Room-temperature quantum optomechanics using an ultra-low noise cavity

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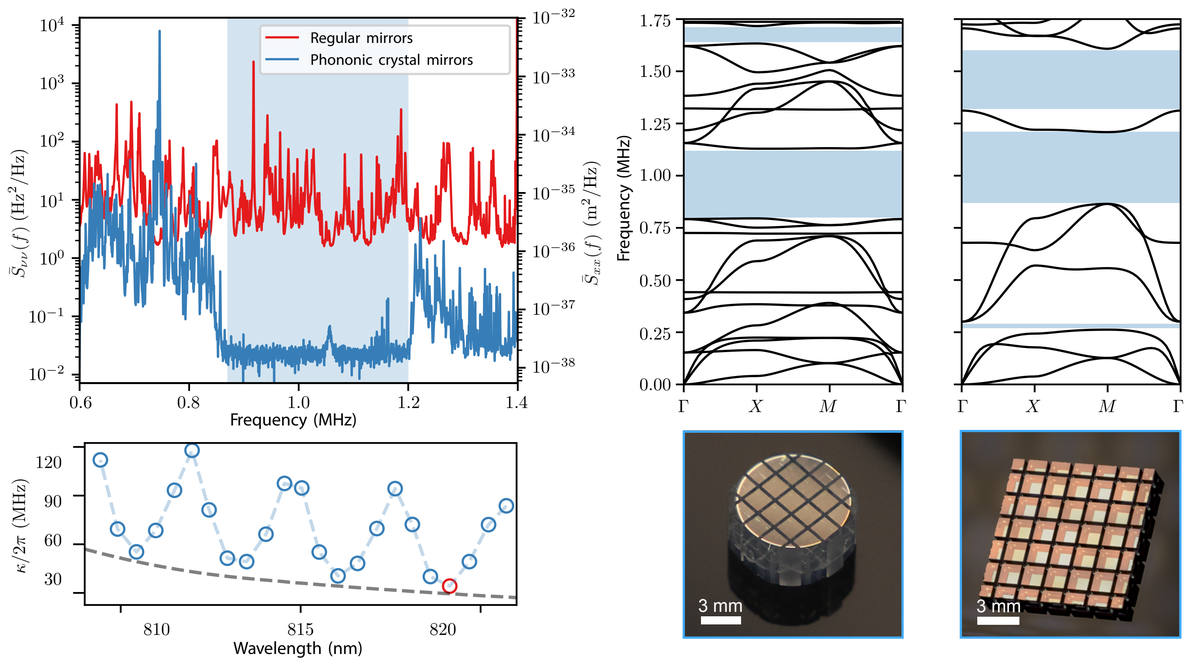
Looking for students and postdocs in my new group at Chalmers!

Main results

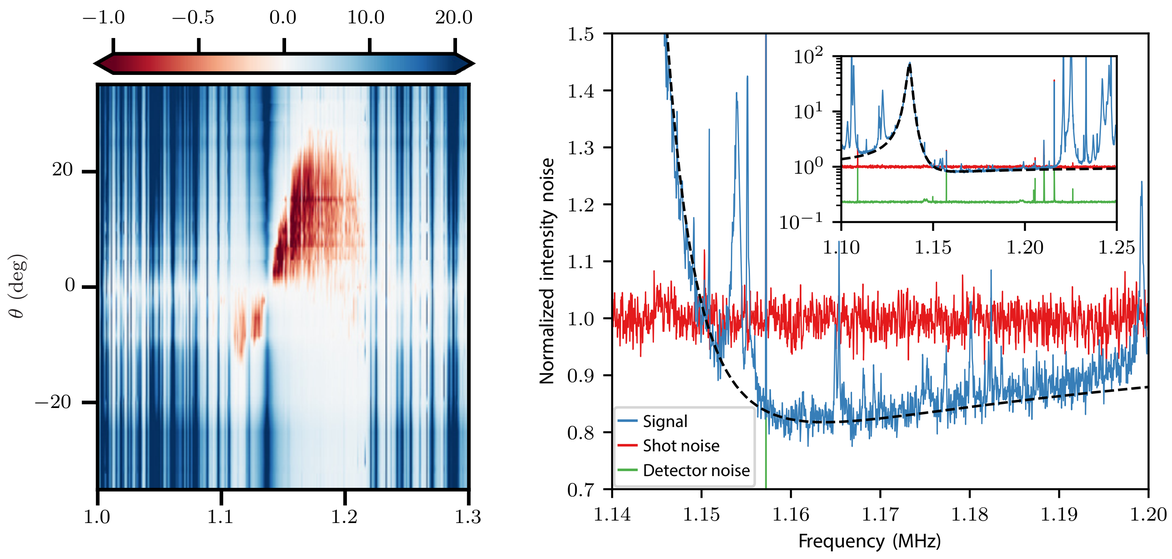
- Room temperature optomechanical squeezing of 1.09 dB
- Optomechanical sensor operating within a factor of 2.5 of the Heisenberg limit
- Conditional displaced thermal states of motion with 0.97 phonon occupation
- Suppression of cavity mirror vibrational noise by a factor of more than 700

Phononic crystal mirror



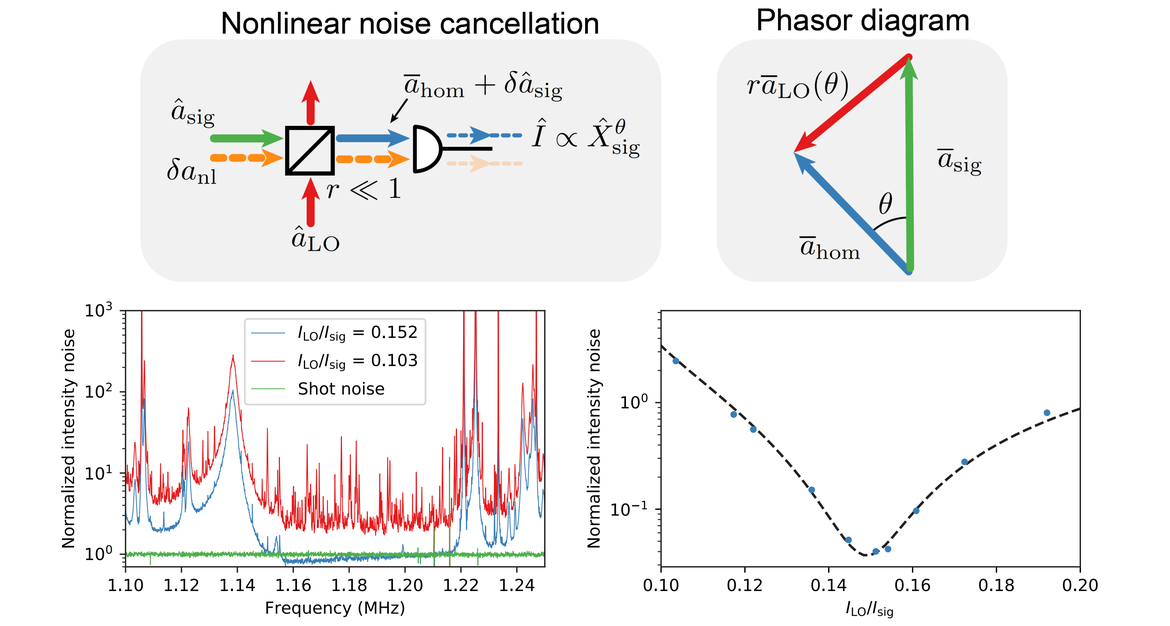
Cavity mirrors patterned with phononic crystals using a precision dicing saw
Mirror vibrations are suppressed 700-fold within the bandgap centered on 1 MHz

Ponderomotive squeezing



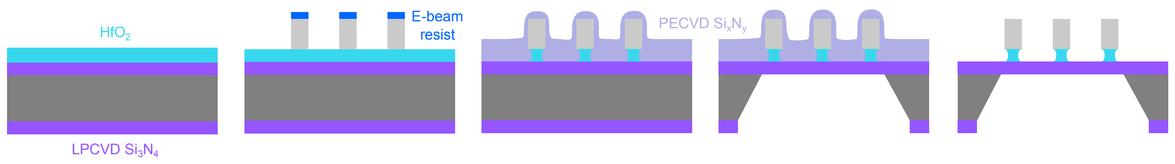
Thermal intermodulation noise (TIN) is suppressed at magic detuning [2]
Localized mode is sideband-cooled to 21 phonon occupancy

Thermal intermodulation noise cancellation



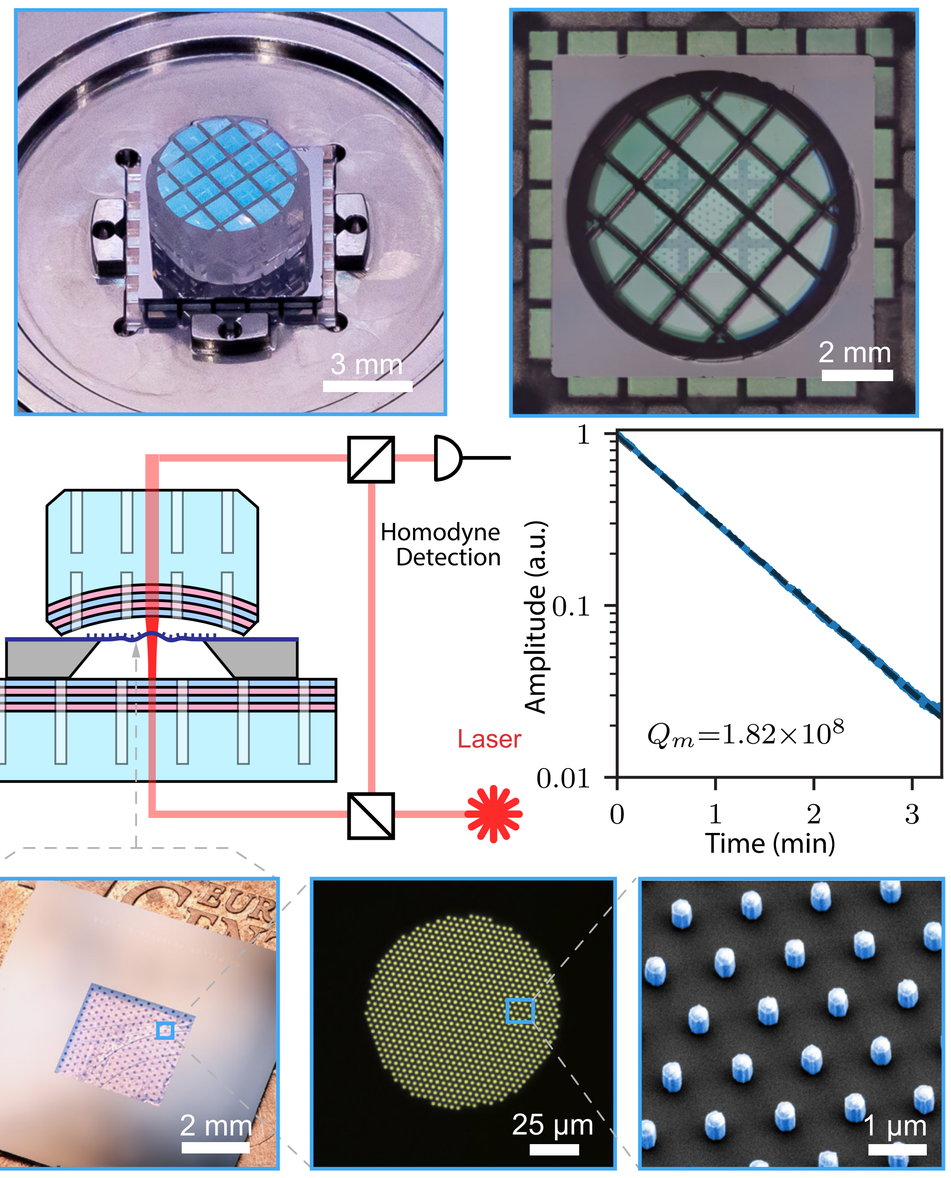
TIN is suppressed in detection with a single-port homodyne scheme [2]

Membrane fabrication process



Pillars of amorphous silicon are patterned on a high aspect ratio Si_3N_4 membrane
A localized mode with $Q = 1.8 \times 10^8$ is realized by phononic-bandgap engineering

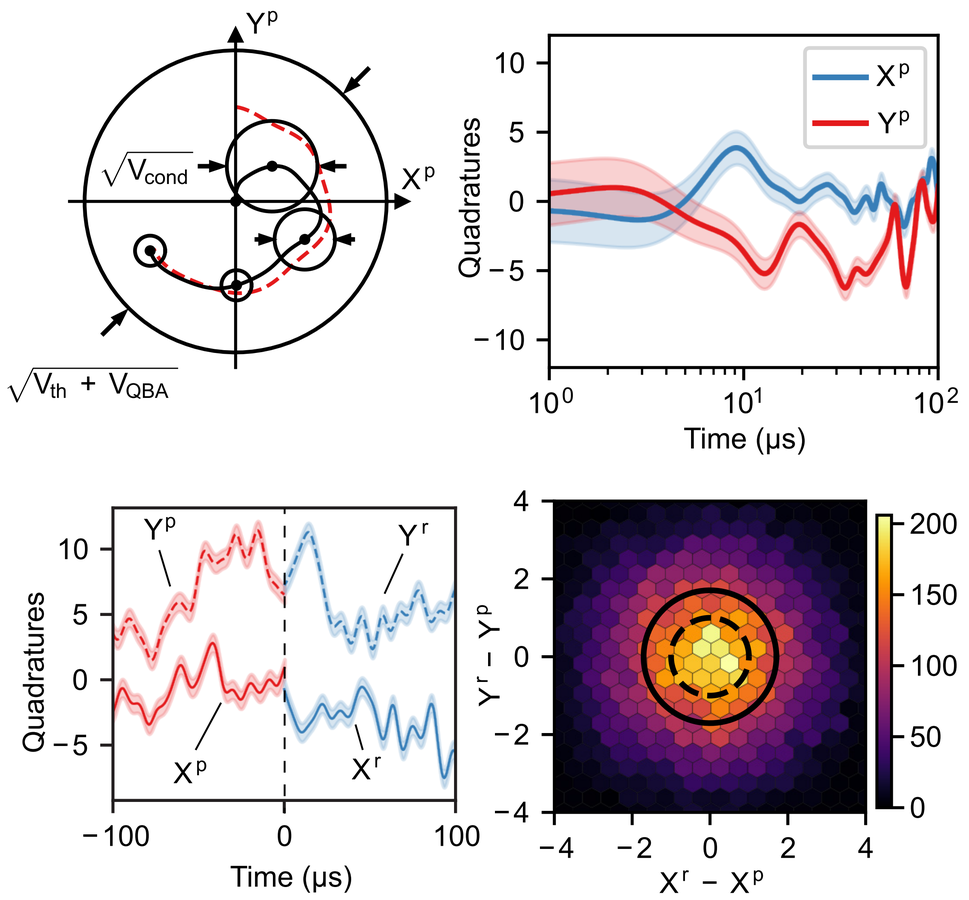
Membrane-in-the-middle system



Membrane-in-the-middle system with phononic-density-modulated membrane [1]
Optomechanical parameters:

$g_0/2\pi = 160\,\mathrm{Hz}$	$\kappa/2\pi = 34.2\,\mathrm{MHz}$	$m_{\rm eff} = 7\,\mathrm{ng}$
$\Omega_m/2\pi = 1.16\,\mathrm{MHz}$	$\Gamma_m/2\pi = 6.4\,\mathrm{mHz}$	$x_{\rm zpf} = 1.0\,\mathrm{fm}$

Conditional state preparation



Conditional states are prepared using a multimode Kalman filter
Total measurement efficiency of $\eta_{\rm meas} = \Gamma_{\rm meas}/(\Gamma_{\rm th} + \Gamma_{\rm qba}) = 0.16$

References

1. G. Huang, A. Beccari, N. J. Engelsen and T. J. Kippenberg, "Room-temperature quantum optomechanics using an ultralow noise cavity", *Nature* **626**, 512–516 (2024)
2. D. Høj *et al.*, "Ultra-coherent nanomechanical resonators based on density phononic crystal engineering," arXiv:2207.06703 (2022)
3. S. A. Fedorov *et al.*, "Thermal intermodulation noise in cavity-based measurements," *Optica* **7**, 11 (2020)

Acknowledgements

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