

Fabrication of Far-Infrared Anti-reflective Metasurfaces and Sub-wavelength Mirrors for Fabry Perots

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Primary CNF Tools Used: ASML PAS 5500, Heidelberg MLA 150 Maskless Aligner, Unaxis 770 Deep Silicon Etcher, Oxford 81/82 Etchers, General Material Anneal 1 Furnace, Odd Hour E-beam Evaporator

Abstract:

Here we fabricate high-performance cryogenic far-infrared silicon-based optics for use in astronomical telescopes. We deep-silicon etch anti-reflective metasurfaces which achieve transmission $>90\%$ at 300GHz. We also pattern gold metal meshes on silicon using a bilayer LoR & photoresist, achieving a wire width of $<2\mu\text{m}$ with high yield.

Summary of Research:

There are two primary projects covered in this report, both of which share a similar goal of creating far-infrared optics for use for astronomical spectroscopy. The first project is fabrication of etalons for a scanning Fabry Perot, being installed on the Fred Young Submillimeter Telescope (FYST) in early 2027. The second project is fabrication of virtually imaged phase arrays (VIPAs), which are a high resolving power spectrometer. The VIPAs fabricated at the CNF will be used as flight hardware on a balloon-based observatory launching in 2029.

Project 1: The scanning Fabry Perot being used on FYST is made up of two silicon wafers with a gold mirror surface on one side, and a deep silicon etched anti-reflective metasurface on the other, shown in Figure 1. The anti-reflective surfaces improve transmission, as vacuum-silicon interfaces result in $\sim 30\%$ of the optical power to be reflected. The anti-reflective metasurface allows for transmission up to $\sim 95\%$. Figure 3 shows the major

fabrication steps to create these two-layer deep-silicon etched structures.

The mirror surface forms a light resonator cavity. The Q-factor (known as finesse) can be tuned by changing the reflectivity of the mirrors. Since the mirrors also need to be low-loss, we choose gold, the lowest loss mirror surface for operation at 4K. Reflectivity is tuned by varying the geometry of sub-wavelength metal mesh structures on the surface of the silicon etalon, as seen in Figure 3.

Project 2: Scanning Fabry Perots can achieve high transmission and high resolving power, however they are prone to vibrations, and require careful mirror alignment at cryogenic temperatures. For these reasons, a solid-state spectrometer is appealing, particularly for air-borne and space observatories. The Planetary Origins and Evolution Multispectral Monochromator (POEMM) mission is a balloon-borne 1.8m telescope using state-of-the-art spectrometers developed here at Cornell and fabricated at the CNF. The VIPA spectrometers are comprised of a highly polished block of silicon, with metal mesh mirrors deposited on both sides of the block. Figure 4 shows an optical diagram of an integrated

VIPA. Side R1 is a solid gold coating for maximum reflectivity, while R2 is a tunable reflective metal mesh (similar to Figure 3). However, these VIPAs operate a shorter wavelength, making the sub-wavelength (generally $\lambda/3$) metal meshes more difficult. We therefore adopt a rounded metal mesh to reduce current density and improve fabrication yield.

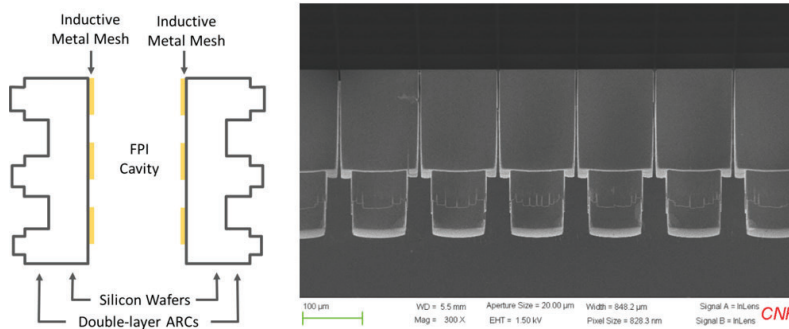


Figure 1: (left) Fabry Perot cavity design (right) cross-sectioned deep silicon etched anti-reflective 'coating' (ARC) metasurfaces.

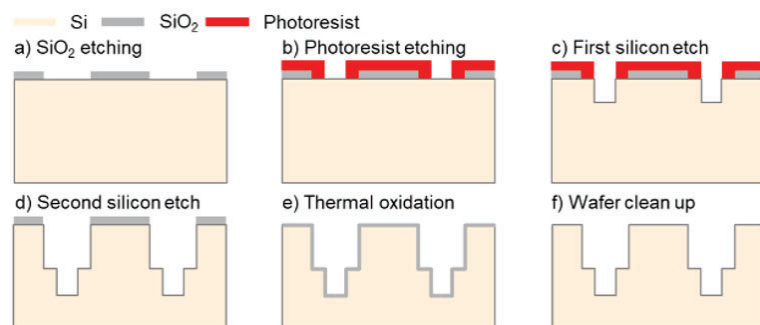


Figure 2: Anti-reflective metasurface fabrication overview.

Conclusions and Future Steps:

Through the end of 2026, we plan to finish fabrication of 150mm Fabry Perot etalons for use on the Fred Young Submillimeter Telescope, being deployed in January 2027. Significant development still needs to be done for fabrication of the VIPA spectrometers. VIPA is particularly difficult to fabricate on due to the substrate's abnormal thickness and shape. Custom fixturing is needed for every step of the fabrication process. This is also anticipated to be completed with flight-ready hardware by end of 2026.

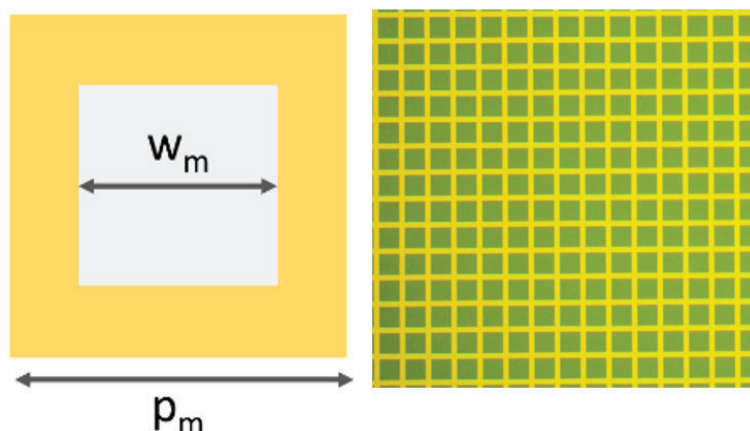


Figure 3: (left) metal mesh mirror surface unit cell (right) fabricated gold mesh on silicon.

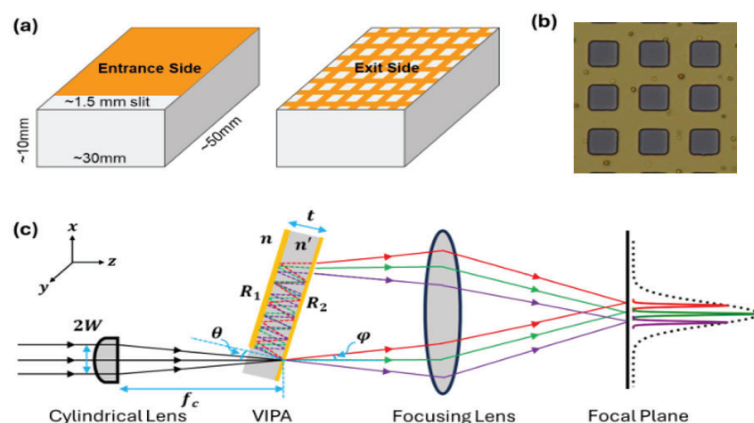


Figure 4: (a) VIPA silicon block (b) fabricated metal mesh pitch=10um (c) VIPA optical diagram.