Photoinduced Effects in Mechanical Loss and Elasticity of GaAs for Ultra-Stable Laser Interferometers

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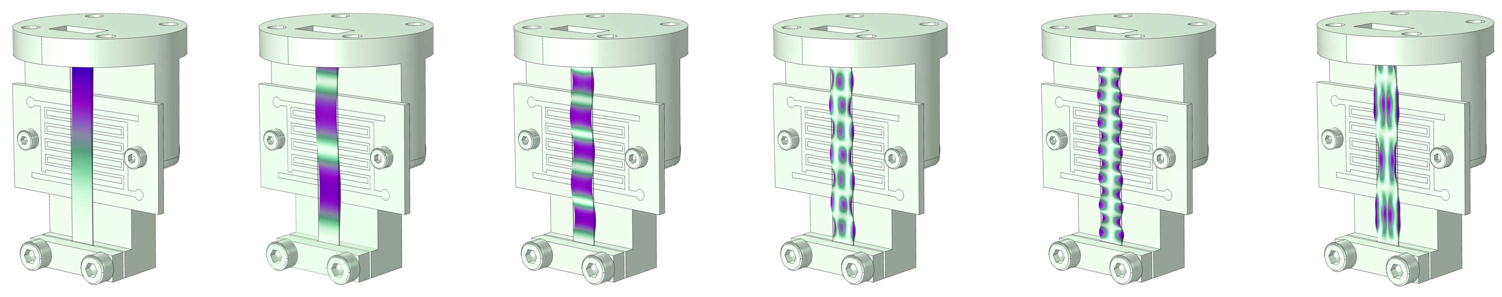
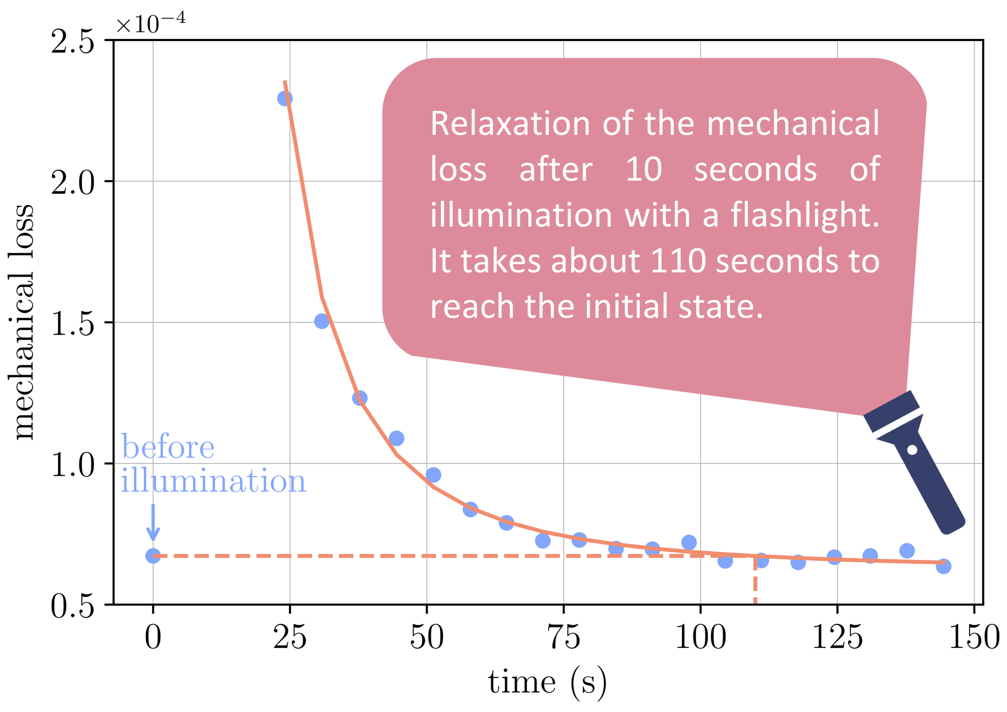
Motivation: Understanding of Noise Behavior of Crystalline Coatings

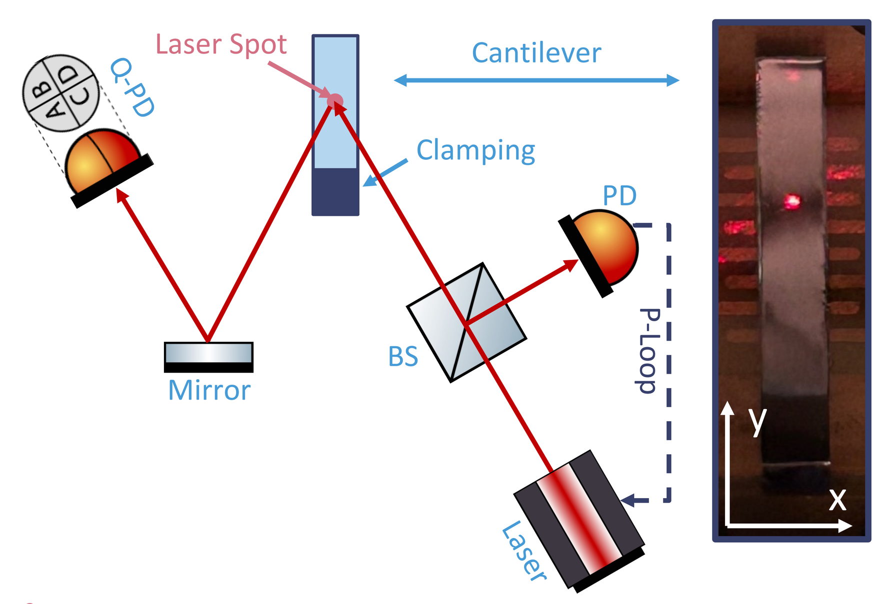
- Ultra-stable laser interferometer are currently limited by Brownian thermal noise of the mirror coatings [1], which depends strongly on the mechanical loss factor $\phi \rightarrow S_x \propto \phi \cdot T$
- AlGaAs/GaAs coatings are a promising candidate due to their low mechanical loss [2,3]. However, unknown excess noise leads to a lower stability than predicted [4,5] and it seems that the excess noise is caused by photoinduced effects [6,7].
- To better understand these photoinduced effects, we investigated the influence of light on the mechanical properties for different mechanical modes:





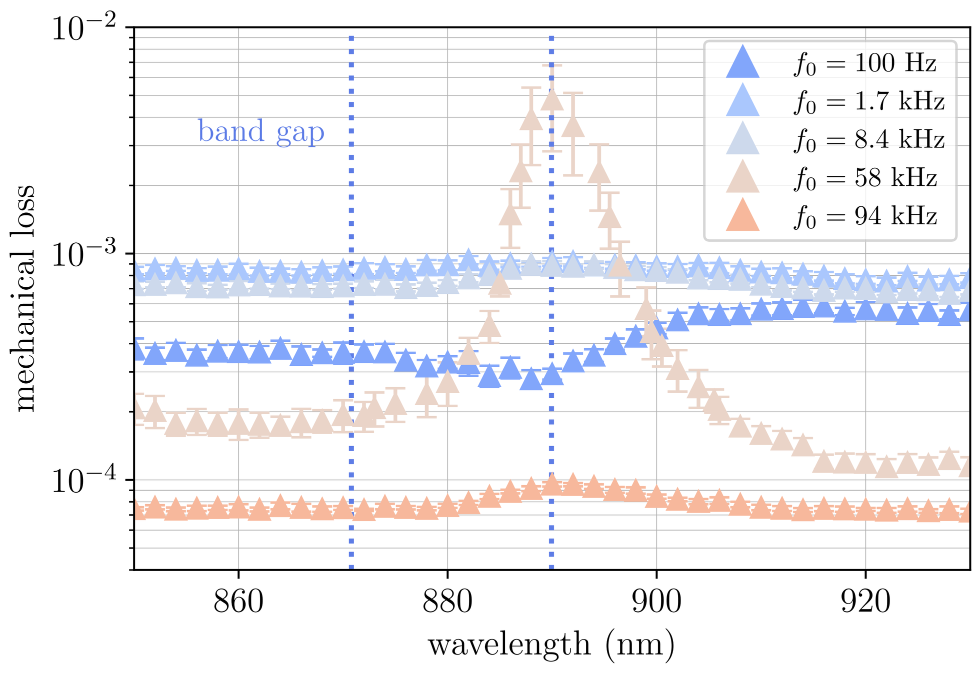
Not in agreement with photoinduced free carrier relaxation times of ns – µs!!

Experimental Setup



- Cantilever structure of bulk GaAs
- Laser: NKT supercontinuum white light source (400 – 2000 nm)
- Optical power @ all wavelengths: 1.5 mW
- Spot size: 2 mm

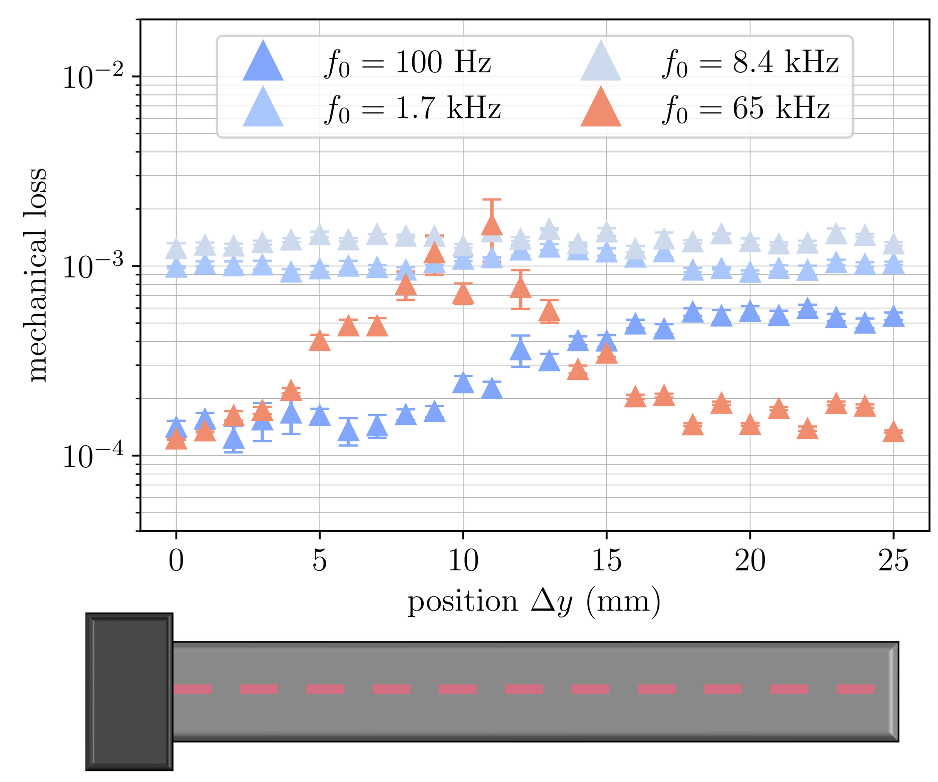
Wavelength Dependence on ϕ



- Spot position: centre & fixed

- Pronounced behavior around $\lambda = 890$ nm
- Fundamental mode shows a decreasing behavior of the mechanical loss
- Loss angle of the other modes increases due to the illumination

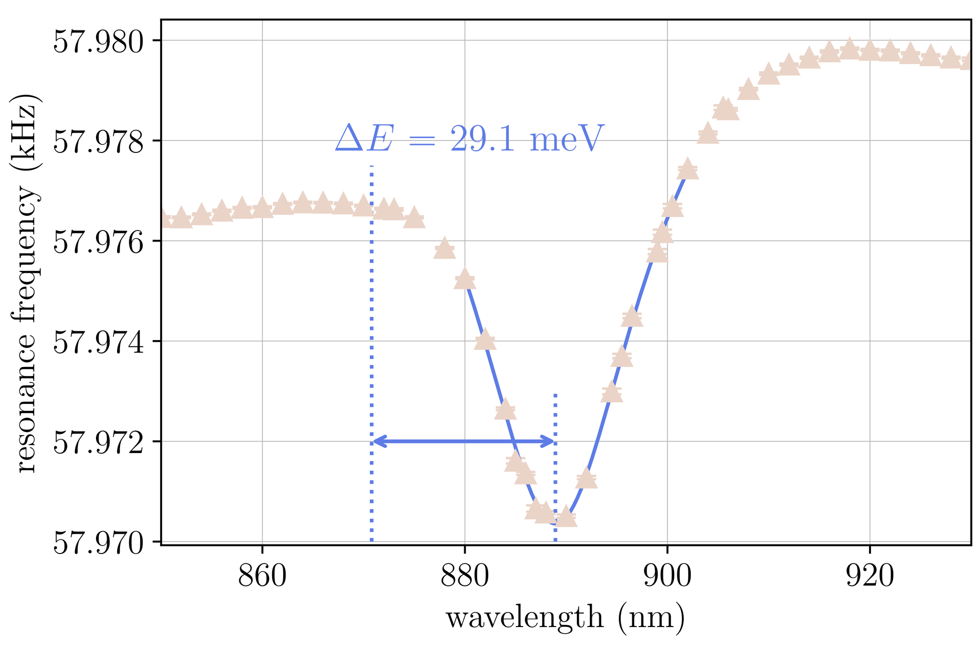
Laser Spot Position Dependence on ϕ



- Wavelength: 890 nm
- Spot position: variable along y-axis

- ϕ depends on laser spot position
- Different behaviors for all eigenmodes
- Fundamental mode's loss can be decreased by a factor of 5

Photoelasticity Effect

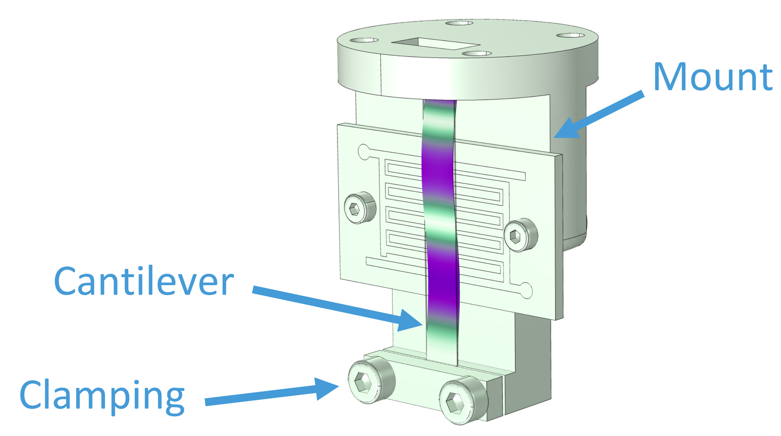


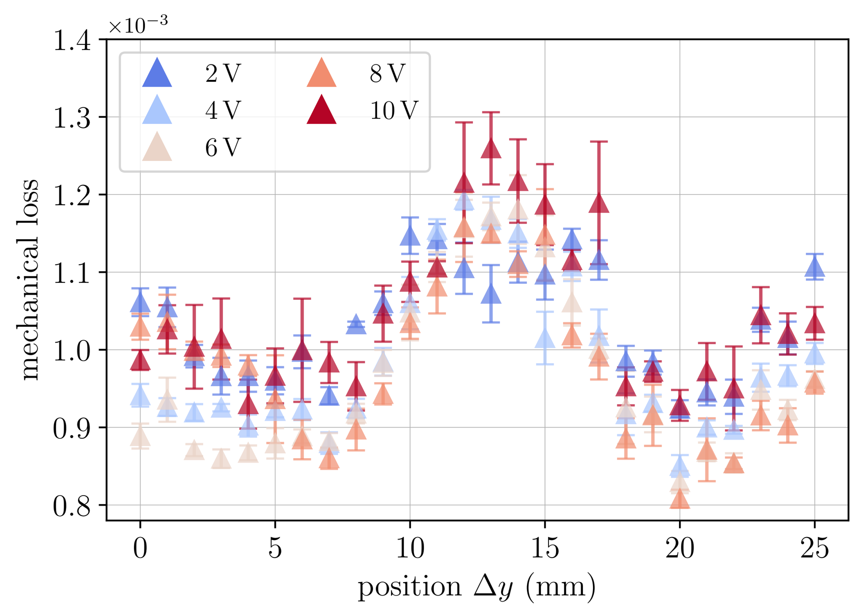
- Spot position: centre & fixed

- Young's modulus change by laser illumination:
  $$Y \propto f_0^2$$
- Maximum of $\Delta Y = 4 \times 10^{-4}$ %was observed
- **OPEN QUESTION:** Correlation to the birefringent line splitting in the AlGaAs coatings [4,7]?

Different Excitation Forces on ϕ

- Wavelength: 890 nm
- Spot position: variable along y-axis





- Investigation of whether the effects are related to the strength of the deformation
- Increasing the piezo voltage of the excitation shows no different behavior

Summary & Outlook

Generally, photoinduced electron-hole pairs could lead to a change of the mechanical strain and therewith to an alteration of Young's modulus manifesting in the change of the resonance frequency. This however, is not compatible with the relaxation times in the range of several minutes and the fact that also photon energies below the bandgap energy of GaAs lead to similar effects. Moreover, it indicates that the effect is mediated by the crystal lattice as discussed for other materials by Dong *et al.* [8].

Next Steps:

1. Investigation of whether the mechanical loss and photoelastic effects originate from the surface or the bulk, through analysis of cantilevers with varying thicknesses.
2. Exploring potential correlations between the observed phenomena and excess noise in optical cavities [4,7].

References

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