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

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Primary CNF Tools Used: ABM contact aligner, Oxford plasma-enhanced CVD, Anatech resist strip, Oxford 82 etcher, Hamatech-Steag wafer processors, manual resist spinners, resist hot strip bath, Heidelberg mask writer - DWL 2000, Plasma-Therm deep silicon etcher, Zygo optical profilometer, Zeiss Supra/Ultra SEM

Abstract:

We have been developing Fabry-Perot interferometers using silicon-based metal mesh filters for the far infrared and sub-millimeter astronomical instruments. The filters comprise gold meshes on one side and metamaterial anti-reflection coatings on the other side to both achieve wide bandwidth transmission and mitigate Fresnel reflection by the un-metalized substrate surface. In the past year we had a paper presented at SPIE Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation III that demonstrates the performance of metal mesh reflectors and anti-reflection coated silicon surfaces by simulation and establishes standard procedures to fabricate these two parts. We are currently polishing the recipe of anti-reflection coatings by fabricating samples on high-resistivity silicon wafers. We will test the optical efficiency of samples fabricated at CNF using a Fourier transform spectrometer.

Summary of Research:

The purpose of the project is to develop Fabry-Perot interferometers for use in the far infrared and sub-millimeter astronomical instruments. They are comprised of metal mesh reflectors and metamaterial anti-reflection coatings. The former part provides high reflectance over the frequency range of interest and controls the resolving power of interferometers while the latter part help mitigate strong Fresnel reflections of silicon and widen the bandwidth.

Our main job at CNF is the development of the fabrication methods of these two parts. We had some preliminary result about the fabrication of anti-reflection coatings published in Applied Optics a few years ago [1]. Last summer we had a paper presented at SPIE Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation III [2] that summarizes the fabrication procedures for metal meshes and anti-reflection coatings and we continued to refine the recipe in order to improve the performance of samples.

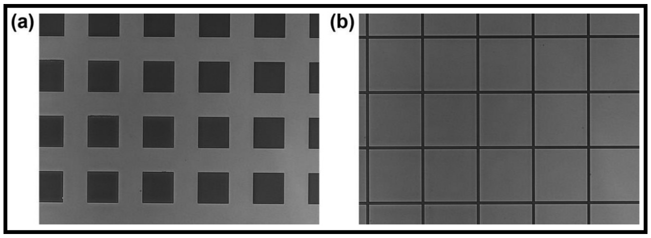

Figure 1: Microscope images of inductive (a) and capacitive (b) metal meshes fabricated by depositing 10 nm of gold on silicon.

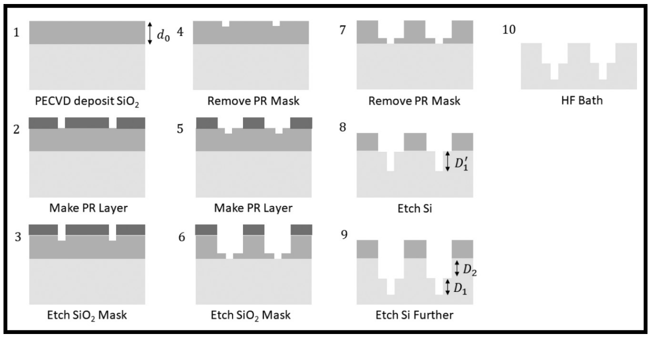

Figure 2: Process flow for fabricating a double-layer ARC on a silicon wafer. Grey represents the oxide. Dark grey represents the photoresist. Light grey represents the silicon wafer.

Figure 1 shows two microscope images (taken by CNF's Olympus MX-50 Microscope) of metal mesh filters. We fabricate metal mesh filters using standard evaporation and lift-off lithography techniques. Negative lift-off photoresist (AZ nLOF 2020) is exposed with the mesh pattern using an ABM contact aligner and then developed. The patterned resist is descummed using an Anatech resist strip. After that, 500 nm of gold are evaporated onto the patterned wafer using a CHA evaporator. Then the wafer is placed in a bath of Microposit 1165 remover and left for 24 hours to clean up the photoresist. Using contact lithography, feature sizes of 1 µm can be achieved.

Figure 2 shows our current recipe for double-layer anti-reflection coatings. We start with depositing the silicon dioxide using an Oxford plasma-enhanced chemical vapor deposition (PECVD) tool. Then two photomasks are correspondingly patterned with oxide etch process in between to define the double-layer structure of anti-reflection coatings. The oxide etch process is achieved by a reactive ion etch tool Oxford 82 and those masks are removed using an Anatech resist strip. The lower layer is then etched using a Plasma-Therm deep silicon etcher. Besides, we add an external thermal oxidation step followed by a buffered oxide etch of hydrofluoric acid and an oxygen stripping step after each silicon etch to remove the passivation layer generated during silicon etch processes, which may form fence-like structure at the boundary of two silicon layers. Figure 3 shows an SEM image (taken by CNF's Zeiss Ultra SEM) of a successful result of this fabrication procedure.

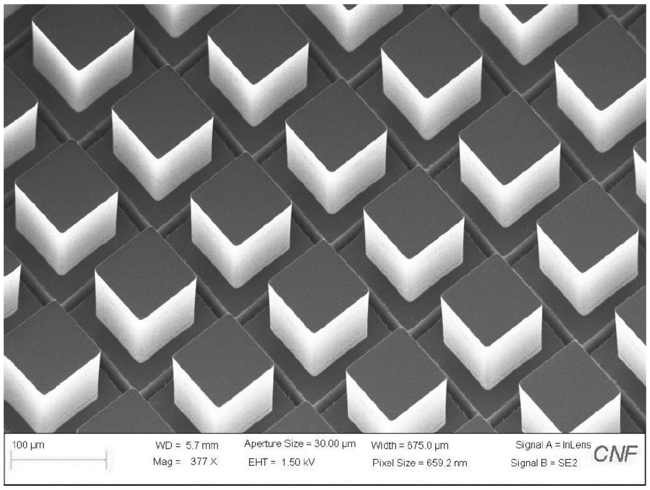

Figure 3: SEM image taken using CNF's Zeiss Ultra SEM showing successful fabrication of our two-layer metamaterial silicon anti-reflection coatings. (See cover.)

The Fabry-Perot interferometers we have been developing will be used in the CCAT-prime telescope located at 5600 meters elevation on Cerro Chajnantor in the Atacama Desert in Chile [3]. One of the science goals of the CCAT-prime telescope is to study the Epoch of Reionization, a time around one billion years after the Big Bang when the first galaxies were assembling. The broad bandwidth of the silicon substrate Fabry-Perot interferometers can efficiently cover the far-IR frequencies required for an intensity mapping of the [CII] fine structure line to probe this era of the universe, and will provide information on the first star forming galaxies.

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:

[1] P.A. Gallardo, B.J. Koopman, N.F. Cothard, S.M.M. Bruno, G. Cortes-Medellin, G. Marchetti, K.H. Miller, B. Mockler, M.D. Niemack, G. Stacey, and E.J. Wollack, "Deep reactive ion etched anti-reflection coatings for sub-millimeter silicon optics," Appl. Opt. 56, 2796-2803 (2017).

[2] N.F. Cothard, M. Abe, T. Nikola, G.J. Stacey, G. Cortes-Medellin, P.A. Gallardo, B.J. Koopman, M.D. Niemack, S.C. Parshley, E.M. Vavagiakis, and K. Vetter, "Optimizing the efficiency of Fabry-Perot interferometers with silicon-substrate mirrors," Presented at SPIE Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation III (2018).

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