From lightyears to nanometers: Gravitational wave detector mirror coating research

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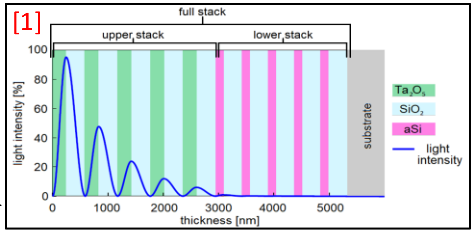
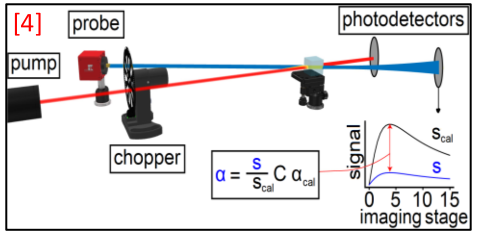
Abstract

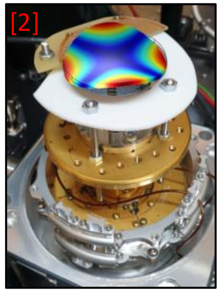
We are now in the era of gravitational wave astronomy. Current detector sensitivity is limited in the most sensitive regime by the thermal noise of their mirror coatings. New coatings must overcome the twofold challenge of yielding significantly lower thermal noise, whilst maintaining high optical performance. To this end we investigate various high-quality materials and novel coating stack topologies.

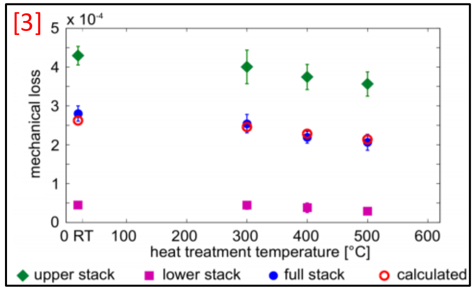
Mechanical loss and absorption setups and results for three-material coating

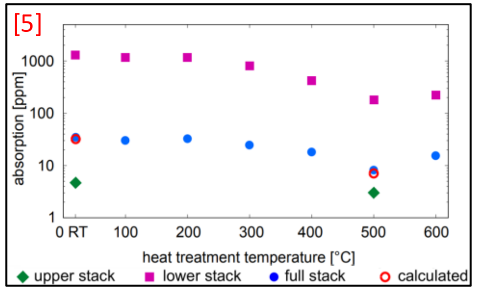
[1] Diagram of the coating stack design.
[2] Photo of mechanical loss, low damping, ringdown measurement GeNS setup.
[3] Average mechanical loss results obtainted after various heat treatment steps.
[4] Key components of the PCI absorption measurement setup. Showing how a absorption value (α) is calculated w.r.t a calibration sample.
[5] Average absorption values obtained.











Project Description

Current gravitational wave detectors employ a Michelson interferometer design, and continuously monitor the position of their test mass mirrors – which are coated with alternating SiO_2/Ti:Ta_2O_5 layers. Any thermally induced fluctuations in these highly-reflecting mirror coating are measured as changes in position of the test mass. This coating thermal noise is directly proportional to the coating stack thickness and its mechanical loss. Also, when light strikes the mirror, some energy is absorbed which leads to internal heating and deformations (via thermal expansion) which reduce sensitivity. Therefore, new coatings must be thin, have low mechanical loss, and low optical absorption. In this project, loss and absorption (α) of new coating materials and topologies are quantified respectively via ringdown and photothermal common-path interferometry measurements. Presented here are results for a novel three-material coating incorporating SiO_2/Ta_2O_5 and low loss but high absorption aSi.

Impact

- This experiment verified the validity of this novel three-material mirror coating stack design approach for future detectors.
- High absorption, high refractive index, aSi was introduced, producing a thinner coating stack [1] with lower mechanical loss than a simple SiO_2/Ta_2O_5 coating [3].
- The high absorption of the aSi was suppressed by a factor of 22 and the full stack has the same order of magnitude absorption of a simple SiO_2/Ta_2O_5 design at 8.1 ppm at an optimal heat treatment of 500^{o}C [5].
- These designs show the promise of using multimaterial designs to meet current gravitational wave detector sensitivity requirements.
- Research is currently underway utilizing these setups to measure new material candidates such as TiO_2:GeO_2 and TiO_2:SiO_2 .

Refs & links: Phys. Rev. Lett. 125, 011102 (2021)