PL-based mechanical measurements in luminescence-driven optomechanical systems

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Optical force, which arises from the momentum transfer of light into matter, has found applications across various disciplines, notably in molecular biology [1,2] and optomechanics [3]. This technique enables precise manipulation of small objects ranging from atoms to micrometers in scale. Our study specifically focuses on optical manipulation based on materials' 'luminescence'. Luminescence, when emitted evenly in all directions, generally does not significantly influence the motion of emitters. However, by designing the dielectric environment around emitters to make an anisotropic luminescent field, we can induce luminescence-induced optical forces (LIOFs) on the emitter itself, causing mechanical motion.

From the above perspective, we designed an optomechanical cavity structure, incorporating a luminescent nanofilm suspended over a metallic mirror (Al) substrate, depicted in Fig 1. In this setup, LIOFs can drive the mechanical vibration, resulting in a coupled system of incoherent light field and mechanical vibration (luminescence-driven optomechanics). Coupling the quantum states of emitters to mechanical modes through luminescence could allow for control over luminescence properties, such as lasing [4], and can pave the way for emitter-specific quantum information transmission mechanisms.

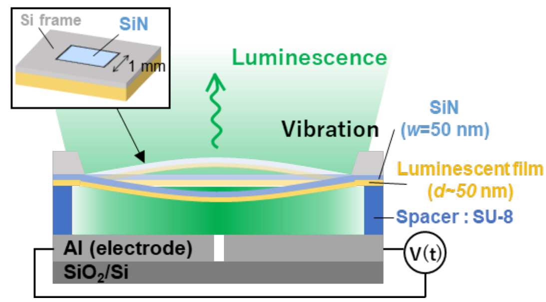

Fig.1. Schematic illustration of the optomechanical resonator. For the luminescent film, perovskite QDs of $FAPbBr_3$ were spin-coated onto a 1 mm × 1 mm square silicon nitride (SiN) membrane with a thickness of 50 nm held in a Si frame. Spacers were fabricated on the substrate to make a gap between the luminescent film and the aluminum (Al) substrate. In the mechanical measurement, the membrane was vibrated by electrocapacitive forces, and the mechanical vibration was detected by PL.

Fig. 2 presents the calculated results of photoluminescence (PL) intensity modulation and mechanical vibration for a membrane with a mechanical frequency of f_m =339.63 kHz and Q factor Q_m=29790. The modulation in luminescence intensity corresponding to mechanical vibrations demonstrates the feasibility of measuring mechanical resonance by probing PL. This theoretical result has been validated by our experiments, which yielded mechanical resonance measurements closely aligned with those obtained by probing the irradiated laser. In addition, our presentation discusses the theoretical evaluation of LIOFs in our assumed system, revealing that LIOFs can shift the mechanical resonance frequency of the resonator (optical spring effect). Our investigations open avenues for novel optomechanical applications that convert luminescence modes into mechanical modes, potentially enabling the transmission of quantum properties from emitters to other quantum systems across different frequency regimes through induced mechanical modes.

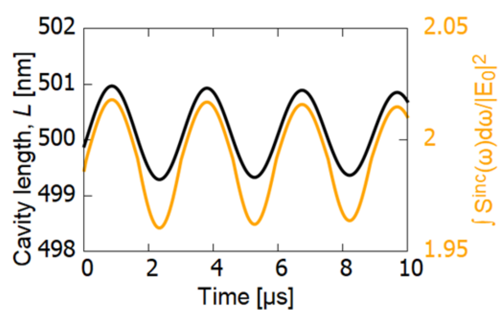

Fig.2. Calculated PL intensity modulation and mechanical vibration. In this calculation, we assumed that the luminescent film is supplied with a steady excitation energy corresponding the excitation light irradiation at an intensity of I=100 W/cm^2. The calculations are conducted with an initial cavity length of 500 nm and the actuation force amplitude of F_{act}= 40 pN.

References

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