High-overtone Bulk Acoustic-wave Resonator (HBAR) gravimetric sensitivity: simulations

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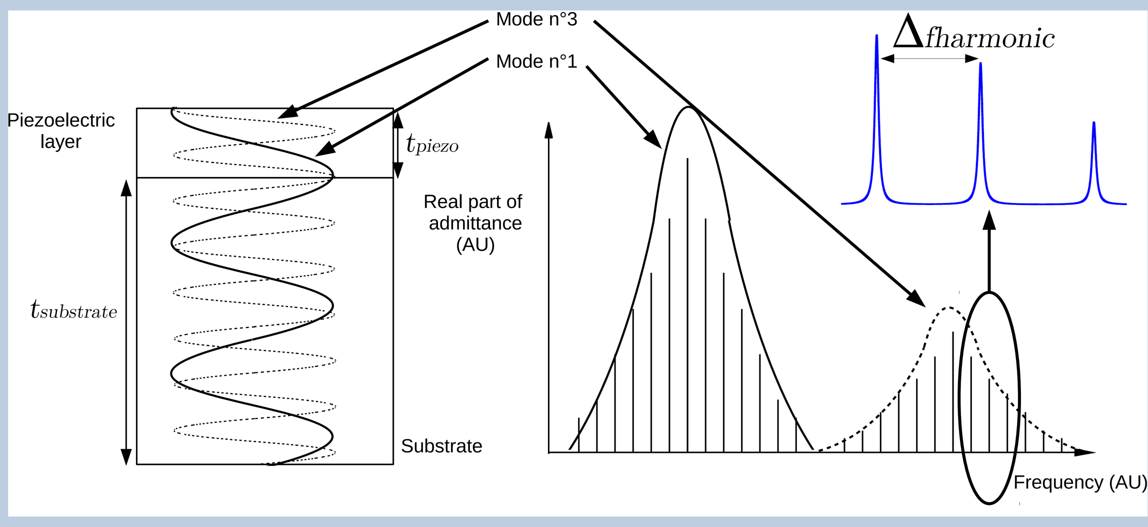
Introduction

- **Hypothesis**: increasing frequency ⇔ increasing sensitivity S
- FBAR is too fragile to be usable
- HBAR: tradeoff between high frequency and robust design
- Sauerbrey: $S = \frac{\Delta f}{f_0} \cdot \frac{A}{\Delta m} \sim \frac{1}{\rho t}$ is independent on overtone number ⇒ HBAR S is given by fundamental mode
- beyond Sauerbrey ... dispersion relation over one frequency decade

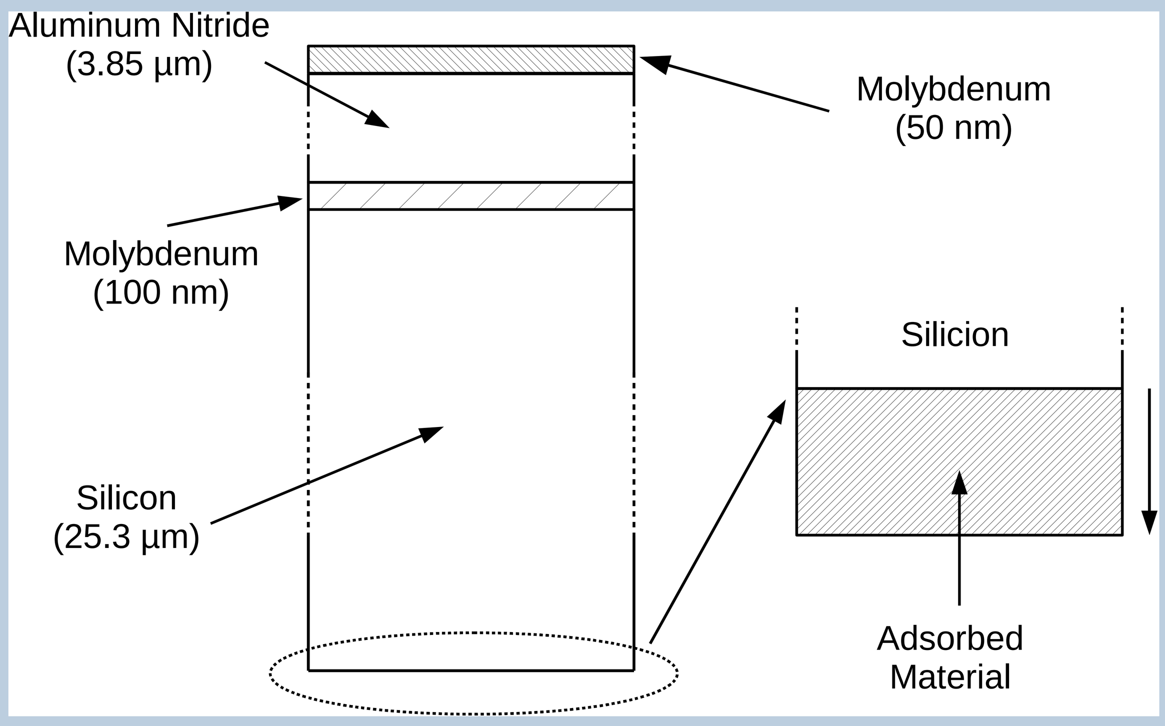
Principles

- HBAR=stack of thin (1-50 μm) piezoelectric film atop thick (30-100 μm) low acoustic loss substrate
- envelope given by piezo layer transfer function (+overtones), mode spacing given by substrate thickness
- comb of modes spanning from 100 to 1000 MHz
- best suited for openloop (network analyzer) probing electronics



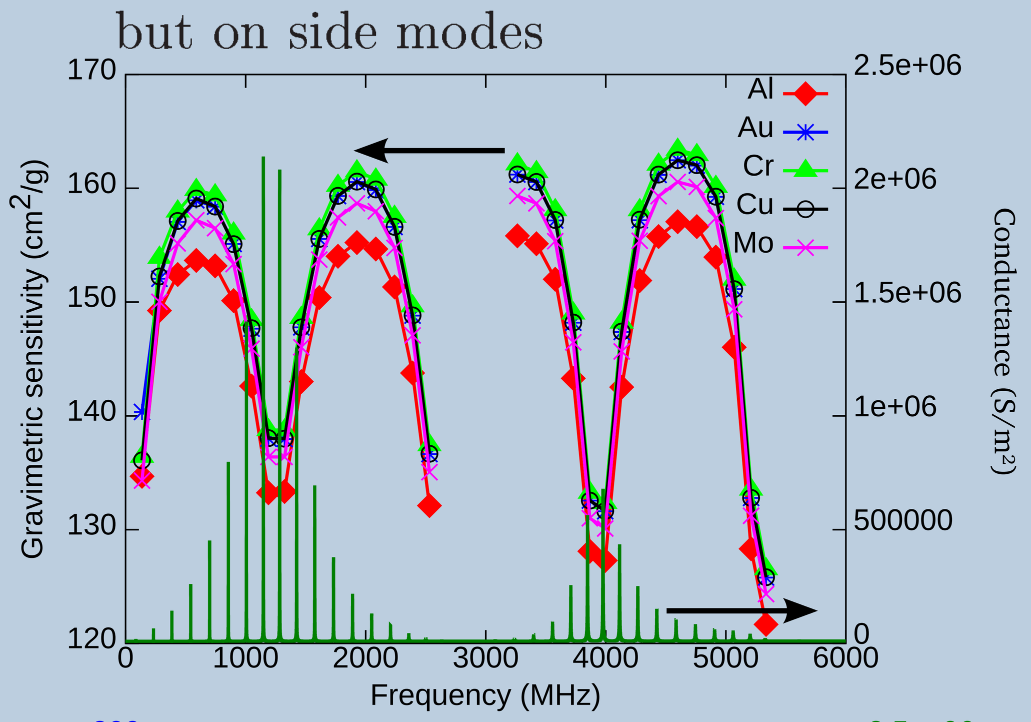
Simulation Concepts

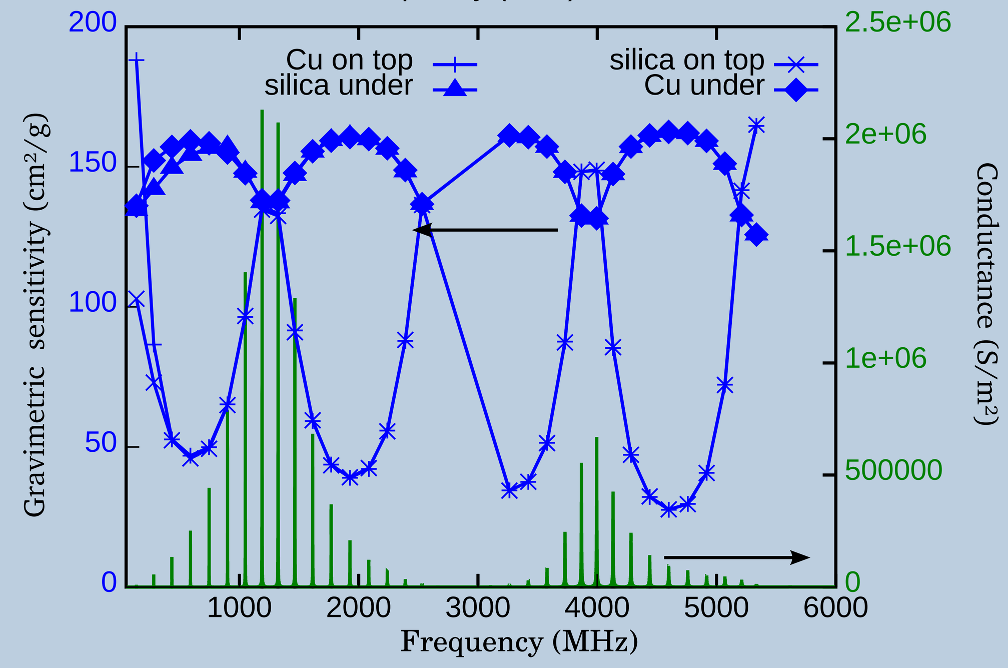
- modeling based on mixed matrix & Green function[1]
- sensing area opposite to (solves the **packaging** issues) or over electrodes
- varying layer density and acoustic impedance
- hint from [2]: sensitivity dependent on adsorbed layer thickness (coupled resonators)
- simulation conclusion: much more complex than [2], energy confinement dependent on acoustic impedance of layer



S dependence with position

- Small thickness ⇒ S independent on material characteristics.
- Strong dependence of S with overtone number
- S is *not* maximum at coupling maximum but on side modes

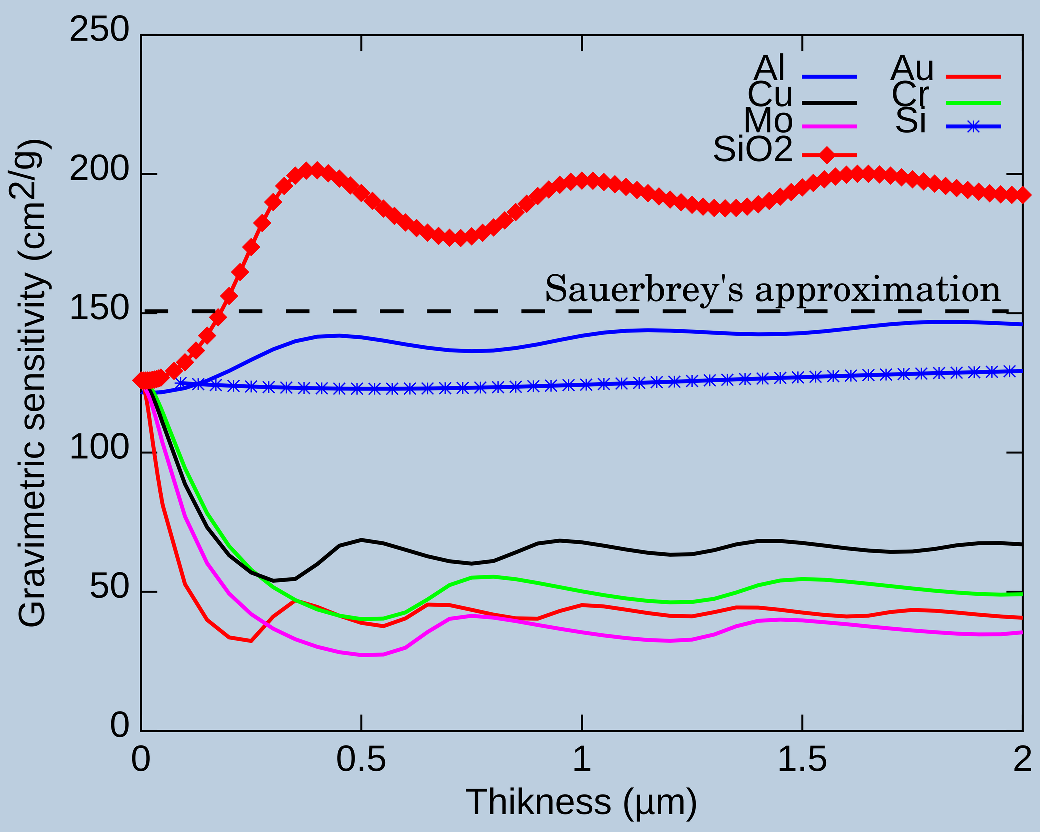




Adsorbed layer over electrode

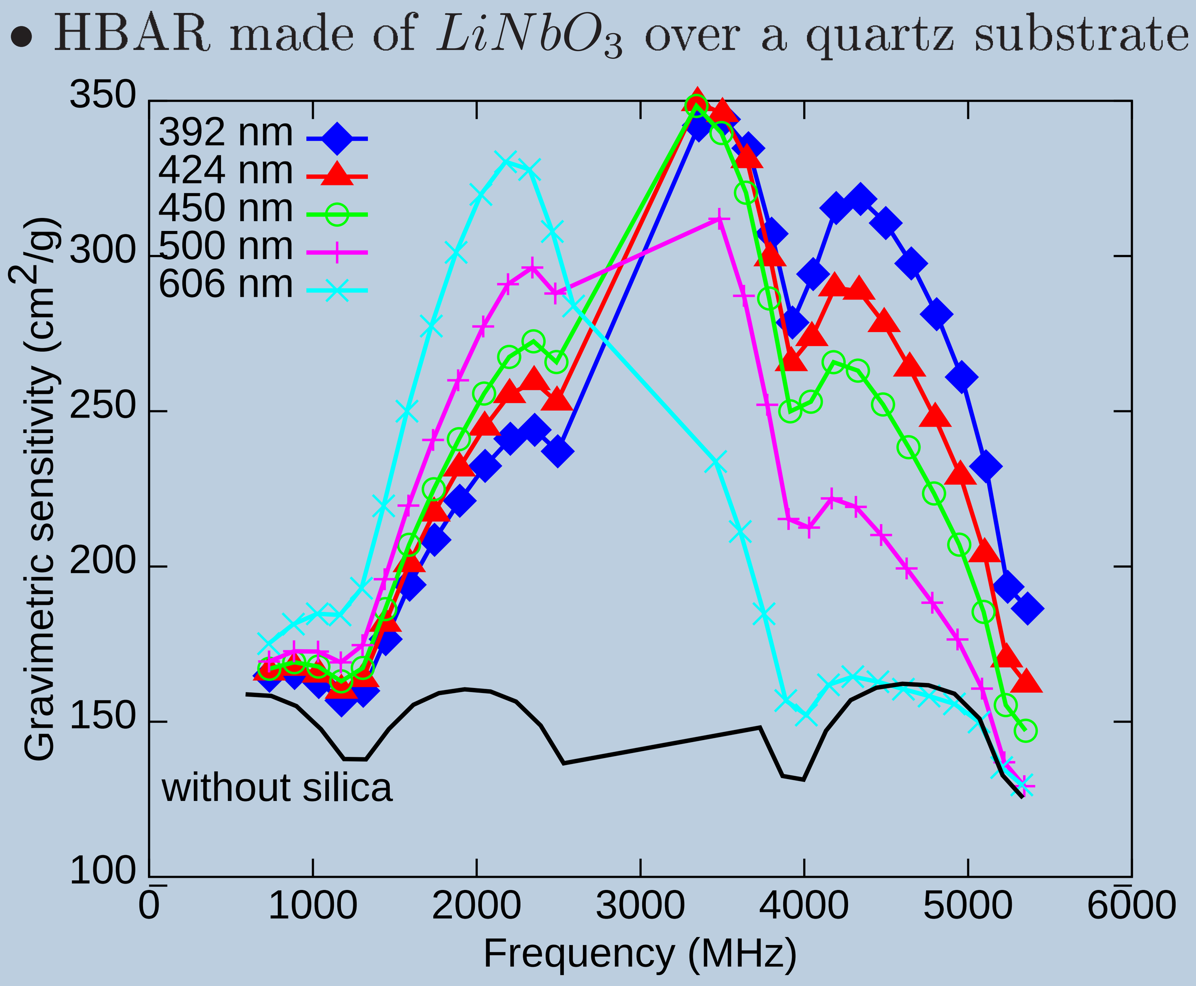
S dependence with material property

- S dependent on overtone number as is temperature sensitivity ⇒ differential measurement
- case of thin AlN over Si (30 μm) ⇒ S compatible with 40 μm-Love mode device
- Large thickness ≥ λ: S dependent on adsorbed layer property (similar to Love ?)
- high acoustic impedance ⇒ S ↓ with thickness ↑
- low acoustic impedance adsorbed layer (case of polymer) increases S wrt Sauerbrey
- Acoustic dispersion relation: λ might change over one decade



Sensitivity improvement strategy

- Gravimetric sensitivity improvement by using a low acoustic impedance material (silica) and by reducing thickness of the substrate.
- HBAR made of $LiNbO_3$ over a quartz substrate with different thicknesses.



Frequency range (MHz)	50 - 150				300 - 550			
Quartz thickness (μm)	450	225	112.5	56.25	450	225	112.5	56.25
number of probed modes	53	28	14	7	51	26	13	8
max. sensitivity (cm^2/g)	10.95	21.28	49.57	118.83	8.34	16.57	32.71	63.85
min. sensitivity (cm^2/g)	7.41	14.43	27.80	46.81	7.88	14.93	27.65	49.07
avg. sensitivity (cm^2/g)	8.67	17.71	36.99	80.43	8.24	16.18	31.21	58.90
theoretical sensitivity (Sauerbrey. cm^2/g)	8.39	16.77	33.54	67.1	8.38	16.77	33.54	67.1

Conclusion:

- beyond Sauerbrey, complex dependence of HBAR sensitivity with mode number
- average sensitivity consistent with Sauerbrey but large fluctuations
- proposed strategy for sensitivity improvement by energy confinement

[1] A. Reinhardt: *Simulation. réalisation et conception de filtre à ondes de volume dans des couches minces piézoélectriques*. PhD thesis 2005 – Université de Franche Comté [in French].

[2] G.D. Mansfeld, *Theory of high overtone bulk acoustic wave resonator as a gas sensor*, 13th Intl. Conf. Microwaves, Radar and Wireless Communications, 2000

Acknowledgements

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