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Optical Simulations of Ion Implanted Layers for Advanced Gravitational-Wave Detection

The next generation of gravitational wave detectors, such as the Einstein Telescope and LIGO Voyager, requires unprecedented sensitivity. A key limitation to this sensitivity is thermal noise from mirror coatings, particularly within their most sensitive frequency range. To address this, next-generation detectors are shifting toward cryogenic low-frequency interferometers, with silicon serving as the primary mirror substrate material. However, conventional coating materials, such as Ta_2O_5 and SiO_2, prove to be insufficient due to their high mechanical losses at these temperatures. Promising alternatives, including amorphous silicon (a-Si) and silicon nitride (SiN), offer improved thermal noise performance; however, the substantial optical absorption of a-Si hinders its practical application. To overcome this, we introduce a novel strategy: fabricating highly reflective structures directly within crystalline silicon (c-Si) mirror substrates using ion implantation, a well-established technique in the semiconductor industry that has not been explored in this context. This method enables the integration of SiO_2 and SiN layers at precisely controlled depths, while maintaining the advantageous optical properties of high-purity c-Si. We present the first successful demonstration of such a multilayer structure, exhibiting no visible surface degradation. The present work reports the optical analysis of single and double silica (SiO_2) layers implanted in a c-Si substrate, as well as single and double silicon nitride layers (SiN) implanted in a similar substrate.

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