Studies of coating absorption for future detectors

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Introduction

As improvements to the current gravitational wave detector network are implemented, and as new detectors are added to the network, any new mirror coating designs must overcome the twofold challenge of producing sufficiently lower thermal noise performance, as well as maintaining a low level of optical absorption. Here we present an update on our research into the room-temperature optical absorption of different mirror coatings; including a novel design multimaterial coating stack containing SiO_2/Ta_2O_5/aSi films deposited via ion plating, as well as our work measuring various doping concentrations of TiO_2:GeO_2 coatings.

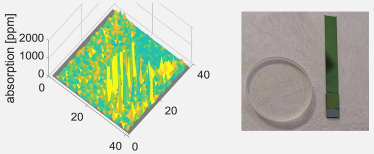

Figure 1. [Left] Example pure germania surface absorption map image. [Right] Image of Ti:Ge 70:30 coating deposited on silicon cantilever and silica disk

Photothermal common-path interferometry

Photothermal common-path Interferometry (PCI) is one of the few techniques capable of measuring low optical absorption [Opt. Exp. V.23. I.17. (2015). pp.21690] [Proceedings of SPIE. (2009). 7193].

Our setup interchangeably operates at 3 wavelengths (1064, 1550, 2000) nm, to provide relative optical absorption measurements (α) relative to a calibration sample of well-known absorption (α_{cal}).

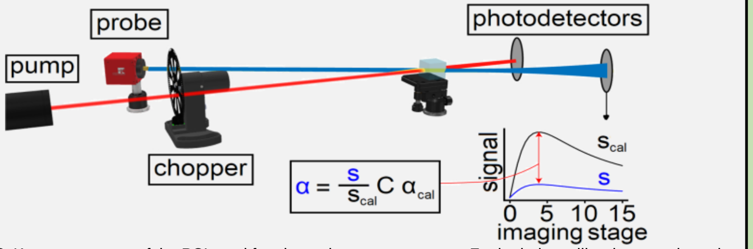

Figure 2. Key components of the PCI used for absorption measurements. For both the calibration sample and sample of interest, the magnitude of the interaction of the unperturbed part of the probe with its perturbed part is captured as a signal (s). To achieve an absorption measurement, the known calibration sample absorption is scaled by the ratio of these signals and by a correction factor (C). C is a scalar number dependant on factors such as the difference in thermal conductivity, and thermo-refractive response of the calibration and measurement samples

Multimaterial coating absorption study: Progressive v.s. direct heat treatment

A three material based multilayer coating comprising of silica (SiO_2), tantala (Ta_2O_5), and amorphous silicon (aSi); optimised for 1550nm was first postulated in 2015 [Phys. Rev. D 91. (2015). 042001 / 042002].

Here we present results for a similar design optimized for reflectivity at 2000nm, which was deposited on silica substrates using ion-plating deposition.

Low absorbing Ta_2O_5 is present in the outermost five coating bi-layers, significantly reducing the light interacting with the lower half of the stack. This allows for the much higher absorption, but lower mechanical loss and higher refractive index aSi to be used in the lower 5 bi-layers.

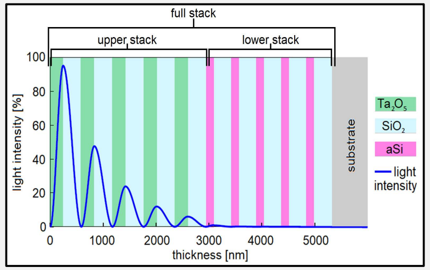

Figure 3. Multimaterial (MM) coating design depicting the light intensity drop with each successive bilayer

Our study of direct-to-temperature heat treatment absorption and mechanical loss of this coating can be found in [Phys. Rev. Lett. 125. (2020). 011102].

A subsequent study into the comparison between direct-to-temperature heat treatment (DHT) of multiple samples v.s. progressive heat treatment (PHT) of the same sample, at the same 4.5 hr 100ºC heat treating steps was conducted.

The PHT samples, reached the same optimal heat treatment as DHT at 500ºC, but with a factor of 2.3 larger absorption at 2000nm than the DHT result of [8.1 ± 1.3] ppm for the full coating stack. This is thought to be largely due to the Ta_2O_5 worsening throughout the significantly longer PHT study – perhaps from water gradually seeping into the sample, or if it was deposited oxygen poor.

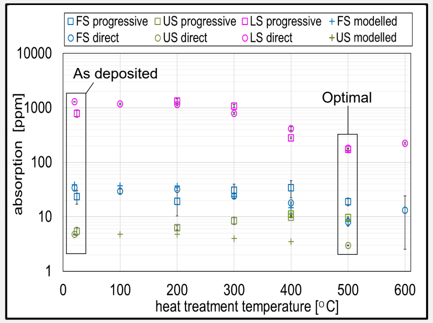

Figure 4. Absorption at 2000nm after progressive (squares) and direct-to (circles) heat treatment stages for the full multimaterial stack (FS) and its two constituent upper and lower stacks (US and LS)

Low loss aSi was implemented in a MM coating stack which significantly mitigated its higher absorption, achieving a factor of 22 reduction. This topology can also be further optimised.

TiO_2:GeO_2 coating studies

Interest in titania (TiO_2) doped germania (GeO_2) follows on from low losses modeled on studies of ZrO_2:Ta_2O_5 [Phys. Rev. Lett. 123. (2019). 045501].

Doping GeO_2 with TiO_2 increases its refractive index, allowing for thinner layers, and less layers required in an HR stack to produce the necessary reflectivity. However, the materials' viability as a coating candidate also depends on it achieving sub ppm absorption whilst simultaneously producing low loss. To this end, investigations into optimum dopant ratio and heat treatment are underway.

At 1064nm, and 1550nm preliminary results of the as deposited samples, coated via PIAD-EBE show no significant extinction trend with doping level.

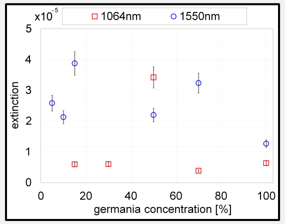

Figure 5. Extinction results for the 7 PIAD-EBE Ti:Ge doping concentrations

A low in extinction was observed at ~3.85×10^{-6} for the 70% GeO_2 concentration. Studies of the effect of post deposition heat treatment will shortly commence.

Planned research for summer 2021

Continue TiO_2:GeO_2 investigations, observing how the different doping concentrations respond to heat treatment, and how different deposition methods effect absorption results.

Carry out room-temperature TiO_2:SiO_2 absorption studies, in tandem with mechanical loss studies.

Study commercial ECR-IBS aSi to determine if exceptionally low absorption shown on a prototype system [Phys. Rev. Lett. 121. (2018). 191101] can be realized on a large scale with good uniformity.

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Further reading

Demonstration of the Multimaterial Coating Concept to Reduce Thermal Noise in Gravitational-Wave Detectors (2020) [Phys. Rev. Lett. 125. (2020). 011102]