Anti-Reflective Technologies for Silicon and Alumina Lenses in CMB Experiments

Next generation experiments at millimeter wavelength require larger optical elements to increase sensitivity and to enable the illumination of 10k-pixels detector arrays, resulting in wider fields of view and larger mapping speed. Conventional plastic lenses are no longer viable due to their high absorption losses, making low-loss materials such as silicon and alumina necessary. However, their high refractive index (~3) leads to significant reflection losses, thus requiring the development of effective anti-reflective (AR) solutions.

In our research, we investigate two AR techniques specifically tailored for these materials. For silicon lenses, we implement a subwavelength surface structuring approach, which involves machining nanostructured patterns directly onto the lens surface using a customized milling machine. These structures are optimized through electromagnetic simulations to minimize reflectivity across the targeted frequency band. The nanostructures are fabricated in-house, and the resulting lenses are experimentally characterized using a Martin–Puplett interferometer coupled to a dilution cryostat hosting Kinetic Inductance Detectors operating at 100 mK.

For alumina, where machining is not feasible due to the material's hardness, we adopt an alternative AR solution based on the deposition of a dielectric coating layer with an intermediate refractive index. The coating parameters, such as thickness and refractive index, are optimized via simulations, and the layer is deposited using a custom-built vacuum system.

Both approaches demonstrate robust, efficient, and reproducible performance, reducing reflection by about a factor of three and showing strong potential for integration into next-generation CMB experiments.