ScAlN/Si SAW devices for surface acoustic wave/spin wave coupling

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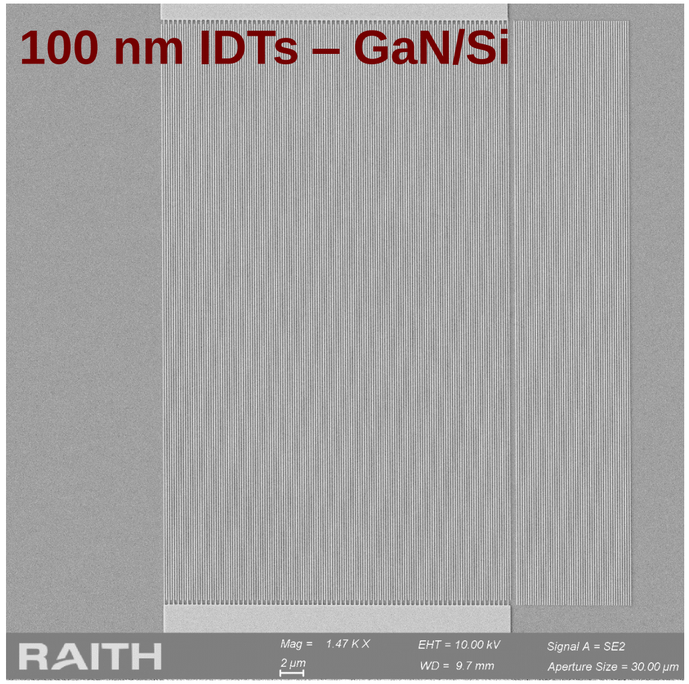
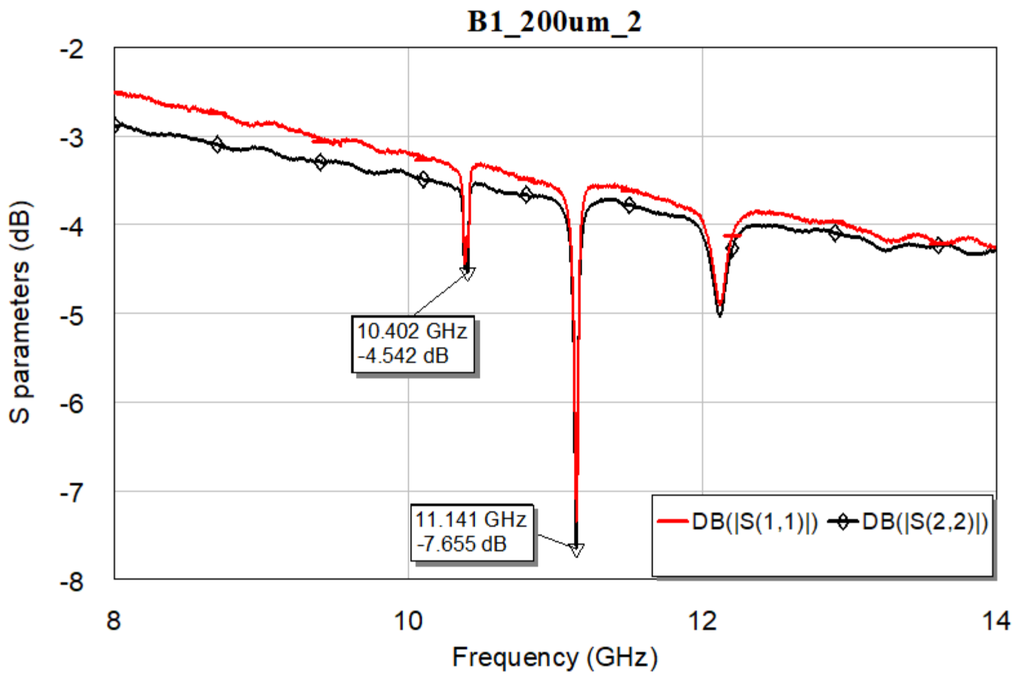
Outline

- **Motivation**
- **SAW devices on ScAlN/Si**
- **Coupling of surface acoustic waves with spin waves**
- **Conclusions**

Motivation – SAW devices

- Surface acoustic wave (SAW) devices on WBG semiconductors represent one of the building blocks of the modern electronics attracting great attention due to their sensing capabilities and suitability for on-chip integration with other devices
- Advanced nano-lithographic technologies can be applied on III Nitride materials and resonance frequencies **up to about 10 GHz** can be obtained on SAW structures



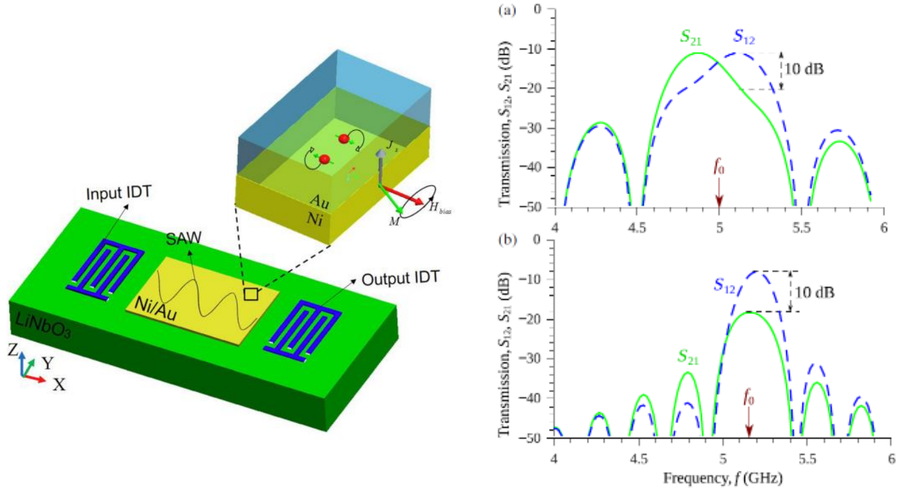


Results on GaN/Si obtained in IMT-Bucharest, 2020

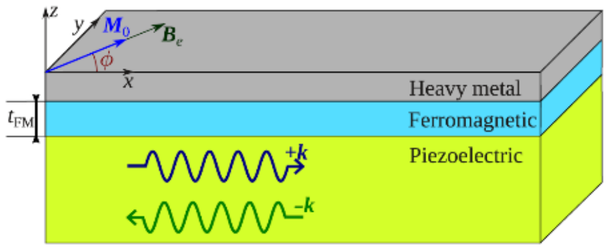
- SAW in GHz frequency range are strong candidates for phonon-qubit-coupled systems with applications in quantum computing architectures

Motivation – SAW devices

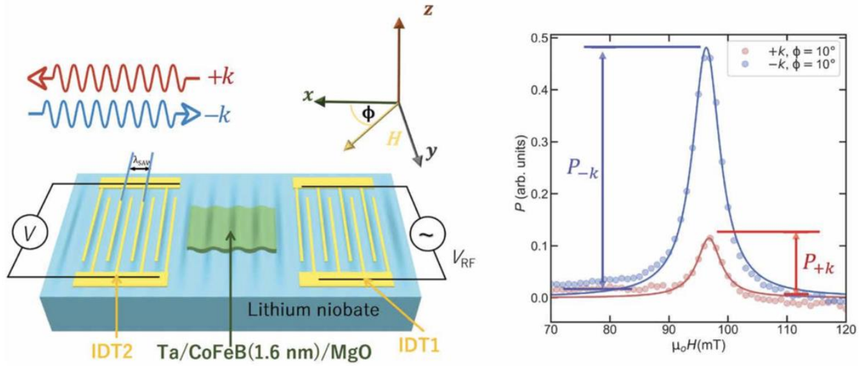
- Most of the works which demonstrate the SAW/SW coupling have used lithium niobate - higher order (and low amplitude) harmonics need to be used in order to fit the SAW resonance to the ferromagnetic resonance, reducing the coupling efficiency.
- Recent experiments have demonstrated that the propagation of SAWs in piezoelectric substrates can be controlled by a thin magnetic layer placed atop the substrate.
- It has been shown that SAWs propagating in a $LiNbO_3$ substrate covered by a thin Ni film demonstrated some degree of non-reciprocity.



Xu Li et.al., JOURNAL OF APPIED PHYSICS 122, 043904 (2017)



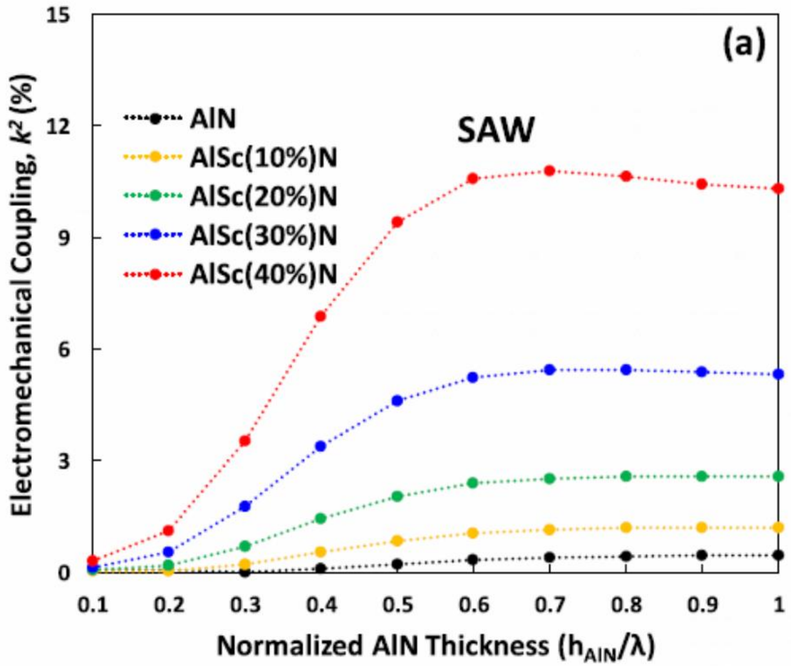
R. Verba et.al., PHYSICAL REVIEW APPLIED 9, 064014 (2018)



M. Xu et al., Science Advances 6, eabb1724 (2020).

Motivation – ScAlN

- Scandium-doped AlN (ScAlN) is considered a novel ultra-wide bandgap material, representing a solution for the next generation of wireless standards (5G communication systems) which target super high frequencies
- ScAlN thin films became very attractive against pure AlN due to their higher piezoelectric constants (up to 4-5 times larger for 40% Sc doped)
- High coupling coefficient, k_{eff}^2 and Q-factors, surpassing reported values for other group III-nitrides
- CMOS compatibility maintained



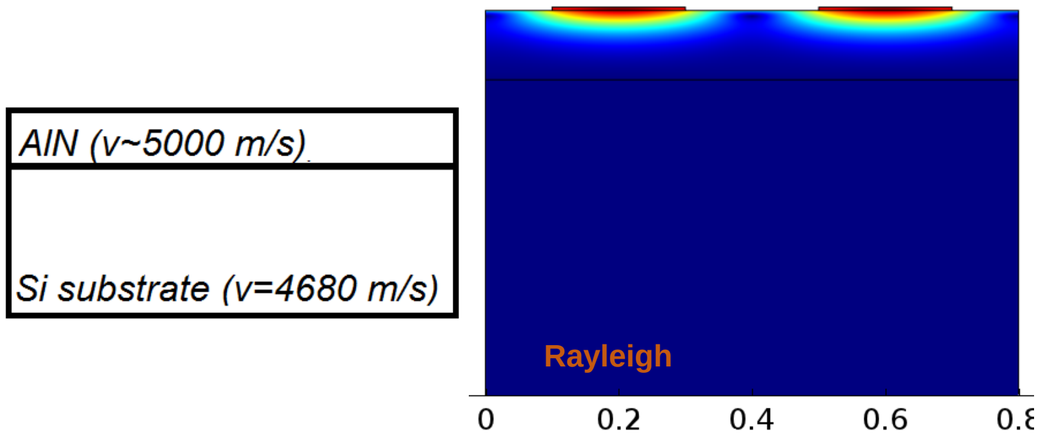
M. Park, et. al, J. Microelectromechanical Syst. 29 (2020) 490–498.

Motivation – ScAlN

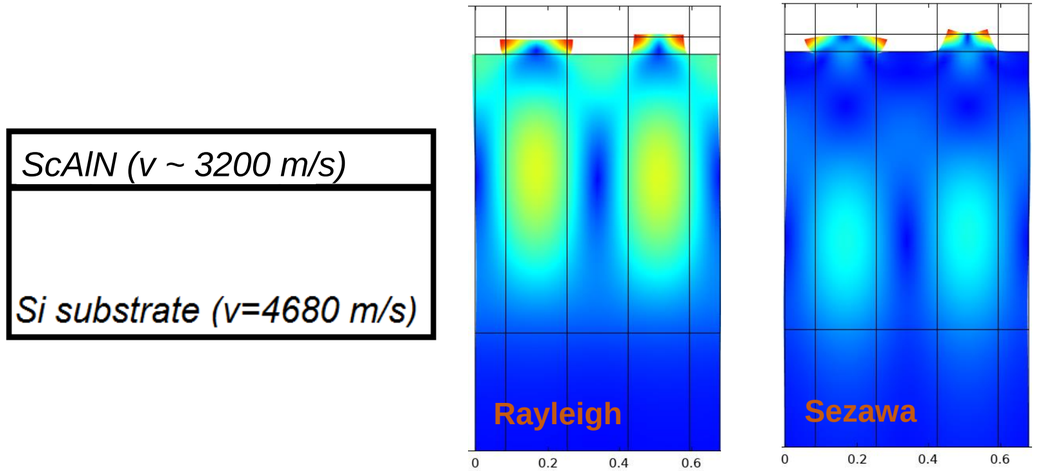
- **Higher order Rayleigh modes, called Sezawa modes can appear** - only if the value of bulk transverse velocity in the substrate, v_{ts}, is higher than transverse velocity in the over-layer (v_{tl}) and for a restricted number of values of the film thickness normalized by the wavelength (h_{ScAlN}/λ)

AlN/Si layered structures - "Fast on Slow" (FonS) type

Only Rayleigh mode



ScAlN/Si layered structures - "Slow on Fast" (SonF) type

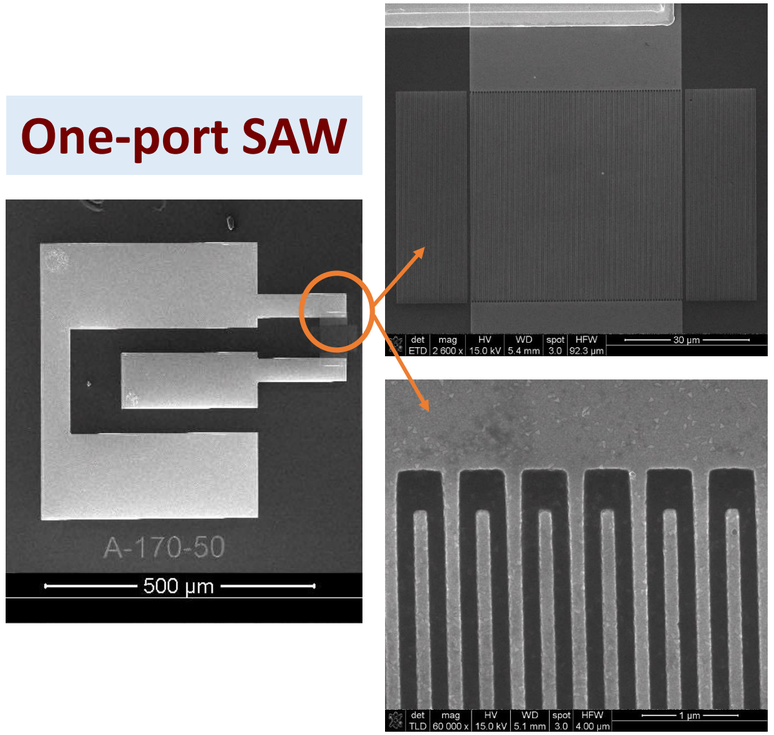


- ***A. Müller, A. Nicoloiu,*** *et. al, International Microwave Symposium 2018, 10-15 June 2018, Philadelphia, USA, session WEIF: Interactive Forum #2, pp938-941*
- ***A. Nicoloiu****, et. al, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, Vol. 68, no. 5, May 2021*

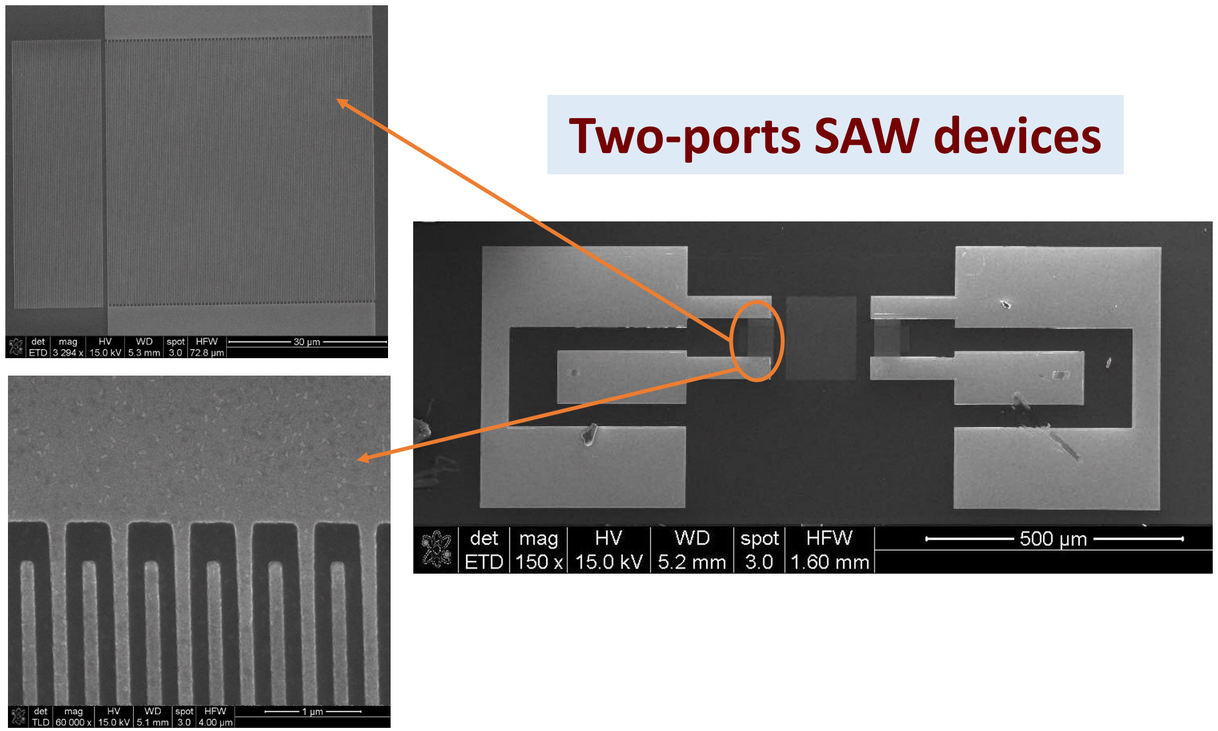
SAW Devices on ScAlN/Si

- ScAlN (30% Sc doped) deposited on HR Si wafers with **Solmates** Pulsed Laser Deposition Equipment (SMP-800)
- IDTs width - 170 nm by e-beam nanolithography (IMT – Bucharest); Ti/Au metallization

One-port SAW



Two-ports SAW devices

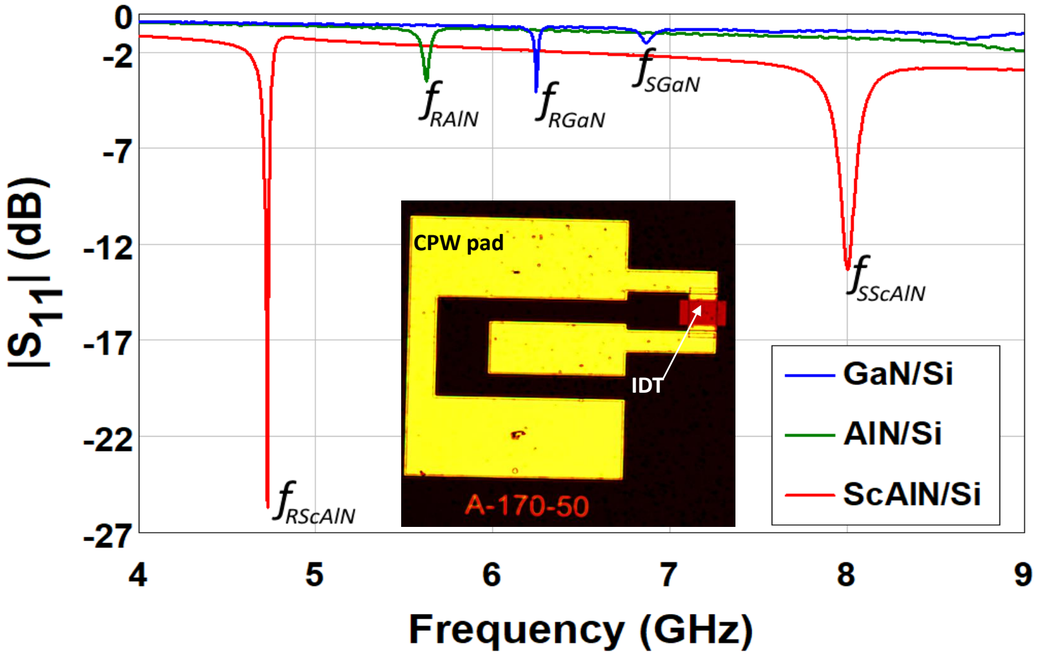


SAW Devices on ScAlN/Si

SAW device substrate	Performance parameters – SAW devices w_{IDT} = 170 nm					
	Rayleigh mode			Sezawa mode		
	f_R [GHz]	Q	k_{eff}^2 [%]	f_S [GHz]	Q	k_{eff}^2 [%]
ScAlN	4.7	957	2.3	8.07	140	4.77
GaN*	6.25	747	0.78	6.86	101	1.89
AlN*	5.6	165	1.9	-	-	-

A. Nicoloiu, et. al, in IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, Vol: 68, Issue: 5, pp. 1938 – 1948, May 2021.

** Thickness: ScAlN 0.8 µm; GaN 1.2 µm; AlN 1 µm

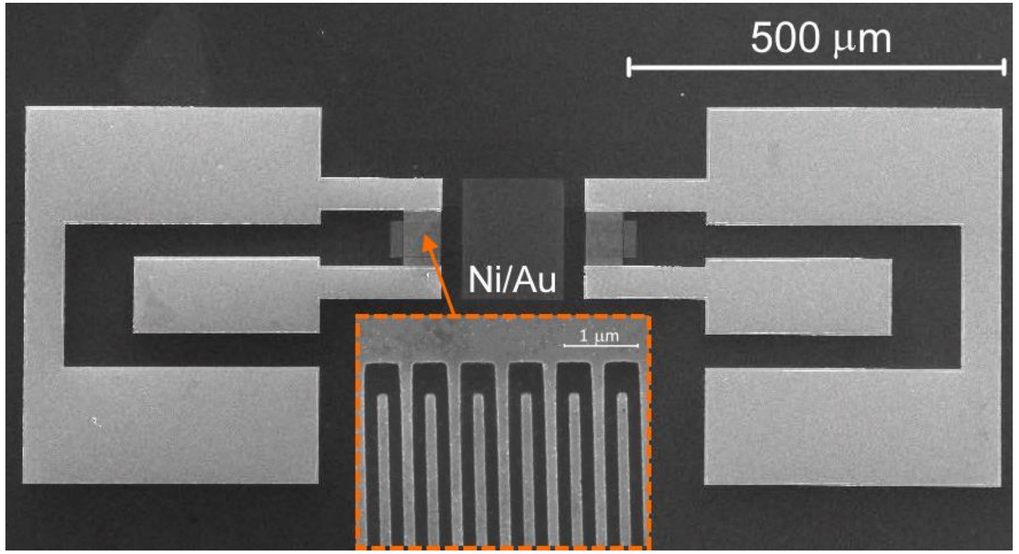


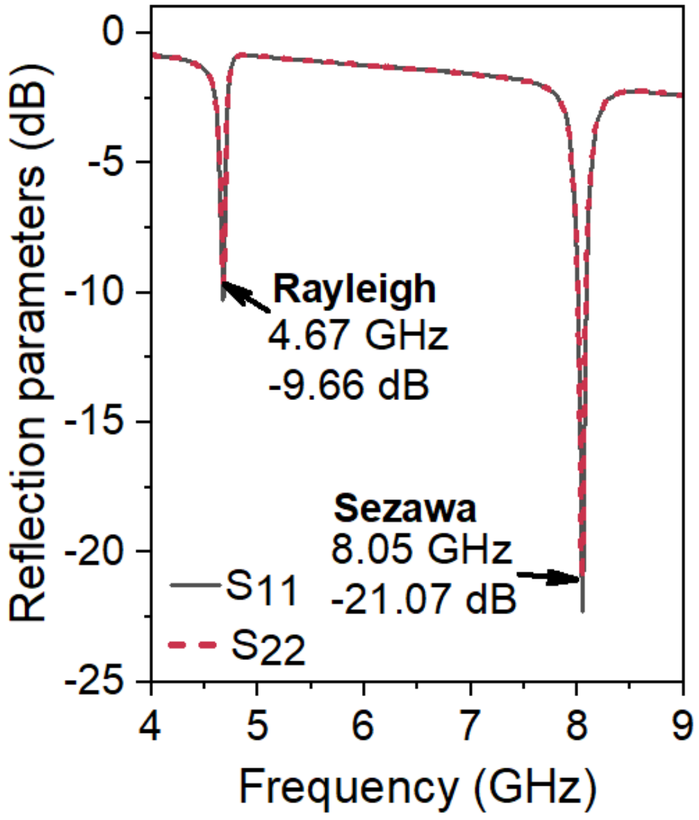
$$k_{eff}^2 = \frac{\pi^2}{4}\left(1 - \frac{f_s}{f_p}\right)$$

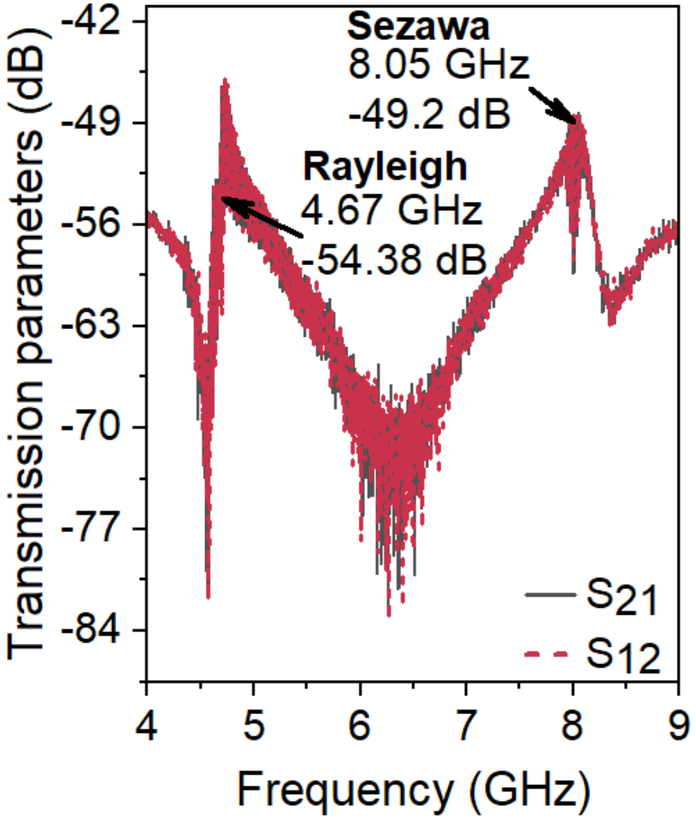
Results presented in:
A. Nicoloiu, et. al, "*Novel ScAlN/Si SAW-type devices targeting surface acoustic wave/spin wave coupling*", 2021 International Semiconductor Conference (CAS), 2021, pp. 67-70

Magnetic field measurements

- SAW with w_{IDT}=170 nm; distance between IDTs 200 µm;
- Ni/Au – 12/3 nm between the IDTs







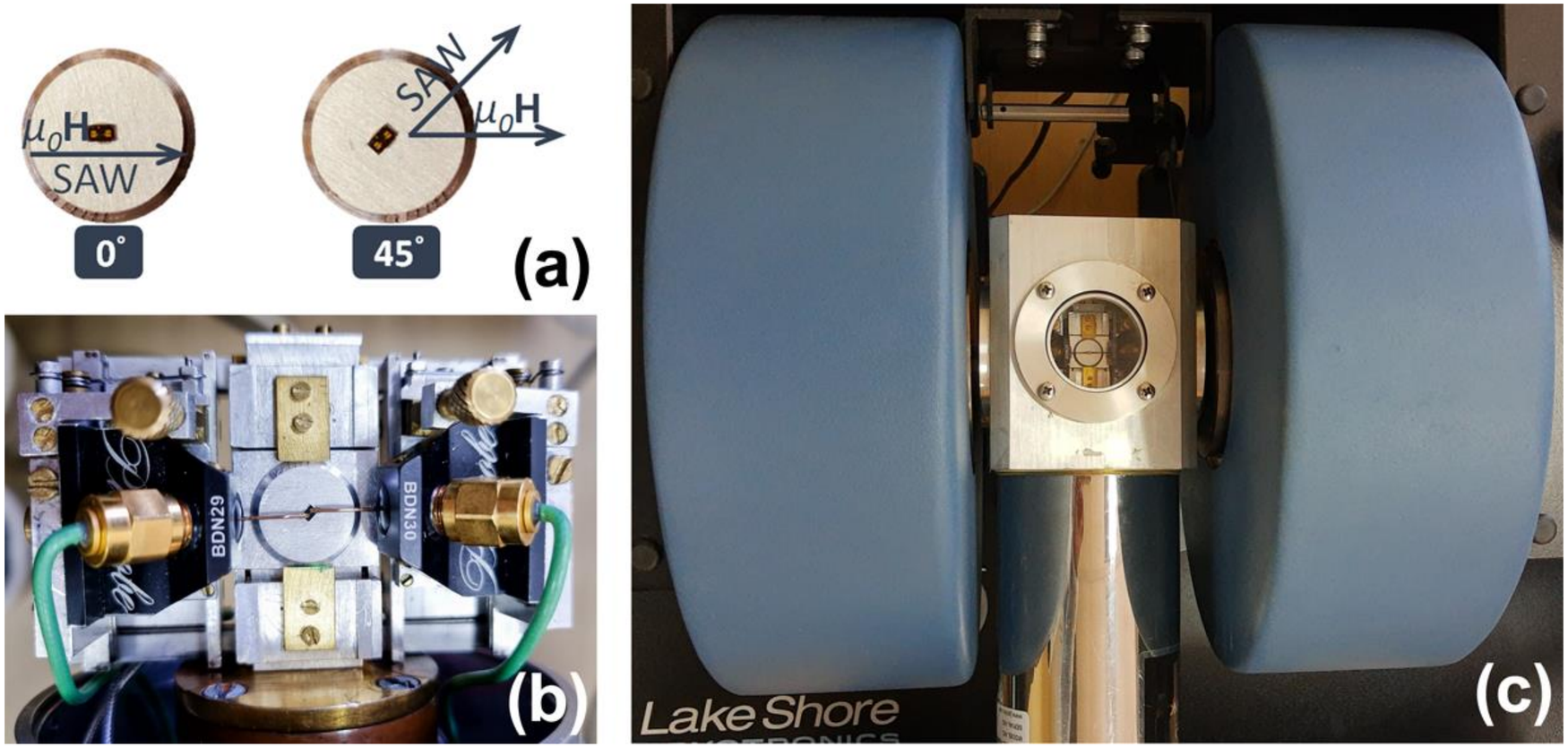
Rayleigh:
Q=366 $\mathbf{k_{eff}^2 = 2.4\%}$

Sezawa:
Q=671 $\mathbf{k_{eff}^2 = 5\%}$

Paper in review at IEEE Electron Device Letters: I. Zdru, C. Nastase, L. Hess, F. Ciubotaru, A. Nicoloiu, D. Vasilache, et al., "*A GHz operating ScAlN based SAW resonator used for Surface Acoustic Waves/Spin Waves Coupling*", TechRxiv. Preprint. https://doi.org/10.36227/techrxiv.19486781.v1

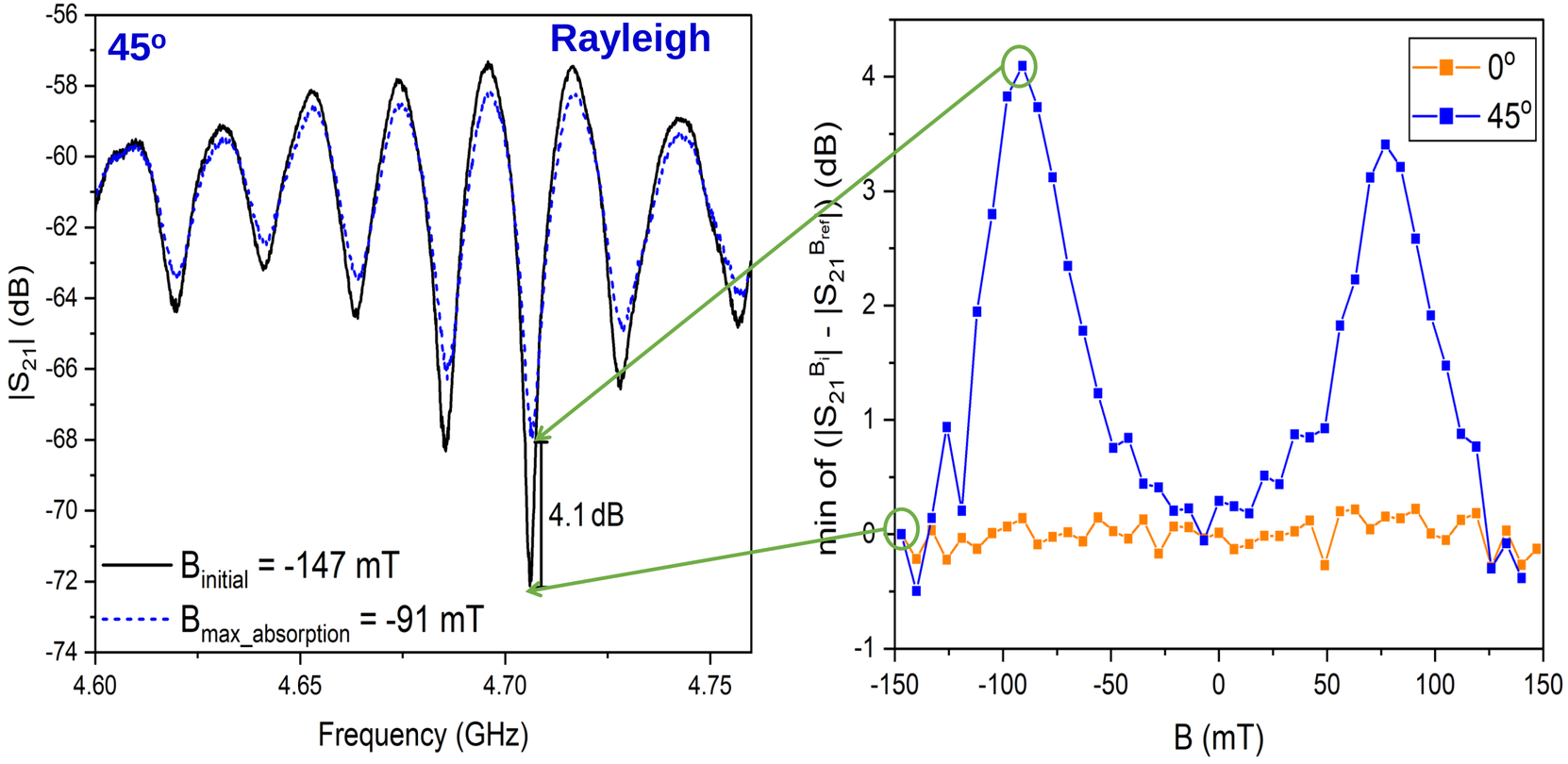
Magnetic field measurements

- The measurements were performed in **magnetic field, at different angles (θ: 0°, 10°, 25°, 35°, 45°)** to the SAW propagation direction
- Cryostat from Janis (which ensures a controlled temperature and pressure during measurements). The cryostat is placed between the two poles of an electromagnet.
- Room temperature
- Non-magnetic probes



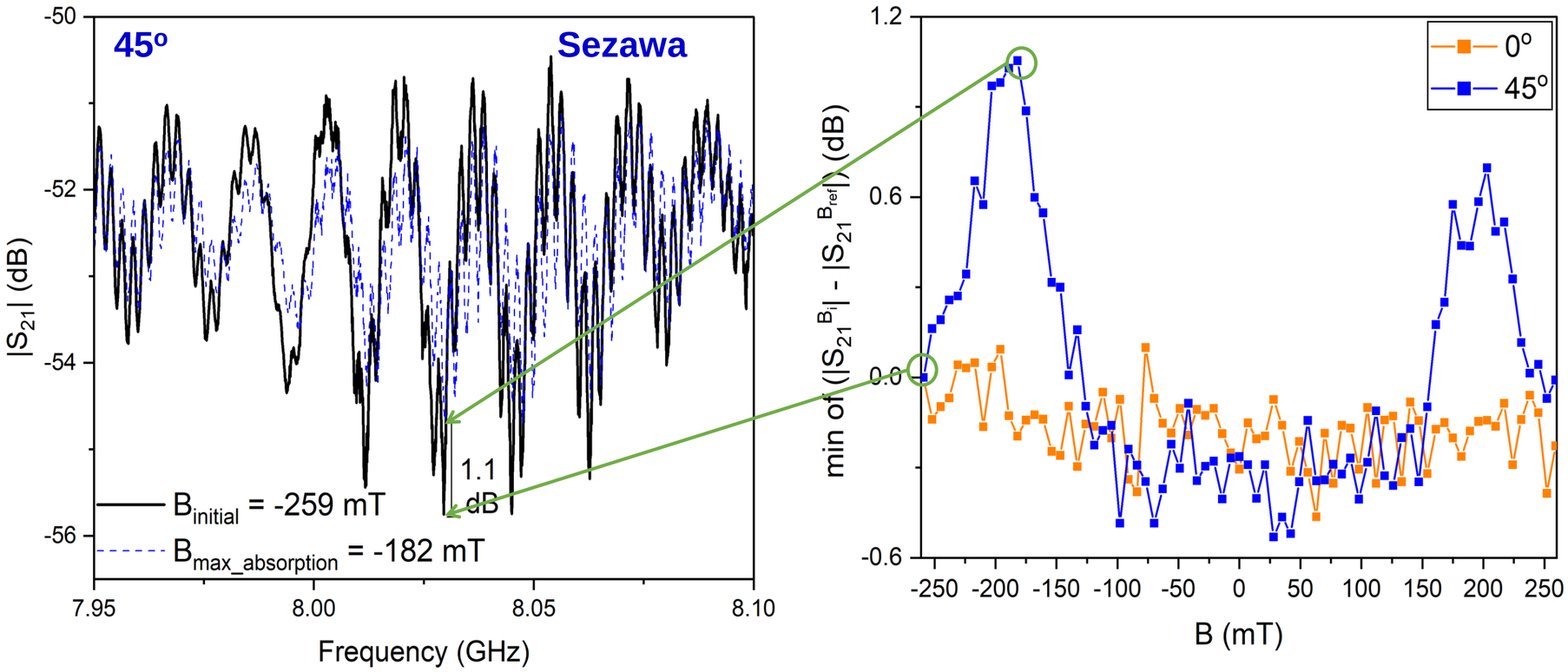
Coupling of SAW to SW

- Measurements performed between -147 mT and +147 mT
- Measured S_{21} vs. frequency, at θ = 45°, for the Rayleigh
- Two different values of the applied magnetic field, B: the reference value, -147 mT and the value where the maximum absorption was observed, -91 mT.



Coupling of SAW to SW

- Measurements performed between -259 mT and +259 mT
- Measured S_{21} vs. frequency, at θ = 45°, for the Sezawa mode
- Two different values of the applied magnetic field, *B*: the reference value, -259 mT and the value where the maximum absorption was observed, -182 mT.



Conclusions

- Novel SAW structures with resonance frequencies higher than 4.6 GHz (Rayleigh) and 8 GHz (Sezawa) were manufactured on Sc(30% doped)AlN on Si.
- Enhanced Q and k_{eff}^2 were obtained compared to other SAW devices on WBG semiconductors.

- SAW/SW coupling was demonstrated for the first time with GHz operating SAW devices manufactured on ScAlN/Si using the fundamental Rayleigh and also the superior Sezawa mode.

- Future work will be focused on a detailed analysis of nonreciprocity as well as on optimization of the ScAlN/Si SAW structures for SAW/SW coupling, including alternative magnetostrictive metallization.

Acknowledgements

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