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innovation for industry

Innovative Acoustic RF Devices for Space Applications

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OUTLINE

1. Introduction

CEA-Leti background, resonators parameters, limitations of AlN

2. New Process for Acoustic Devices

Smart Cut™, bonding/grinding

3. New Materials for Acoustic Devices

Higher coupling, higher frequencies …

4. New Concept for Acoustic Devices

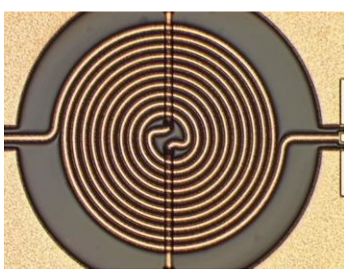
High Overtone Bulk Acoustic (HBAR) resonators

5. Conclusion

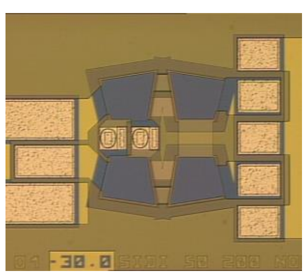
1. Radio-Frequency Components Lab

- **Develop silicon process and components for *More Than Moore***
  - → RF MEMS and passive components
  - → 200mm silicon integration, proof-of-concept, industrial prototypes
- **25 Engineers & Technicians**
  - → Process & materials
  - → Simulation & design
- **5 main topics of research**

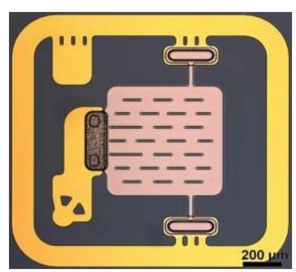
Passive
Magnetic Inductors
2D&3D Capacitors



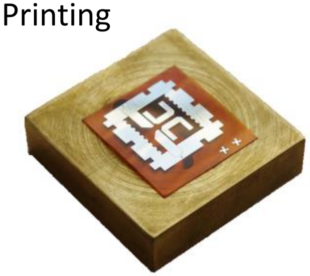
Acoustics
BAW & SAW filters
Lamb Wave
HBAR



RF MEMS
RF switches
Reed-relays
Si resonators

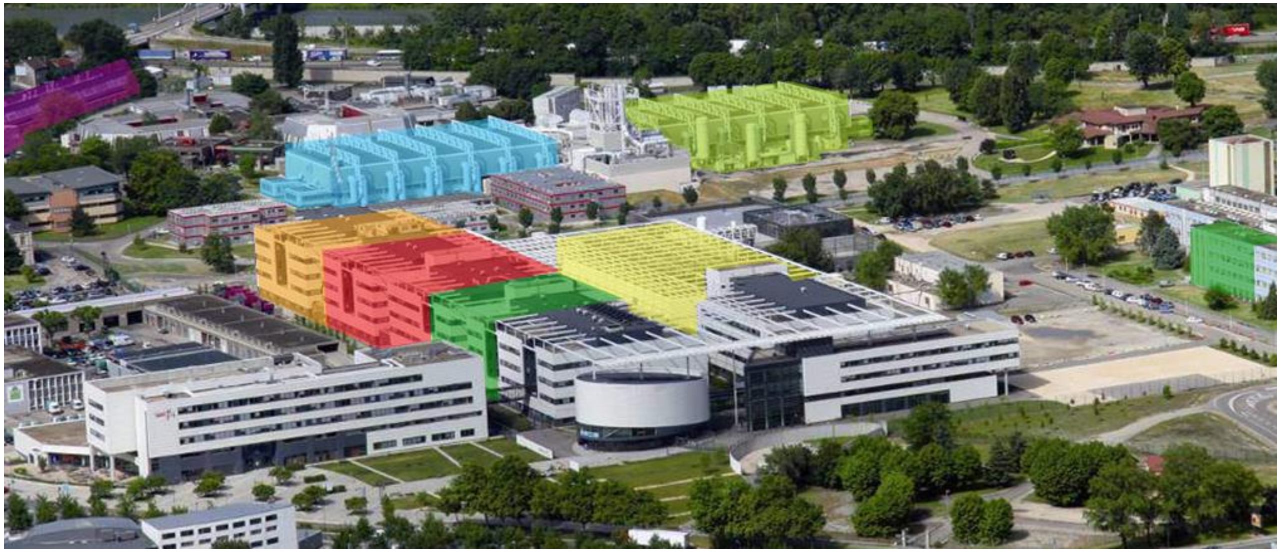


Materials & Process
Antenna substrates
Nanocomposites
Printing



Energy harvesting
Piezo & electret vibrational
Smart material movement

1. LETI's Research Platforms



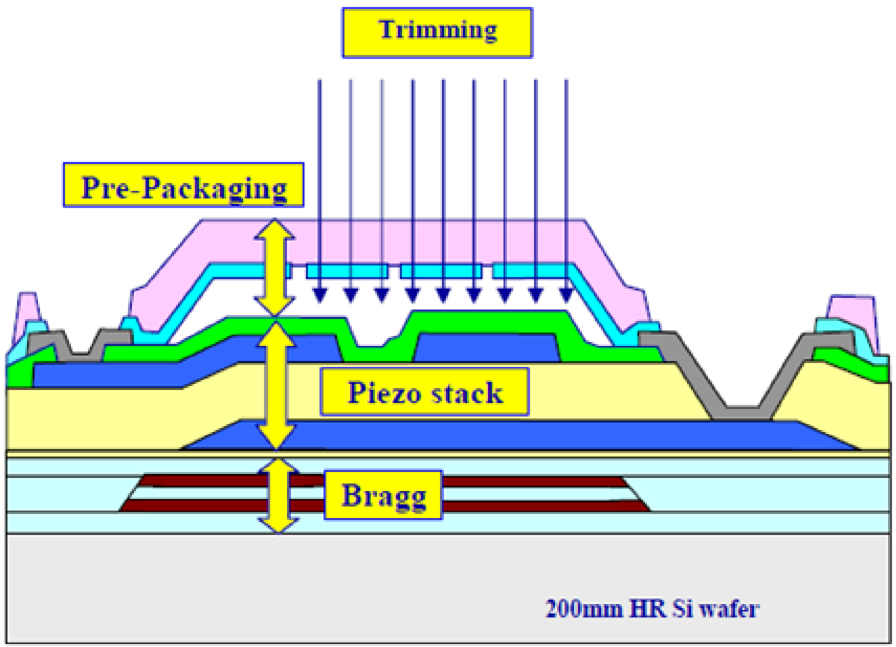
- Nanotec 300
- Advanced CMOS 200
- MEMS 200
- Nanoscale Characterization
- Smart Systems Integration
- Design
- Integrative Chemistry & Biology
- Photonics

- **One of the world's most advanced state-of-the-art research facilities for MEMS**

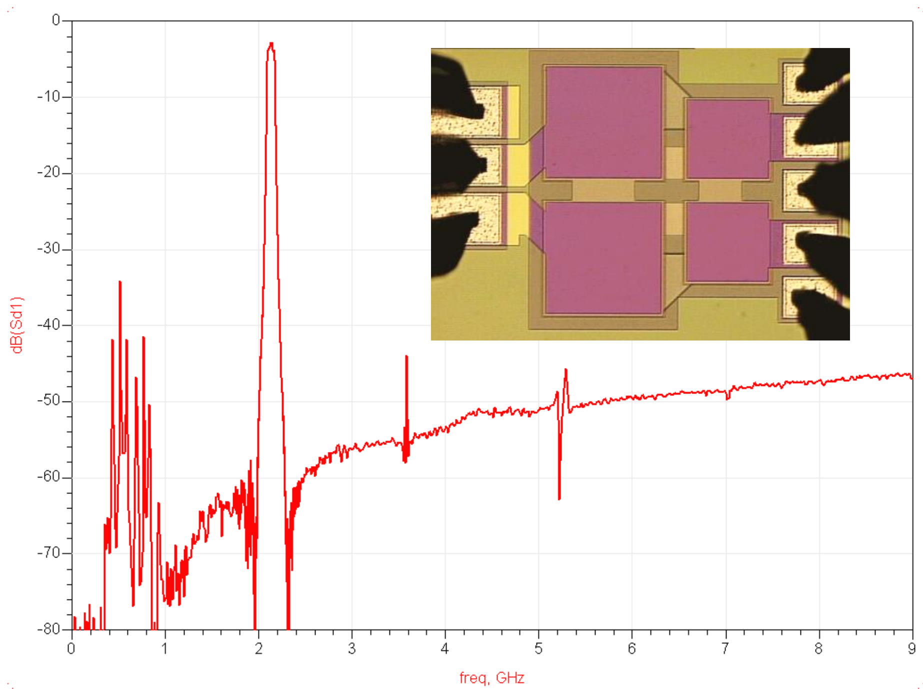
→ 8" facilities, class 10 clean rooms, 24x7 operation & maintenance support, more than 250 production grade process & metrology tools, diverse set of materials and processes capabilities (ALD, sol-gel, magnetic IBS, nanowires…) , process library with over 2700 precipes, off-line characterization tools (vacuum RF prober, XRD, XPS, TEM…)

1. Acoustic Device Background

- **Technology developed for STMicroelectronics from 2003 to 2009**
  - → ~13 mask levels (including packaging)
  - → Highly mature 200mm process for BAW filters
  - → Coupled resonator technology (CRF) also demonstrated in 200mm

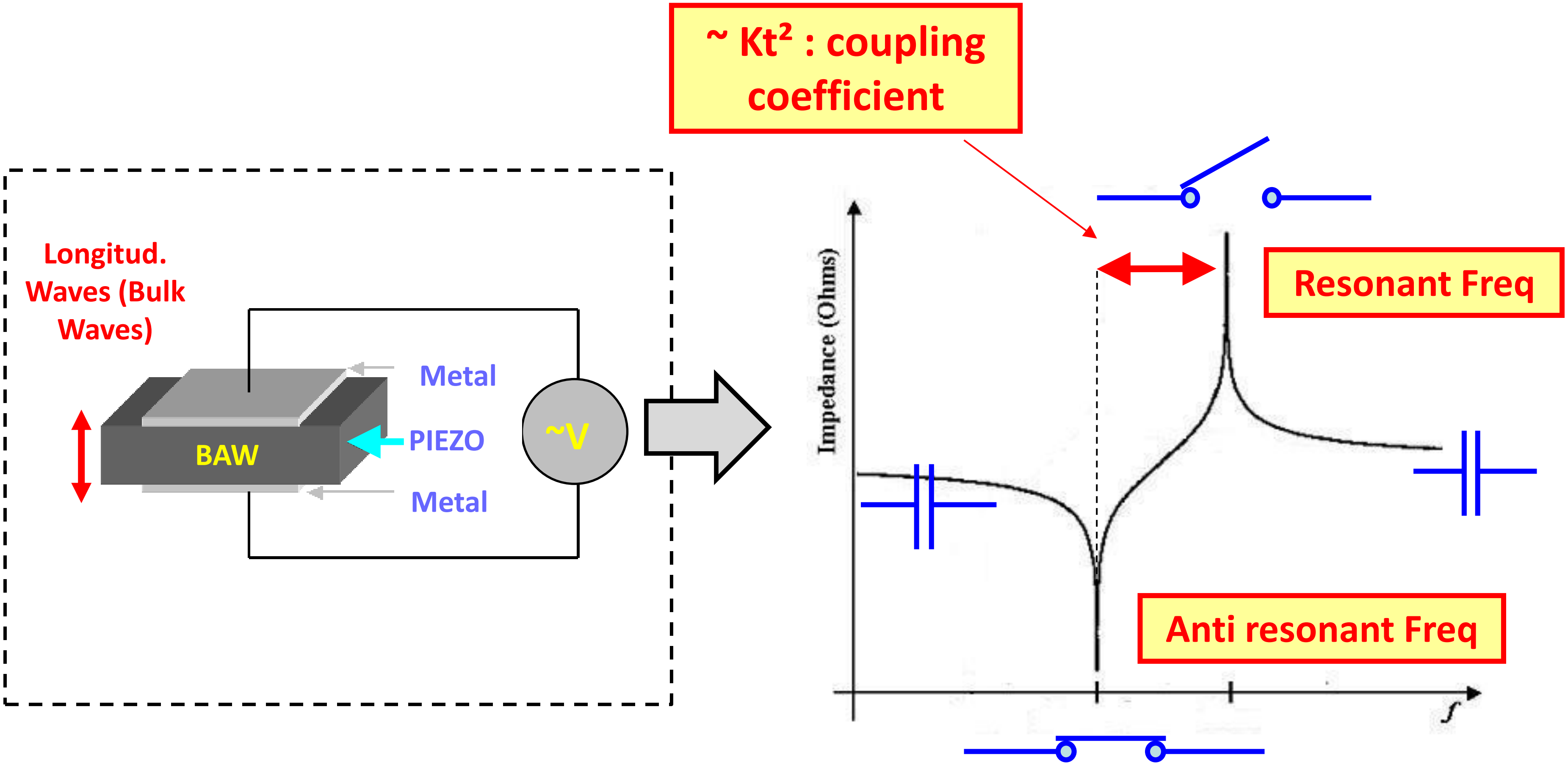


50 Ω single - 100 Ω diff



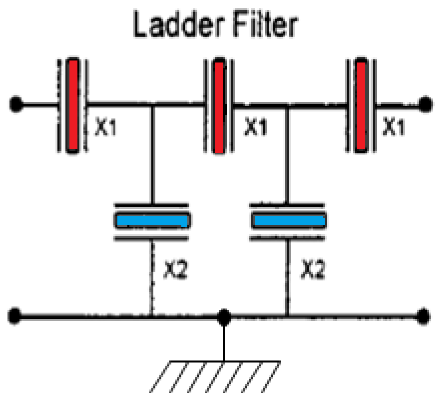
1. Acoustic Device Parameters (1)

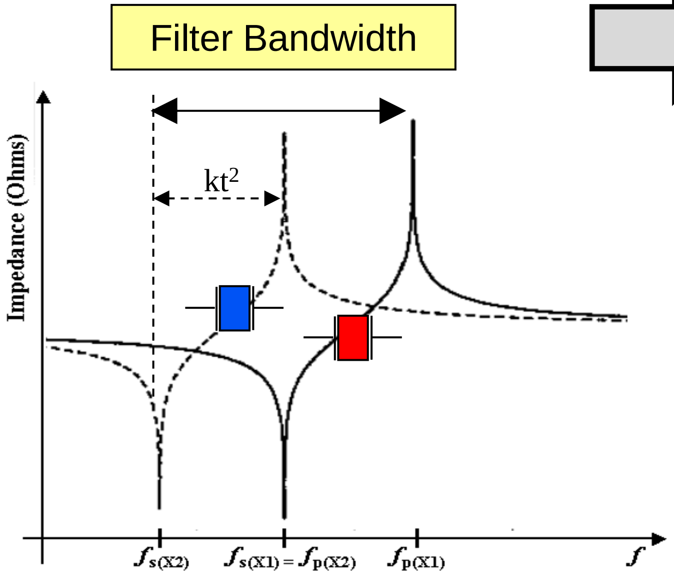
- **Resonance frequencies, kt^2**

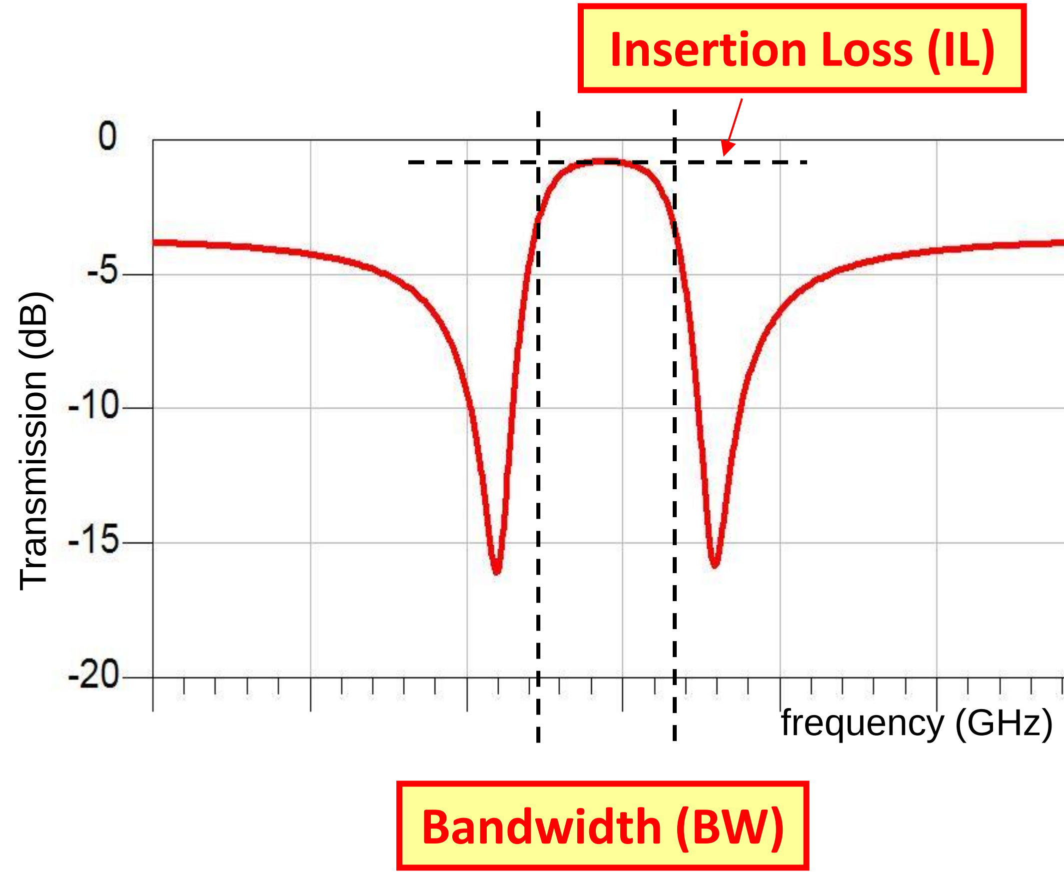


1. Acoustic Device Parameters (2)

- **Bandpass Filter = association of 4 to 10 resonators**

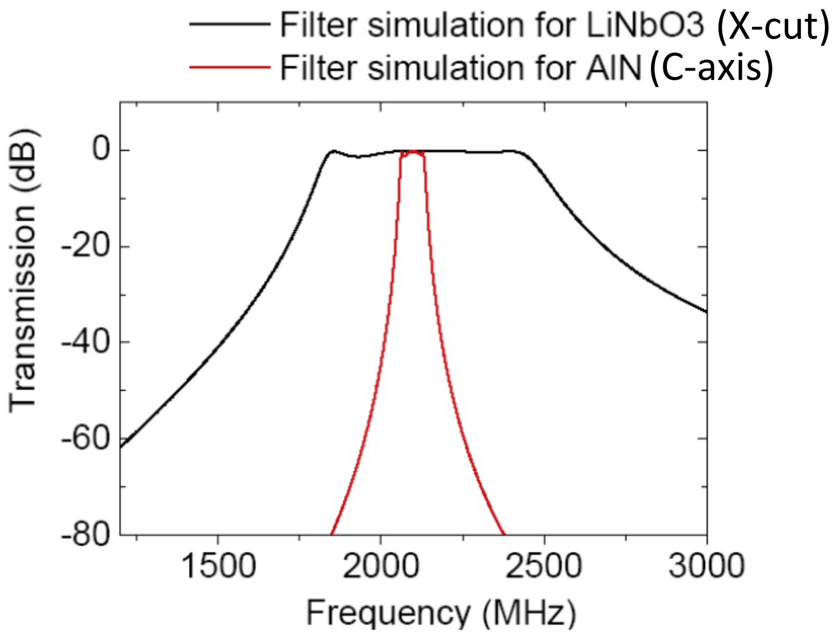






1. Motivations for Single Crystal Piezo Thin Films

- **Limitations of Aluminum Nitride (AlN)**
  - → k_t^2 of AlN (6,5%) limits **bandwidth** (80MHz@2GHz)
  - → Thickness (0,2µm to 5µm) limits **central frequency** (1GHz to 5GHz)
  - → Q-factor (3000) limits **insertion loss** or **oscillators performances**
- **Motivation : find other materials, processes or concepts**
  - → Challenge : oriented µm-thin $LiNbO_3$ films can't be sputtered !



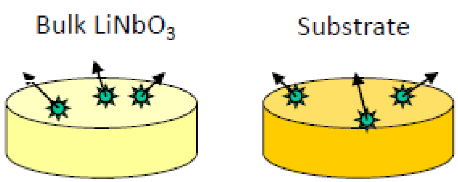
K_t^2 AlN = 6,5%

K_t^2 $LiNbO_3$ = 45%

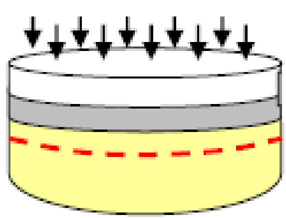
2. SMART CUT™

- **Transfer of very thin layers**
  → Upper limit of 800nm due to implementation depth control
  → 1% uniformity on thickness

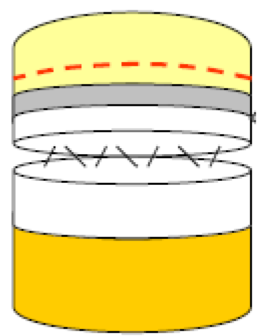
1- Cleaning



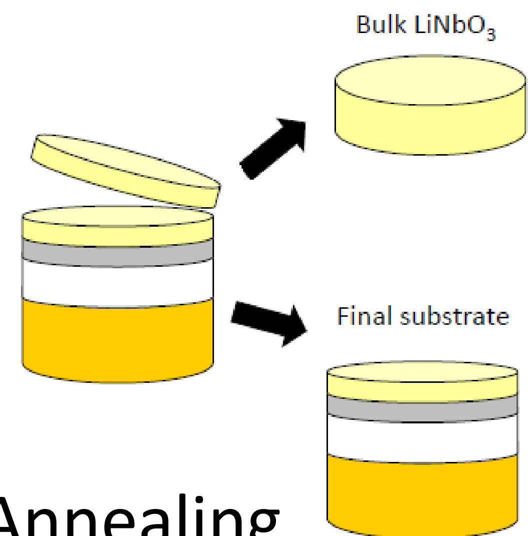
2- Deposition (Me, SiO2) Ionic Implementation



3- Direct bonding



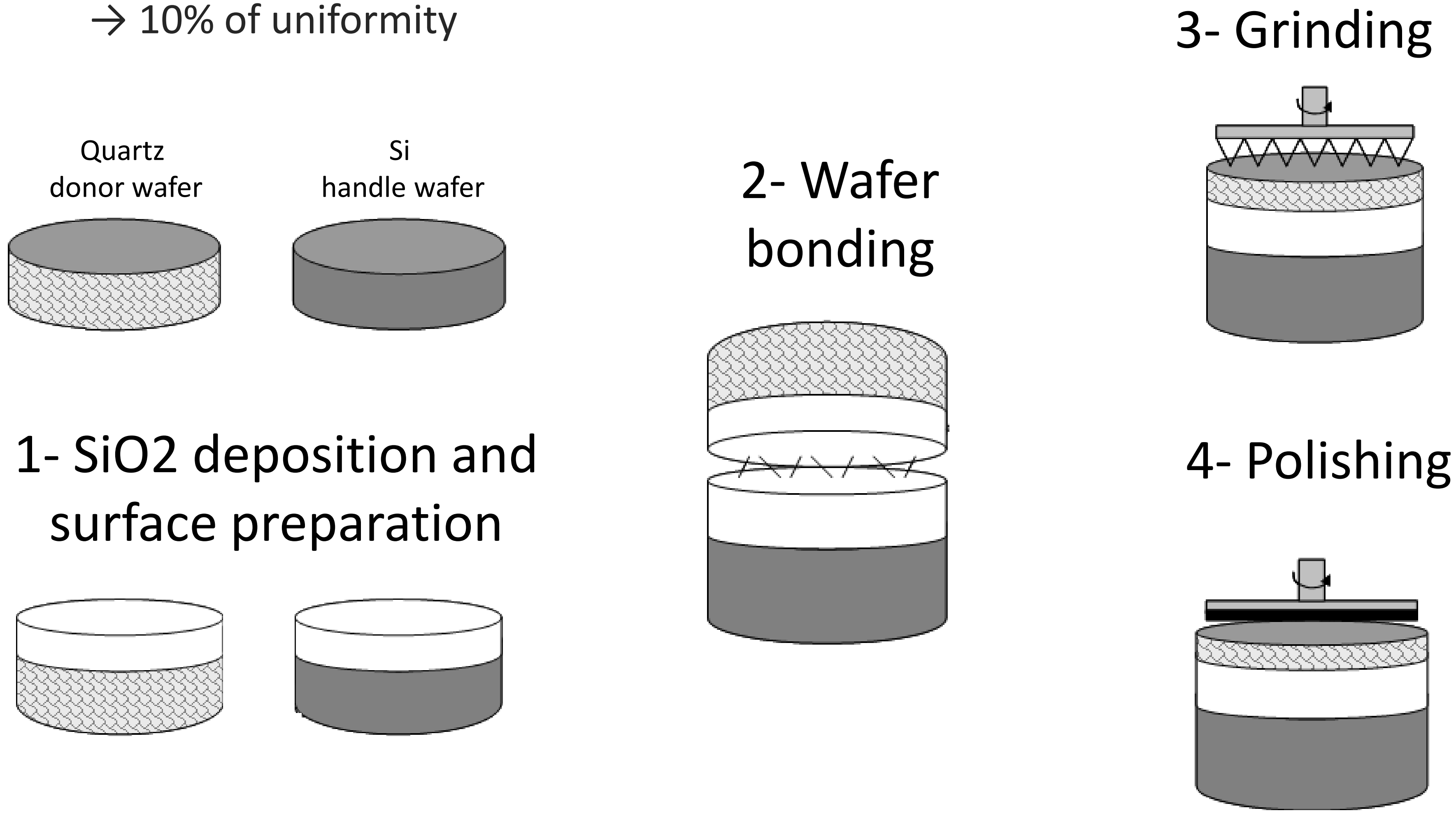
4- Splitting (thermal)



5- Annealing and polishing

2. Bonding / Grinding

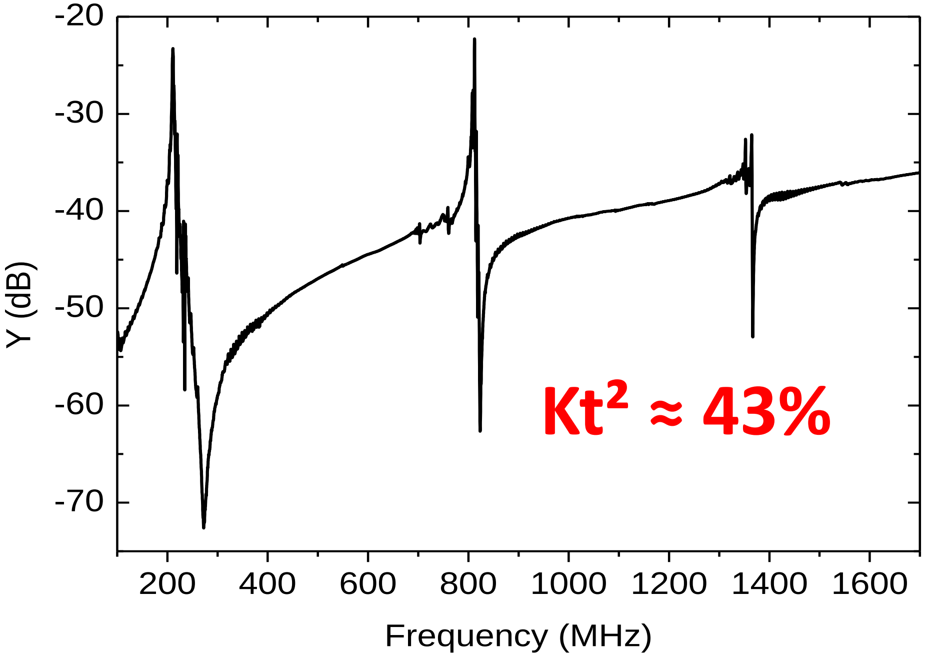
- **Transfer of thin to medium-thick layers**
  - → from 5 µm
  - → 10% of uniformity



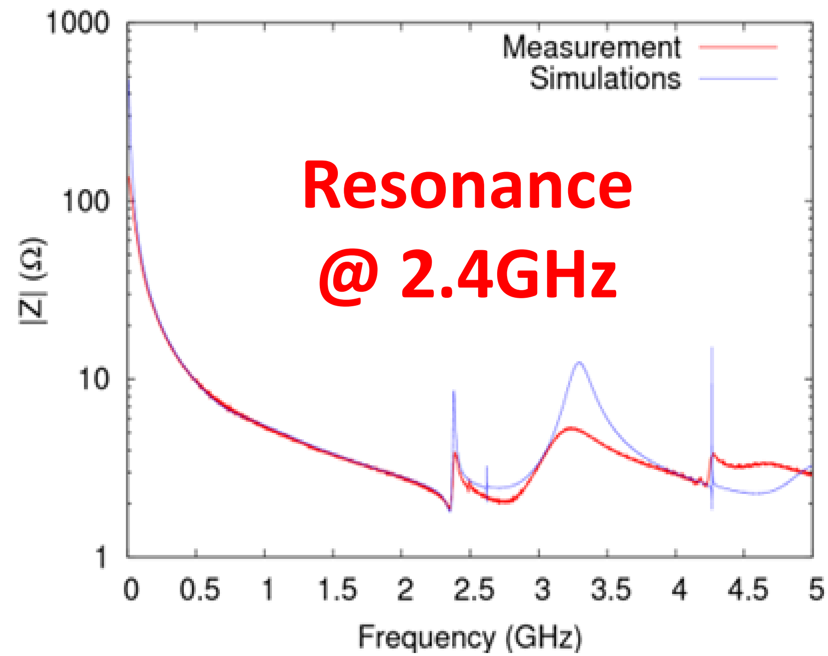
3. High Coupling Resonators

- **Transfer of LiNbO3 single crystal piezo films**
  - → kt^2 = 43% (theoretical bulk value is 45%)
  - → Q < 100 due to thickness inhomogeneity (estimated to be > 5000)

① Bonding/grinding - 6,6µm $LiNbO_3$



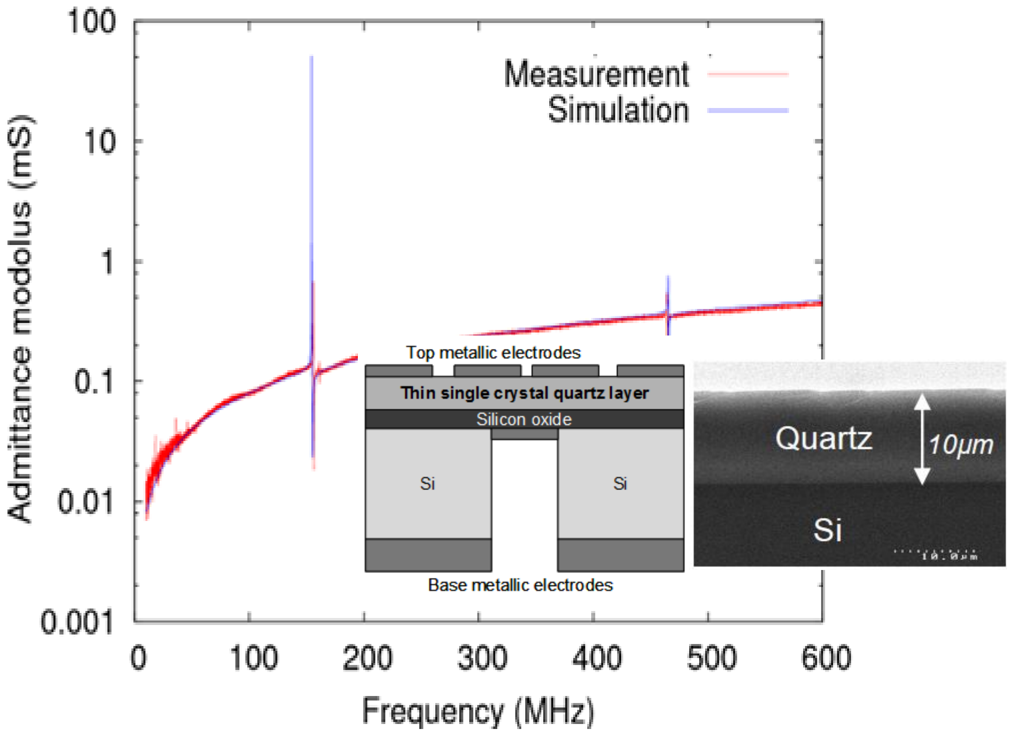
② Smart Cut™ - 1µm LiNbO3



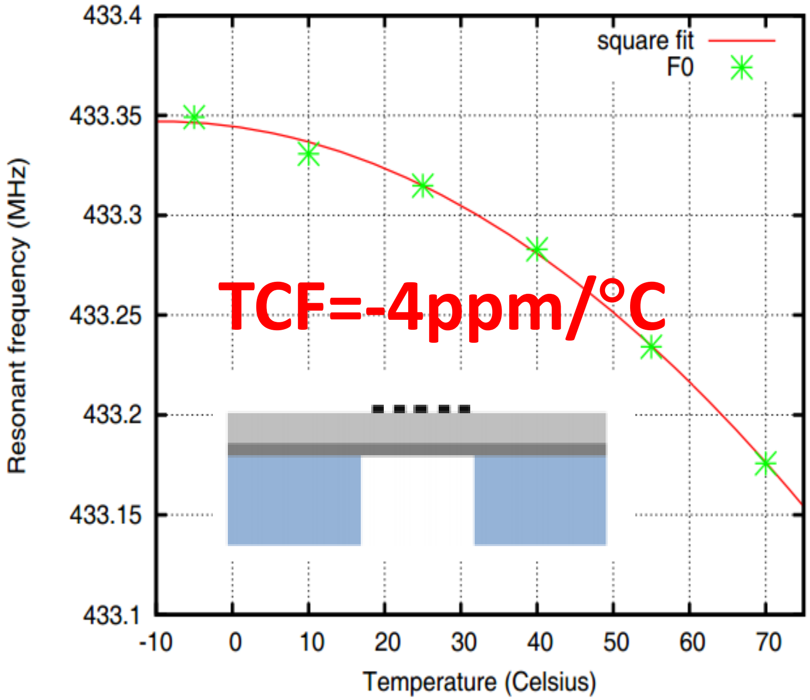
3. Integrated Quartz Resonators

- **A solution to integrate quartz on silicon**
  - → Transfer of quartz by direct bonding + grinding down to 10µm
  - → FBAR resonating at 156 MHz, Q = 2500
  - → SAW pressure sensor : 100µm Quartz on Si, Q = 12500 @ 430MHz

Quartz FBAR

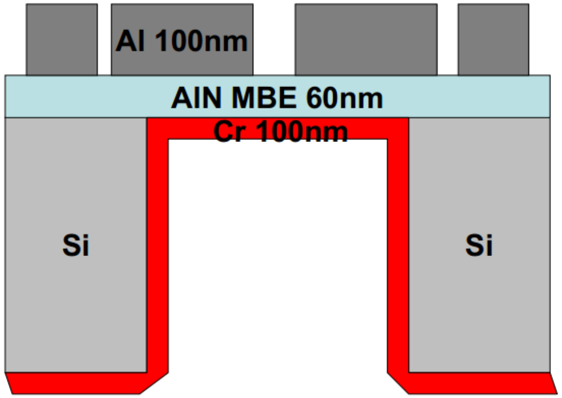


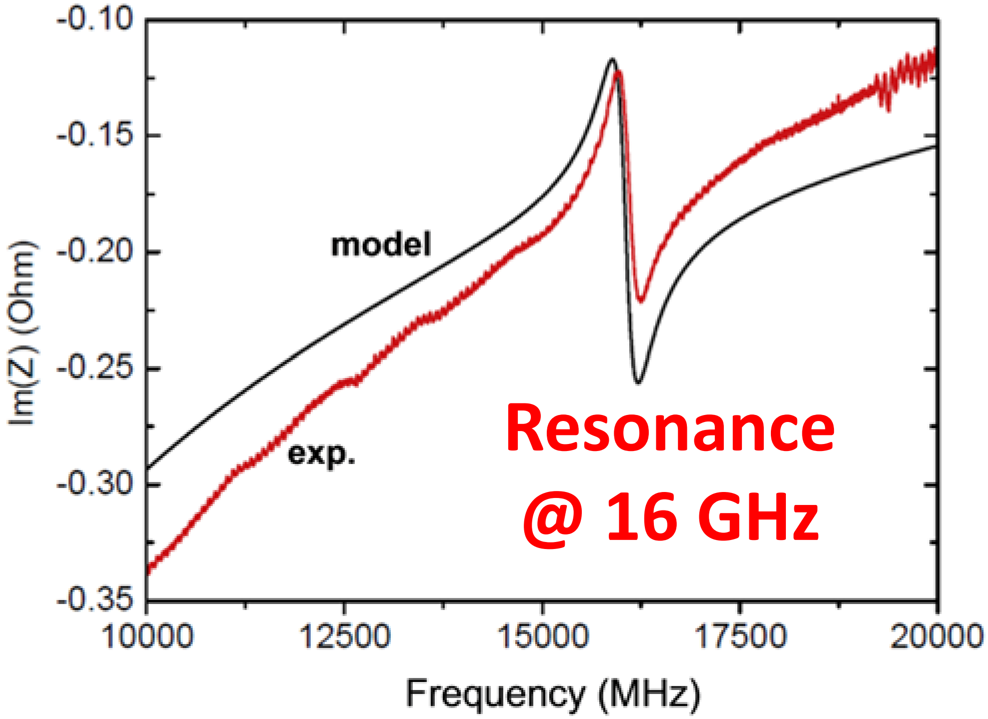
Quartz SAW Pressure Sensor



3. High Frequency Resonators

- **Ultra-thin epitaxial ALN**
  - → 65nm AlN epitaxial layers grown by Molecular Beam Epitaxy (MBE)
  - → 1st resonance at 16 GHz
  - → kt^2 of 6,5%, same as sputtered AlN
  - → Q~55, Q.f ~9.10^{11}



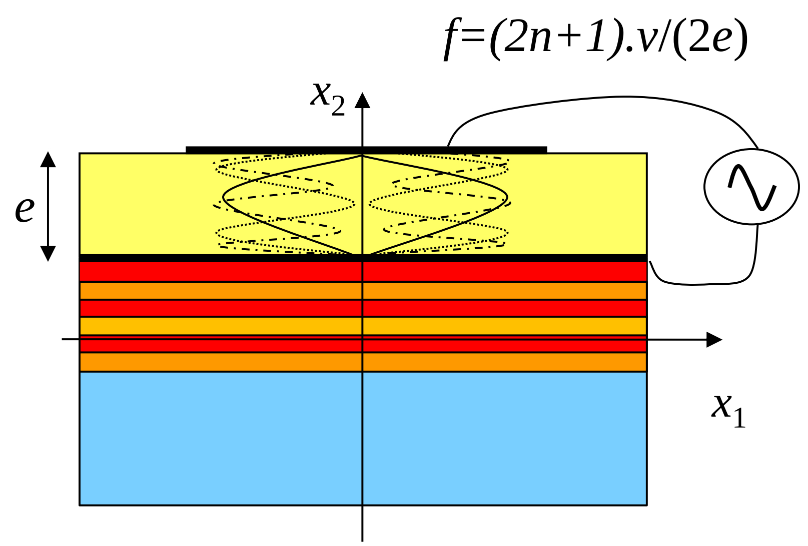


Resonance @ 16 GHz

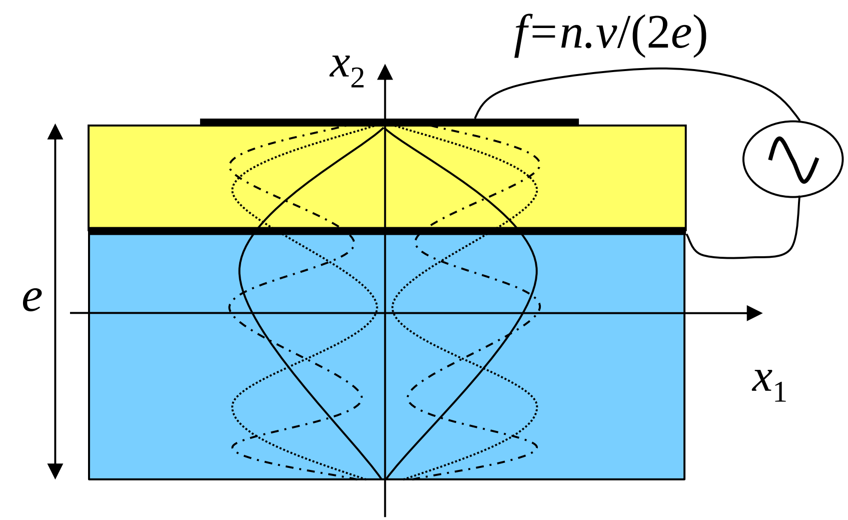
4. HBAR Resonators

- **HBAR = High-Overtone Bulk Acoustic Resonator**
  - → Substrate is the propagation medium
  - → Very high Q determined by acoustic property of the thick substrate
  - → GHz operating frequency

Schematic view of SMR FBAR



Schematic view of HBAR

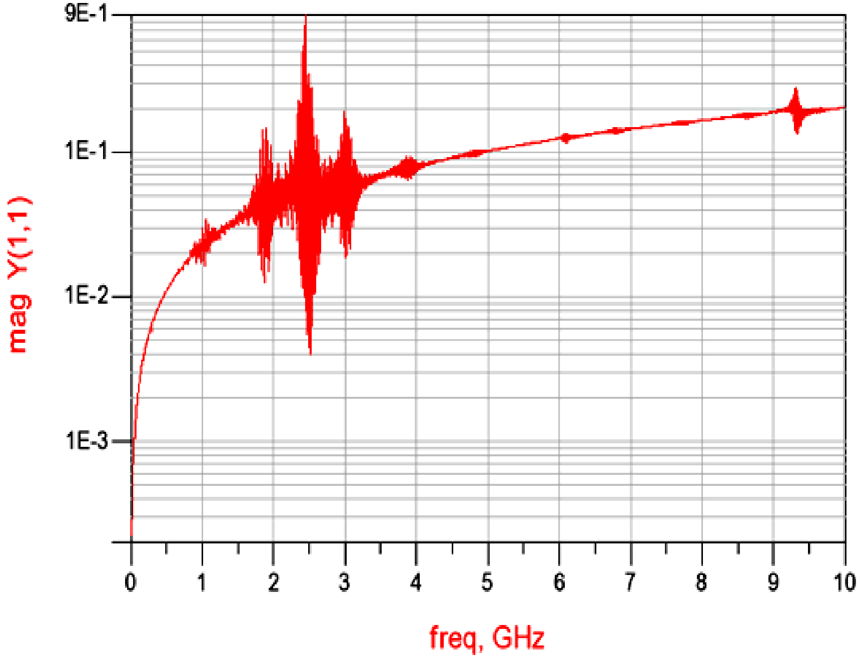


Acoustic waves in the whole material stack

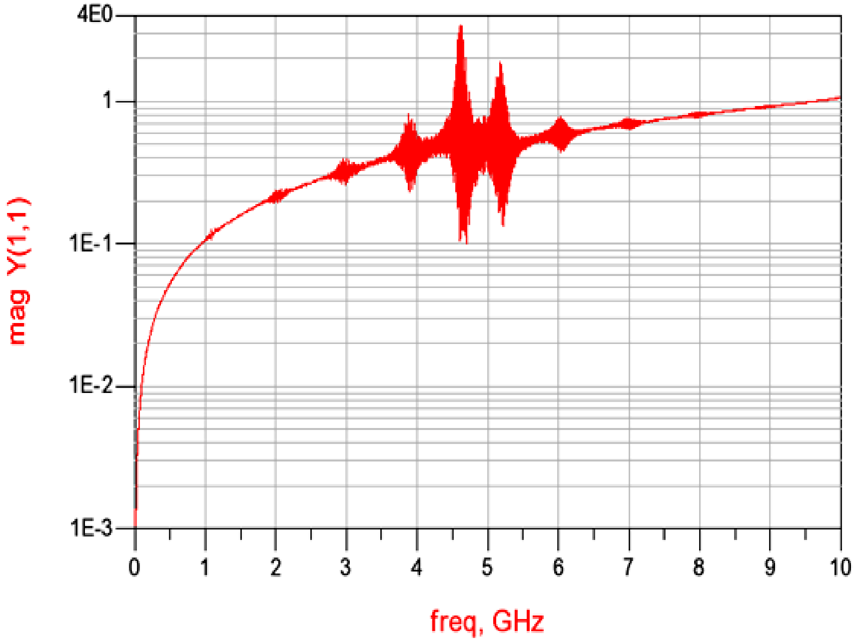
4. Electrical Response

- **Comb of modes in the frequency domain**
  - → Multiple resonances equally spaced by tens of MHz
  - → Localization around the transducer resonances
  - → Need to suppress the adjacent unwanted modes to build an oscillator

Trans. resonances @ 2.5 GHz



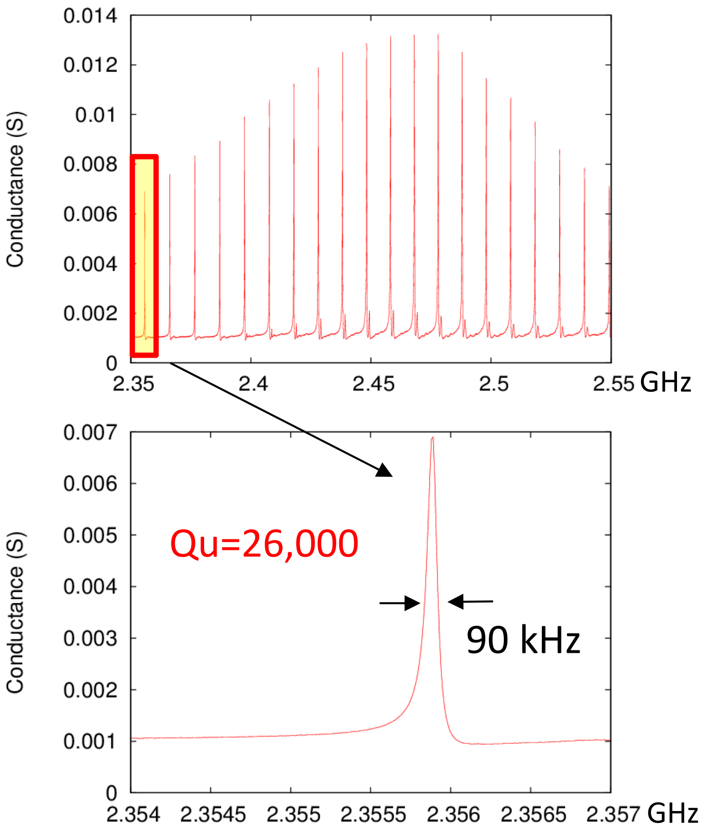
Trans. resonances @ 4.6 GHz

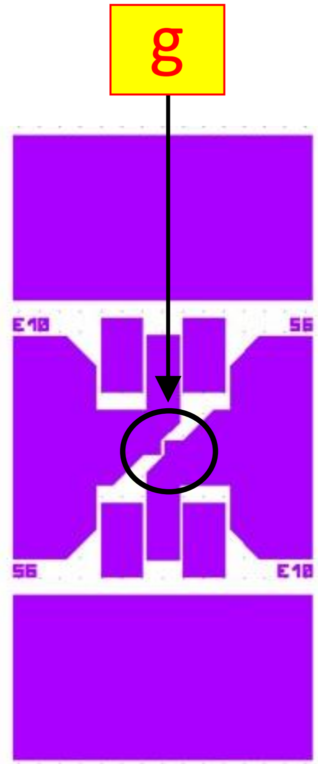


4. Lateral Coupling

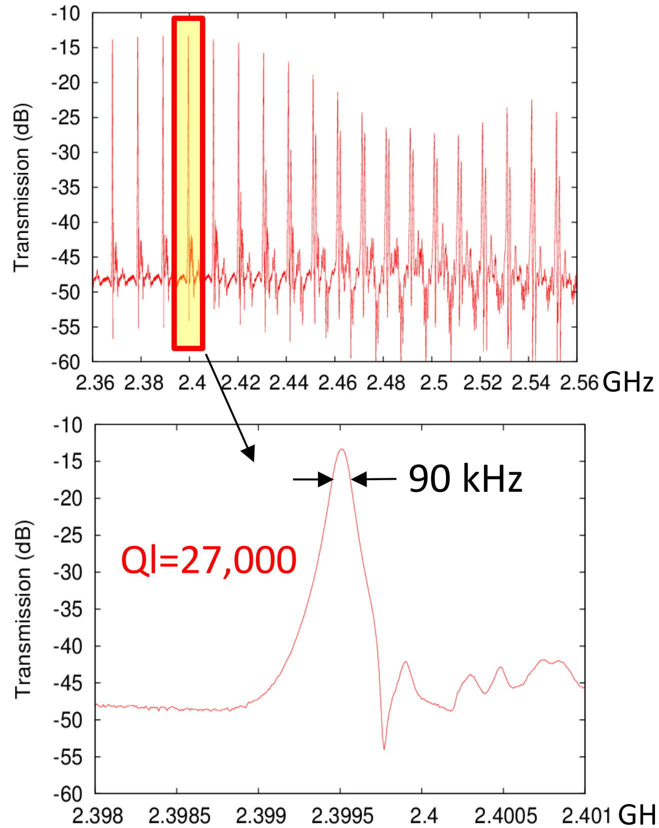
- **Lateral acoustic coupling to built 4-ports devices**
  - → Better suited to insertion in oscillator loop
  - → No change in Q-factor

1-port Resonator



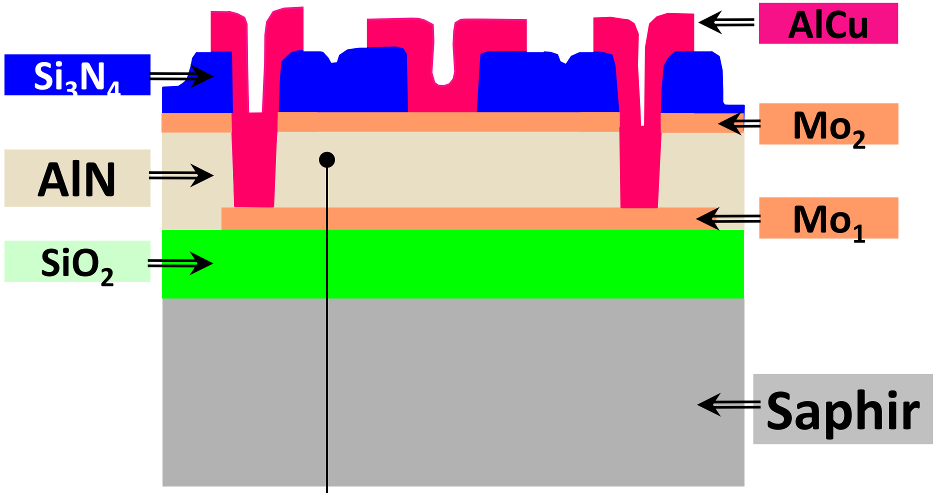


Coupled Resonators

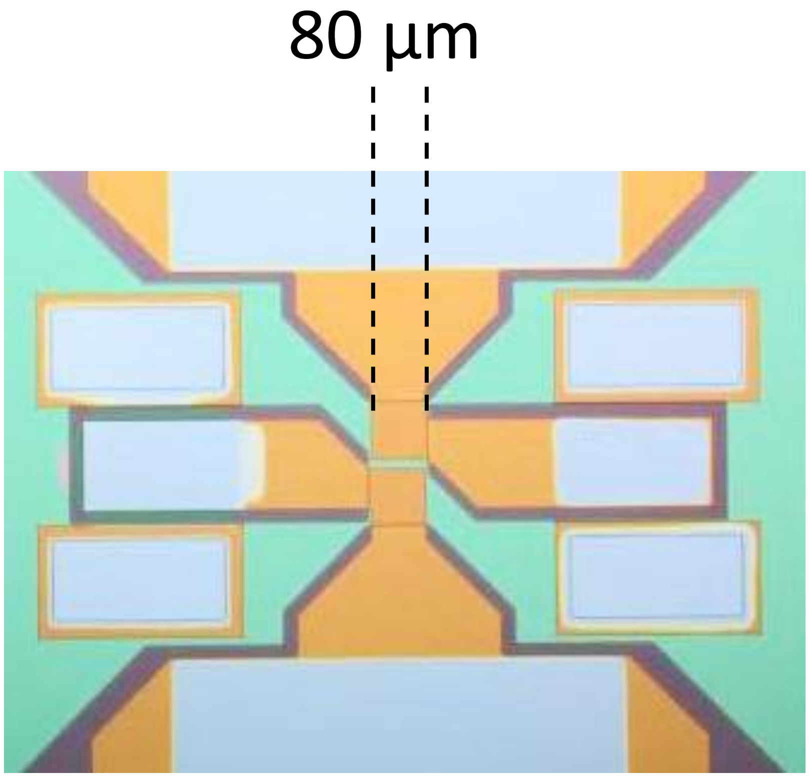


4. HBAR Technology

- **Well-controlled AlN/Saphir process**
  - → Moving to 200mm process = thickness control, repeatability, yield …
  - → Thin film (TFP) or wafer level (WLP) packaging



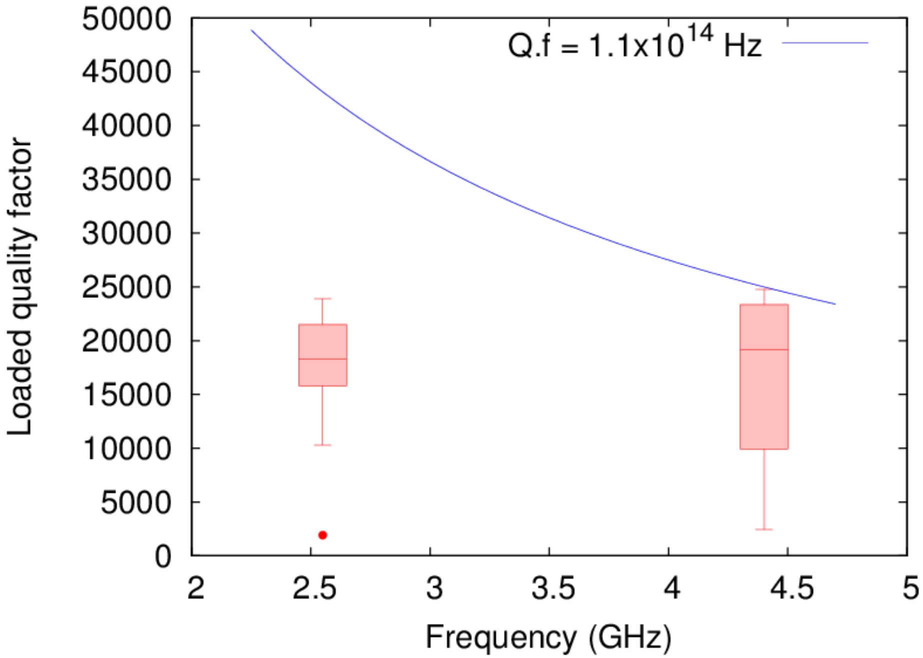
AlN : 1µm (2.4 GHz)
0.5µm (4.4 GHz)



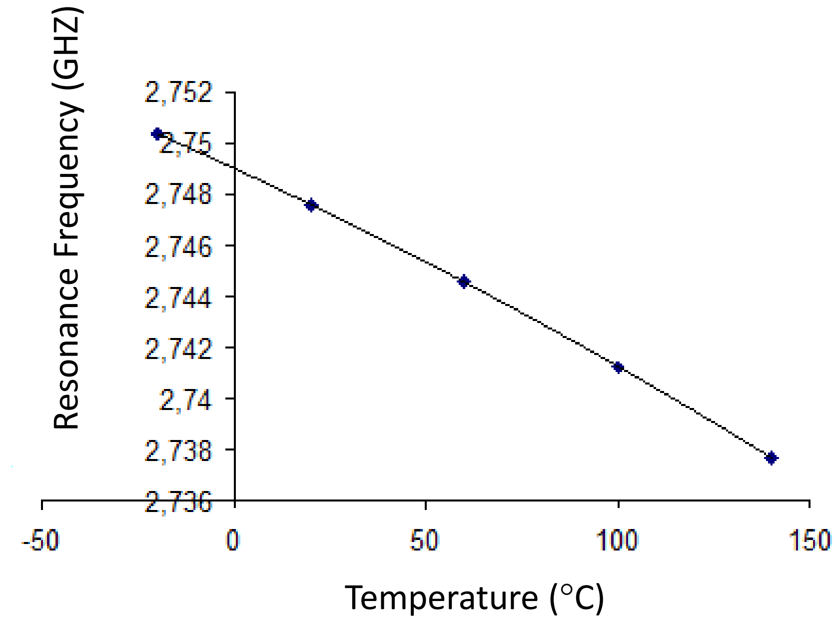
4. QxF Products

- **We established a new state-of-the-art !**
  - → Q=25000 @ 4.4 GHz, Q x f > 1,1 .10^{14}
  - → Temperature variation : -27ppm/°C

Q-factors versus frequency



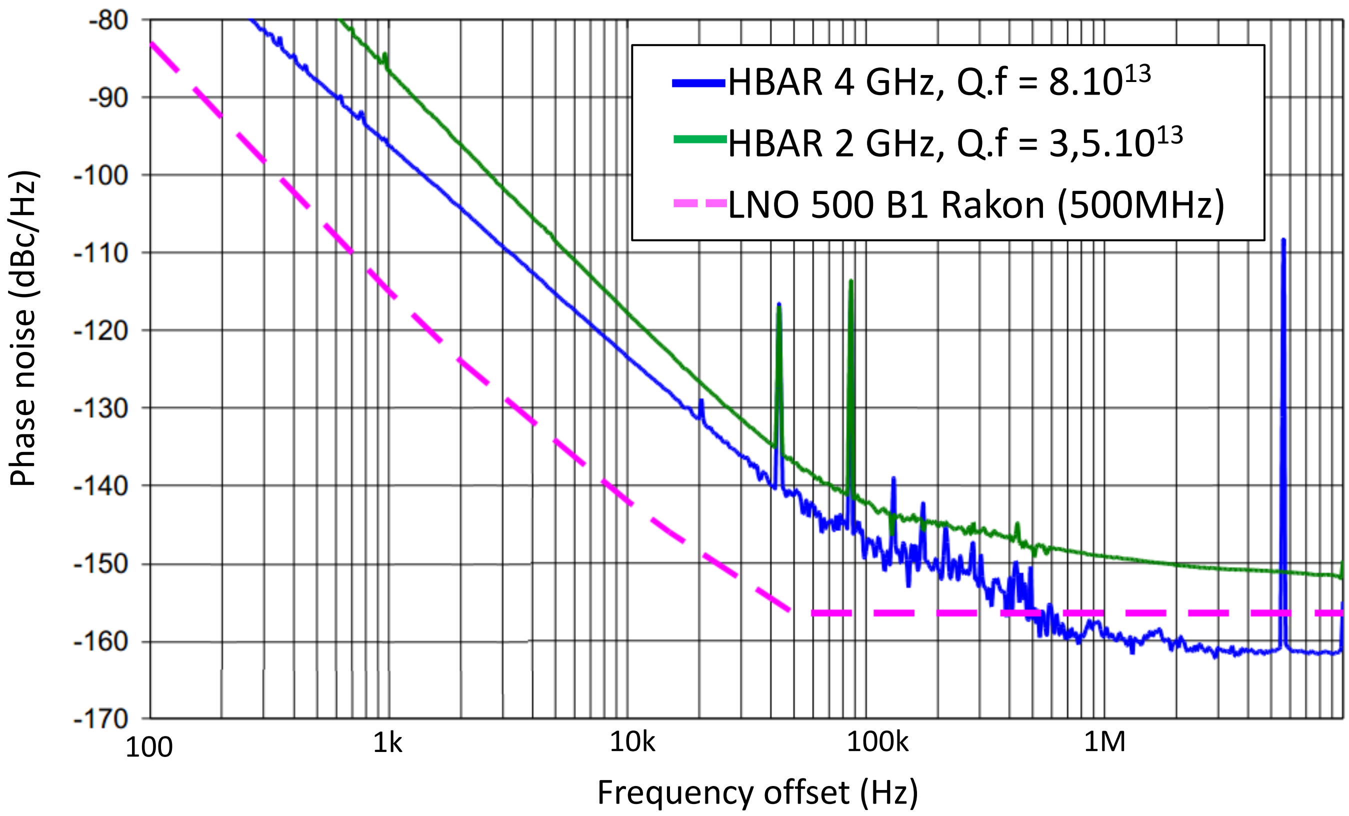
TCF Measurements



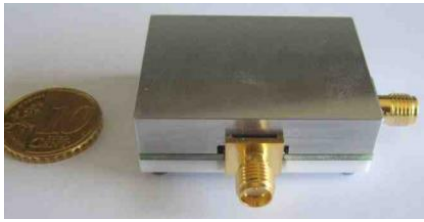
4. HBAR Oscillators

- **Compact oscillators for X-band**
  - →Noise floor improvement versus SAW oscillators

Phase noise at 10 GHz



2x3 cm^2



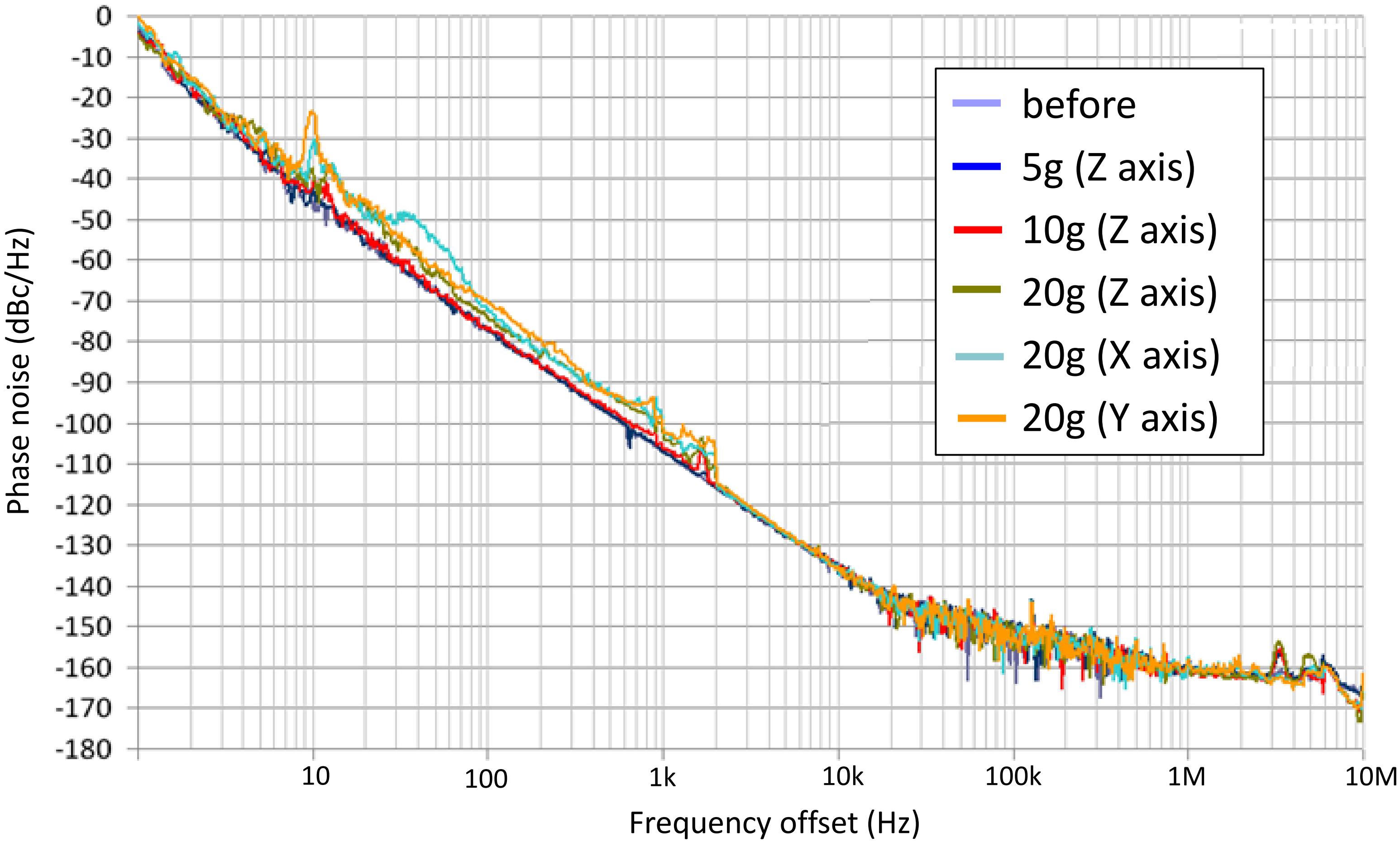
7x9 cm^2

rakon

4. Shock & Vibration Performances

- **Very low vibration sensitivity oscillators**
  → $3{,}14.10^{-11}$ /g

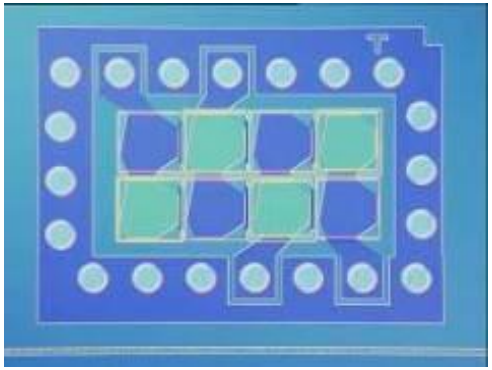
Phase noise versus g (2.36 GHz osc.)

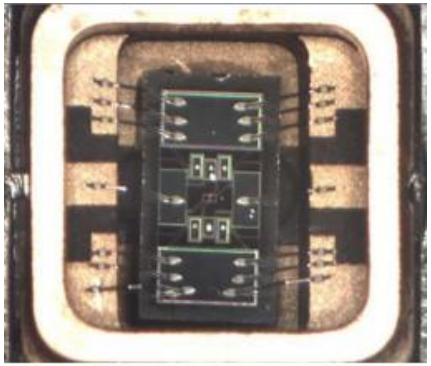


5. Space Applications

- **High frequency and wide-band filters**
  - → Band C and band X
  - → High rejection, low loss
  - → Highly compact

- **X-band oscillators**
  - → Direct frequency synthesis
  - → Low complexity architectures
  - → Low vibration sensitivity





5. Conclusion

- **A new maturity level reached**
  → Major improvements in Smart Cut and bonding/grinding processes
  → 200mm process soon available for HBAR
  → We can now enter in an optimization phase !

- **Next steps**
  → LNO filters and resonators
  → Packaging and thermal compensation of HBAR
  → Realization of highly compact oscillators for X-band

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