PhD annual report

First Year

PhD student: Shima Samandari

Cycle: XXXVIII

Year: 2023-2024

Supervisors: Prof. Maurizio Canepa and Dr. Michele Magnozzi

Contact: Shima.Samandari@edu.unige.it

Abstract:

The main research topic of my first-year Ph.D. activity has been the characterization of multilayer optical coatings used in a future advanced gravitational wave detector (GWD) (Einstein Telescope experiment).
In this project the idea is to investigate the optical properties of mirrors, based on the so-called Distributed Bragg Reflectors (DBR), which have been recently proposed for next-generation interferometric detectors of gravitational waves (GW). DBRs are an example of metamaterial, i.e., a composite system whose collective properties exhibit characteristics that are not possessed by any of its individual components. The optimization of DBR mirrors requires a detailed knowledge of the optical properties of their individual components. The objective of my project is to optimize the performance of the materials composing the mirrors in future GWDs. The tasks for this project will involve the study of refractive index, thickness, optical absorption, composition, and density of the materials for DBR.

Research:

For this purpose, a proper knowledge base about theoretical properties of mirrors and method of characterization must be established.
The high- and low- index materials to be studied in my PhD project provided in the form of single- and multilayer coatings within the ET collaboration. I studied the physical origins of optical losses in DBR by means of multi-technique characterization and data analysis. Several materials were tested, including amorphous oxides (TiO_2:Ta_2O_5, TiO_2:GeO_2, HfO_2 and nitrides (Si_3N_4)) to find the most suitable combination of high/low index materials in the DBR. These materials will be deposited on different target substrates (for instance fused silica or crystalline Si) depending on the specific requirements of the investigation technique.

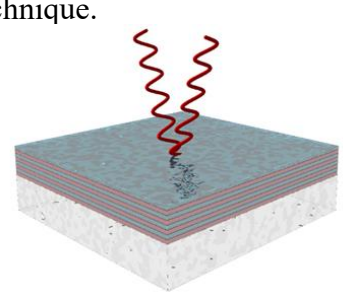

Fig. 1. Schematic image that shows the high-low index layers in a DBR.

Characterization methods

- Optical spectroscopies to determine the parameters of interest for the DBR - including the refractive index, the extinction coefficient, the thickness, and the optical gap. This is achieved by means of spectroscopic ellipsometry.
- Vibrational spectroscopies to establish a link between the optical and microstructural properties of materials. This is achieved by means of Raman spectroscopy.

Future perspectives:

- **Cryo – Ellipsometry:** To reduce noise in upcoming GWDs, the focus will be on operating at lower temperatures. As a result, improvements are being made to the high-vacuum chamber cryostat for ellipsometry, allowing measurements at 75 K or 4 K.
- **Infrared Ellipsometry:** The vibrational modes of the layer are crucial. Therefore, we will study the infrared spectra of the materials for GWD mirrors using infrared spectroscopic ellipsometry.

Publication:

- S. Colace, S. Samandari et al., Monitoring the evolution of optical coatings during thermal annealing with in situ spectroscopic ellipsometry. Manuscript to be submitted soon to Classical & Quantum Gravity.

Courses and Exams:

- Spectroscopies and photonics course: Prof. Maurizio Canepa, Dr. Francesco Bisio, Dr. Michele Magnozzi (48h) — Passed
- Microscopic and Spectroscopic Techniques: Renato Buzio, Andrea Gerbi, Letizia Savio (20h) — Passed

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Activity:

Attended events:

- 70th Anniversary of the "Enrico Fermi “International school of Physics”, Jun 23-2023, Varenna, Italy.
- The 12th Workshop on Spectroscopic Ellipsometry, September 19 to 21-2023, Prague, Czech Republic.
- KV 2023 meeting_Toyama_Japon_ (online)
- Virgo and ET meetings_(online)