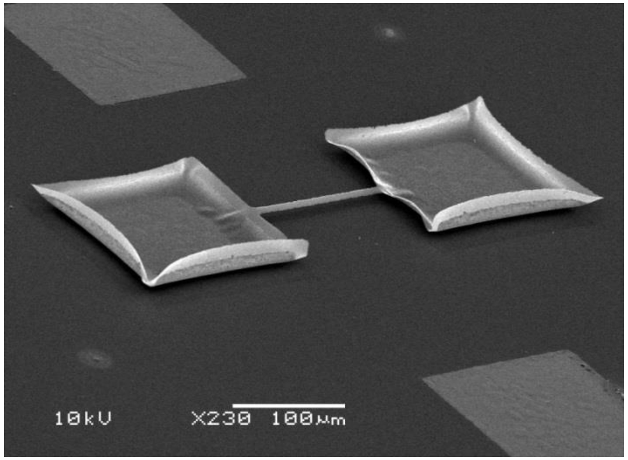
Characterisation of nanographite for MEMS resonators



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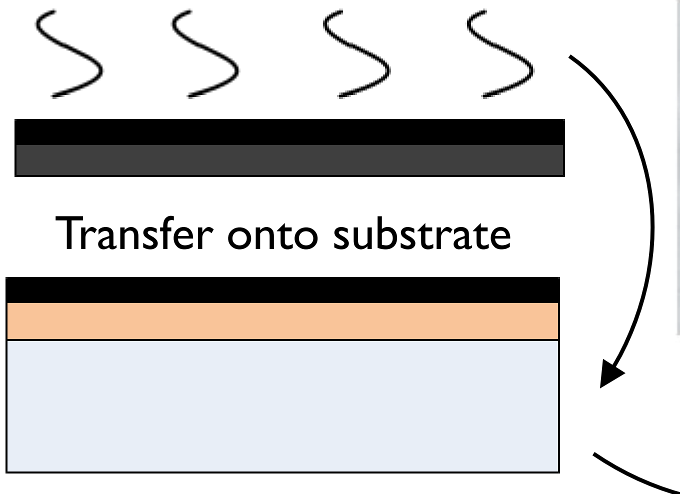
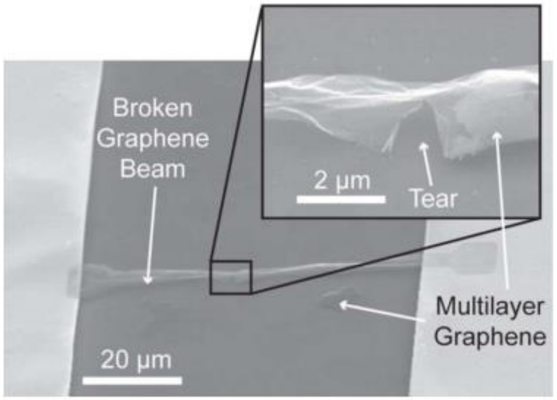
Carbon materials for MEMS and NEMS

- Investigated materials: diamond-like carbon, graphite, graphene
- Applications: switches, low friction materials and resonators
- Good mechanical properties and device scalability
- AIM: Demonstrate fabrication and characterisation of nanographite MEMS resonators without transfer

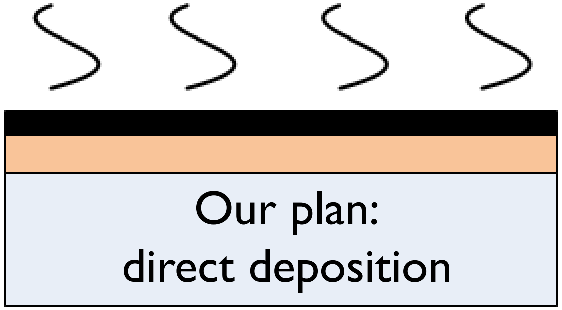


CVD onto catalyst

Transfer onto substrate



Low yield for fragile NEMS



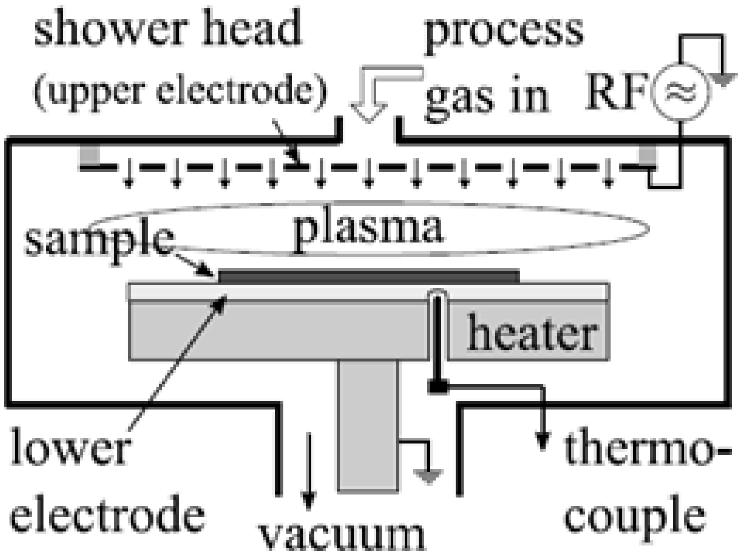
Our plan:
direct deposition

K.M. Milaninia, Appl. Phys. Lett. 95 (2009)

Nanocrystalline graphite deposition

- 6-inch silicon wafer substrate
- Oxford instruments Nanofab PECVD
- Scalable and reproducible →

standard microfabrication process

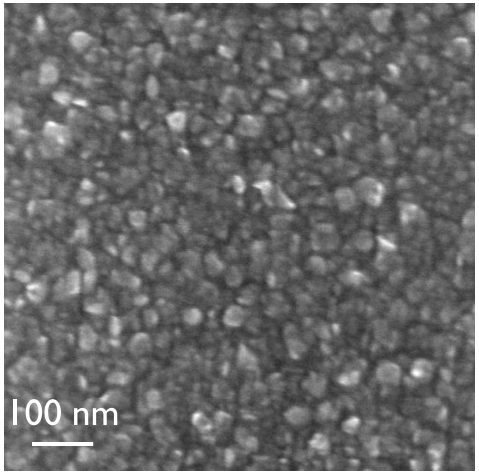


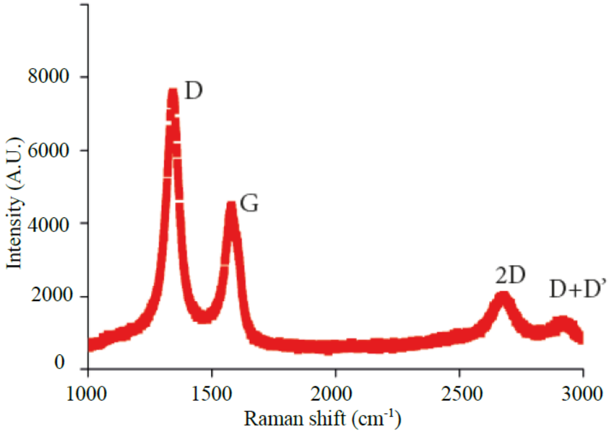
Temperature (°C)	750
Methane flow (sccm)	75
Hydrogen flow (sccm)	60
Pressure (mTorr)	1500
RF Power (W)	100

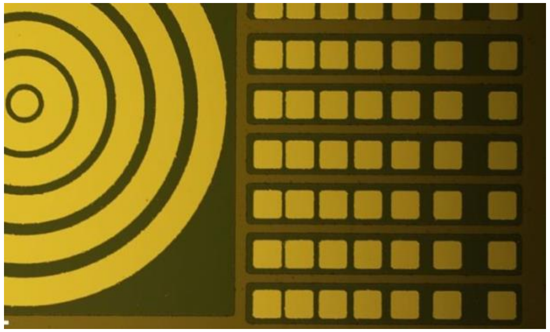
M.E. Schmidt et. Al, Mater. Res. Exp. 1 (2014).
www.azom.com

Material characterisation

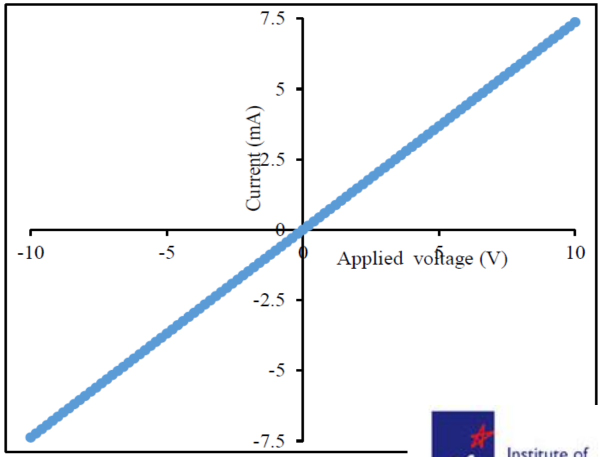
- Raman and SEM confirm nanocrystalline grain structure
- Electrical resistivity 10.0 mΩ cm
- XRR measurement – density ρ 1900 kg/m^3
- Typical roughness 3 nm RMS from AFM contact mode
- Film thickness between 8 and 340 nm



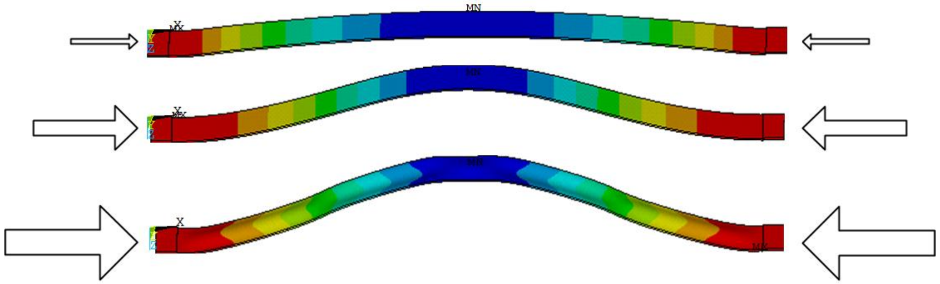




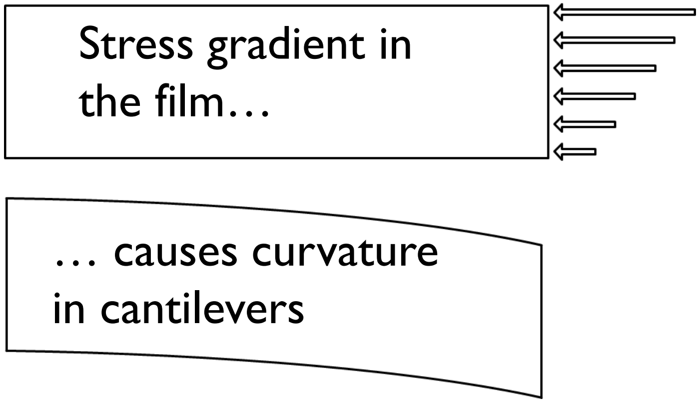
Resistivity by electrical measurements



Film stress



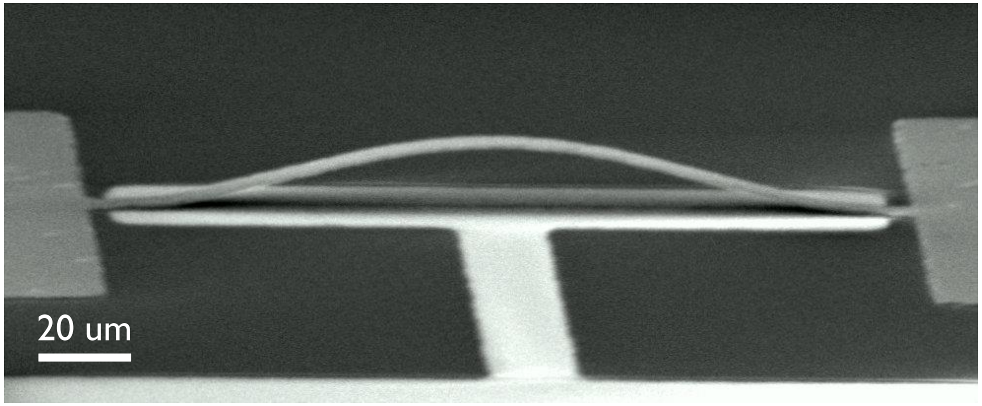
Average compressive stress causes buckling in doubly clamped beams

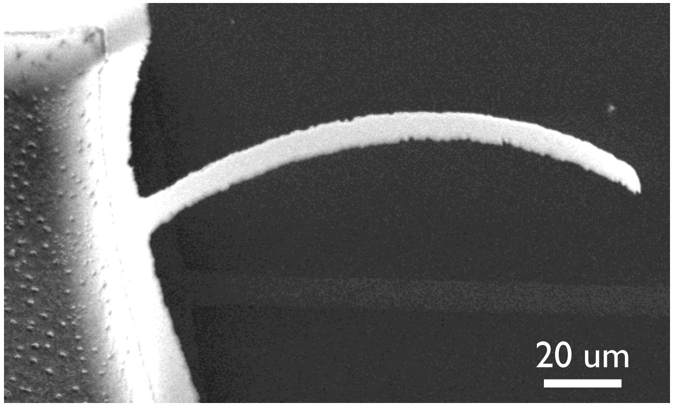


Applied stress

Stress gradient in the film…

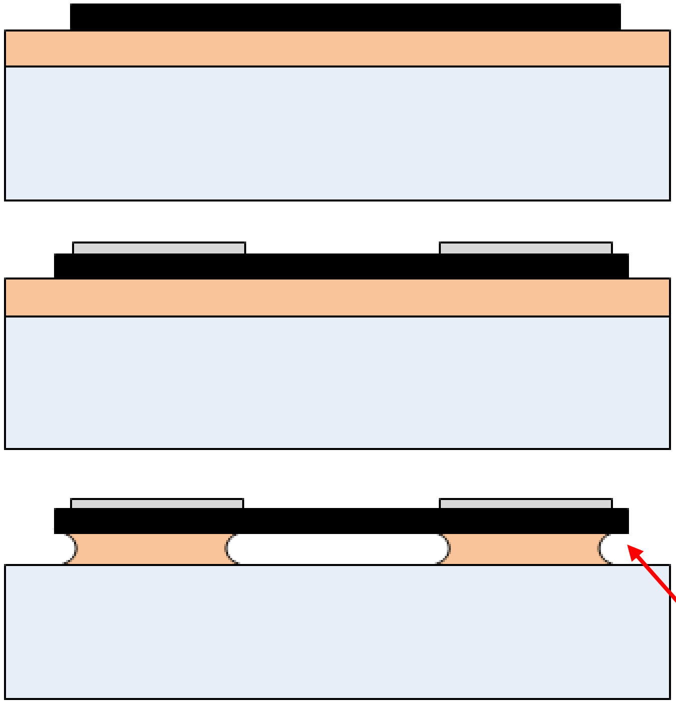
… causes curvature in cantilevers



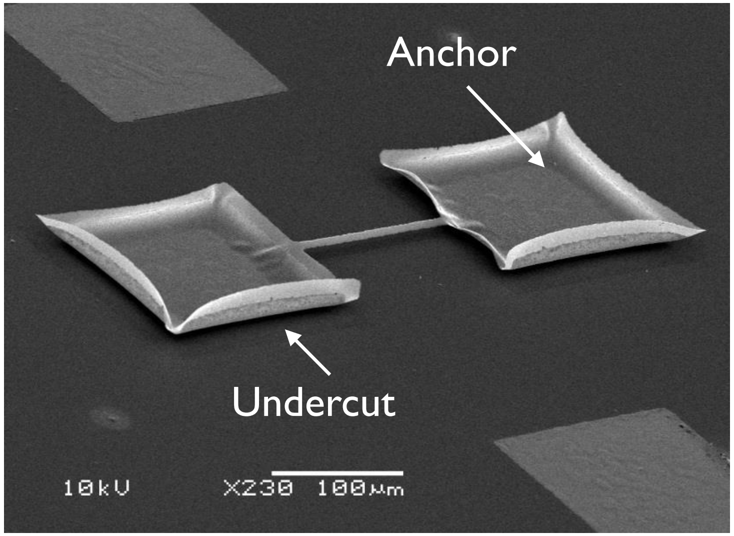


Device fabrication

- Surface micromachining, optical lithography



- Pattern and etch nanographite into beam shape
- E-beam evaporated Ni/Ti electrodes
- HF vapour isotropic etch for beam release



Undercut changes stress in beam section

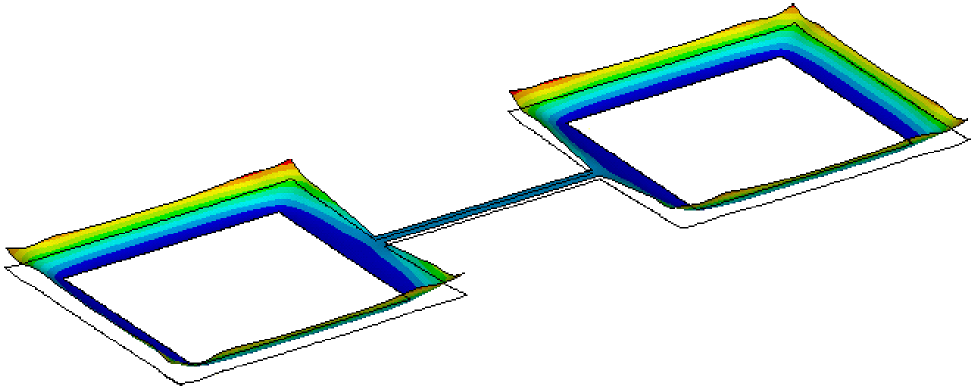
KEY:
■ Nanographite
🟧 PECVD Silicon dioxide
⬜ SC Silicon substrate

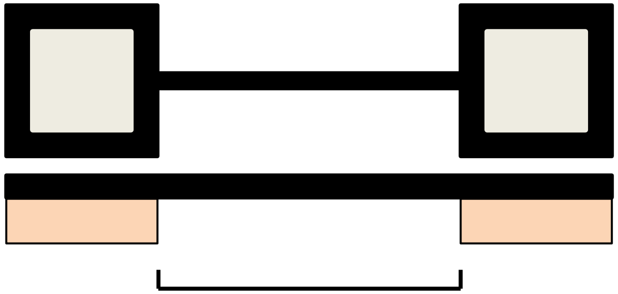
Simulation

- Modelled as classic beams under tension where Natural frequency *f* varies with : Length *L* , Stiffness *E*, density *ρ* ,Stress *S* and Moment of Inertia *I* :

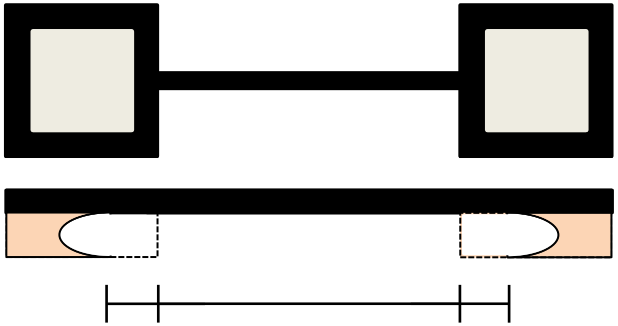
$$f \propto \frac{\pi^2}{L^2}\sqrt{\frac{EI}{\rho}}\sqrt{1+\frac{SL^2}{EI\pi^2}}$$

- Finite element simulation shows added length due to the undercut ~ 3%





Nominal length



Effective length

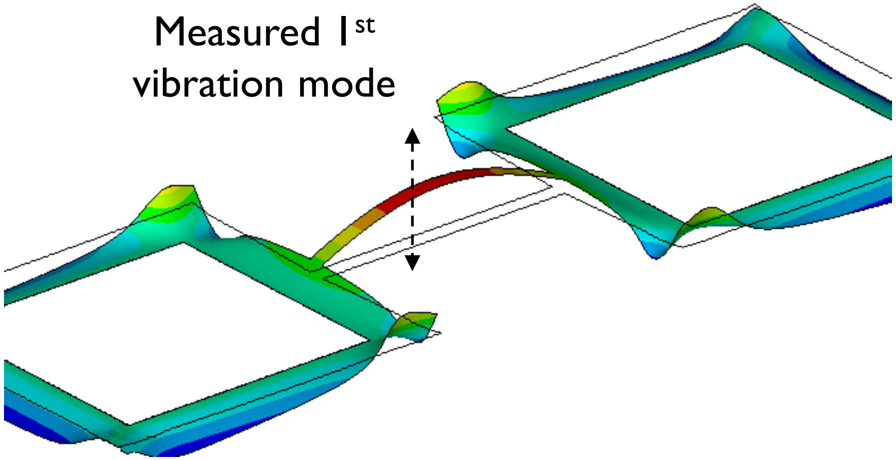
Actuation and measurement

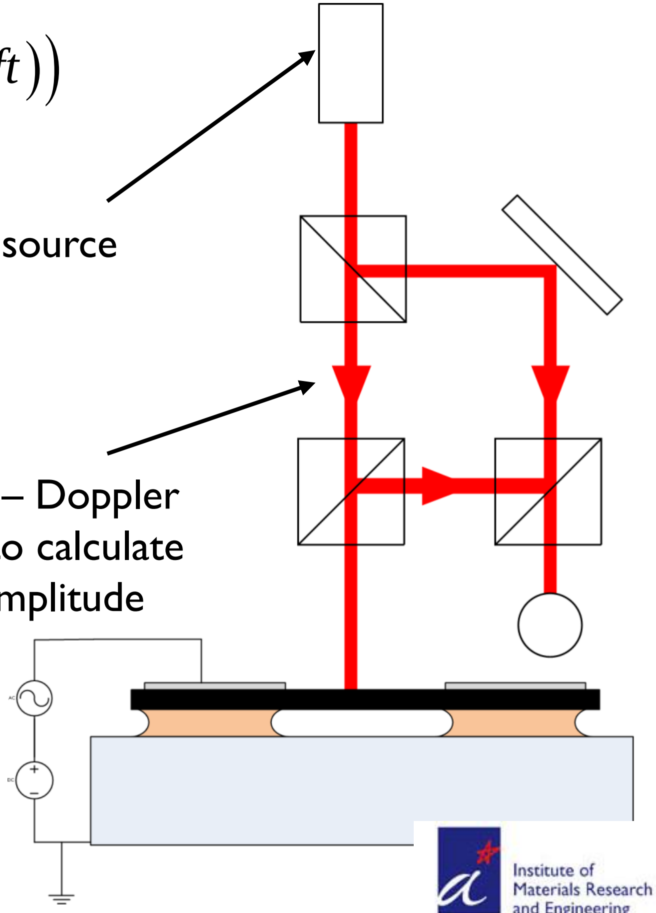
- DC V_{DC} + AC V_0 voltage creating electrostatic force F to actuate the beam
- Sweep AC voltage at frequency f and measure the vibration using vibrometer

Actuation

$$F = \frac{1}{2}\frac{\partial C}{\partial r}V^2 \approx \frac{1}{2}\frac{\partial C}{\partial r}\left(V_{DC}^2 + 2V_{DC}V_0\sin\left(2\pi ft\right)\right)$$

Measured 1st vibration mode



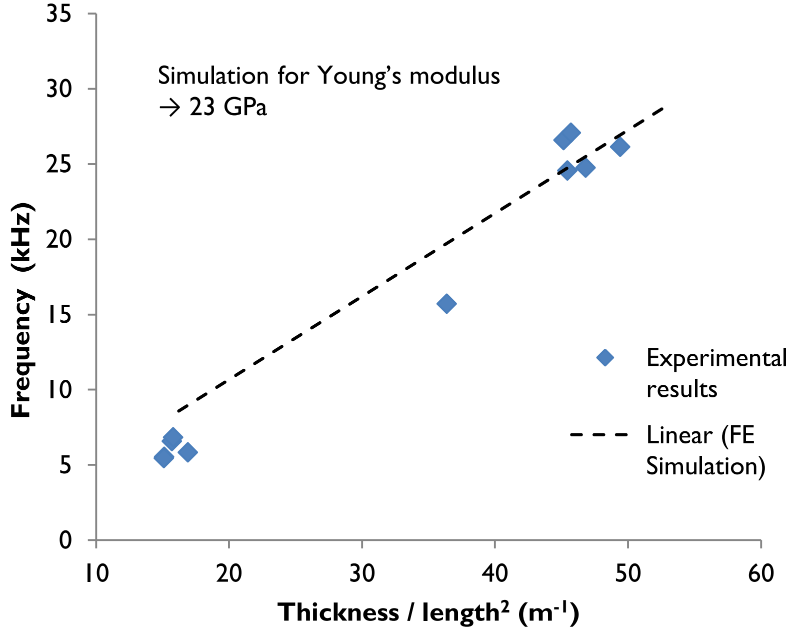


Laser source

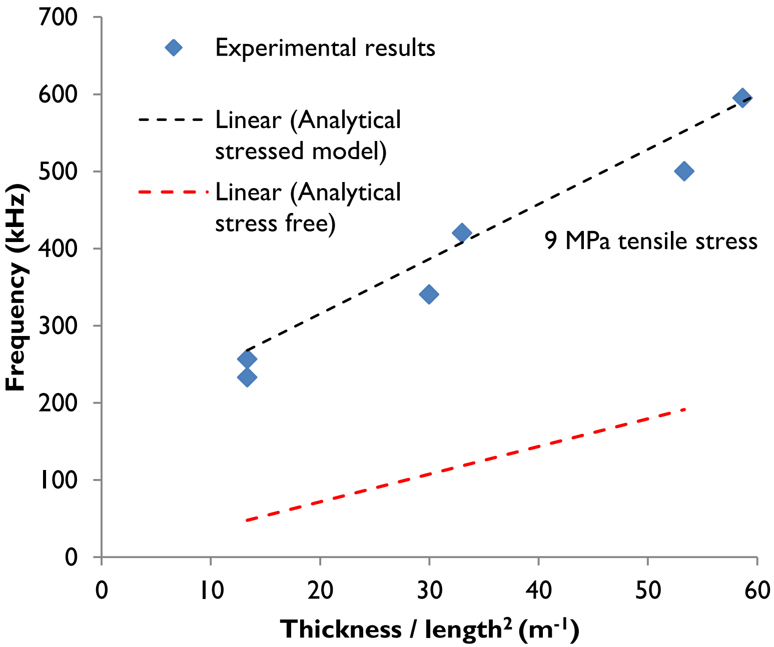
Split beam – Doppler shift used to calculate vibration amplitude

Resonance results

- Verification from the finite element model
- Young's modulus from the cantilevers is 23 GPa
- Frequency of the doubly clamped beams dominated by stress



Cantilever results

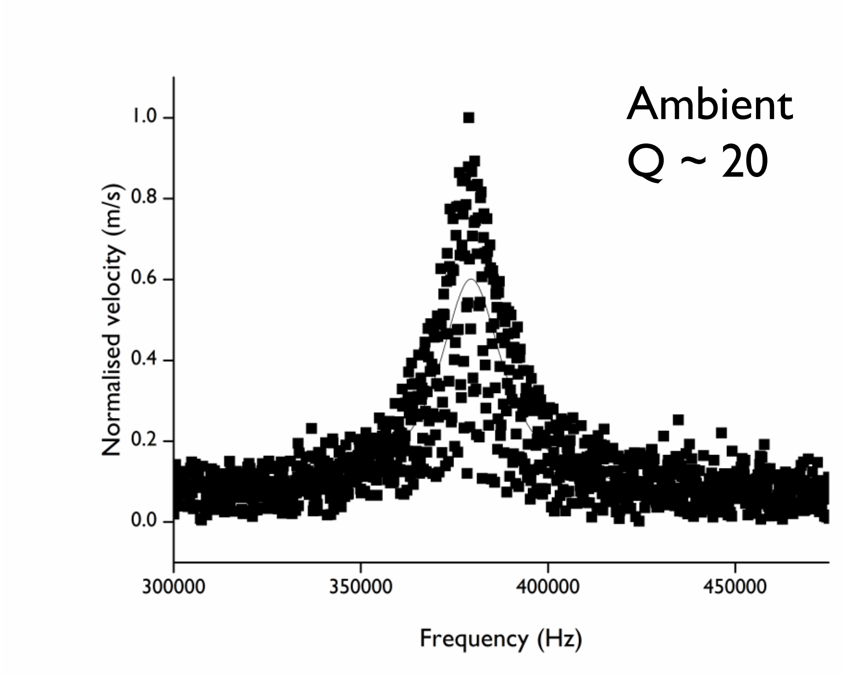


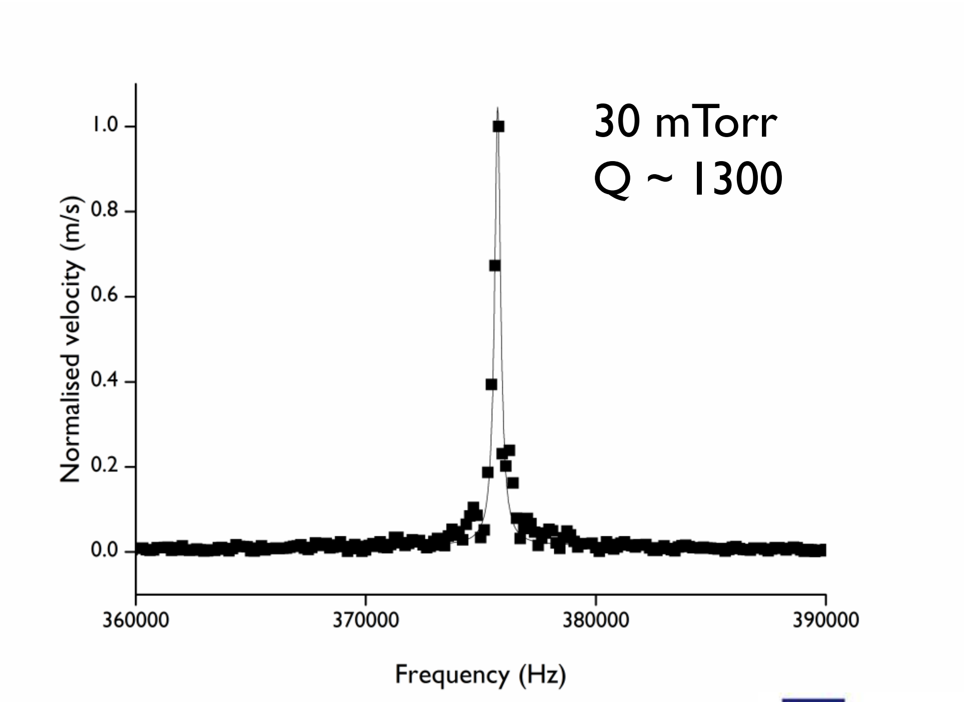
Doubly clamped beam results

Device lengths 75 to150 µm. Thickness 300 nm to 340 nm

Results - quality factor

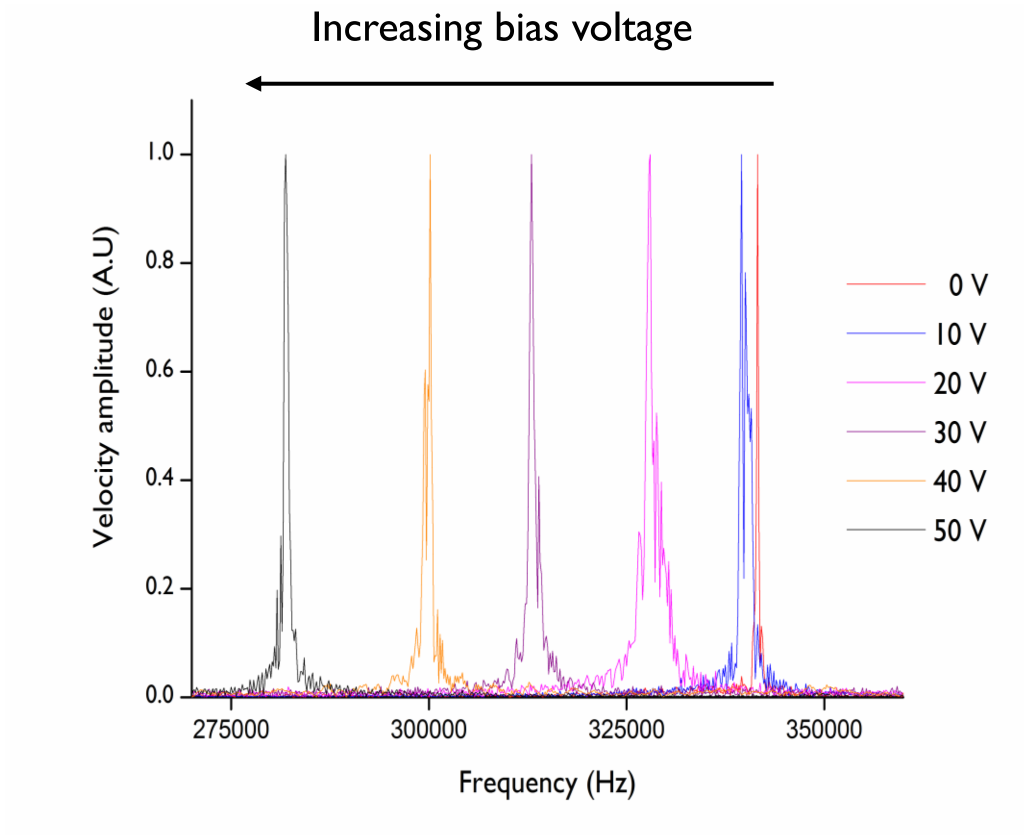
- Quality factor ‘Q’ – energy loss at resonance. Calculated from the FWHM of fitted curve
- Losses are intrinsic, clamping, extrinsic

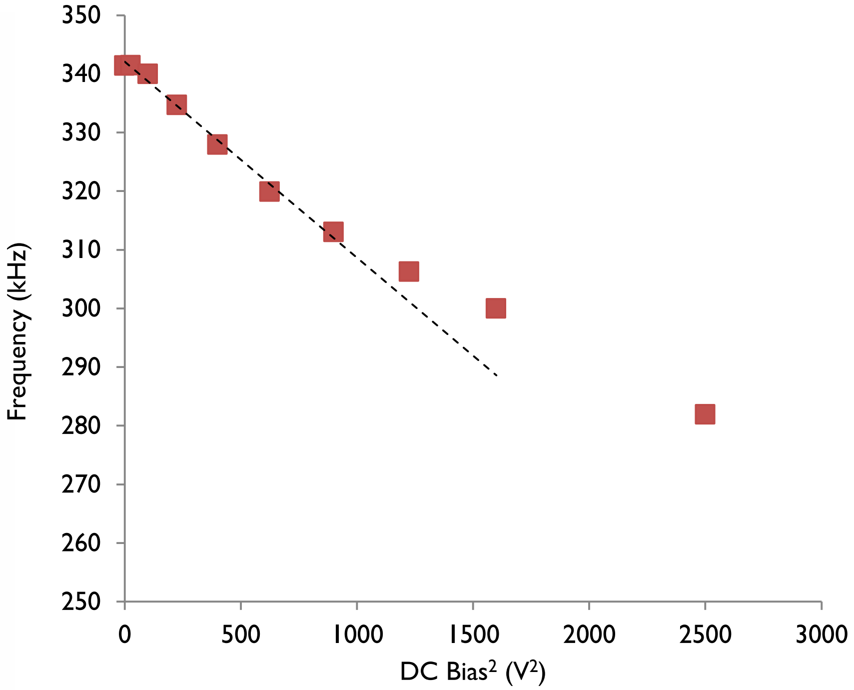




Tuning the natural frequency

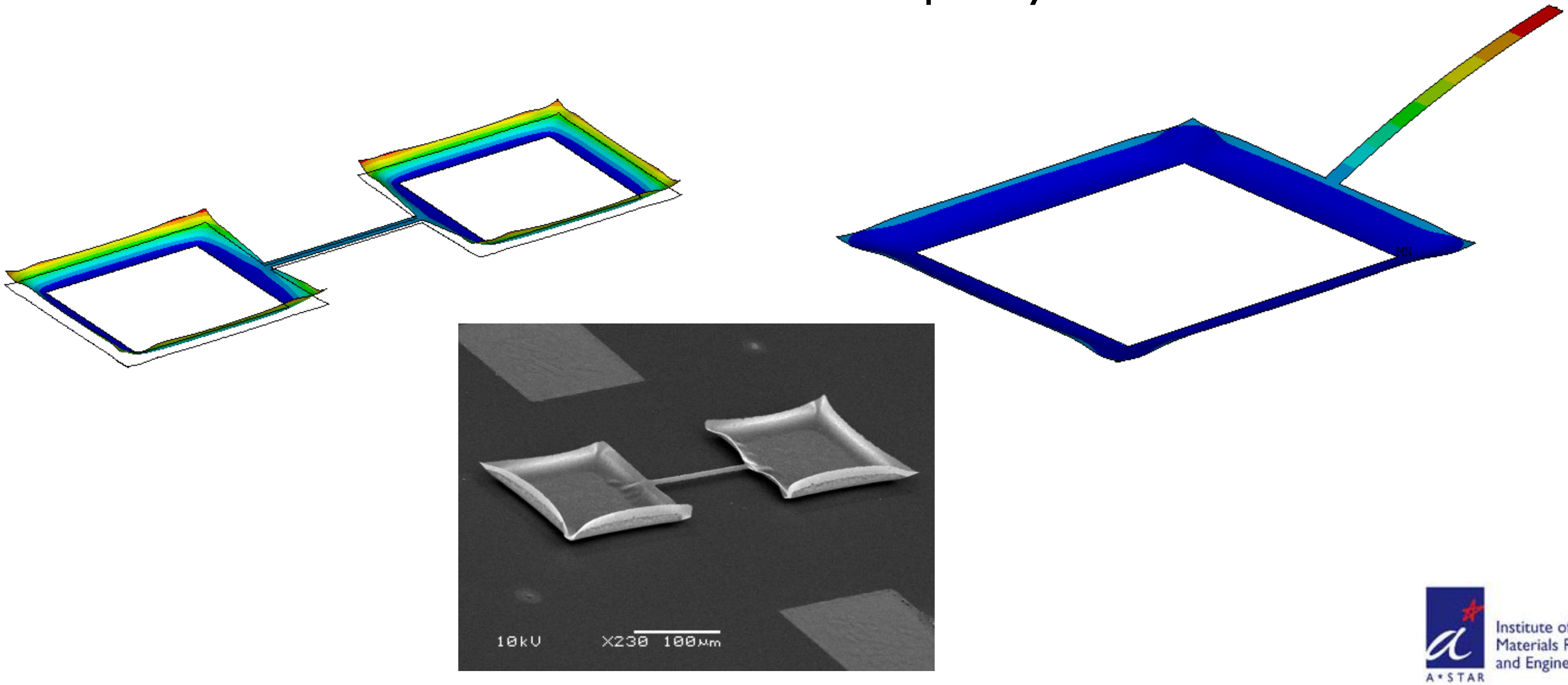
- Increasing the DC bias causes electrostatic spring softening to change the natural frequency
- 0.2 % per volt average tunability in linear range





Conclusions

- Route to standard fabrication of thin nanographite and nanographene devices by PECVD
- Electrostatically actuated and tuned resonator device
- Low modulus, high stress material → used the stress gradient to create tensile devices which raises the vibration frequency



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Thank you - Any questions?