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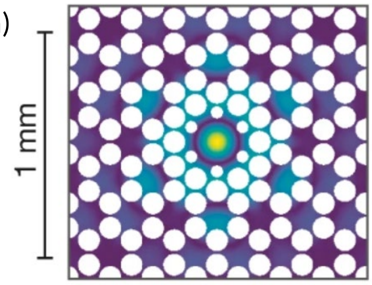
Ultrahigh-Q crystalline nanomechanical resonators for quantum sensing

Background: Mechanical resonators are widely used as displacement sensors with applications ranging from vibration sensors in mobile phones to detection of gravitational waves in LIGO. A key property of the mechanical resonator is its isolation from the environment, quantified via the mechanical quality factor Q. The larger the Q, the lower the mechanical dissipation and the larger the sensitivity of the mechanical resonator to an external signal. High-stress SiN is a widely used material to develop ultrahigh-Q nano- and micromechanical resonators [1]. This is achieved by use of phononic shields [see Fig.1 (a)] and additional strain engineering. In our lab, we are pioneering the crystalline material InGaP with the goal to access novel regimes for minimizing mechanical dissipation and maximizing the interaction with an optical light field, which is required to read-out the mechanical displacement. We aim at implementing phononic shields and employing strain engineering methods in nanomechanical resonators fabricated from InGaP [see Fig.1 (b)]. Our improvements promise to lead to a new generation of optomechanical devices accessing novel applications in quantum sensing.

(a)



(b)

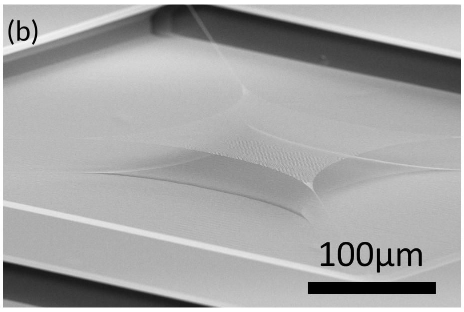


Figure 1 (a) SiN-based micromechanical resonator engineered with a phononic shield achieving a mechanical quality factor larger then 10^9 [1]. (b) High stress InGaP mechanical resonator of trampoline-shape fabricated in the Wieczorek group at MC2.

Goals of the thesis:

- Design of nanomechanical resonators exploiting strain engineering and dissipation dilution techniques in high stress InGaP:
  - Utilize COMSOL to engineer a phononic shield with a desired bandgap to isolate the mechanical mode of interest from the environment.
  - Utilize COMSOL to analyze strain engineering methods for minimizing clamping loss.
  - Utilize COMSOL to estimate the theoretically achievable mechanical quality factor.
- Fabrication of high stress InGaP nanomechanical resonators in MC2's cleanroom:
  - Use of a standard fabrication process, see [2], consisting of EBL lithography, RIE-ICP dry etching, wet chemical etching, and critical point drying.
- Characterization of the mechanical properties of the fabricated devices:
  - Measure the mechanical frequency and damping (to determine the experimental mechanical quality factor) of the eigenmodes of the fabricated devices in a high-vacuum environment using an existing optics interferometry measurement setup.

What will you learn?

- The complete cycle of design, simulation, fabrication and measurement in the development of nanomechanical resonators.
- Learn the basic physics of nanomechanical resonators, their coupling to light and their application in quantum sensing.
- Research in a stimulating environment.

References

[1] M. Rossi et al., *Nature*, **563**, 53 (2018)
[2] S. K. Manjeshwar et al., *Appl. Phys. Lett.* **116**, 264001 (2020)

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