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Laser-based ultrasonic characterisation of Ge membranes

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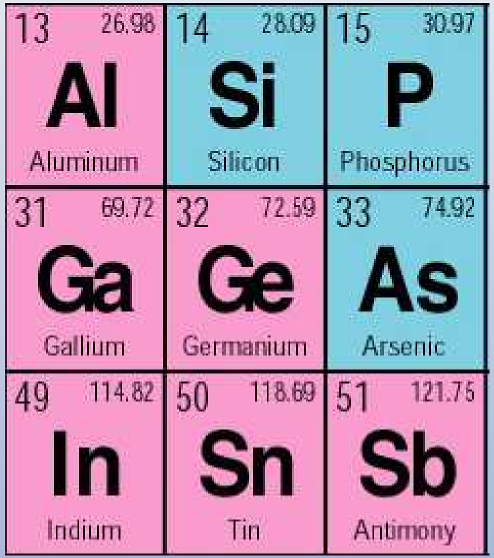
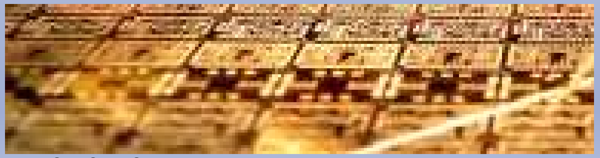
Germanium



13 26.98 **Al** Aluminum	14 28.09 **Si** Silicon	15 30.97 **P** Phosphorus
31 69.72 **Ga** Gallium	32 72.59 **Ge** Germanium	33 74.92 **As** Arsenic
49 114.82 **In** Indium	50 118.69 **Sn** Tin	51 121.75 **Sb** Antimony

Ge on Si:

- Sensors
- avalanche diode detectors
- photonic modulators
- solar cells
- heterojunction bipolar transistors



Ge membranes - more rapid and higher sensitivity response

0.7μm thick, 965μm x 965μm single crystal Ge membrane on Si

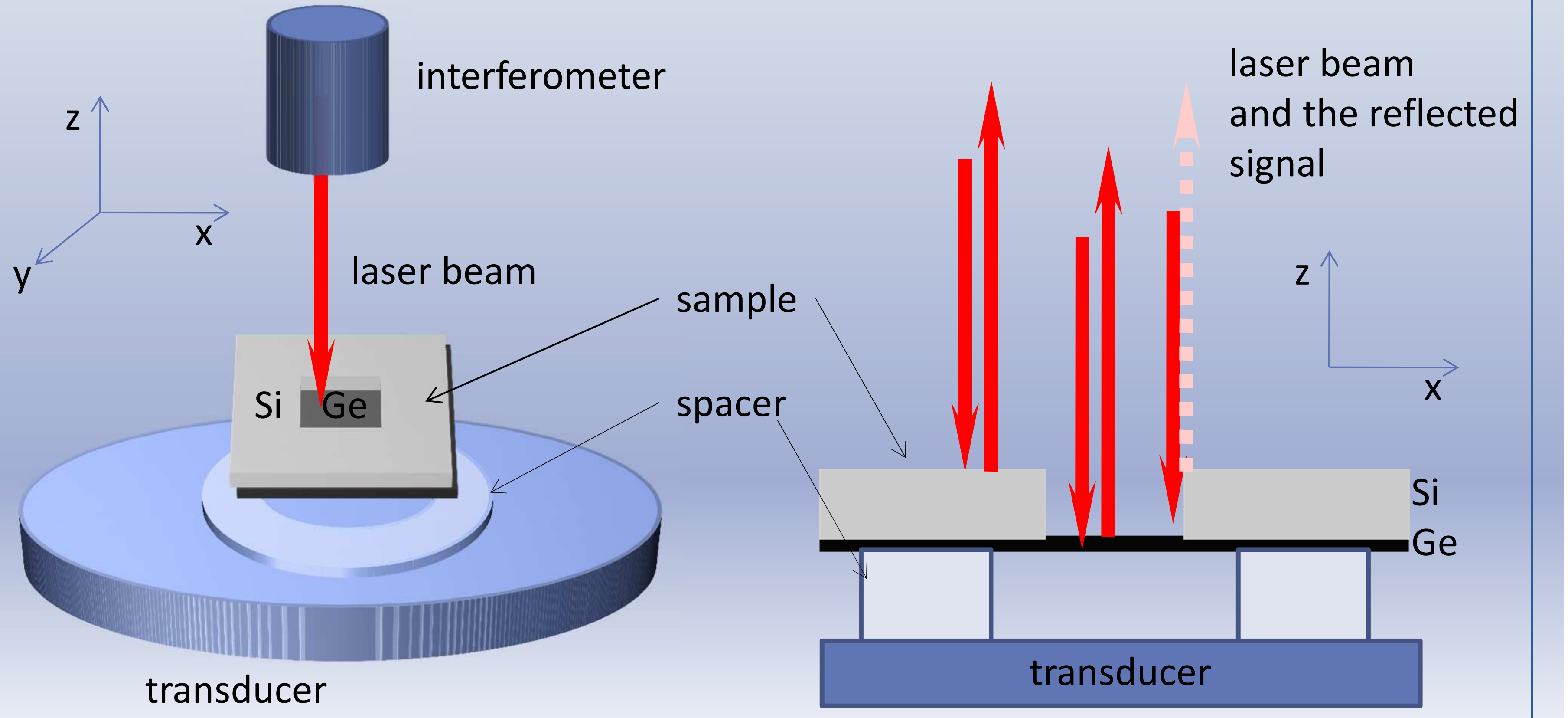
Interested in:

vibrational frequencies, quality factor Q

residual stress or Young’s modulus

robustness to shock

Experimental setup, >100 kHz



two-wave mixer laser interferometer IOS AIR-1550-TWM
calibrated to give the absolute out-of-plane deflection amplitude

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Modes, theory

Frequency of vibrating membrane
(internal tensile stress is significant)
in vacuum

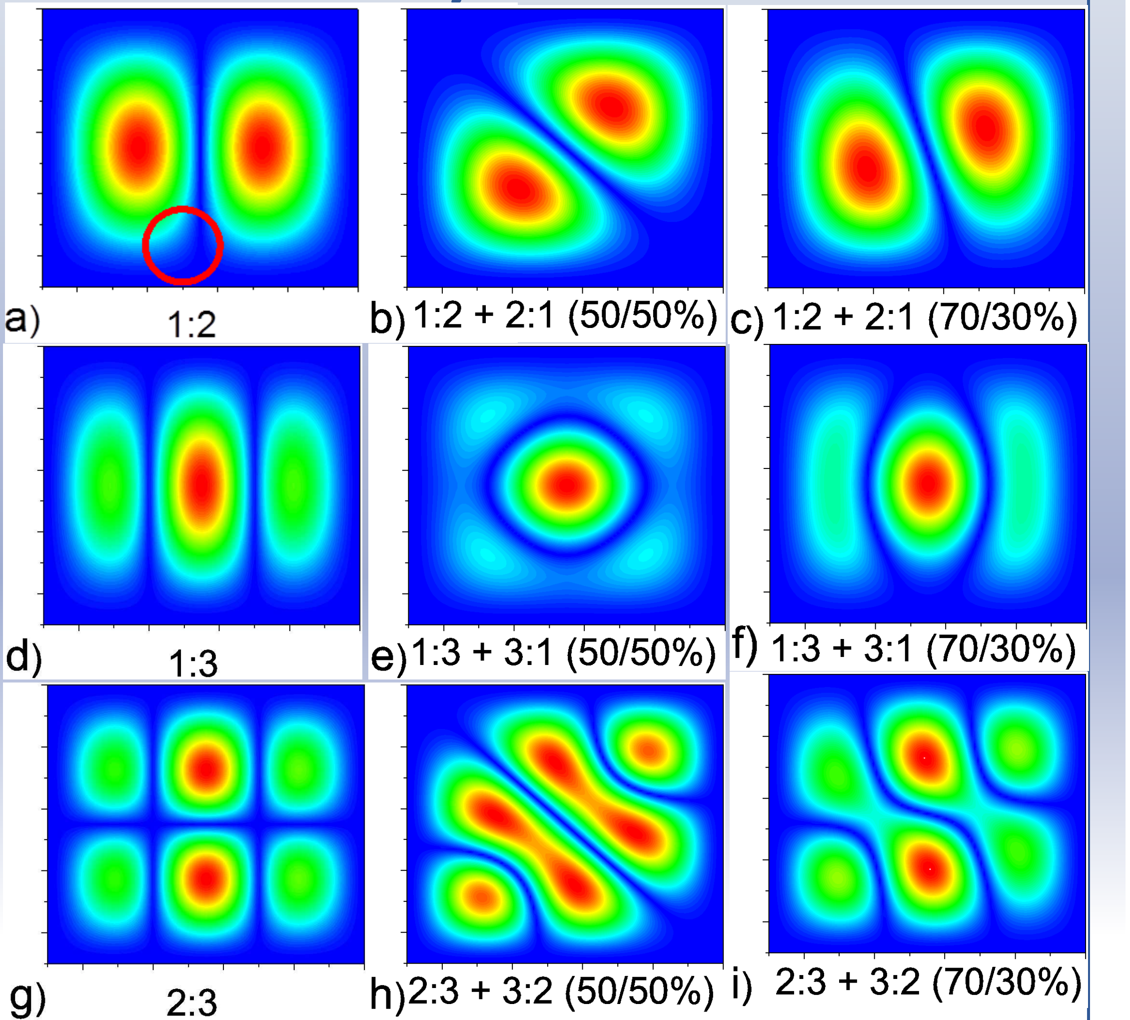
LE Kinsler, AR Frey, Physical Acoustics in the Solid Phase, NY, 1962

$$f^{vac}_{nm} = \frac{1}{2}\sqrt{\frac{\sigma}{\rho}\left(\left(\frac{n}{a}\right)^2+\left(\frac{m}{a}\right)^2\right)}$$

σ – stress; ρ –density
a – side length
d - thickness
n, m – mode number

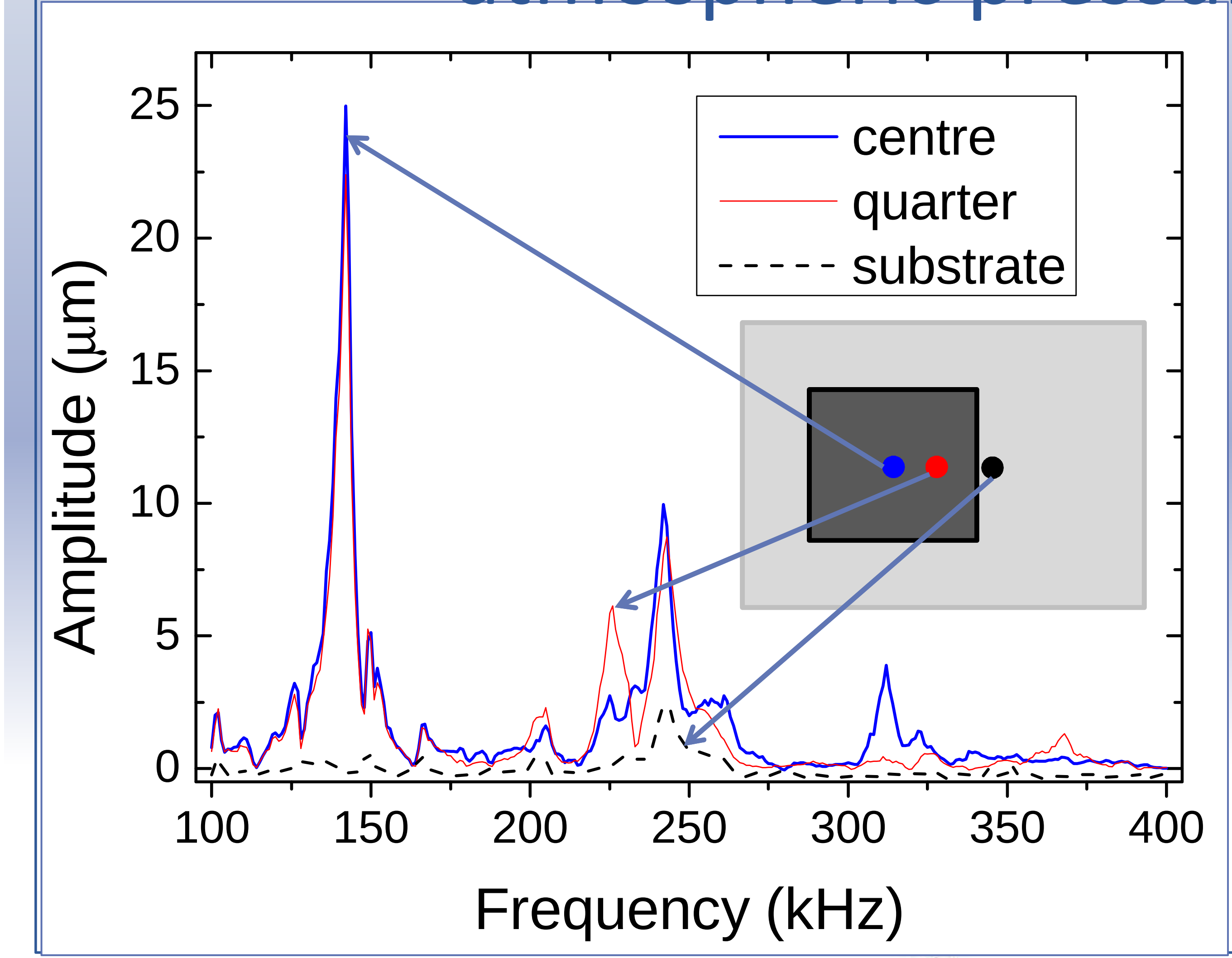
Correcting for atmospheric damping
Karnezos, JVacSciTechB, 4, 226, 1986

$$f_{nm} = \frac{f^{vac}_{nm}}{\sqrt{1+1.34\frac{a\rho_{air}}{\rho d}}}$$


a) 1:2
b) 1:2 + 2:1 (50/50%)
c) 1:2 + 2:1 (70/30%)
d) 1:3
e) 1:3 + 3:1 (50/50%)
f) 1:3 + 3:1 (70/30%)
g) 2:3
h) 2:3 + 3:2 (50/50%)
i) 2:3 + 3:2 (70/30%)

Calculated mode profiles for modes and their mixing
The red circle represents interferometer laser spot (200µm)

Frequency spectra, atmospheric pressure



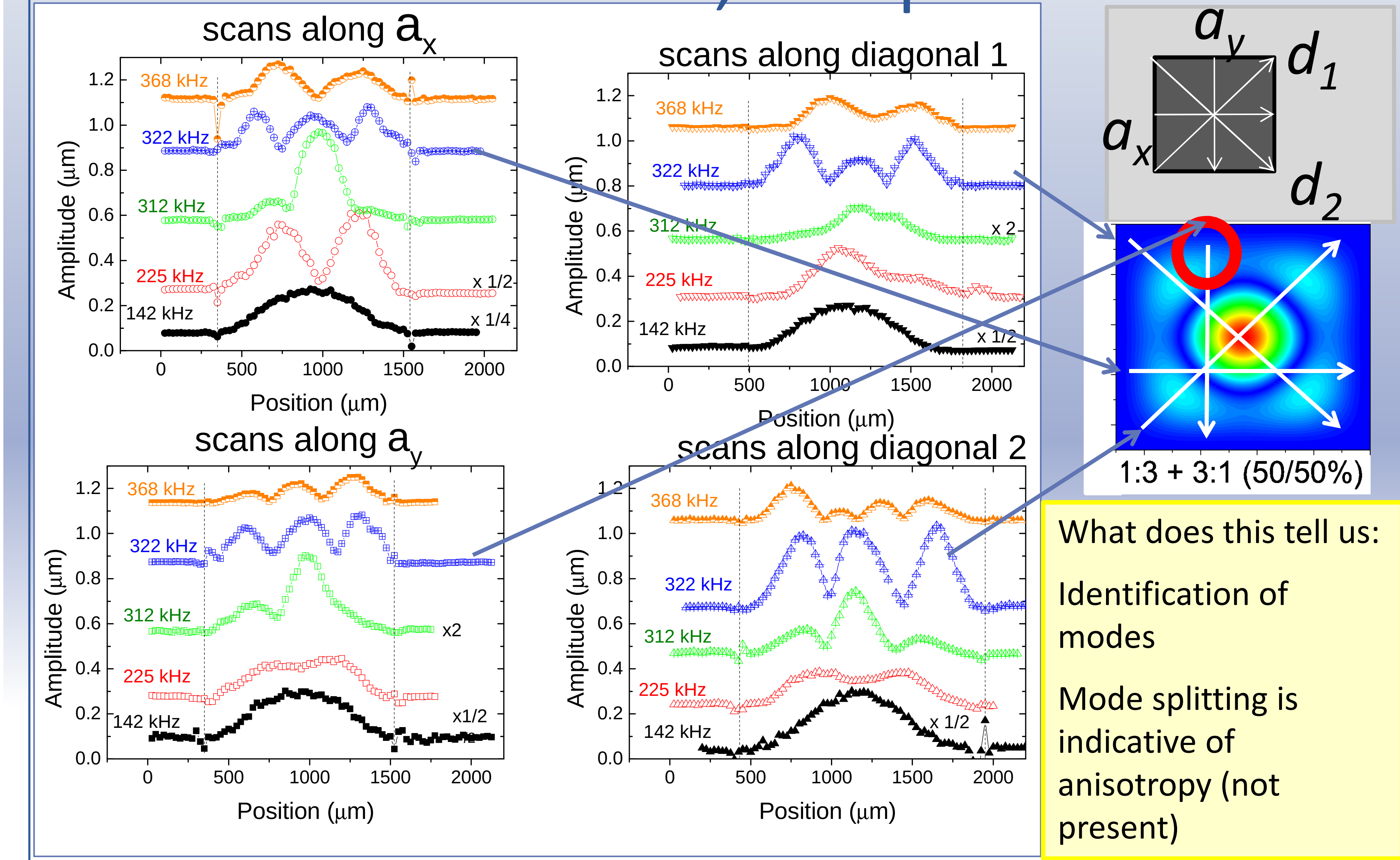
What does this tell us:

Can see the fundamental and several other modes

Q factor (for atmospheric pressure)

Tensile stress in the membrane

Position scans, atm pressure

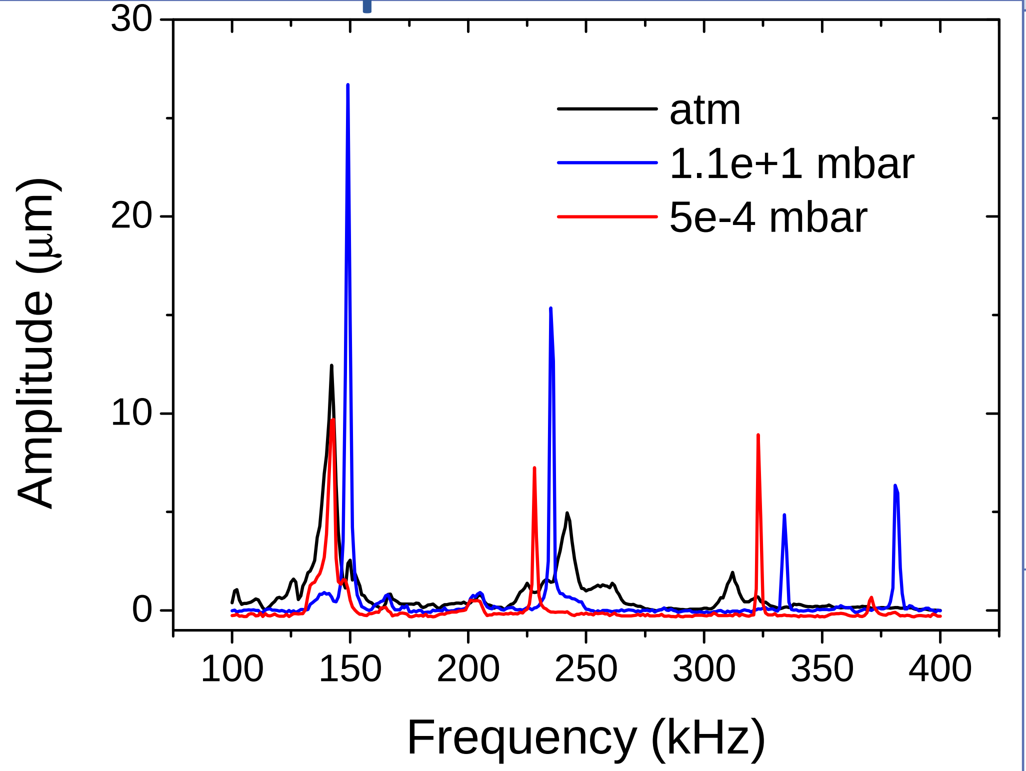


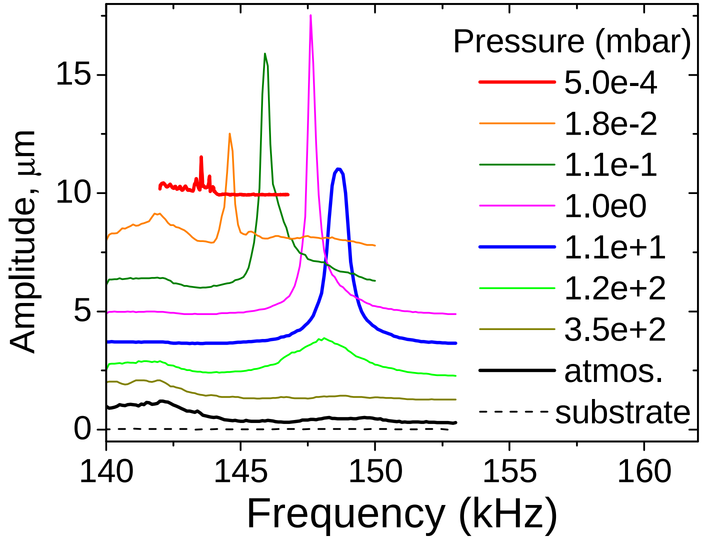
What does this tell us:

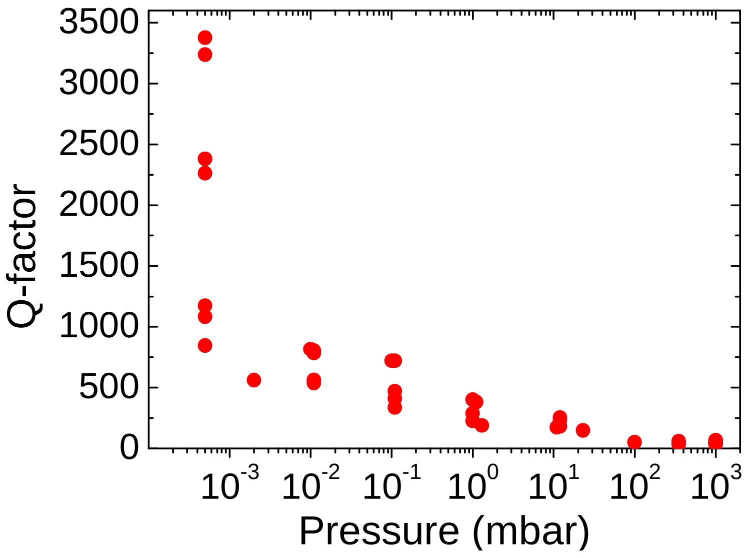
Identification of modes

Mode splitting is indicative of anisotropy (not present)

Spectra evolution in vacuum







Less damping in vacuum, hence
- Better defined modes
- Upshift in frequency
- Increase in Q factors

but

Downshift in frequency at <10 mbar - **heating**

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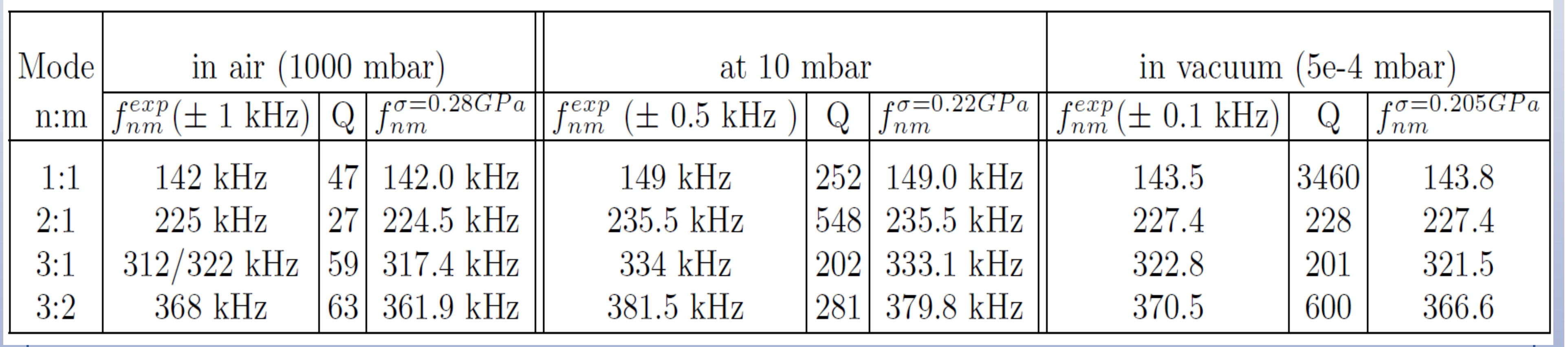
Stress and Q factors



Mode	in air (1000 mbar)			at 10 mbar			in vacuum (5e-4 mbar)		
n:m	f_{nm}^{exp}(± 1 kHz)	Q	$f_{nm}^{\sigma=0.28GPa}$	f_{nm}^{exp} (± 0.5 kHz)	Q	$f_{nm}^{\sigma=0.22GPa}$	f_{nm}^{exp}(± 0.1 kHz)	Q	$f_{nm}^{\sigma=0.205GPa}$
1:1	142 kHz	47	142.0 kHz	149 kHz	252	149.0 kHz	143.5	3460	143.8
2:1	225 kHz	27	224.5 kHz	235.5 kHz	548	235.5 kHz	227.4	228	227.4
3:1	312/322 kHz	59	317.4 kHz	334 kHz	202	333.1 kHz	322.8	201	321.5
3:2	368 kHz	63	361.9 kHz	381.5 kHz	281	379.8 kHz	370.5	600	366.6

Experimental vs calculated membrane frequencies at several pressures, stress in the calculation is chosen for the best match with the experimentally observed frequencies;
the table also shows experimental Q factors

- Stress expected from growth conditions - **0.18 GPa**
- Stress calculated from experimental frequencies using modes up to 3:2 - **0.2 – 0.28 GPa**
- Q-factors of 1:1 mode : **47** at atmospheric pressure,
  3460 at $5\cdot10^{-4}$mbar

Conclusions

- The method is fast and non destructive
- Allows to calculate Young's modulus if sample behaves as a vibrating plate (no stress)
- Allows to calculate tensile stress if sample behaves as a membrane (in this work $\sigma = 0.22$ GPa)
- Quick assessment of Q factors (47 at 10^3mbar and 3460 at $5 \cdot 10^{-4}$mbar)
- Allows to evaluate anisotropy (in this work membrane was isotropic)
- Robustness to shock of membranes can be implied from vibrational frequencies and Q factors
- Suitable for life testing
- It is important to control heating which becomes significant in vacuum

More detail in *STAM* **15** (2), p 025004 (2014)

Future:

- Looking at more complex structures such as beams and spider web structures
- Entirely different but related to optics: liquid crystals for ultrasound sensing

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