A method to determine coating's Young's modulus from frequency shift of silicon cantilevers

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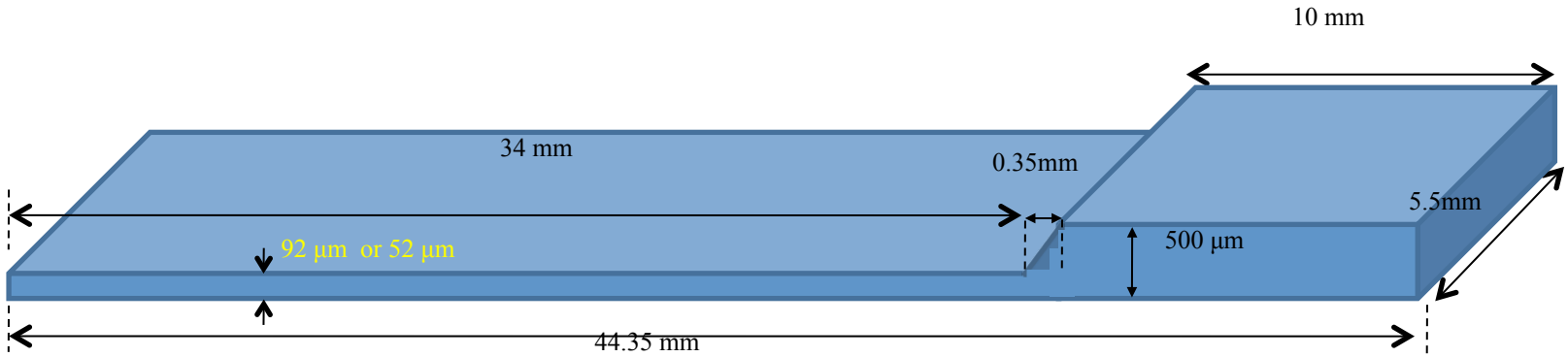
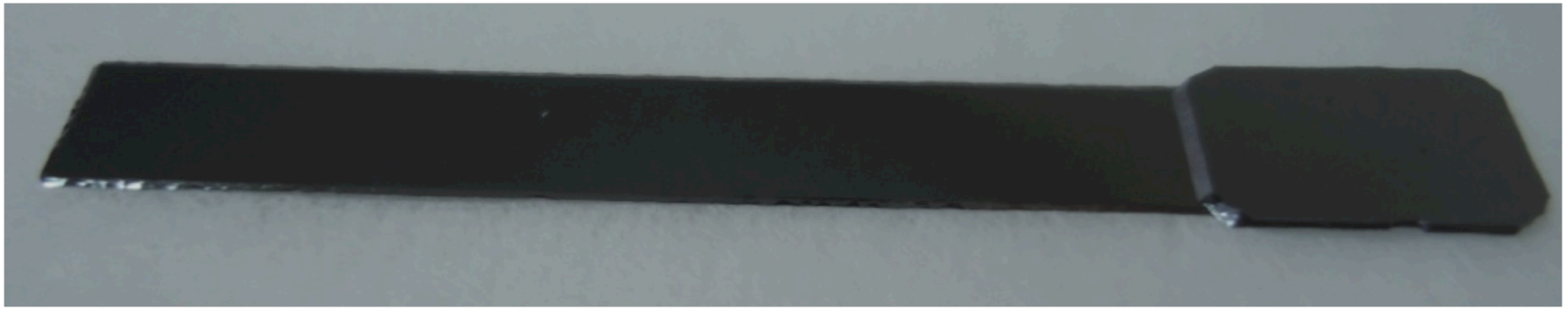
The physical effect

- Adding a coating makes a cantilever stiffer
- Resonant frequency moves up in frequency
- Comparing the frequency shift measured with a Finite Element Model one can allow us to extract the coating Young's modulus

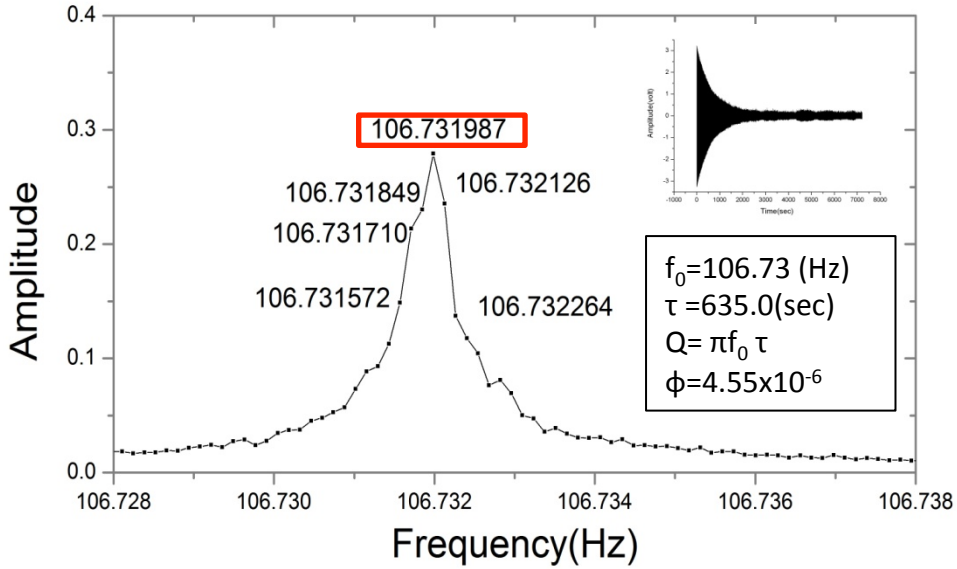
The enabler

- Thick holding pad reduces re-clamping error and produce high measurement precision

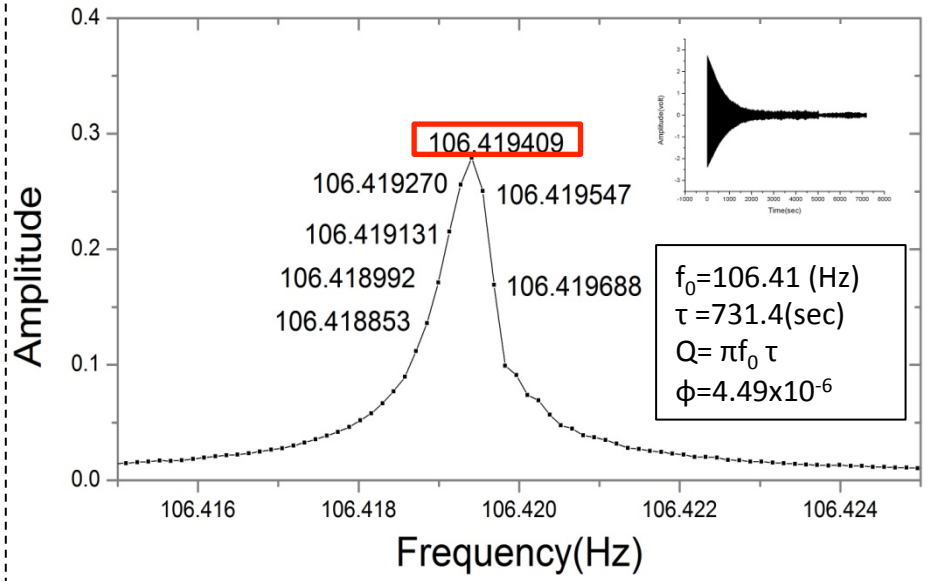


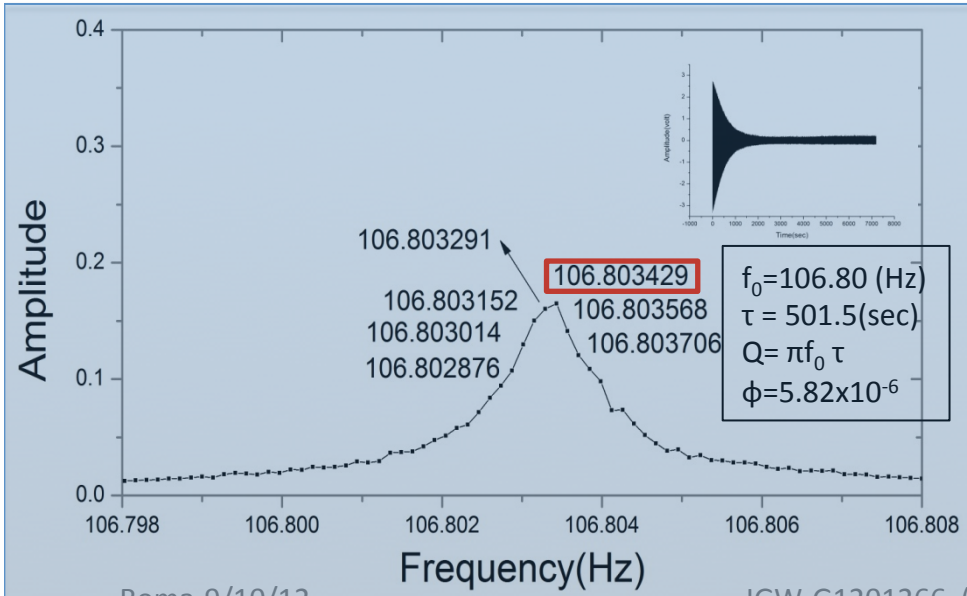


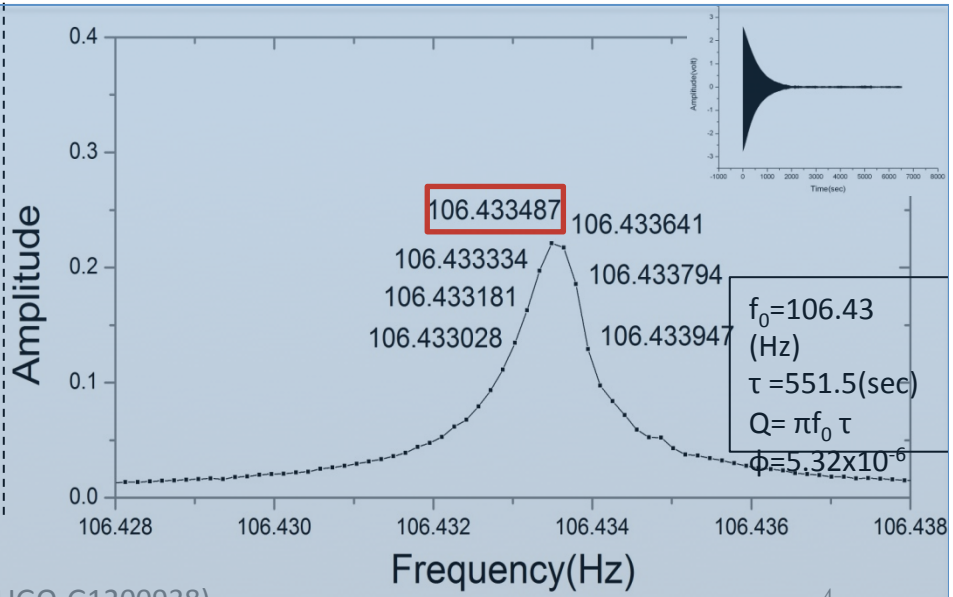
Frequency of silicon cantilever substrate
And with 3 nano-layers coated



Frequency of silicon cantilever substrate
And with 19 nano-layers coated



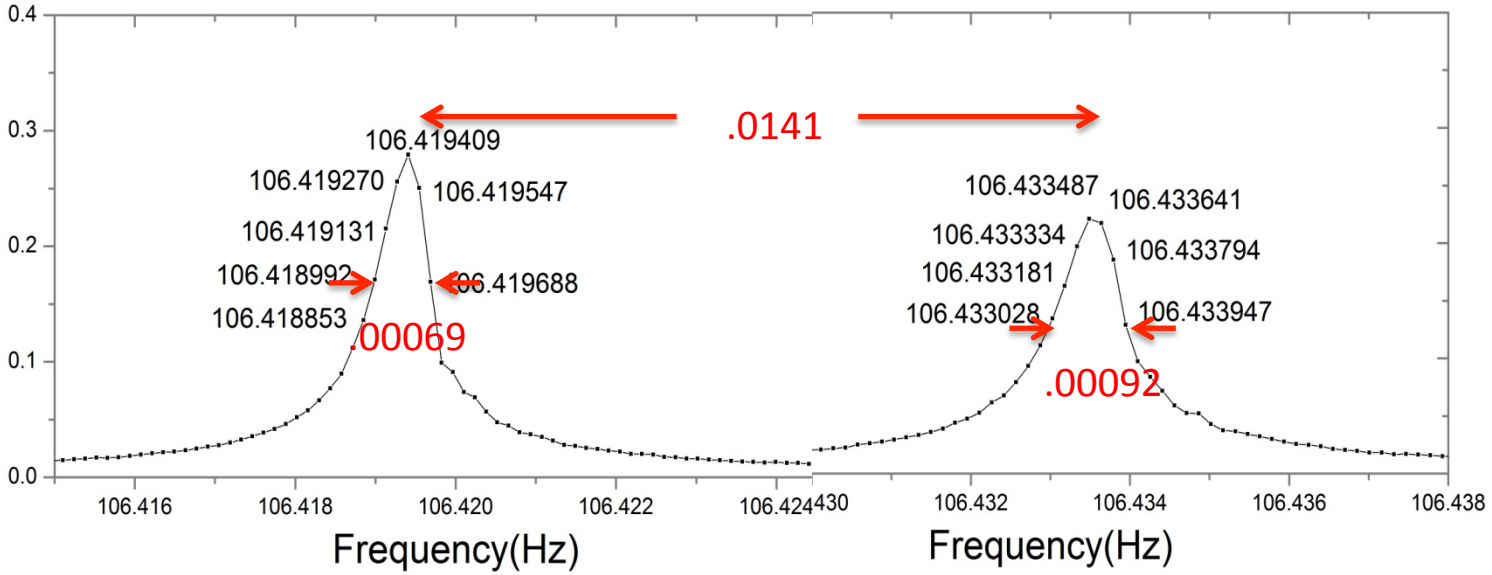


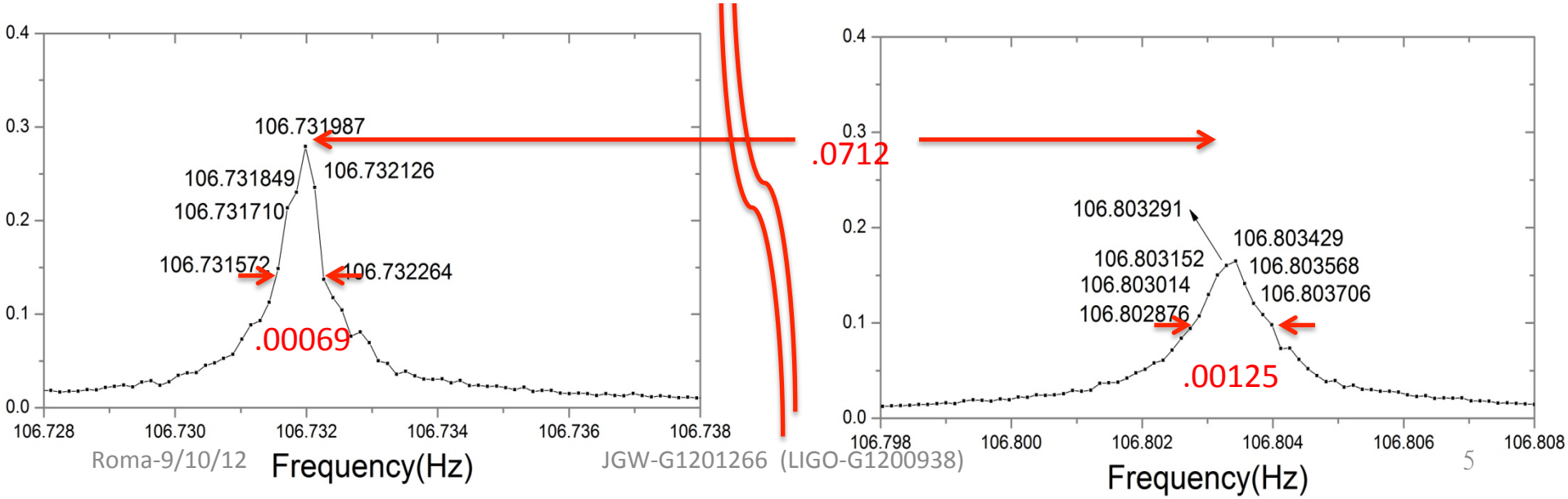


Can measure the frequency shift caused by coating with precision < 10^{-3}

Thermal frequency shifts likely dominate

MUST measure temperature to measure thermal shift





Thermal effects

$$f \propto \sqrt{Y}$$

- $\partial Y/\partial T = 127 \times 10^{-6}/^{o}C$

- Thermal shift $\partial f/\partial T \sim 50\ 10^{-6}\ /^{o}C$
- Measured $\Delta f \sim 100\text{-}600\ 10^{-6}$
- Temperature affects the result

Question 1

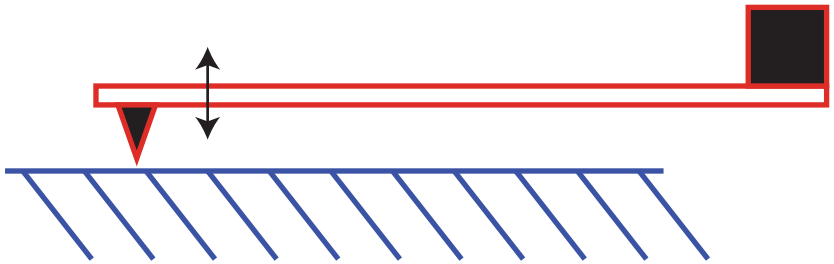
- Will the sensitivity be enough?
- Frequency measurements at 10^{-6}, OK
- Simultaneous measurements over several higher mode resonant frequencies will increase the sensitivity

Question 2

- Is this the desired Young's Modulus?
- This measurement extracts the parallel Young's Modulus
- Coating thermal noise requires the perpendicular Young's Modulus

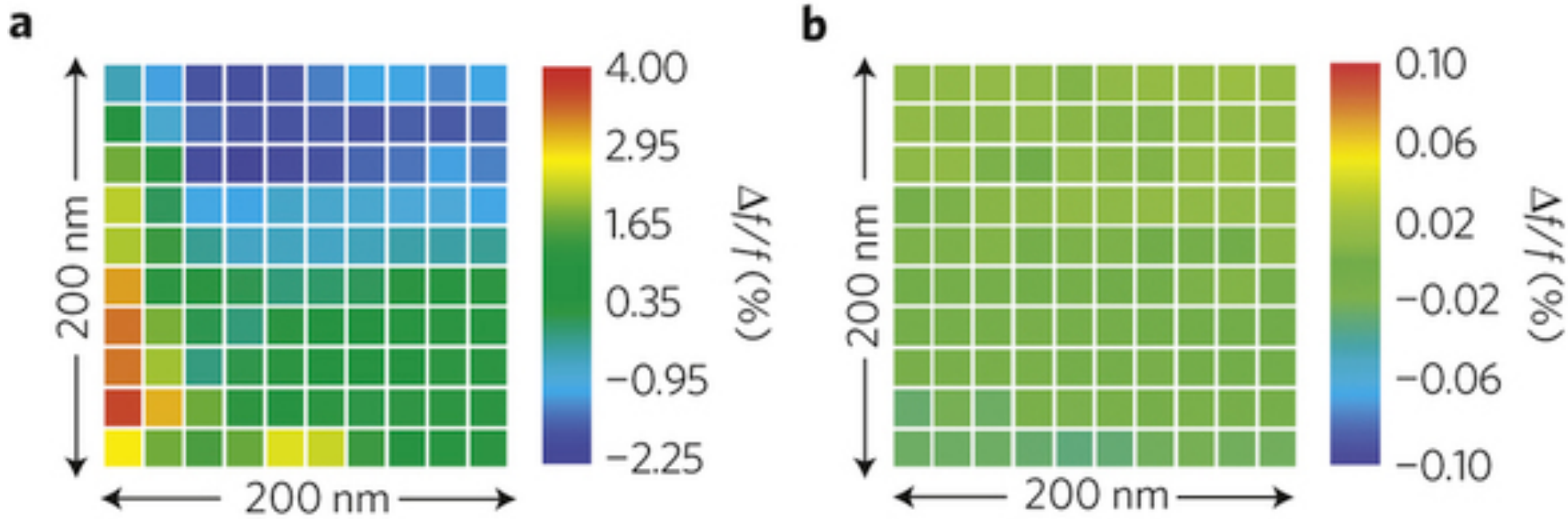
How to measure the // Young's Modulus

- Konrad Samwer uses a modified Atomic Force Acoustic Microscope to measure the local elasticity with a no-indentation method
- The atomic force microscope needle is brought in contact, in the elastic regime
- From the variation of resonant frequency of the needle's cantilever the local Young's modulus of the material is measured



Local elastic properties of a metallic glass Hannes Wagner, Dennis Bedorf, Stefan Küchemann, Moritz Schwabe, Bo Zhang, Walter Arnold & Konrad Samwer Nature Materials 10, 439–442 (2011)
And supplemental material

Typical AFAM *scan*



- **a**, Map of the local contact-resonance frequencies on amorphous glass. **b**, on crystal. Both maps represent the results of AFAM data at 100 different positions on the samples surfaces

Good and bad

- Samwer's technique only measures Young's modulus over the first nanometer depth
- A mixture of parallel and perpendicular Young's modulus is measured
- The perpendicular Young's modulus can be disentangled with the cantilever frequency shift information