nm-Layered Glassy Oxide Composites for 3rd Generation Interferometric Gravitational Wave Detectors

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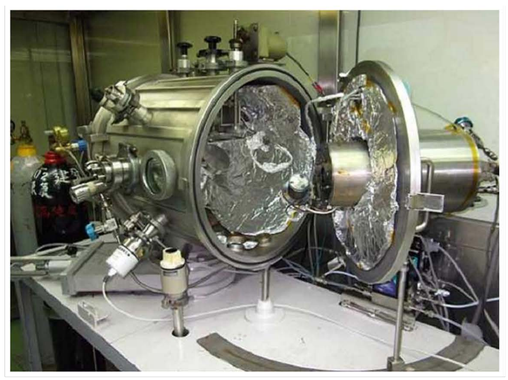
Glassy-oxide composites based on low-loss, high-index cryo-friendly materials like Hafnia, Titania or Zirconia are possible options for the highly reflective test - mass coatings of next generation interferometric detectors of gravitational waves.

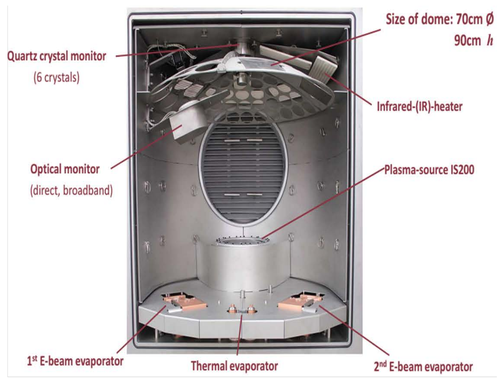
Pure TiO_2, HfO_2, and ZrO_2 crystallize upon thermal annealing, which blows up their optical (absorption / scattering) and mechanical losses.
Silica doping contrasts crystallization in these materials [1], but optimal doping formulation still requires extensive trial-and-error.

Nanolayered composites consist of alternating nanometer-scale layers of TiO_2 or HfO_2 or ZrO_2 , and a stable glass-former (SiO_2 or Al_2O_3). They are effectively homogeneous as regards their visco-elastic and optical (far from grazing incidence) properties, that are easily modeled [2]. They do not pose any hard processing challenge, and are nicely tolerant of deposition (in-)accuracies.
Compared to co-sputtered mixtures with the same composition, they may be optically denser, and exhibit lower mechanical losses [3].
The glassy layers hinder crystallization of the high-index component upon annealing [4], by inhibiting crystallite growth.
Nanolayered films with the same effective optical and viscoelastic parameters can be designed using different numbers of layers with different thicknesses [5]. Titania/Silica nanolayered films with thinner layers tolerate higher annealing temperatures before crystallizing [6] (similar to Hafnia/Alumina nanolayered composites [7]) resulting into lower mechanical losses, down to $\varphi \approx 10^{-4}$ [8].
The possible impact of the large number of interfaces on optical scattering properties, will be next investigated, before designing a whole HR small-scale coating prototype.

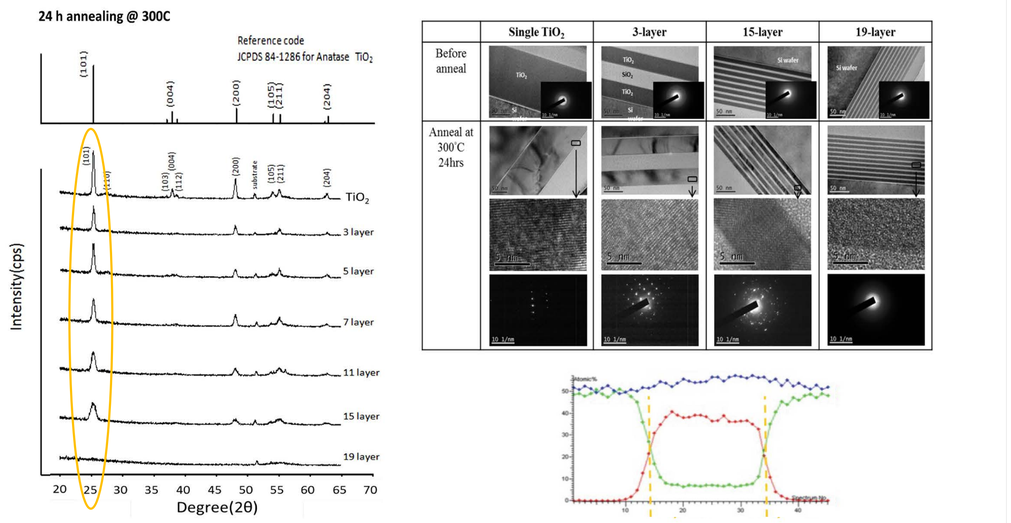
The idea of nanolayered glassy oxide composites has been proposed, and the related research work is carried out in LIGO, by the LSC Groups at NTHU, USannio and CSULA.

This work has been sponsored in part by the Italian National Institute for Nuclear Physics (INFN, CSN-5) under the MIDI-BRUT and AdCOAT grants, and by the National Science Council of Taiwan under project NSC-100-2221-E-007-099.

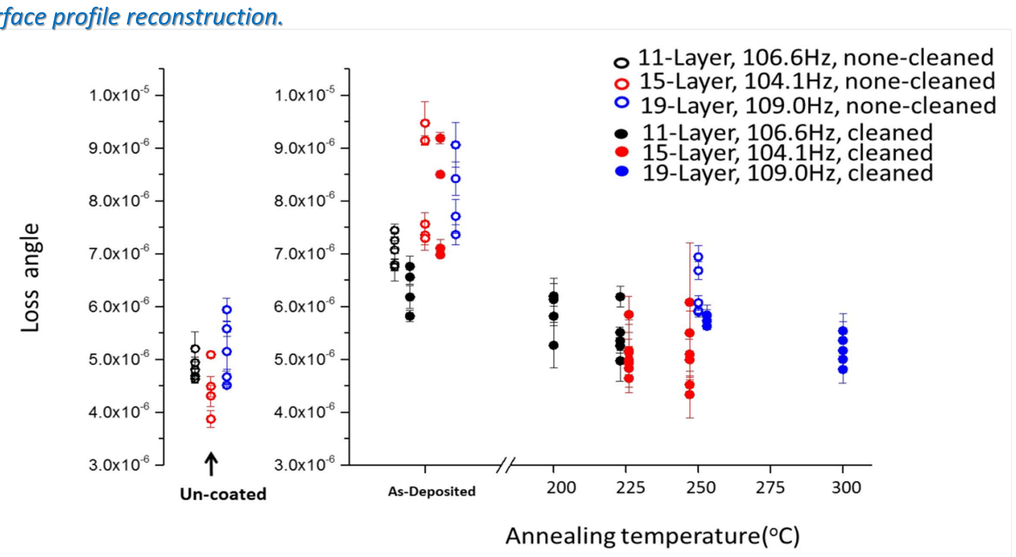




The NTHU (left) and soon-to-be available USannio (right) deposition facilities.



Equivalent (n=2.065, QWL) Titania/Silica nanolayered films, with different nanolayer number/thickness. Left: XRD spectra after 24h annealing @ 300C. Top-right: TEM and ED images . Bottom-right: EDXRD interface profile reconstruction.



Measured loss angles of nanolayer coated cantilevers

References

[1] W.-H. Wang and S.Chao, "Annealing Effect on Ion Beam Sputtered Titanium Dioxide Films," Opt. Lett., 23, 1417 (1998).
[2] I.M. Pinto M. Principe and R. DeSalvo, "Subwavelength Layered Titania-Silica Mixtures for Advanced Interferometer Coatings," LIGO Doc. G1100586 (2013).
[3] M. Principe, "Reflective Coating Optimization for Interferometric Detectors of Gravitational Waves," Optics Expr. 23, 10938 (2015).
[4] H. Sankur and W. Gunning, "Crystallization and Diffusion in Composite TiO_2=SiO_2 Thin Films," J. Appl. Phys. 66, 4747 (1989).
[5] I.M. Pinto P. Addesso, S. Chao, R. DeSalvo, H. Pan, Y.-H. Huang, L.- C. Kuo, V. Pierro, S.-J. Song, S.-J. Wang., "Nanometer Composites for Low Noise Optical Coatings Status and Perspectives," LIGO Doc. G-1301061*
[6] H.-W. Pan, S.-J. Wang, L.-C. Kuo, S.Chao, M. Principe, I.M. Pinto and R. DeSalvo "Thickness Dependent Crystallization on Thermal Annealing for Titania-Silica nm-Layered Composites Deposited by Ion Beam Sputtering Method," Optics Express 22, 29847 (2014).
[7] M. Liu, G. He, L.Q. Zhu, Q. Fang, G.H. Li and L.D. Zhang, "Microstructure and Interfacial properties of HfO_2/Al_2O_3 Nanolaminate Films," Appl. Surf. Sci. 252, 6206 (2006).
[8] S. Chao, H.-W. Pan, L.-C. Kuo, I.M. Pinto, R. deSalvo, M. Principe,, "Mechanical Loss Reduction for nm-Layered Composites by Thermal Annealing," LIGO Doc. G1501024 (2015).