SAW devices for GHz applications based on nanoprocessing of GaN/Silicon

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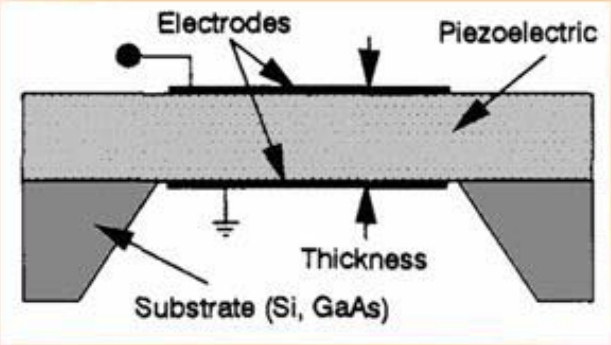
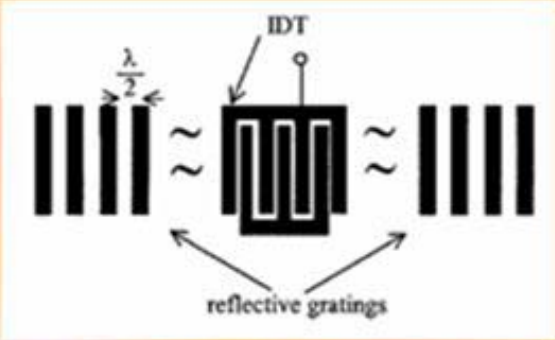
Acoustic resonators

FBAR



SAW



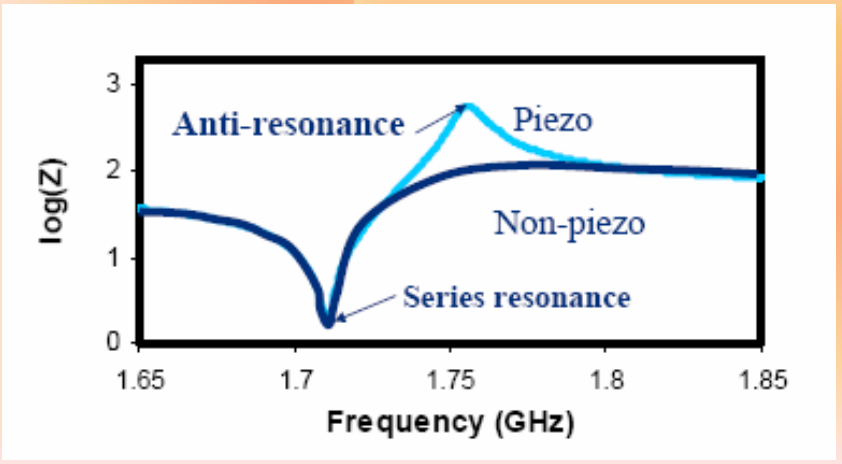
$d = \lambda/2 = v_s/2f_r$ (resonance)

$2w = \lambda/2 = v_s/2f_r$

$f_r = v_s/2d$

$f_r = v_s/4w$;

v_s~km/s; d, w ~ μm ; f_r ~ MHz …..GHz



Resonance **occurs when the input impedance is at a minimum and** ***anti-resonance*** **occurs when it is at a maximum.**

Acoustic devices in the GHz range obtained by micromachining and nanoprocessing of the WBG semiconductors – AlN and GaN

Why to increase the operating frequency?

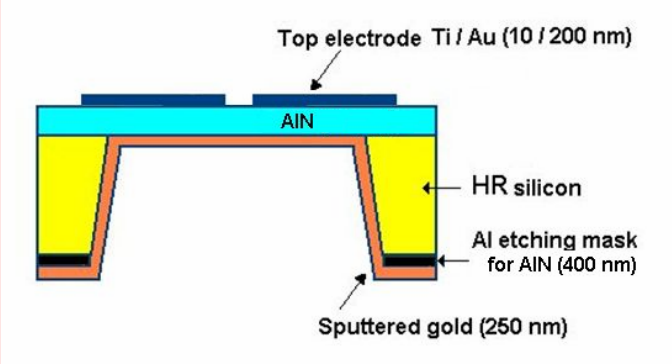
- **Mobile telephony is going from 3G to 4G. It is expected that the 4G systems to work in the 3 - 6 GHz frequency range.**
- **Sensors based on SAW and FBAR structures have the sensitivity ~f^2**

- **Clasical technologies for SAW rezonators and filters based on non-semiconductor materials (quartz, lithium niobate) are limited at frequencies < 2 GHz**
- **Most of the FBAR structures reported in the last years, were manufactured on ZnO, material incompatible with monolithic integration**
- **Using technologies based on WBG semiconductors (GaN/Si) acoustic devices working in the GHz range, can be monolithic integrated with other circuit elements (including HEMT transistors), in wireless circuits.**

- ***FBAR structures operating in the GHz frequency range can be obtained using micromachining techniques of AlN/Si and GaN/Si***

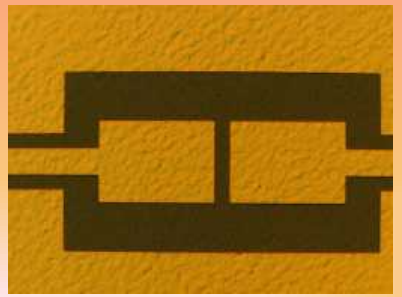
- ***SAW resonators for GHz frequencies on AlN/Si and GaN/Si having IDTs obtained by nanolithographycal techniques (fingers and interdigits 100–300 nm wide),***

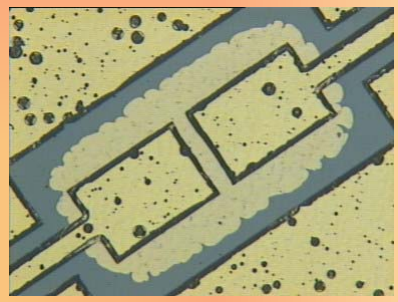
First FBAR structures manufactured on GaN /Si (2006-2008)



Cross section of the FBAR structure with the evaporated Ti/Au for the top metallization and sputtered Au for the bottom contact. Sputtered Al is used as mask for the bulk-micromachining of the membrane

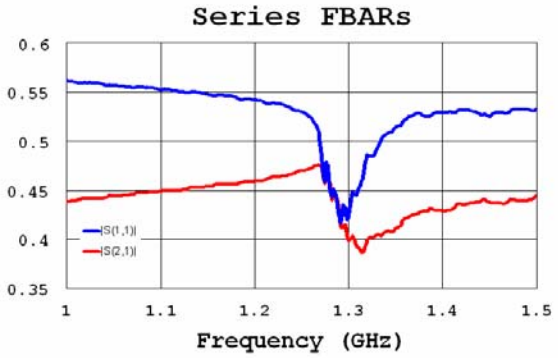
First GaN membrane FBAR structures





GaN membrane supported series connection of two FBAR structures (test structures)

The thickness of the membrane was 2.2μm



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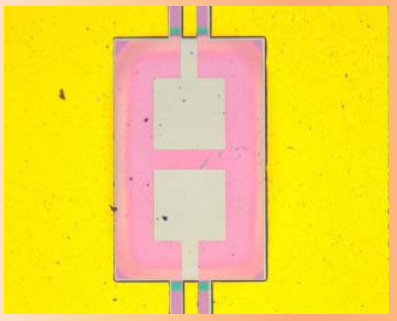
GaN FBARs obtained by micromachining of GaN/Si

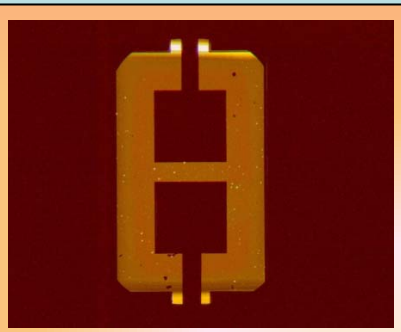
IMT and FORTH
July 2008

-340 nm (GaN) +200nm (buffer) thin membrane supported FBAR structure based on GaN micromachining

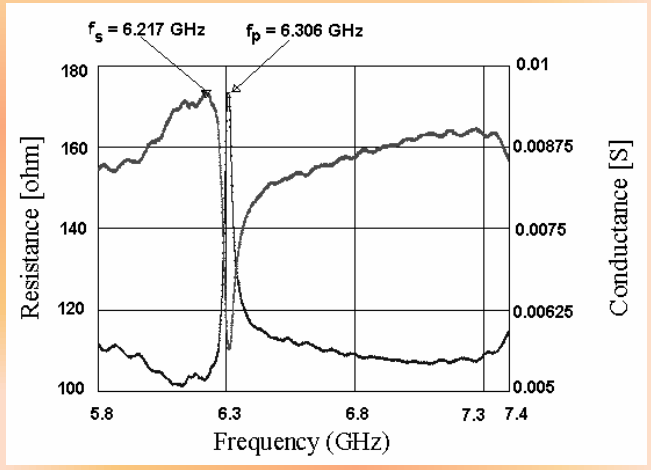
-50nm thin Mo metallization *GaN/Si wafers from NTT AT Japan*

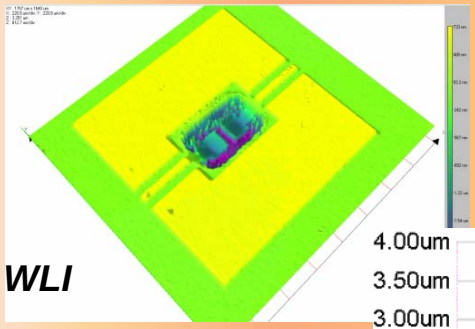


Top view with top illumination

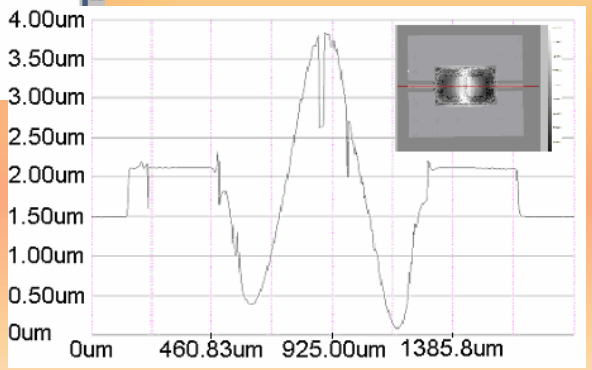


Bottom view with top illumination

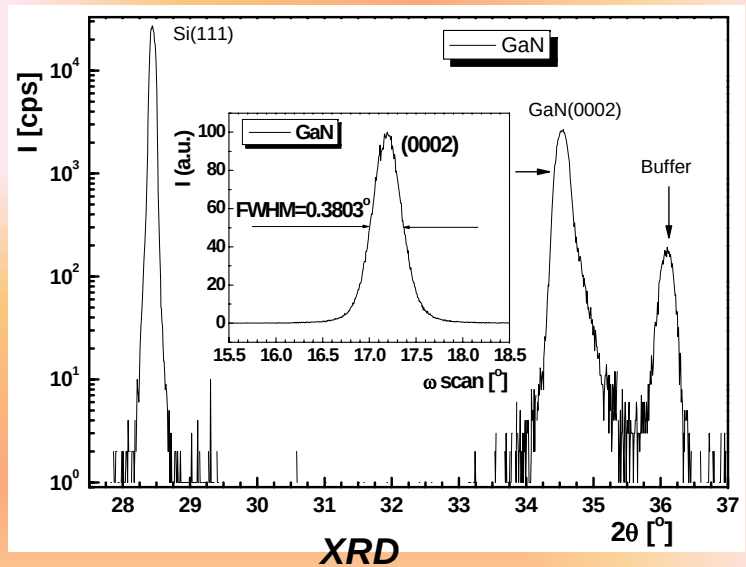




WLI



Maximum deflection 2.7μm

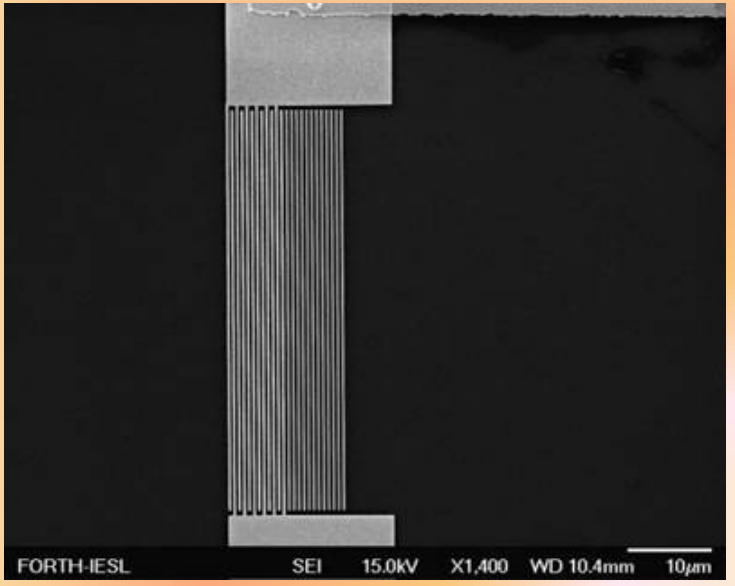


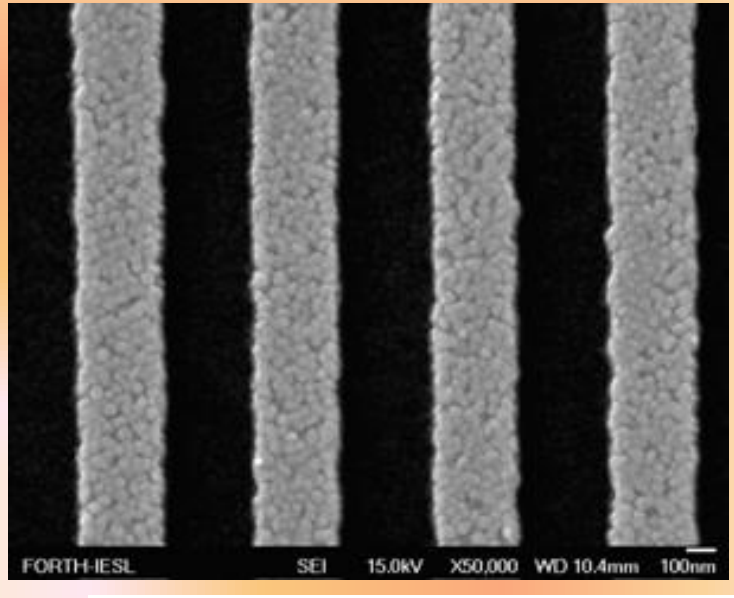
XRD

$\varepsilon = \Delta c/c_o = 1.9*10^{-3}$

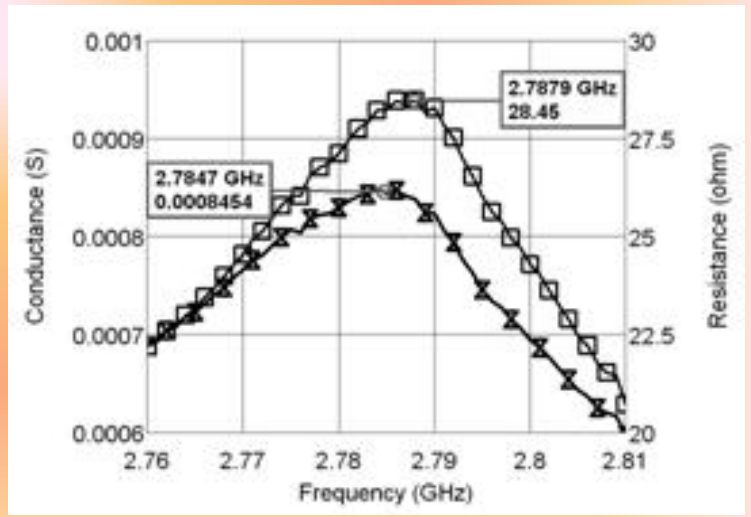
SAW devices for GHz applications with nanolithographic IDTs
First results obtained on AlN

AlN





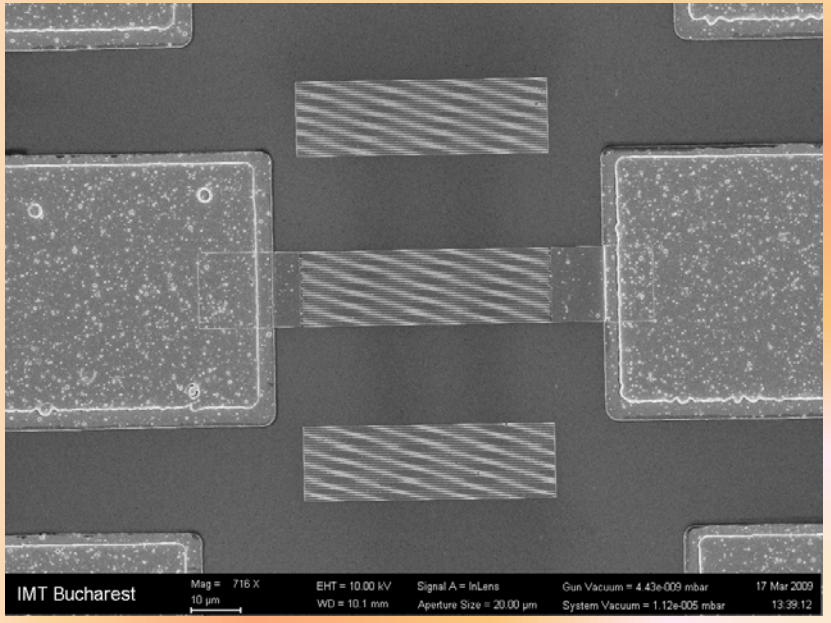
Experimental AlN SAW structure for GHz applications manufactured and measured at IMT-Bucharest . Fingers and pitches with a width on 300 nm have been obtained with the nanolithographic equipment (Vega-SEM and Elphy Plus EBL



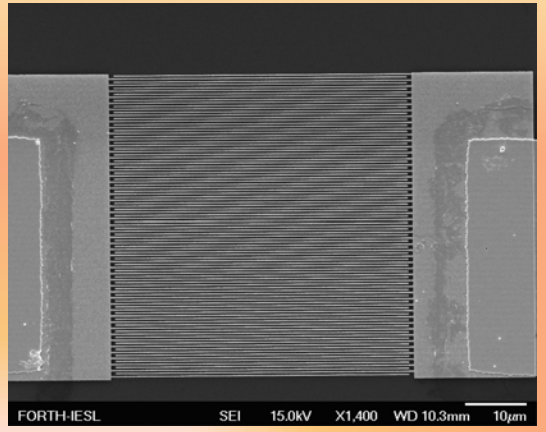
IMT-FORTH-NIMP 2007

AlN/Si SAW structure with and without reflectors

IMT- FORTH-NIMP 2009

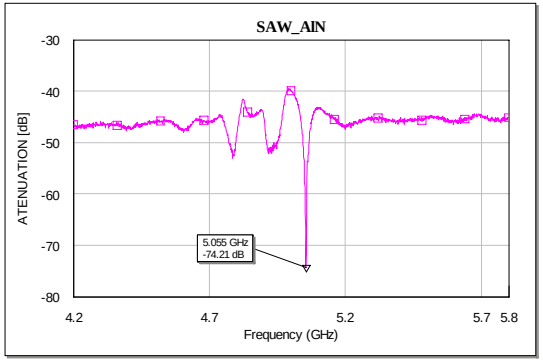


Series connection of SAWs (detail) (w=250nm)



Fingers and interdigits 250nm wide

AlN on silicon was deposited by magnetron sputering at NIMP



Best results obtained up to now:

SAW device operating in the 5 GHz range, based on AlN/diamond, obtained with electronic lithography was reported [*P. Kirsch et al. Appl Phys. Lett.88, 223504, 2006] The attenuation (rejection) at the pole was about 15 dB.*

Nanolithography on GaN -a challenge

E-beam lithography is the most versatile technique to manufacture submicronic devices on Silicon and also GaAs; resolutions down to 20nm can be obtained.

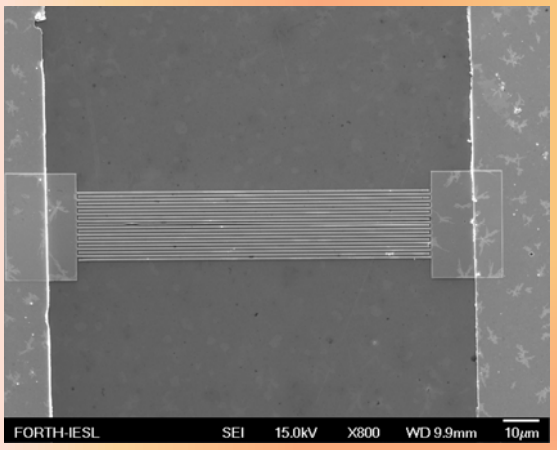
On GaN and AlGaN the high resitivity of the wafer , and the big atomic mass of Ga impede the evacuation of electrons injected by the e beam As a result, Au can not be lifted-off after the e beam process.

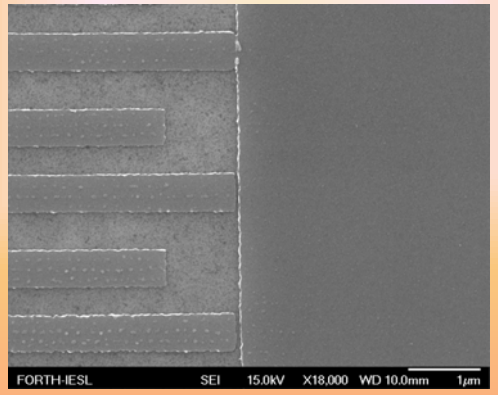
Techniques used to avoid these drowbacks;

-two steps lithographic process

-a very thin Al deposition on the substrate to overcome charging effects

-very thin metalization layers .





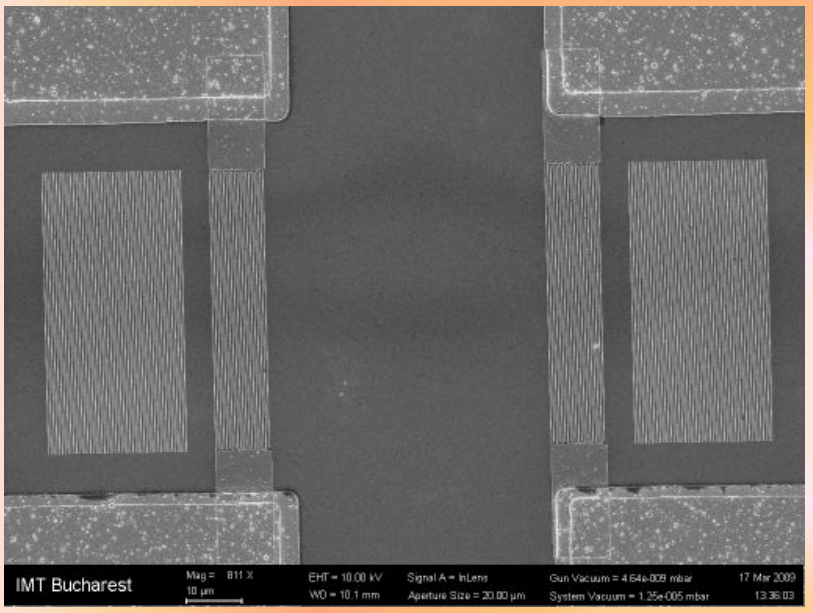
MSM UV Photodetector structures supported on thin GaN membranes obtained using a very thin semi-tansparent metalization (NiAu 5/10nm)

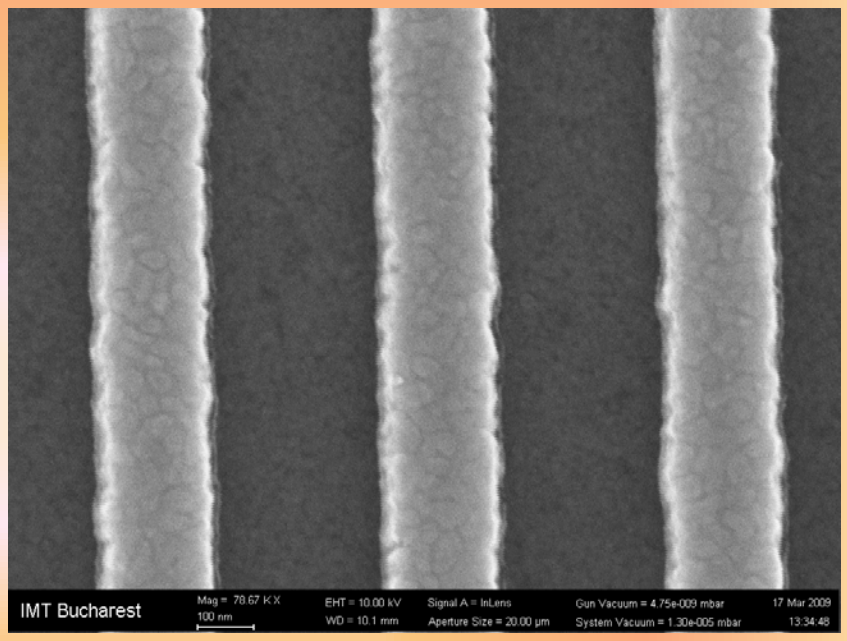
Fingers and interdigits of 500nm have been obtained The yield was about 3-4%

For smaller dimensions the yield was zero.

•Nanolithography (Vega SEM from Tescan and Elphy Plus EBL from Raith) to define the MSM interdigtated structure. PMMA about 50nm high

GaN SAW structures manufactured using nanolithography



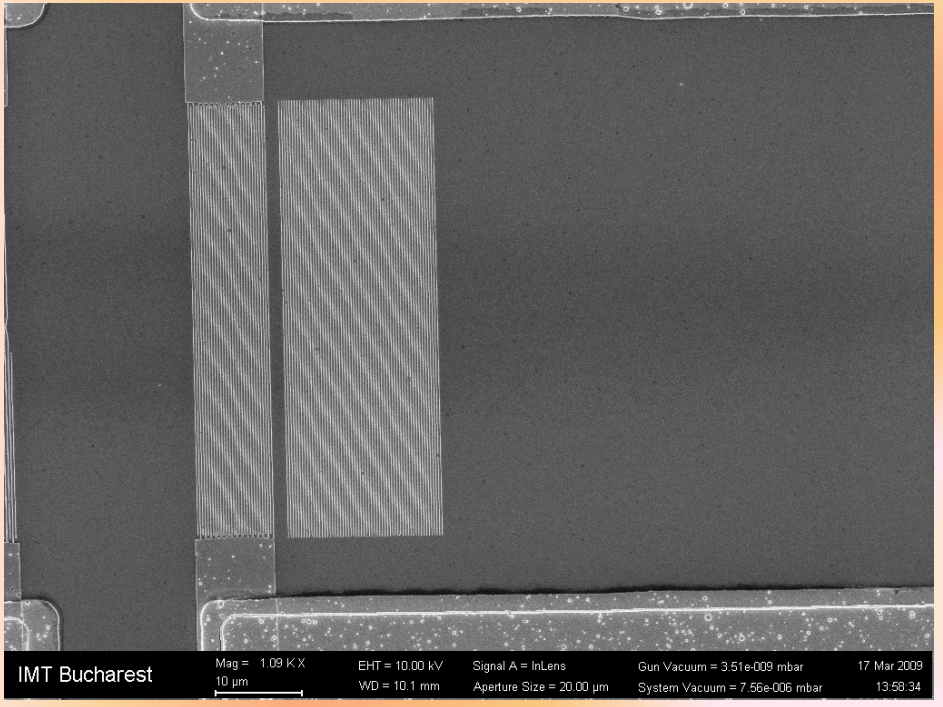


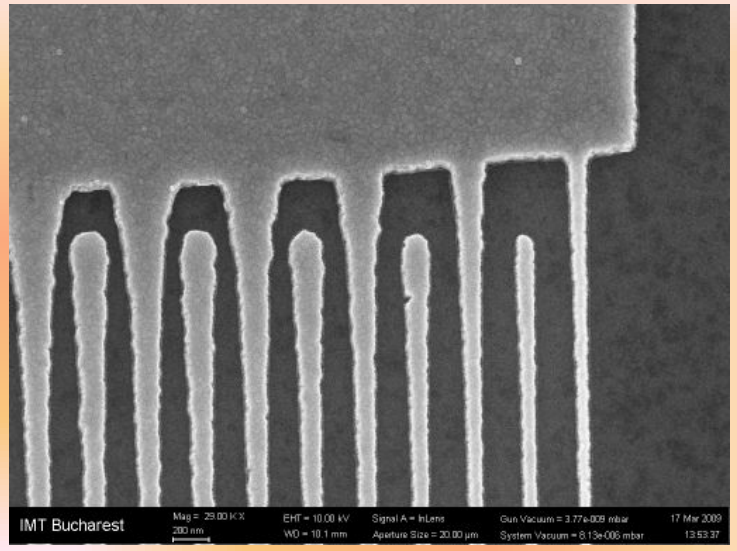
SAW resonator (with reflectors) on GaN/Si with 250nm fingers and interdigits *patterned in IMT on the new "E-Line" equipment*

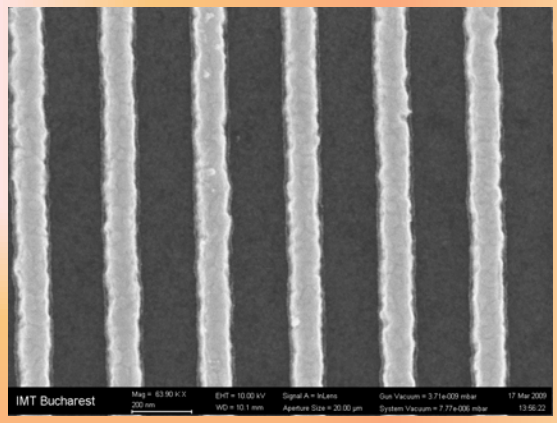
PMMA 200nm thick metaization Ti/Au 100nm thick

GaN/ Si from Azzuro Magdeburg (1μm thin GaN layer)

Details with 150nm lines on GaN

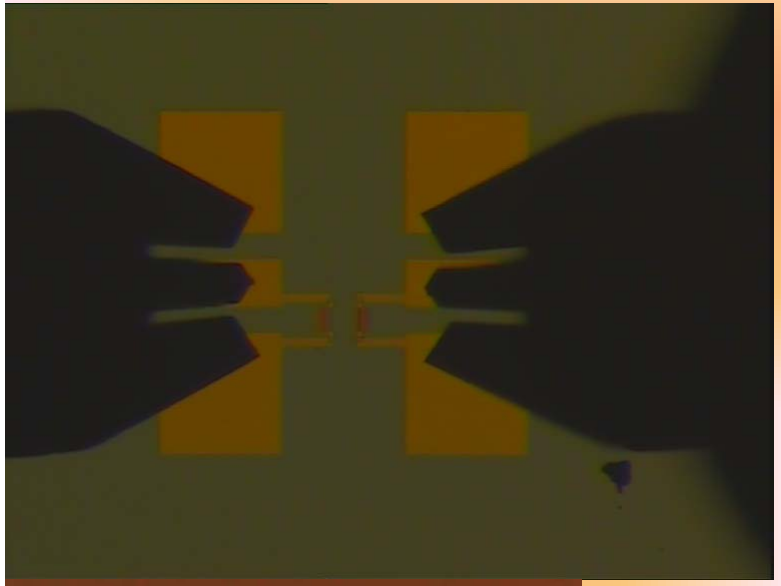


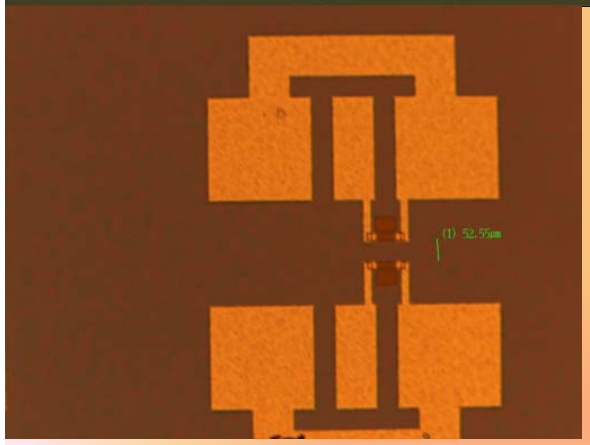


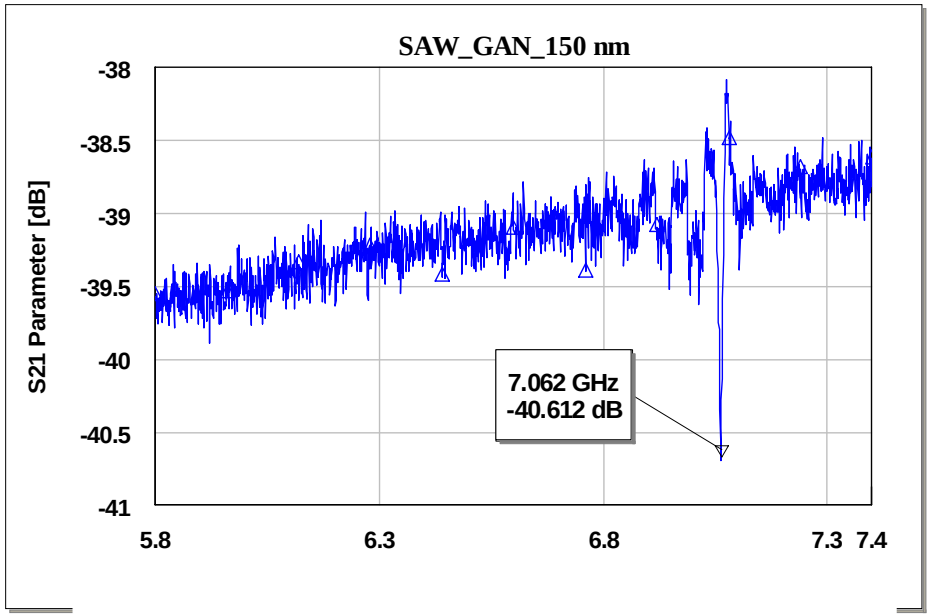


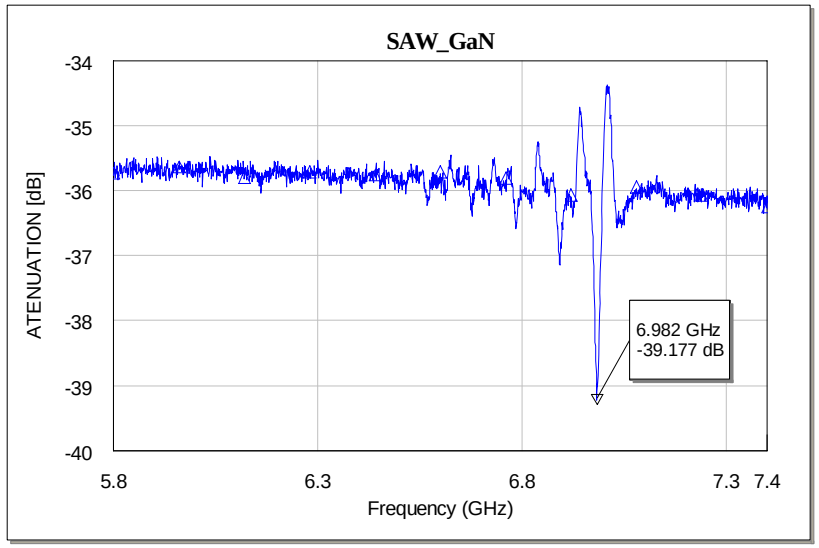
SAW structure on GaN having fingers and interdigits of 150 nm patterned in IMT on the "E-Line" equipment

7 GHz rezonance on a SAW structure manufactured on GaN/Si









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Best results reported up to now on GaN are at about 1 GHz

CONCLUSIONS

- **Nanolithographic process was succesfuly developed on GaN. IDTs with fingers and interdigits 150nm wide have been obtained with an yield of about 70-75%**
- **SAW structures with resonance of about 7 GHz have been obtained using nano-lithographic tehniques on GaN.**