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Measuring the mechanical and optical losses of coatings in cryogenic conditions using an optomechanical cavity

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One of the most critical components of gravitational wave interferometers are their mirror test masses which are coated with multilayer dielectric films to achieve the required reflectivity. However, these coatings introduce coating thermal noise (CTN) that limits the sensitivity of the detectors, particularly in the crucial frequency band from 20 to 2000 Hz. To reduce CTN, one of the two nested interferometers composing Einstein Telescope (ET-LF) is designed to operate under cryogenic conditions. However, characterizing both mechanical and optical losses in mirror coatings under realistic conditions is challenging, especially at cryogenic temperatures, where thermo-elastic interactions between the coating and the substrate makes very hard to use standard characterization methods based on the measurements of mechanical Q factors of substrates coated with the materials to be characterized.
To address this issue, we propose an innovative experimental setup to measure both optical losses and mechanical dissipation in freestanding coating membranes over a broad temperature range. By suspending the coating in the form of a thin membrane, the thermo-elastic interactions between the coating and the substrates are minimized, which enables precise measurement of the coating's properties in the whole range between room temperature and few Kelvins.
Our experimental apparatus features a low-vibration cryostat housing a high finesse optical cavity and piezo actuators for precise membrane positioning and alignment. The measurement consists in placing the membrane inside the resonator so that it couples with the stationary electromagnetic field circulating inside the cavity. The optical losses are determined by monitoring the finesse of the Fabry-Perot cavity as a function of membrane position along the optical axis. The mechanical dissipations are instead measured using the cavity as a sensitive transducer of the membrane vibration spectrum, with dissipation values extracted through a dedicated data analysis procedure.
Preliminary tests on low-stress silicon nitride (SiN) membranes confirm the functionality of the setup. We are now optimizing a reliable fabrication process to enable the routine preparation of membranes starting from arbitrary coatings. These developments will help in expand the study to other materials and optimizing the apparatus.

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