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Reduction of mirror coating thermal noise via thermal treatment and material optimization.

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Reducing coating thermal noise (CTN) in mirrors for gravitational wave (GW) interferometers is pivotal to improve sensitivity in the mid-frequency range. Mirror coatings are Bragg's mirrors alternating between high and low refractive index layers.
Commonly, amorphous coatings are heat-treated post-deposition in order to both reduce their internal strains and improve their optical quality. The current standard treatment for GW coatings consists in a 10 hours thermal annealing at 500°C. Treating the samples at higher temperatures and/or for longer annealing times may lower the mechanical losses of the samples but it may also lead to the formation of crystalline regions inside the coating, which are generally considered detrimental from the optical point of view. It is however not clear to what point the annealing procedure can be pushed in order to achieve the best performances, eventually allowing for the presence of a small amount of crystallized material.
In this work we present two examples of two different approaches used to reduce CTN.
The first case consists in performing controlled thermal annealing treatments on amorphous tantalum oxide (tantala, Ta2O5) thin films in order to achieve varying degrees of crystallized fraction. After thermal treatment, the amorphous films comprise randomly distributed crystalline grains, whose density and average size depends on the duration of thermal treatment. When assessing mechanical losses via a Gentle Nodal Suspension (GeNS) system, we detect a substantial reduction in the coating's mechanical loss angle with respect to unannealed amorphous coatings. This reduction in mechanical losses however, comes at the expense of a strong increase in optical scattering.
The second approach consists in test-annealing amorphous HfO2:Ta2O5 thin films with different HfO2 concentrations. The inclusion of HfO2 increases the material's crystallization temperature, allowing us to push further the annealing temperature without experiencing crystallization. We found an optimal HfO2 molar concentration for our material at the 60% concentration allowing the film to be treated at 800°C for 10 hours. We then used this material to deposit a multilayer mirror and measure its CTN as a function of annealing temperature. We observe a dramatic decrease in CTN due to annealing, showing the potential of HfO2:Ta2O5 as candidate for future GW mirrors coatings.

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