Development of Single and Double Layer Anti-Reflective Coatings for Astronomical Instruments

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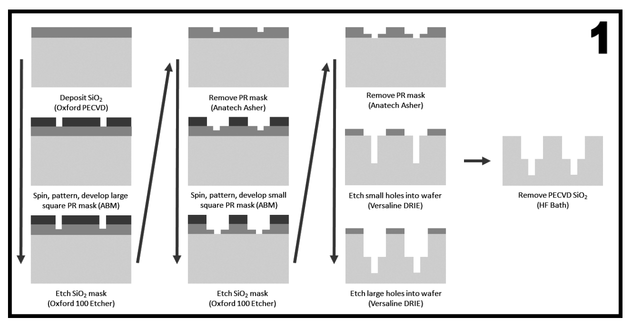
Primary CNF Tools Used: Oxford PECVD, Anatech resist strip, Oxford 82 & 100 etchers, manual resist spinners, resist hot strip bath, Plasma-Therm deep silicon etcher, ASML 300C DUV stepper

Abstract:

We are developing microfabricated, silicon-substrate based mirrors for use in cryogenic Fabry-Perot Interferometers (FPIs) for astronomical instruments in the mid-infrared to sub-mm/mm wavelength regime. These mirrors consist of silicon substrates that are lithographically patterned with metal mesh reflectors on one side and metamaterial anti-reflection coatings (ARC) on the other side. In the past year we published a paper in the Journal of Low Temperature Physics that illustrates the design of the CCAT-prime Epoch of Reionization Spectrometer instrument and how the microfabricated FPI fits in the module and enables our scientific goals. Currently we are refining our ARC fabrication recipe to improve the quality and accuracy of the microfabricated structures. Optical performance measurements for our samples are ongoing using Fourier transform spectrometers.

Summary of Research:

The goal of the project is to develop microfabricated, silicon-substrate based mirrors for use in cryogenic Fabry-Perot interferometers for astronomical instruments in the mid-infrared to sub-mm/mm wavelength regimes. The mirrors consist of high-purity, float-zone, 500-µm-thick silicon wafers that are lithographically patterned with frequency-selective, gold mesh reflectors. We use a combination of inductive and capacitive meshes to maintain uniform high reflectance and hence nearly uniform resolving power over the FPI bandwidth. Due to the high index of refraction of silicon, the other side of the mirror must be patterned with an ARC to achieve broadband capability and to mitigate contaminating resonances from the silicon surface [1,2].



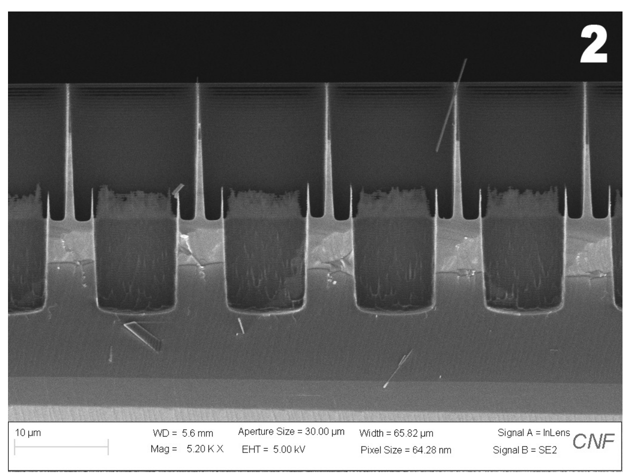


***Figure 1, top:** Process flow for fabricating a double-layer ARC on a silicon wafer. **Figure 2, bottom:** SEM image taken using CNF's Zeiss Ultra SEM showing the two-layer structure of anti-reflection coatings.*

The bulk of our work this year has been the development of the fabrication methods of the ARC. Figure 1 shows our current recipe for a two-layer ARC. First, silicon dioxide is deposited on the wafer using the Oxford plasma enhanced chemical vapor deposition (PECVD) tool. Then, two layers of photoresist are patterned correspondingly to be etched into a two-layer oxide pattern using the Oxford 100 etcher. We use either the ABM contact aligner or the ASML stepper to pattern the photoresist depending on the feature sizes of our structures. After that, the two-layer silicon structure is formed by etching the wafer using the Plasma-Therm deep silicon etcher using the oxide layer as the etch mask. A scanning electron microscope (SEM) image of the cross section of the ARC is shown in Figure 2.

Unwanted fence-like structures can be found at the boundary of two silicon layers. We believe they are caused by the passivation layer generated during silicon etch processes. We found that an external thermal oxidation postprocessing step can remove these structures. We are currently working to improve our control of this method and we are also looking for other methods to prevent the formation of this structure.

In addition, our fabrication process for metal mesh reflectors has been improved over this past year. We have successfully deposited 10-micron scale capacitive and inductive gold meshes on samples using AZ nLOF 2020 photoresist and the CHA evaporator. The lift-off procedure is done using heated Microposit 1165 Remover.

We have fabricated both ARC and metal mesh reflectors on several optical quality silicon wafers and are now measuring their frequency dependent transmittances in the mid-infrared to sub-mm/mm wavelength regimes using Fourier transform spectrometers. Our progress on these devices is discussed in a paper published in Journal of Low Temperature Physics which illustrates the design of the CCAT-prime Epoch of Reionization Spectrometer instrument and how the microfabricated FPI fits in the module and enables spectroscopic observations of the early universe [1].

The silicon-substrate based mirrors that are developed in CNF will be used in the upcoming scanning FPI instrument Prime-Cam in the CCAT-prime observatory, which is located at 5600 meters elevation on Cerro Chajnantor in the Atacama Desert in Chile [3]. CCAT-prime will use our FPI for one of its main science goals, that is to study the Epoch of Reionization of the universe via [CII] intensity mapping in the 750-1500 μm regime. Our instrument will enable the intensity mapping observations by providing high-sensitivity, wide-field, broadband spectroscopy. These measurements will tell us about how the first stars and galaxies evolved in the early universe.

Conclusions and Future Steps:

In the past year we have made great steps towards achieving our goals at CNF. We have demonstrated our ability to fabricate double-layer ARCs for different wavelengths and metal meshes with different feature sizes. We have used many of the fabrication and metrology tools at CNF. Our next steps are to better characterize our etched geometries and improve our metamaterial ARCs. We will be using Fourier transform spectrometers to measure our samples optical performance and using the results to iterate on our fabrication design.

References:

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[3] http://www.ccatobservatory.org/