Contribution ID: **42** Type: **poster**

Metasurface-Bragg-Mirror-Stacks: A Pathway to Low-Noise, Ultra-Reflective End-Test Masses for the Einstein Telescope

The thermal noise of the end-test-mass mirrors in gravitational-wave detectors remains a major sensitivity limitation, largely due to the multi-layer Bragg-mirror-stacks required to achieve ultra-high reflectance. For the next-generation Einstein Telescope (ET), we propose a stacked-mirror approach that combines the complementary advantages of metasurfaces and Bragg mirrors, while mitigating their individual drawbacks. Our design integrates a super-polished silicon substrate coated with a Bragg-mirror-stack, an anti-resonant Fabry–Pérot spacer, and a structured amorphous-silicon metasurface layer on top.

While silicon is the target substrate foe ET mirrors, as a first experimental step, we are fabricating fused-silica test wafers with amorphous-silicon metasurfaces to assess robustness against fabrication-induced uncertainties. Reflection measurements will benchmark optical performance (reflectivity and noise), while numerical simulations based on rigorous coupled-wave analysis (RCWA), finite-element method (FEM), and finite-difference time-domain (FDTD) methods are used to predict fabrication tolerances and thermal-noise behavior in advance.

This hybrid concept offers for relevant substrate sizes a promising technology pathway toward mirrors with simultaneously extremely high reflectance and reduced thermal noise, paving the way for improved performance of ET end-test masses.

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Session Classification: Poster Session

Track Classification: ISB: Optics