Development of a 100MHz Quartz-MEMS resonator

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Overview[1]

What is a Quartz-MEMS resonator ?

An ideal resonator features for time & frequency domain due to :

Quartz crystal + ***MEMS***

Advantages[1]:

- ***High Q-factor***
- ***High thermal stability***
- ***Naturally piezoelectric***
- ***Low power consumption***

Advantages[1]:

- ***Collective process***
- ***High production efficiency***
- ***Easy integration***
- ***Miniature size***

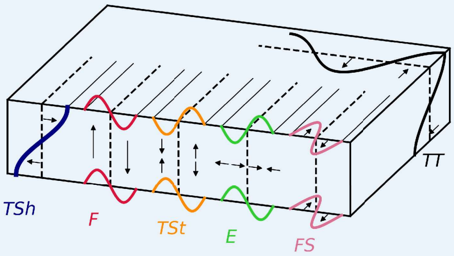
Application

What's the link with space?

New Space:

- **Miniaturization of satellites**
  → **Cost reduction**
- **Increase of equipment flow rates**
  → **As Telemetry, Telecommand & Inter Satellite Links**
- **Increase accuracy of navigation systems**
  → **Multi-GNSS Timing and Localization**

Design[2]



- **E: Extensional**
- **F: Flexural**
- **FS: Face-Shear**
- **TSh: Thickness-Shear**
- **TT: Thickness-Twist**
- **TSt: Thickness-Stretch**

First six vibrational mode of a quartz plate

Which one to choose to achieve 100MHz?

Thickness-shear:

- **Usually used for high frequencies**
- **High Q-factor**
- **Low motional resistance (R_m)**

How to achieve 100 MHz with thickness-shear vibration ?

$$f = \frac{n}{2h}\sqrt{\frac{C_{66}}{\rho}}$$

n : mode number (n = 1 , fundamental)
h : blade thickness (15µm)
C_{66} : stiffness matrix component (34,8GPa)
ρ : density (2648 kg / mm³)

→ Necessity of a thin plate of 15µm (Hair diameter ≈ 100µm)

How to reach high performance ?

$$R_m = \frac{(\pi n)^2 h}{8k_{26}^2 \varepsilon C_{66} S}$$

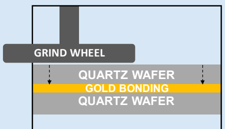
S : electrode surface area (1mm²)
k_{26} : electro-mechanical coupling factor (0,77%)

→ Necessity of a compromise:

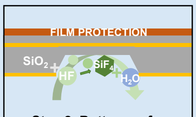
- ***Thin plate***
- ***Fundamental mode***
- ***Large electrode surface area***

Fabrication

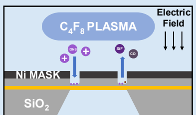
How to fabricate a Quartz-MEMS resonator ?



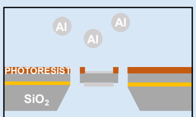
Step 1: Wafer thinning



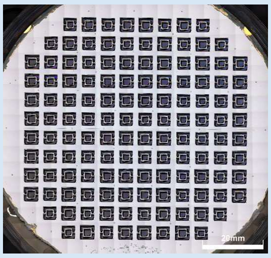
Step 2: Bottom wafer chemical etching



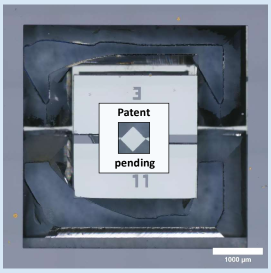
Step 3: Top wafer deep reactive ion etching



Step 4: Electrodes deposition by evaporation



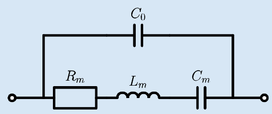
4" wafer after chemical etching in hydrofluoric acid



Final state of one resonator

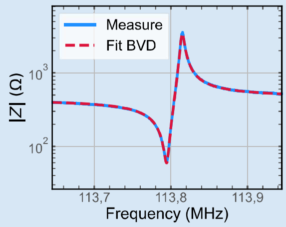
Characterization[3]

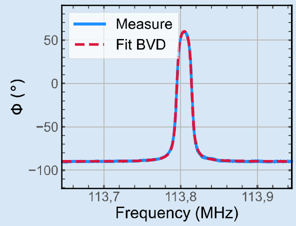
What is the real performance?



Butterworth Von Dyke equivalent circuit

	Fundamental
Frequency	114MHz
Q-factor	24 000
Motional resistance	60Ω
Q×f Product	2.5×10¹²Hz





Impedance frequency response Measurement

Encouraging performance allowing a Q.f product of *2.5×10¹²Hz on the fundamental and 1.3×10¹³Hz on the 5th overtone* near the theoretical limit of quartz of 3.2×10¹³Hz in the Akhiezer regime[2] for a surface lower than *10mm²*.

Outlook

- ✓ **This work demonstrates the possibility of using a quartz-on-quartz wafer with deep reactive ion etching (DRIE) to produce a miniaturized self-suspended resonator with encouraging performance.**
- ✓ **Future work will focus on characterizing the resonator mounted as an oscillator.**

Bibliography

[1] G. Pillai and S. -S. Li, 'Piezoelectric MEMS Resonators: A Review', IEEE Sensors Journal, vol. 21, no. 11, pp. 12589–12605, 2021.

[2] R. W. Cernosek, S. J. Martin, A. R. Hillman, and H. L. Bandey, 'Comparison of lumped-element and transmission-line models for thickness-shear-mode quartz resonator sensors', IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 45, no. 5, pp. 1399–1407, Sep. 1998.

[3] S. Ghaffari et al., 'Quantum Limit of Quality Factor in Silicon Micro and Nano Mechanical Resonators', Scientific Reports, vol. 3, no. 1, p. 3244, Nov. 2013.

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This work was partly supported by the french RENATECH network and its FEMTO-ST technological facility.