature
- Test other cuts for $LiNb0_3$ and other materials

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Thank You!

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