13th Edoardo Amaldi Conference on Gravitational Waves

High-Quality Oxide Coating Materials for Gravitational-Wave Detectors: Optical and Mechanical Properties Correlation and Future Developments

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High-reflection mirror coatings of the largest ground-based gravitational-wave detectors are the dominant source of coating thermal noise, expected to limit the sensitivity in the detection band $10^2 - 10^3$ Hz. Such coatings are Bragg reflectors deposited by ion beam sputtering (IBS) at the Laboratoire des Matériaux Avancés (Lyon, France). In particular silica (SiO_2) and titania-doped tantala ($Ti{:}Ta_2O_5$) on fused silica substrate have been adopted by Advanced LIGO (aLIGO) and Advanced Virgo (AdV), whereas SiO_2 and tantala (Ta_2O_5) deposited on a sapphire (Al_2O_3) substrate is adopted by KAGRA. Such mirrors are developed in order to comply with the extreme optical and mechanical specifications required by the detectors and for this reason the coatings must undergo a deep optical and mechanical characterisation. An intense research program points to improve coating mechanical properties. In particular, the mechanical loss angle, which quantifies the energy dissipation in coatings, is a key parameter in lowering coating thermal noise, as stated by the fluctuation dissipation theorem. There are several strategies aiming to decrease thermal noise and the knowledge of the refractive index and thickness are of fundamental importance in order to develop thinner high-reflection mirrors: a high refractive index contrast allows to reduce the total thickness of the mirror, hence the total amount of the dissipative materials. Adding to this, in order to study the mechanical properties of coating materials and obtain information about the loss angle it is important to know the coating thickness and to evaluate the density of the materials under investigation. We used Spectroscopic Ellipsometry (SE) to investigate optical properties and thickness of coating materials. Here we report about a correlation between the internal friction and the Urbach Energy in coating materials. Furthermore, we report on our latest research activity on low-noise coatings at LMA, from updated values for the current Ta2O5, Ta2O5-TiO2 and SiO2 coatings of the Advanced LIGO, Advanced Virgo and KAGRA detectors to recent results from sputtered Nb2O5, TiO2-Nb2O5, Ta2O5-ZrO2, MgF2, AlF3 and Si3N4 coatings.

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