Testing Novel High-Reflectivity Mirror Technologies from Room-Temperature to 4 K

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Thermal noise of traditional Ta_2O_5/SiO_2 high-reflectivity mirror coatings constrains the stability of state-of-the-art optical resonators and limits the performance of many precision laser experiments. As an alternative crystalline AlGaAs/GaAs multilayer coatings offer significant thermal noise reduction[1] and resonators equipped with these coatings have demonstrated a performance near the predicted thermal noise floor at room-temperature[2]. However, these coatings exhibit significant birefringence which can be modified by illumination with infrared or visible light[3]. Moreover, two experiments at 4 K - 16 K and 124 K revealed spontaneous fluctuations of the coating's birefringence and an additional noise source with hitherto unknown origin limiting the frequency stability above the expected thermal noise flicker floor at cryogenic temperatures[4,5].

We present a closed-cycle, low-vibration cryostat setup for characterizing high-reflectivity mirror coatings from room-temperature to 4 K using multiple techniques to circumvent technical noise related to residual vibrations and temperature fluctuations. Currently focusing on the investigation of AlGaAs/GaAs coatings, a dual frequency modulation technique allows us to remove the anti-correlated birefringent noise of these coatings by locking on the average frequency of two different polarization eigenmodes while simultaneously tracking the birefringent line splitting. Aiming for a frequency instability for differential measurements in the 10^{-17} region, this setup will enable analyzing the birefringent line splitting and its fluctuations of crystalline coatings across a broad range of temperatures. The results are expected to help understanding the underlying birefringent effects in crystalline coatings, gain further understanding in the source of the observed excess noise and possibly find strategies to suppress or mitigate it.

This setup will also be used to verify thermal noise estimates and rule out yet unknown noise sources in other novel highly reflective mirror technologies such as nanostructured meta-etalons[6] over a temperature range relevant for applications in ultra-stable optical resonators and in next generation gravitational wave detectors.

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