Wireless high-temperature surface acoustic waves sensors: material challenges

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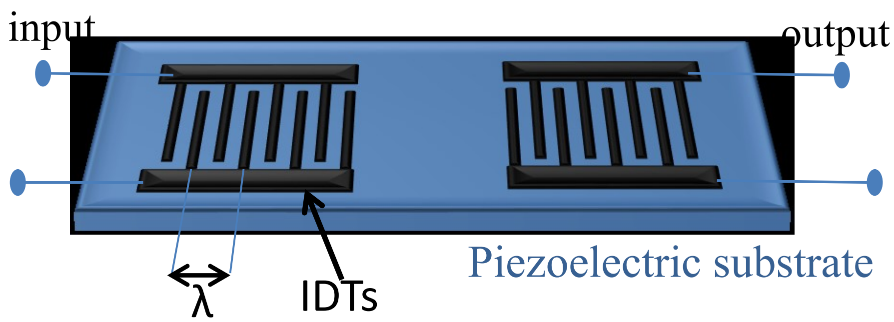
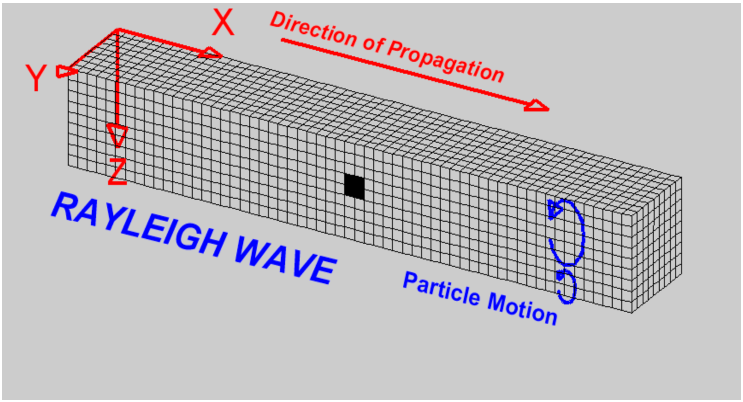
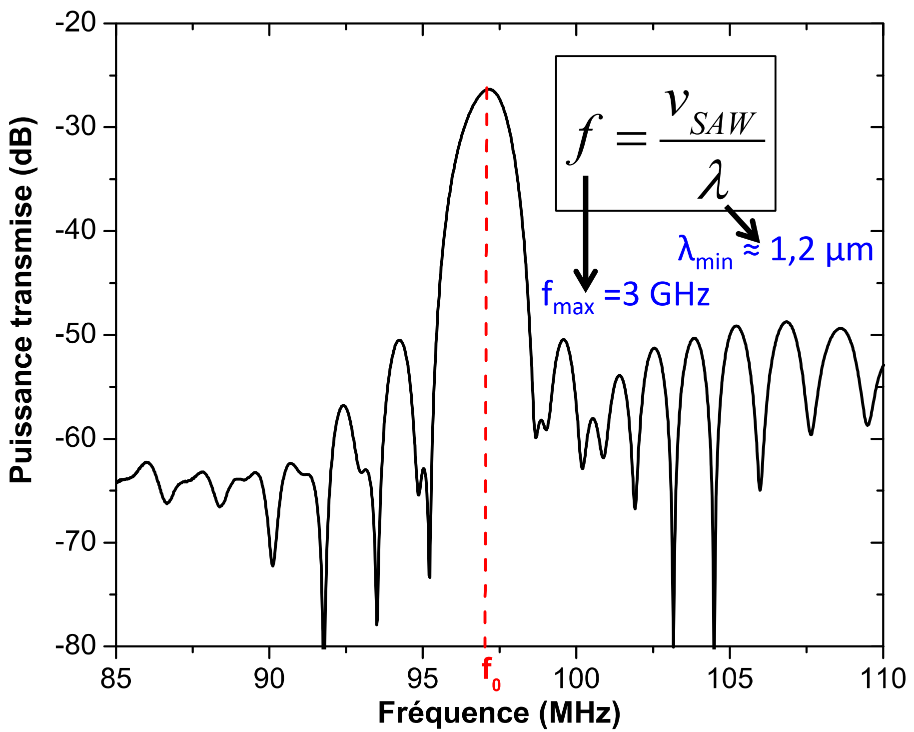
Introduction

Surface Acoustic Waves (SAW) Technology

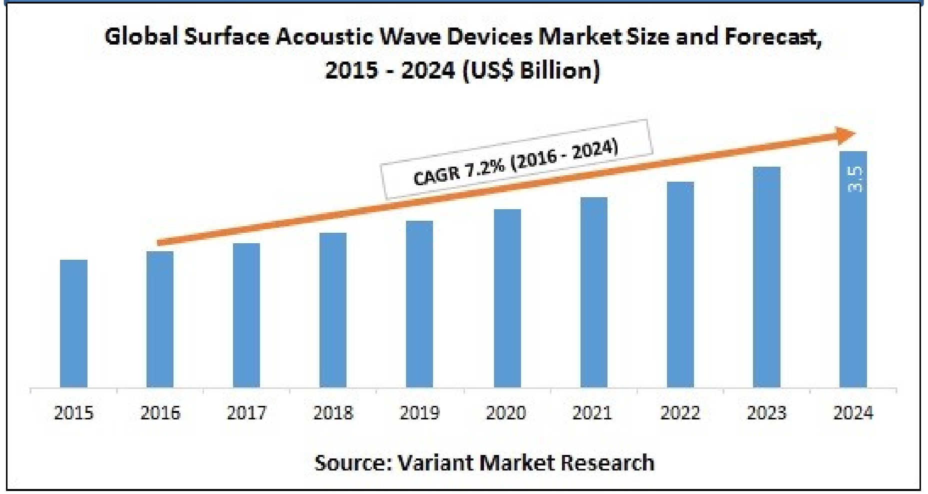




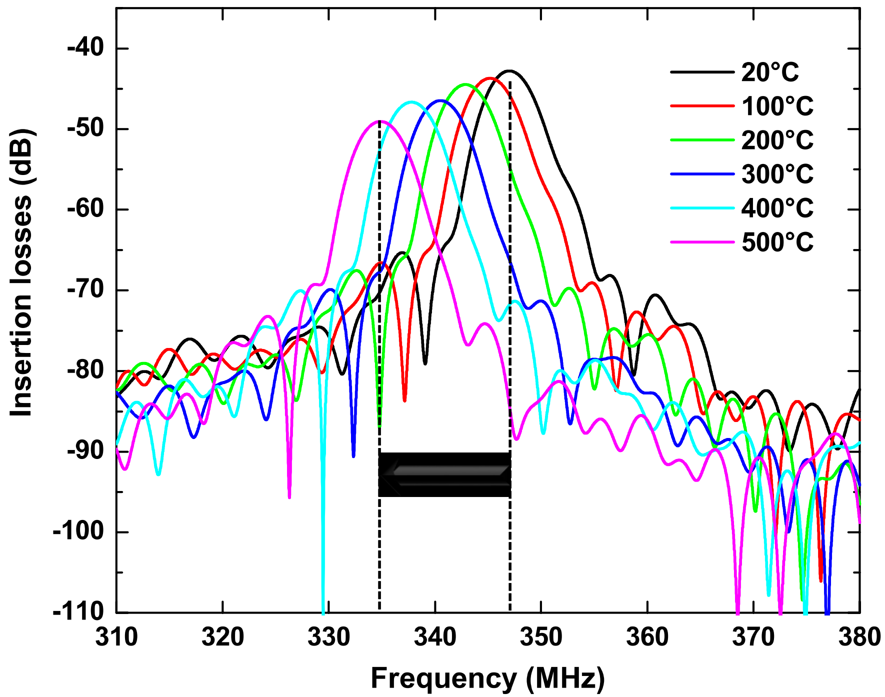


Global SAW market:

≈ 3 G€ in 2018 and 3.5 G€ foreseen in 2024



High-temperature Passive & Wireless SAW Technology

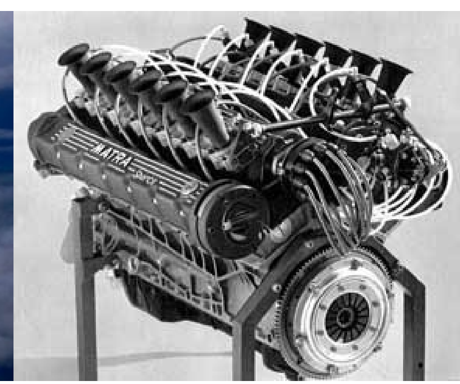


Passive & Wireless Technology

Remote measurements at high temperatures (200 – 1000°C)

Metallurgy

Aeronautics



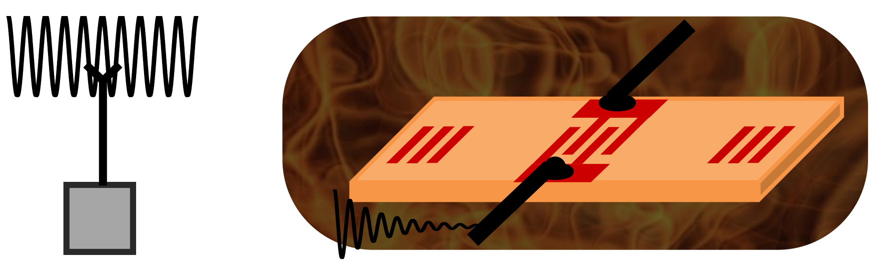
Automotive

Power plants

High-temperature SAW sensors basics

Piezoelectric material	SAW velocity (m/s)	Electromechanical Coupling k^2 (%)	Maximum temperature	Dysfunction Origin
Quartz	3500	0.1	450°C	Structural disorder
Lithium Niobate ($LiNbO_3$)	4000	5	**$\lesssim$ 600°C**	HT Conductivity Crystal segregation
Lithium Tantalate	?	2	300	Structural disorder
Langasite ($La_3Ga_5SiO_{14}$)	2700	0.4	**750°C**	HT Conductivity
AlN	5500	0.3	**$\gtrsim$ 1000°C**	-

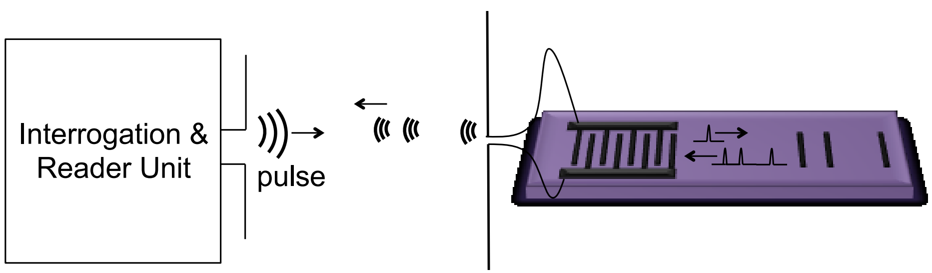
Resonator configuration



☺ Substrates with low k^2 can be used (**LGS**, **AlN**)

☹ Sensor identification is not trivial

Reflective delay line configuration



☺ ID Tag included

☹ High k^2 ($\gtrsim$ 1%) requested (**$LiNbO_3$**)

High-temperature wireless SAW sensors : State-of-the-Art

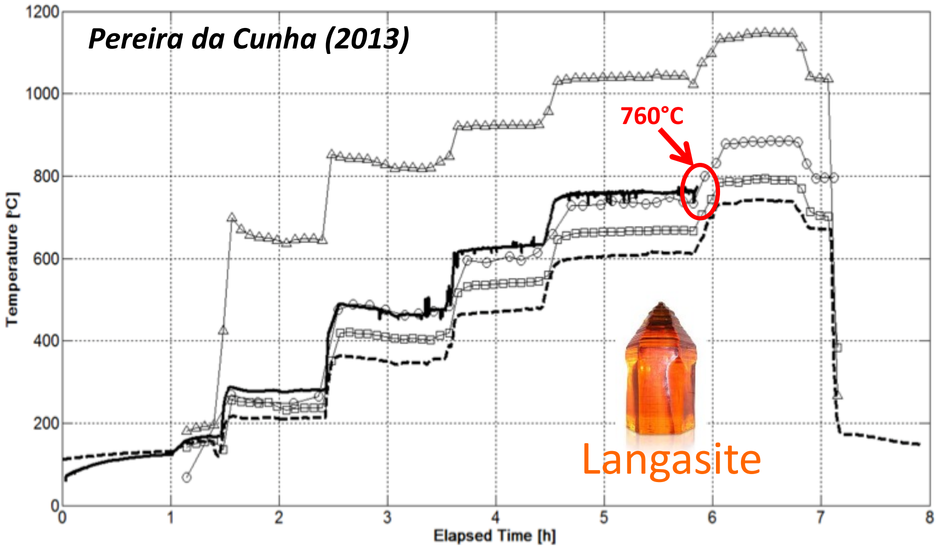
Reflective delay line configuration

Temperature	Lifetime
300°C	> 4000 hours
350°C	> 250 hours
400°C	< 10 hours

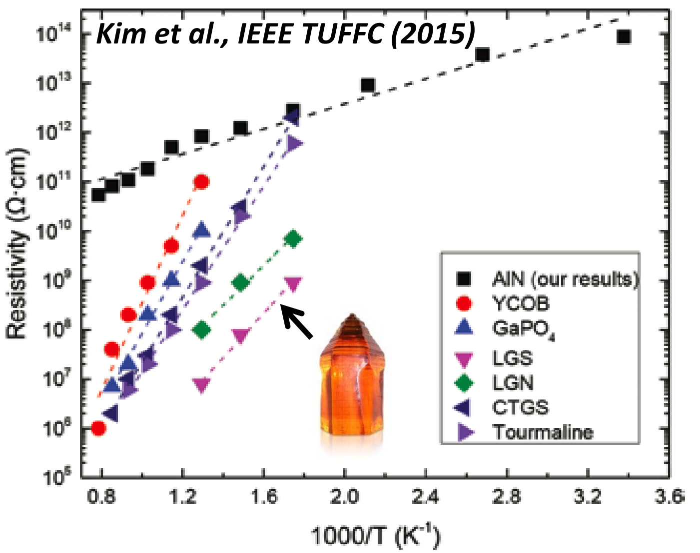
Lifetime limitation origins

- 350 nm wide aluminium IDTs (2.45 GHz ISM band)
- $LiNb_3O_8$ phase segregation

Resonator configuration

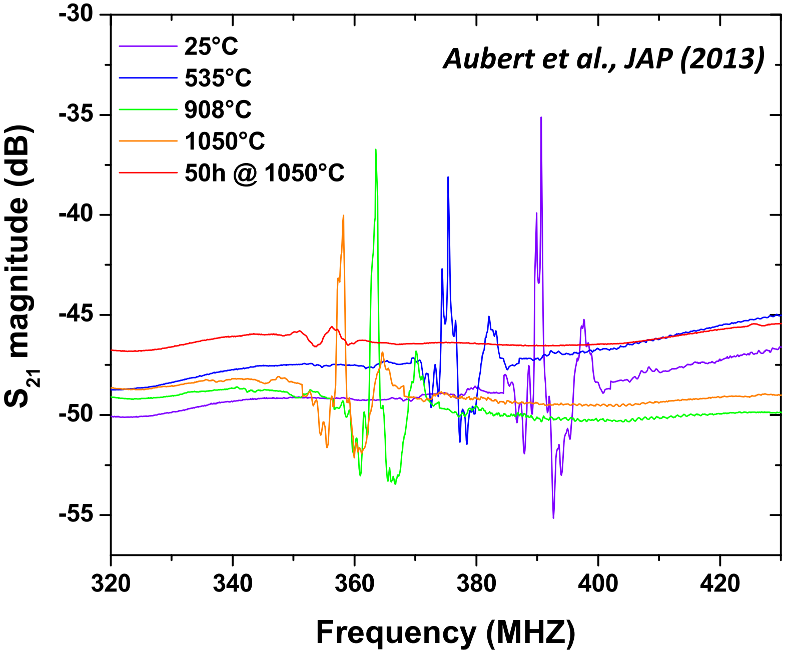


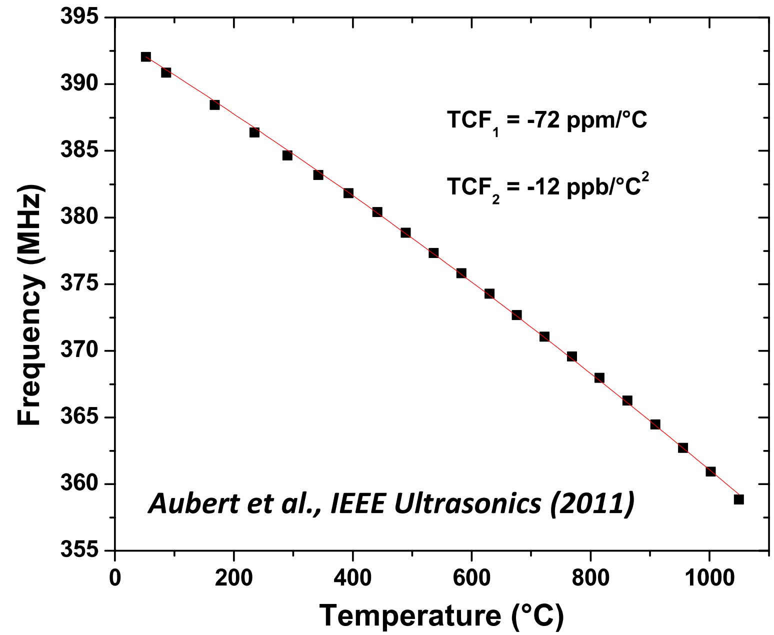
Temperature limitation origin

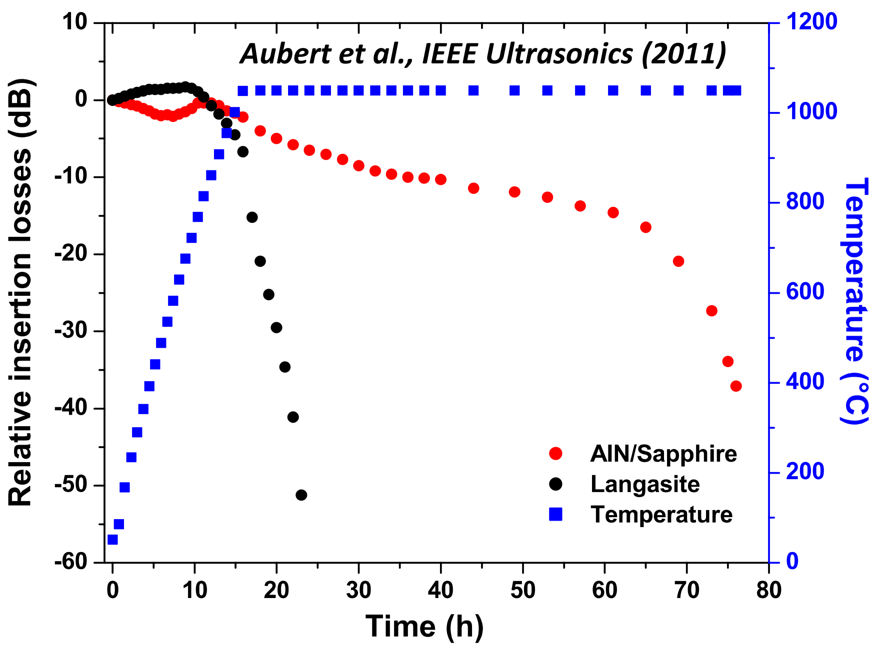


Beyond Langasite-based SAW sensors: AlN/Sapphire structure for high-temperature SAW applications

Suitability of AlN/Sapphire structure for HT SAW applications

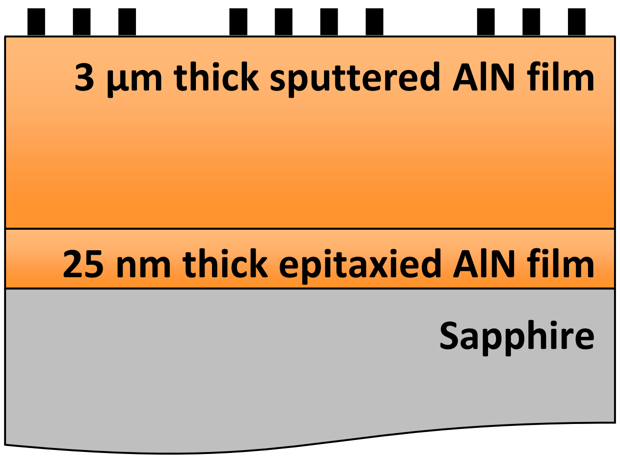




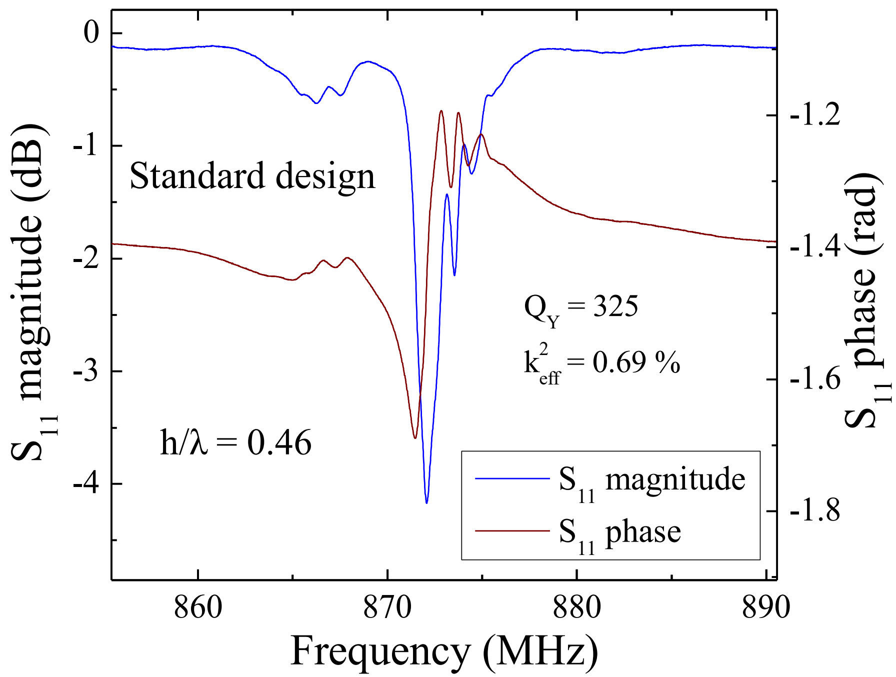


Towards an AlN/Sapphire-based SAW sensor

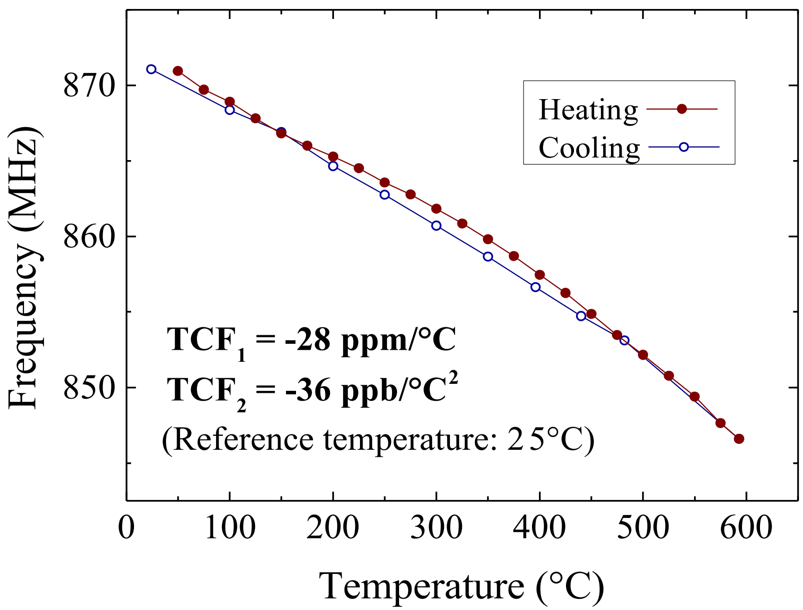
① *Growth of high-quality AlN films*



② *Synchronous resonator test*

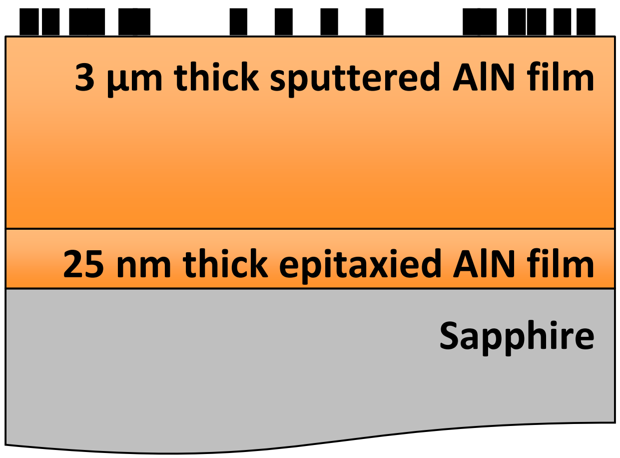


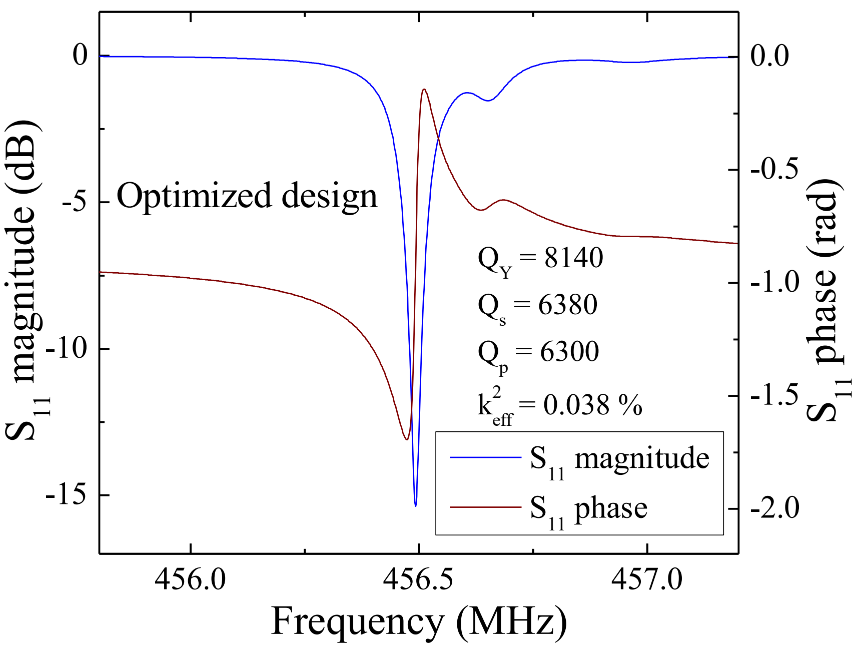
③ *High-temperature characterization*



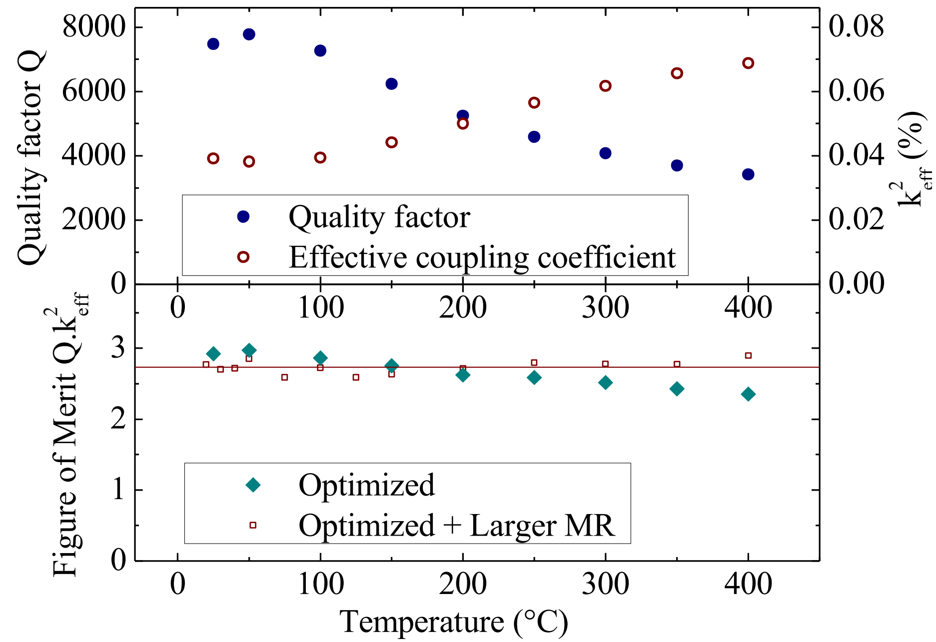
Towards an AlN/Sapphire-based SAW sensor

1 *Redesign of quasi-synchronous resonators*





2 *High-temperature characterization*



Towards an AlN/Sapphire-based SAW sensor

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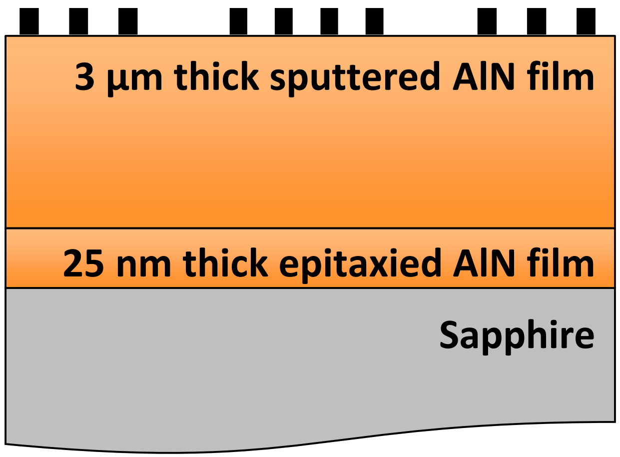

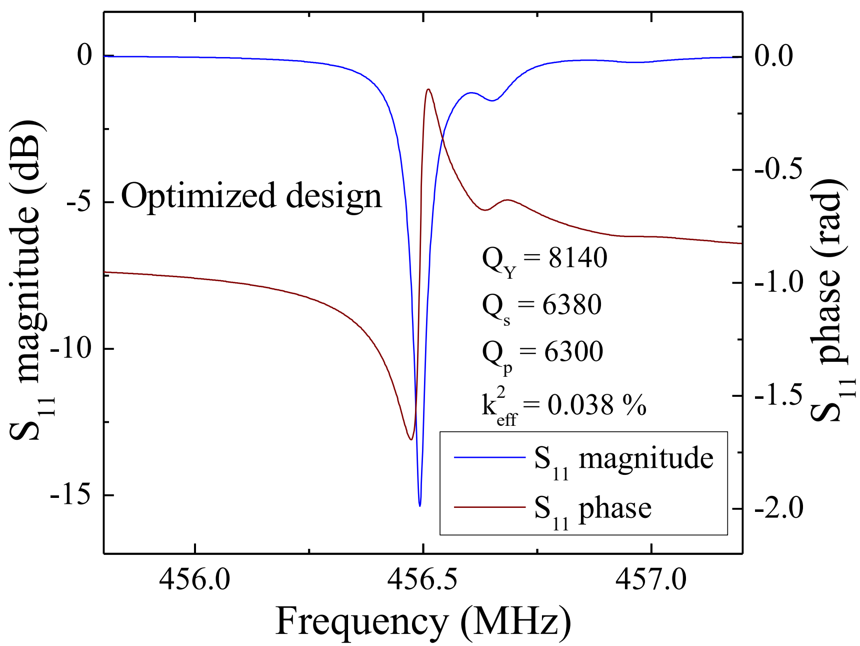

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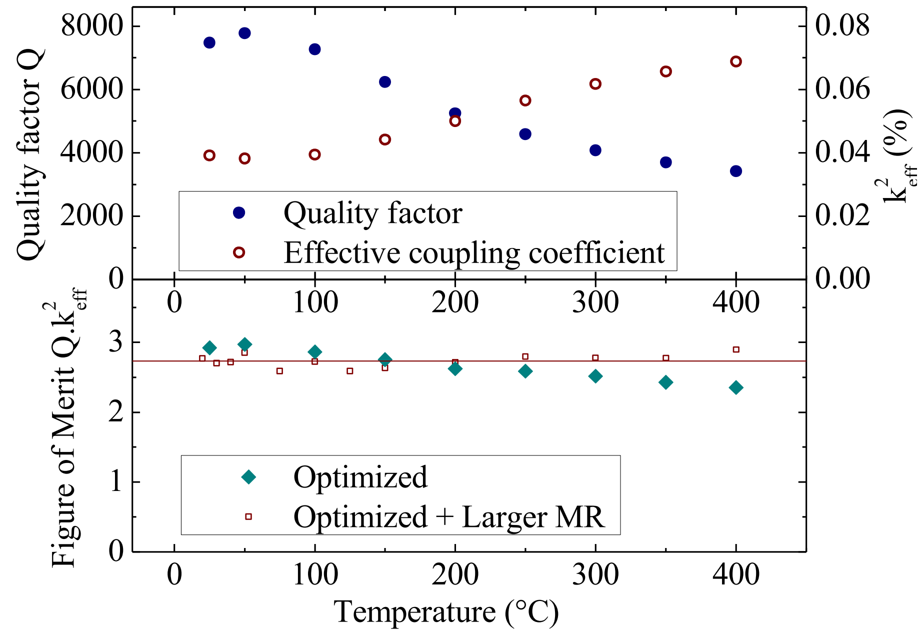


Perspectives

- ➢ Develop IDT material with high acoustic performance and good resistance to oxidation
- ➢ IDTs with higher metallization ratio perform better

↓

Larger and thicker IDT finger

↓

Larger wavelength

↓

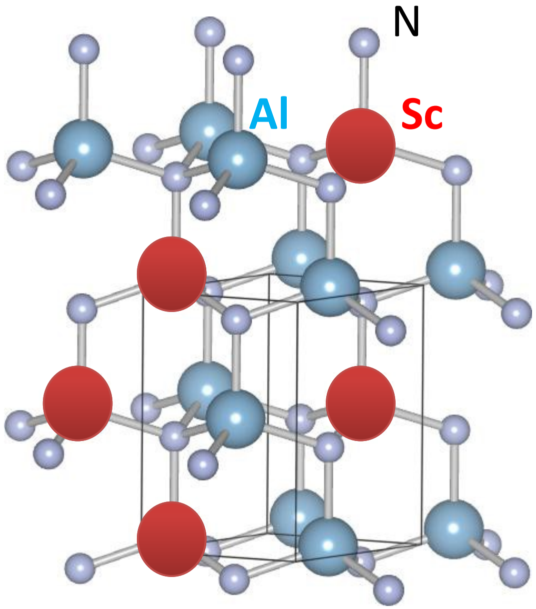
Substrate with higher acoustic velocity?

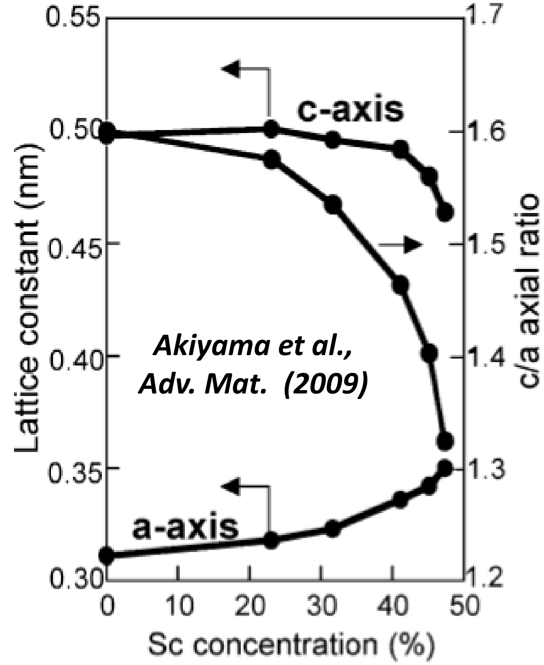
AlN/Sapphire 2.0

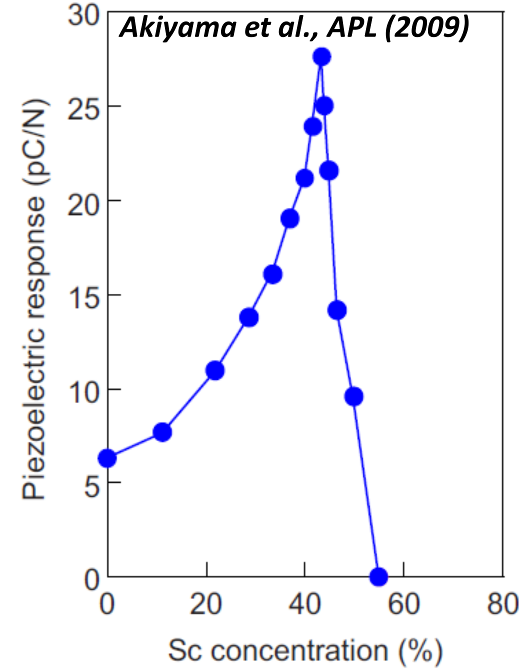
↓

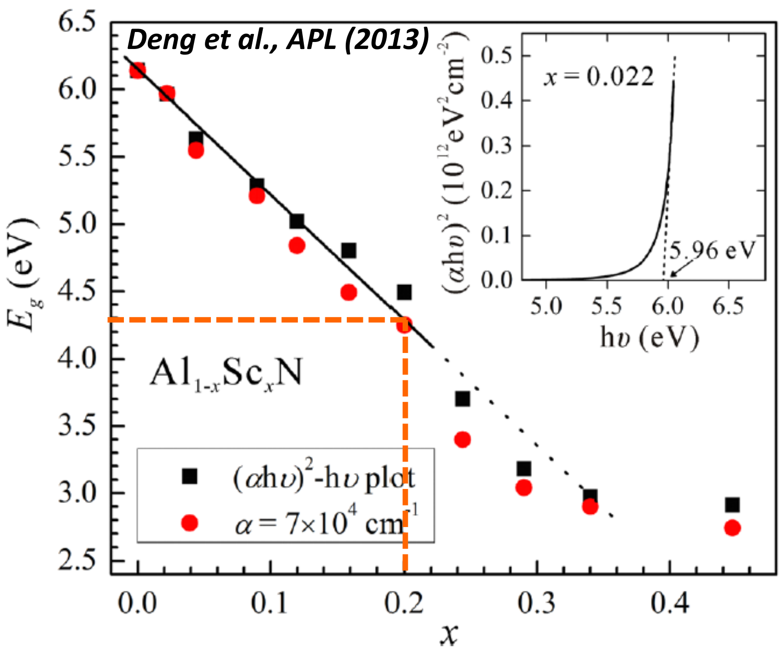
ScAlN/Sapphire?

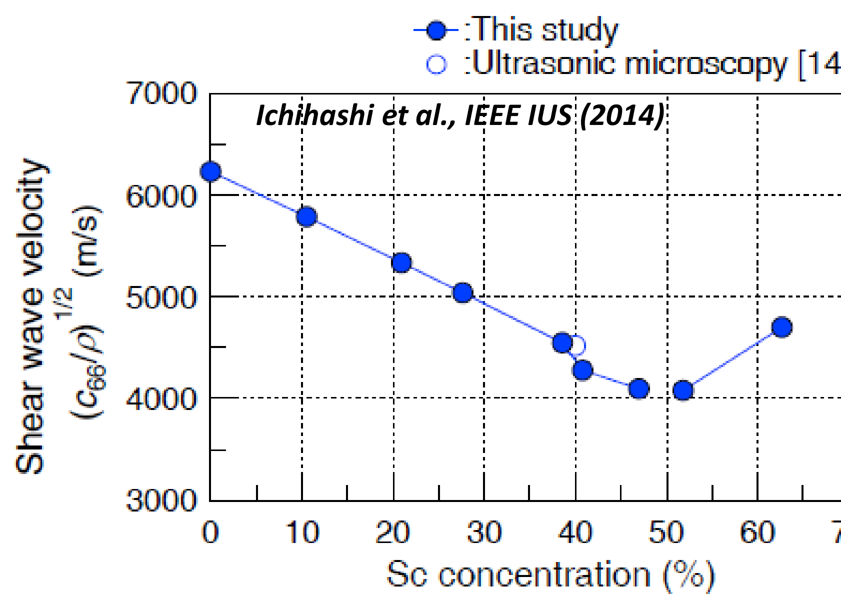
From AlN to $Sc_xAl_{1-x}N$ …



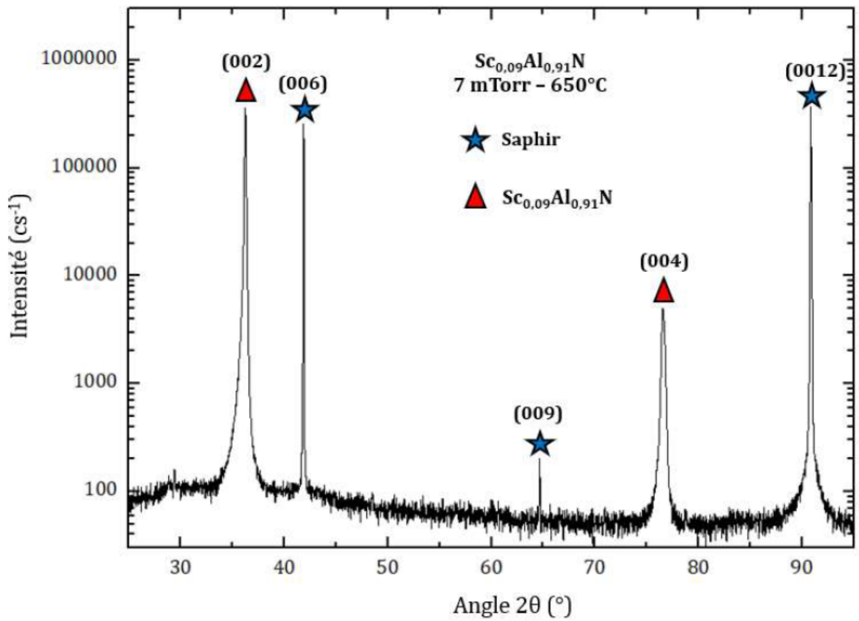


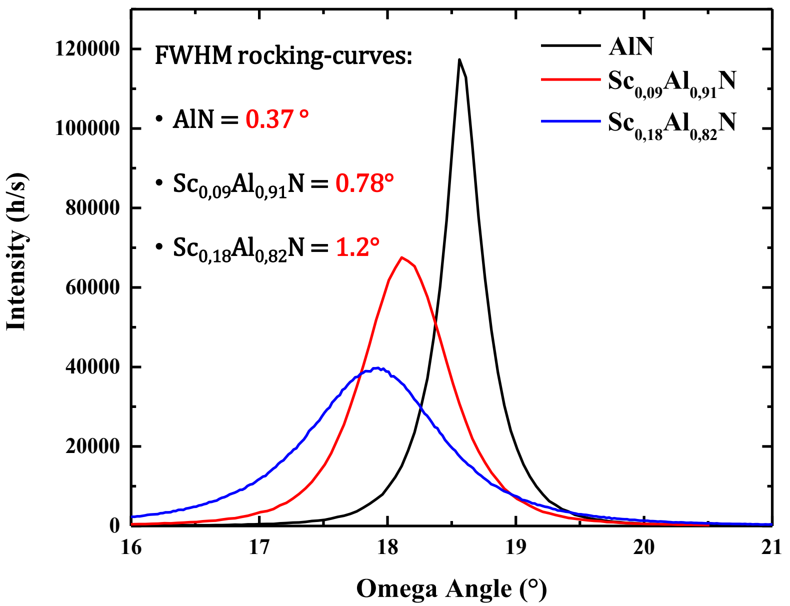






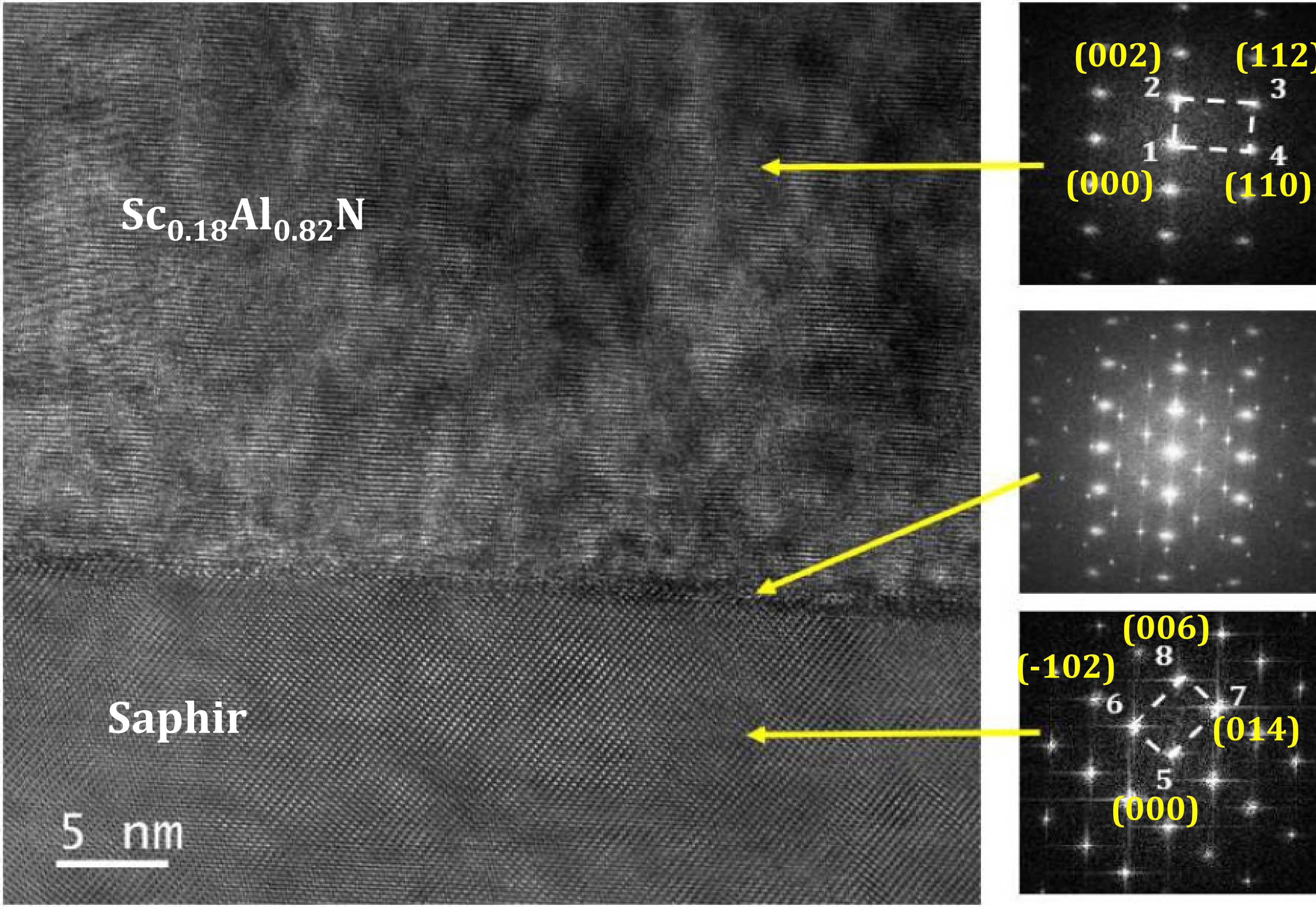
Highly-textured growth of ScAlN films on Sapphire by sputtering



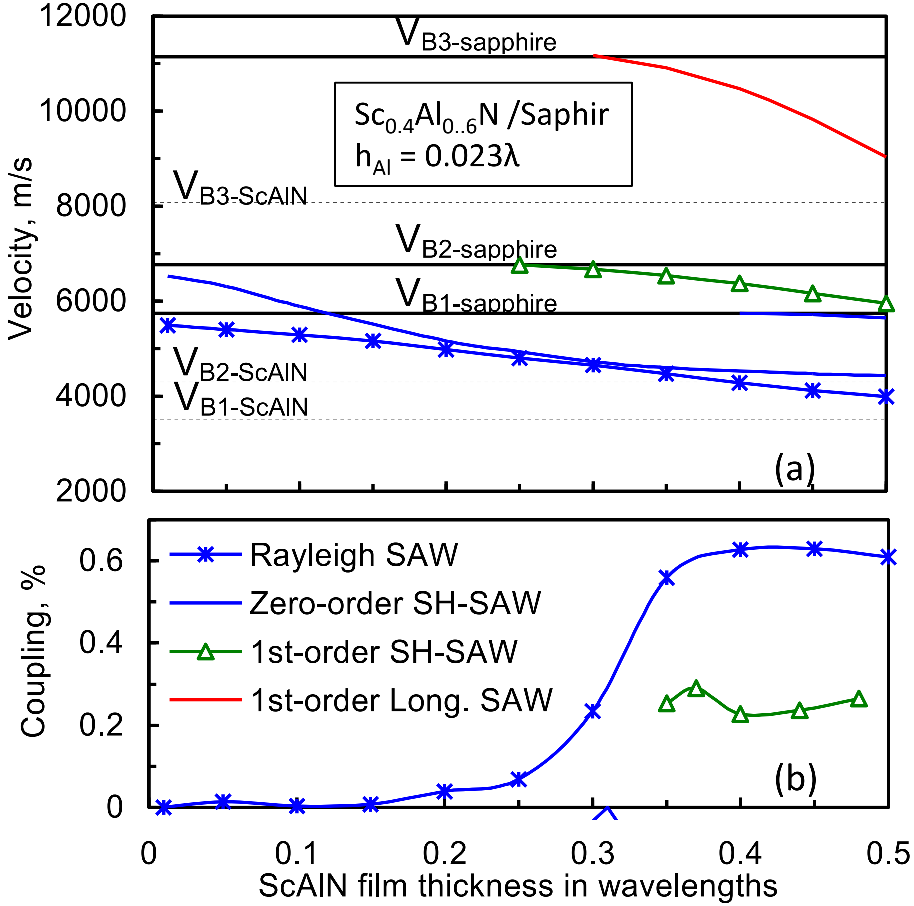


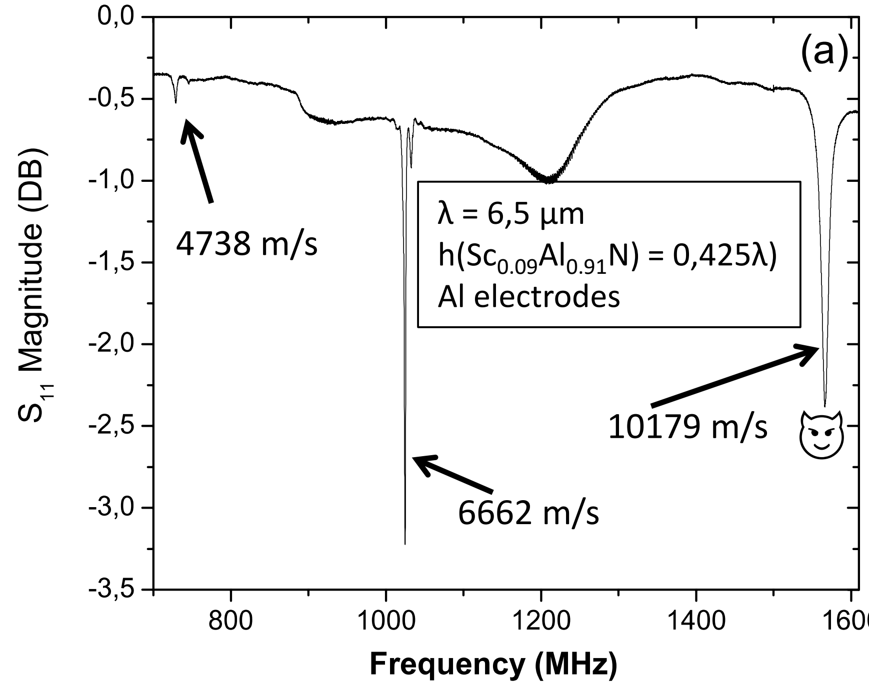
Equipe	Année	Taux Sc	FWHM rocking-curve
M. A. Moreira *et al.*	2012	9% et 15%	2,19° et 2,01°
J. Yhang *et al.*	2013	6%	3,5°
W. Wang *et al.*	2014	27%	0,36°
Y. Zhang *et al.*	2015	6%	2,5°
Li *et al.*	2016	10%	1,2°
V. V. Felmetsger	2017	7%	1,55°
M. D. Henry *et al.*	2018	12%	2,016°
Bartoli *et al.*	**2018**	**9% et 18%**	**0,78° et 1,2°**

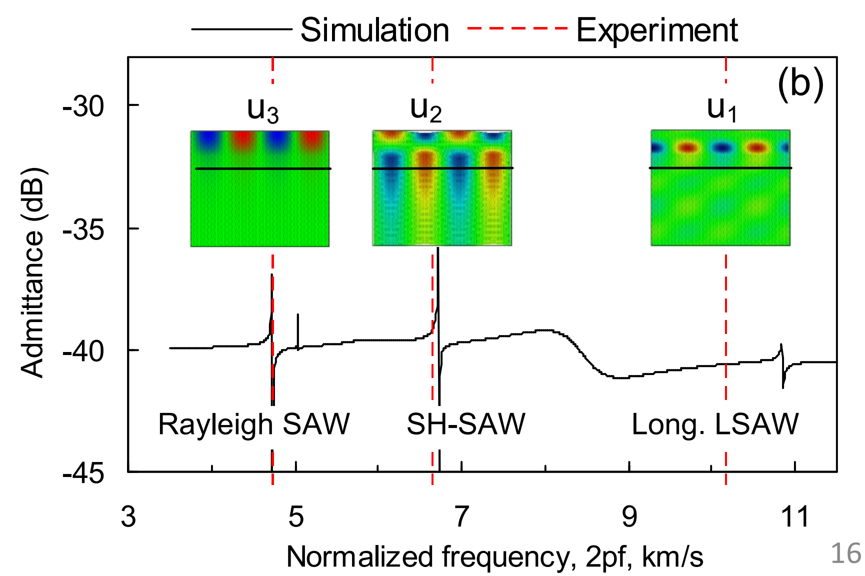
Highly-textured growth of ScAlN films on Sapphire by sputtering



SAW investigation of the $Sc_{0.09}Al_{0.91}N$/Sapphire structure





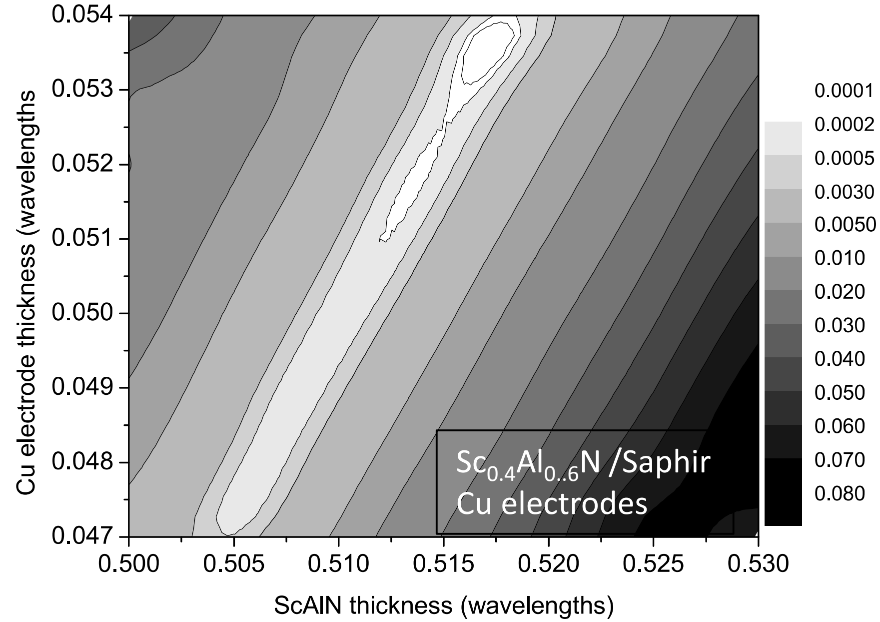


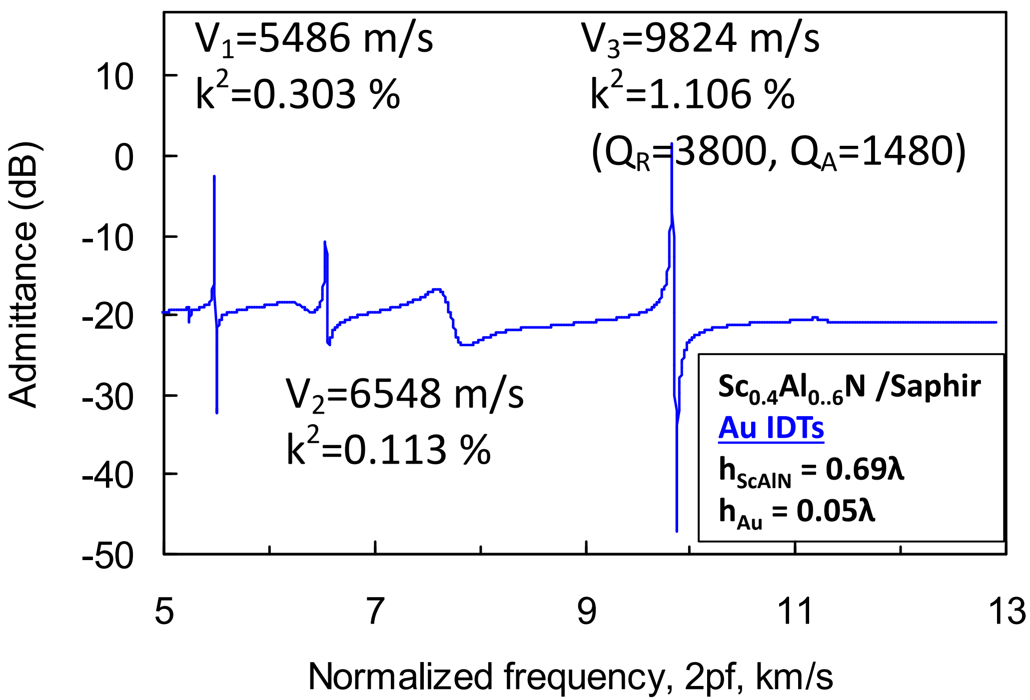
- Several modes can be generated in ScAlN/Sapphire:
  - Rayleigh SAW
  - SH-SAW
  - Longitudinal (leaky?) SAW

Can the longitudinal SAW mode be guided in surface??

Numerical simulations show that the attenuation of the longitudinal SAW mode can be minimized by a correct choice of:

- the electrode thickness
- the film thickness
- the electrode nature





Conclusion

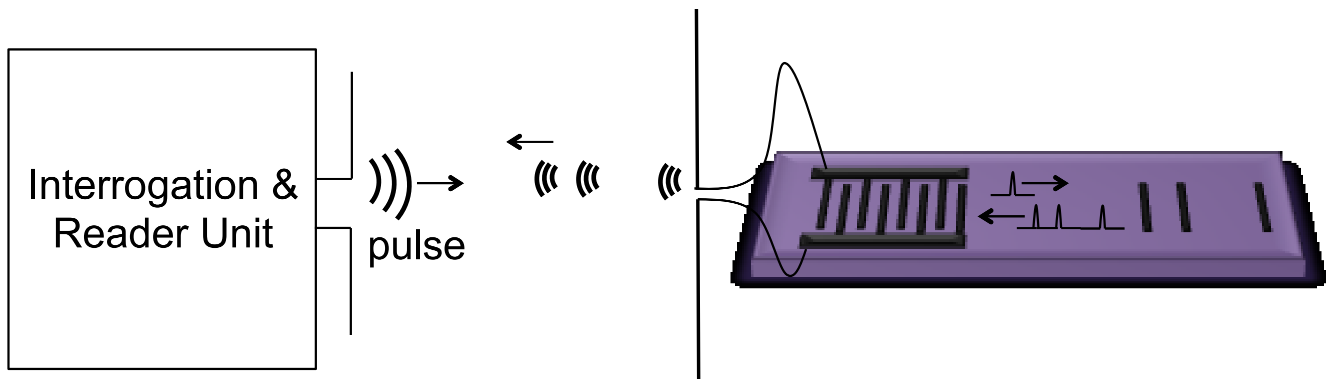
$Sc_xAl_{1-x}N$/Sapphire structures offer a unique combination for SAW high-temperature applications :

- **gap > 5 eV (pour x ≈ 0.1)**
- **k^2 > 1%**
- **v ≈ 10 000 m/s for robust IDTs**

Aubert et al., APL (2019)

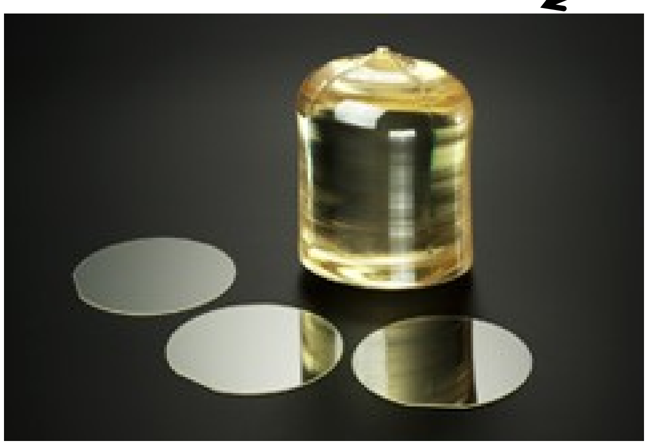
Stoichiometric lithium niobate crystals for high-temperature SAW applications

High-temperature SAW sensors & lithium niobate crystals

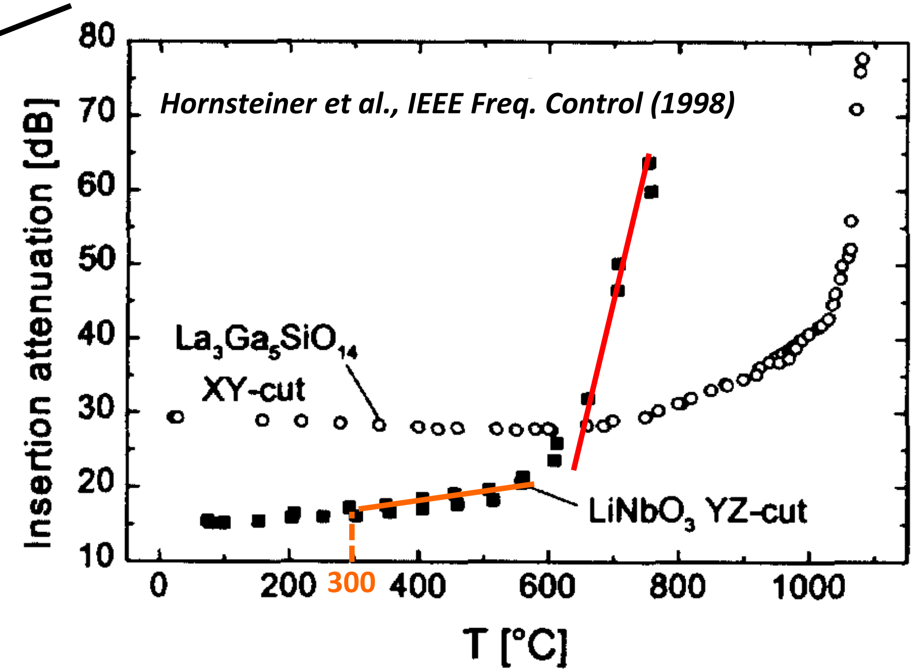


Reflective delay lines:

Identifiable but piezo crystal with high k^2 (some %) is required!

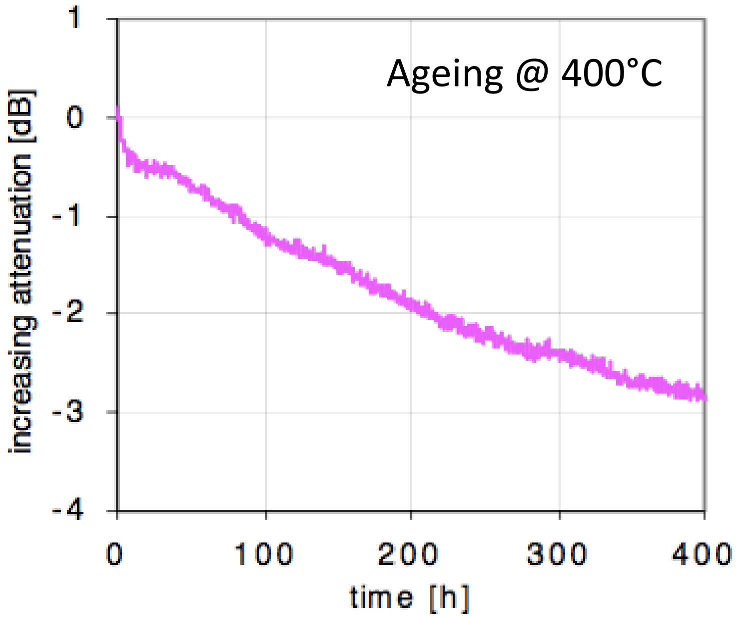


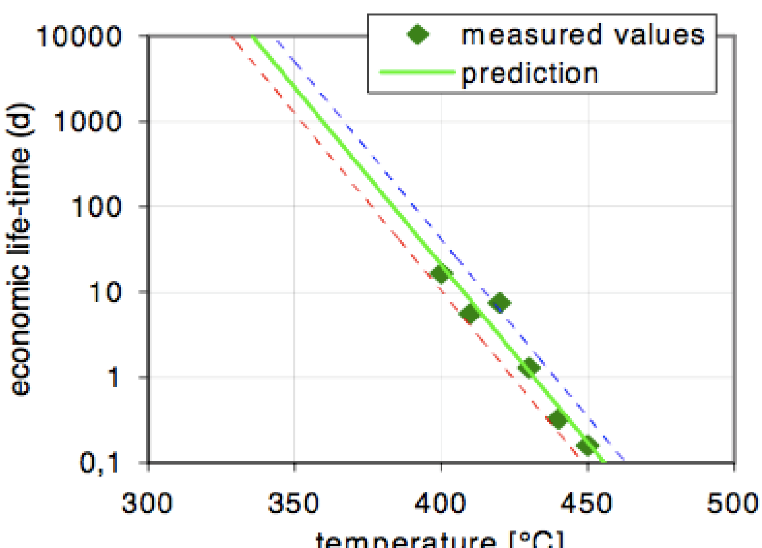
Congruent lithium niobate crystals



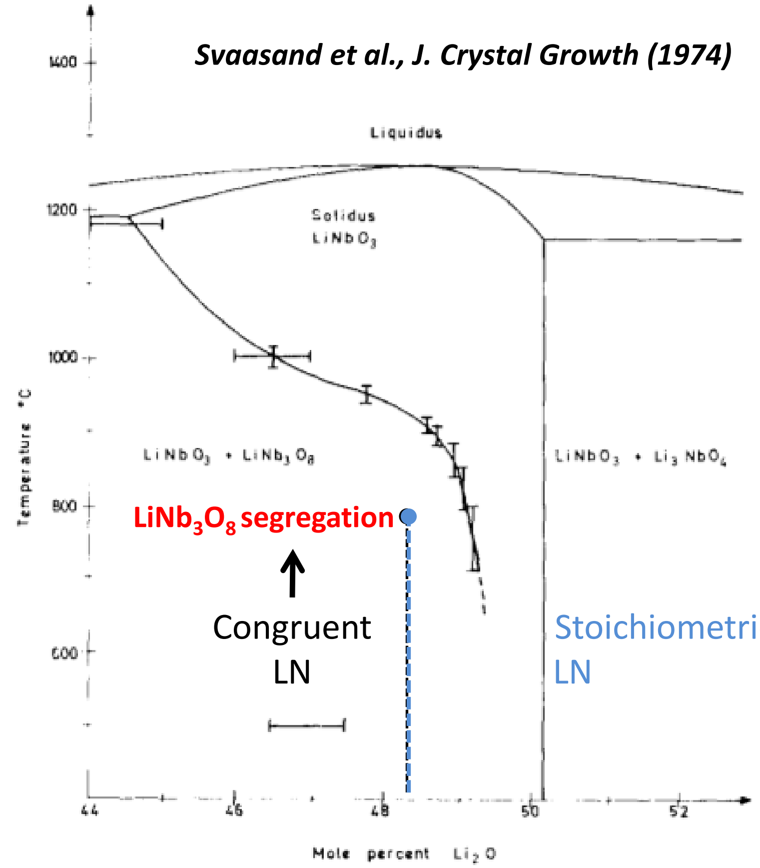
High-temperature SAW sensors & congruent lithium niobate crystals

Hauser et al., IEEE Ultrasonics (2003)



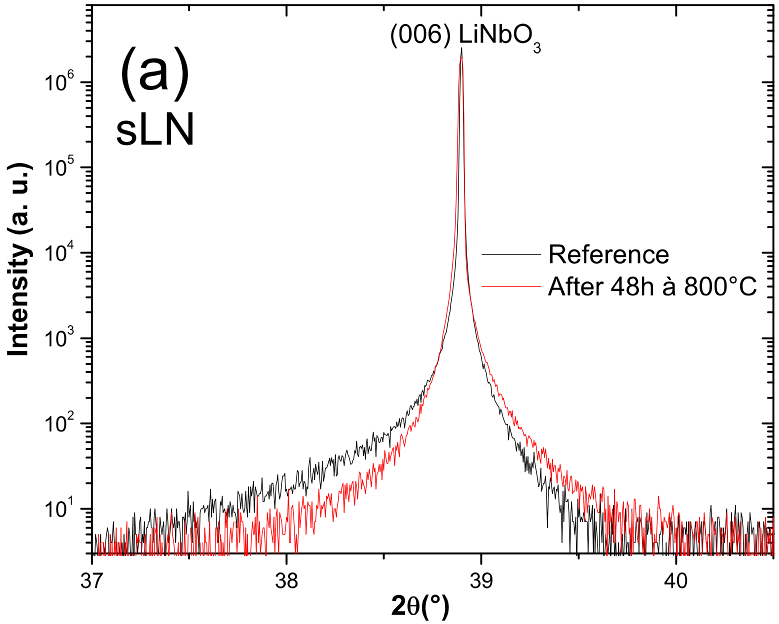


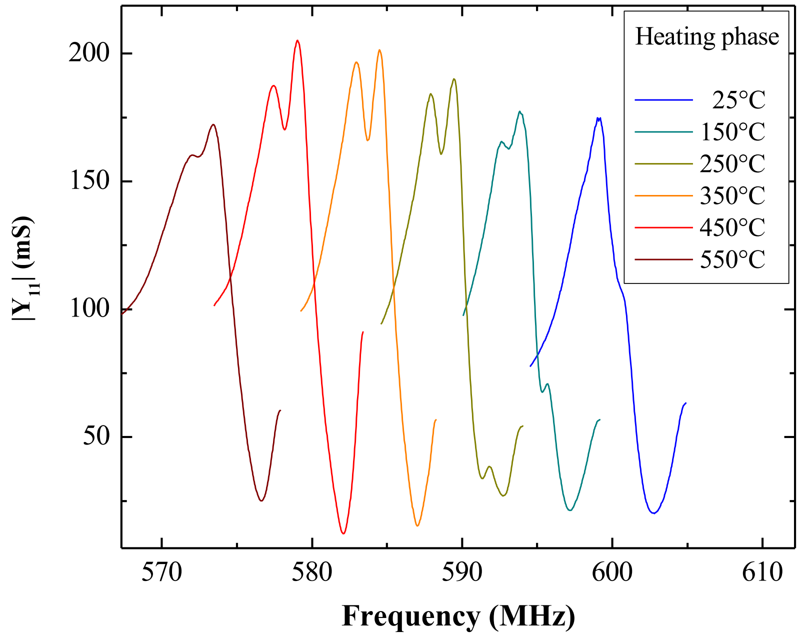
Svaasand et al., J. Crystal Growth (1974)

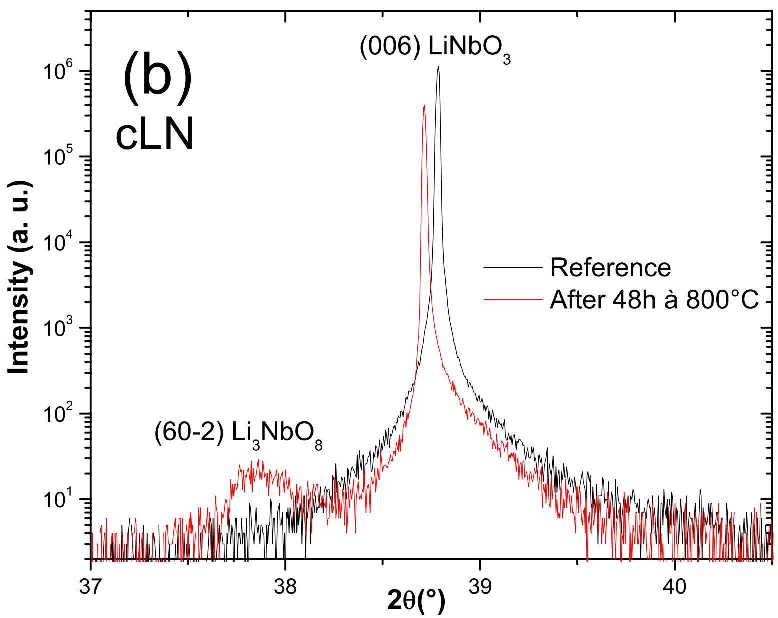


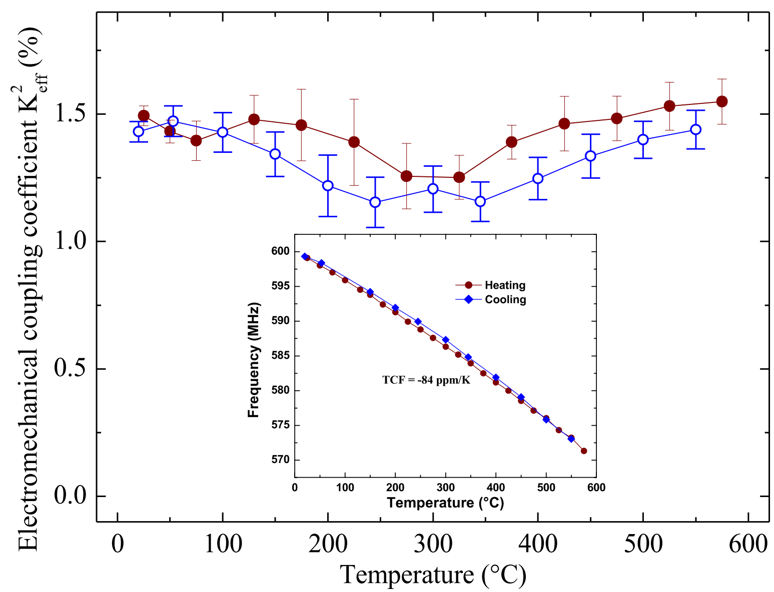
T	Lifetime
300°C	> 200 d
350°C	> 10 d
400°C	< 1 d

First investigations on stoichiometric lithium niobate crystals









Acknowledgments - Collaborators

- French team (LMOPS – IJL)

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F. Bartoli

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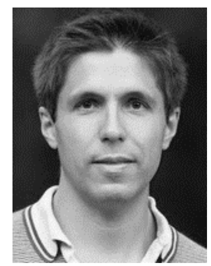

J. Streque

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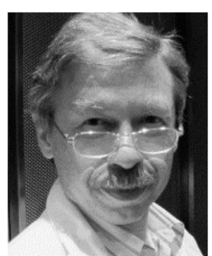
N. Naumenko

P. Nicolay



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