National Aeronautics and Space Administration

Development of silver-based plasmonic on-chip filters

Principal Investigator: Alexander Soibel (389); Co-Investigators: Tobias Wenger (389)

Program: FY22 R&TD Innovative Spontaneous Concepts

Objectives: The objective was to demonstrate proof-of-concept optical bandpass filters made of silver operating at mid-infrared wavelengths. This project has included simulation and design, as well as fabrication and subsequent testing of fabricated filter arrays.

Background: There is a growing need at JPL and NASA for optical filters that operate across wide spectral bands. Many commercial filters provide the desired spectral transmission but do not block light at wavelengths farther away from the peak transmission wavelength. Another problem with existing filter technology is the creation of multiband filters such as butcher-block filters. Fabrication of such filters is a complicated multistep task resulting in filter cost of $100Ks. Recent advances in metasurface-based flat optical components and plasmonics has opened new paths to develop ultra-compact wavelength-selective filters. Such filters can be fabricated as complex butcher block filter in one lithographic step because their wavelength selection properties are inherently dependent on in-plane degrees of freedoms (such as sizes of holes and distances between them). Moreover, such filters can be fabricated directly on the pixels of focal plane arrays – enabling on-chip multispectral imagers or even spectrometers.

Approach and Results: Using the FDTD (Finite-Difference Time Domain) simulation software Lumerical, we designed and optimized filter arrays where each filter was made of hexagonal arrays of subwavelength nanoholes in a metal film. The filters consist of a thin metal film deposited on top of an undoped silicon (Si) substrate which is transparent at infrared wavelengths. This project was focused on silver (Ag) filters, but for baselining our fabrication methods we also worked with gold (Au) filters (because Au is a very stable material not prone to degradation during microprocessing). Silver has very good plasmonic properties, but tends to tarnish in ambient conditions and therefore requires a capping layer to prevent degradation. In this work we used a novel method to protect Ag filters with an ultrathin layer of aluminum oxide (Al2O3) deposited with an atomic-layer deposition (ALD) system available at JPL's microdevices laboratory (MDL).

Our first step towards filter fabrication was to develop a good Ag evaporation method. Directly evaporating Ag on a Si substrate was found to lead to large surface roughness of the film which would lead to high losses in the filter. We therefore experimented with applying a seed layer under Ag to create smoother films and found that 2 nm of germanium lead to much better film quality. Due to a tendency of Ag to tarnish during fabrication the protective coating need be applied. To address this issue, we developed a fabrication method where we used Al2O3 as a protective layer. The final fabrication processes consisted of hole patterning in PMMA using electron-beam lithography, opening the Al2O3 hardmask using dry etching in chlorine chemistry, removing the PMMA in acetone, and finally patterning the metal using argon ion milling. Fig. 1 shows SEM images of one fabricated nanohole array. We used this fabrication method for both silver and gold filters (the only difference was that the gold was sputtered, and for gold we used a titanium adhesion layer of 2 nm). Fig. 2 shows photographs of a gold filter array and a silver filter array fabricated during this project.

The fabricated filter arrays were mounted in a Nicolet FTIR and we measured their spectral transmission properties which were compared with simulated results, see Fig. 3. We demonstrate filter arrays in the mid-IR with peak transmission above 60% for silver, and 50% and above for gold filter arrays. Our measured results match our simulations well, albeit some room for fabrication improvement remains.

Significance/Benefits to JPL and NASA: We successfully demonstrated filter arrays using a single lithography step, enabling us to rapidly fabricate multiband filters. The demonstrated silver (Ag) filters have excellent transmissions of up to 60%. We have shown that silver filters have higher transmission than transmission of the gold filters (about 50%). We have also developed technology to prevent tarnish of Ag that has previously degraded performance of Ag filters. The filter peak transmission wavelength has been varied from 2.5 μm to 6.5 μm by filter design. Filters with different wavelengths can be fabricated together thus enabling one-step fabrication of multiband filters such as butcher-block filters. Our development of lithographically fabricated filter arrays enables significantly more spectral channels fabricated simultaneously as well as much-improved customizability of the physical size of the spectral channels. This means that the physical size of individual instrument channels can be tailored to the science target for each band. For instance, having larger physical size for channels with low SNR and small physical size for high-SNR channels, thereby maximizing the science return. Moreover, our filter fabrication method can significantly increase the number of spectral channels and is fundamentally limited only by the number of pixels in the imager used.

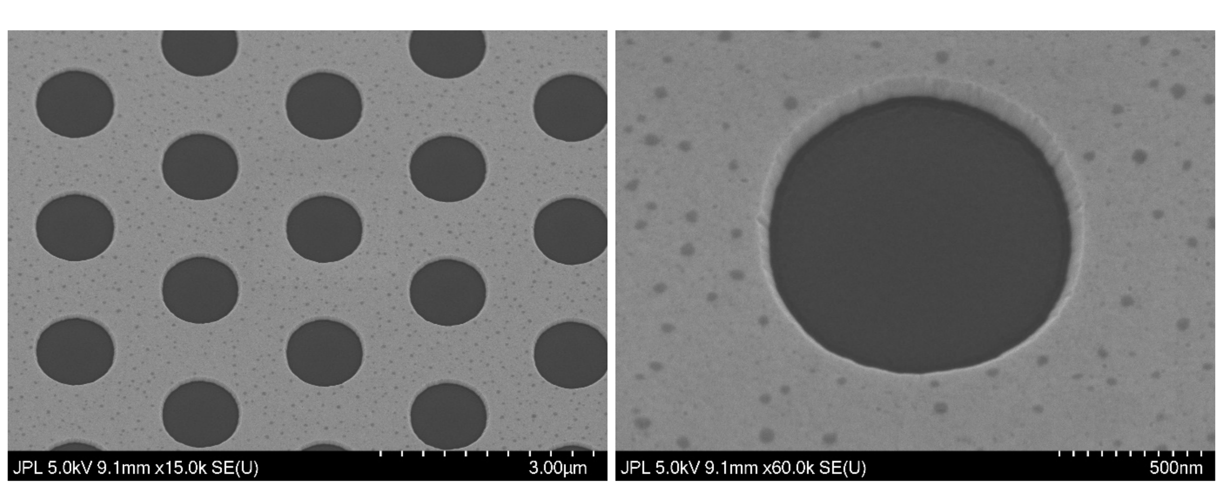

Figure 1. Scanning electron micrographs of one gold filter, showing the hexagonal hole array (left) and a close-up of a single hole (right). The holes are approx. 700 nm in diameter. The dark material visible is the Si substrate, and the brighter material is a thin layer of Al2O3 on top of gold.

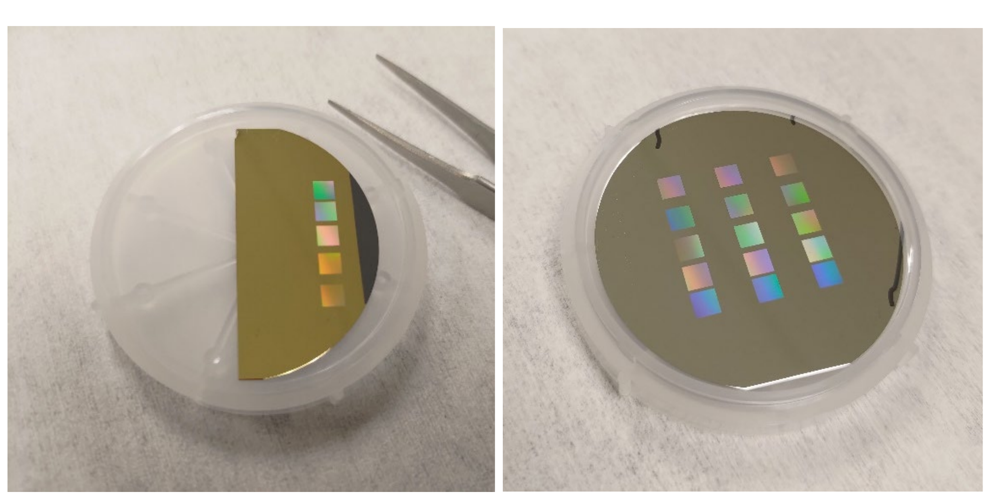

Figure 2. Photographs of filter arrays fabricated during the project. The left panel shows a gold filter array and the right panel shows a silver filter array. Both filter arrays were fabricated using the same fabrication process, each individual filter is 4x4 mm^2, shown in these photographs on a halved 2-inch Si wafer (left) and a full 2-inch wafer (right).

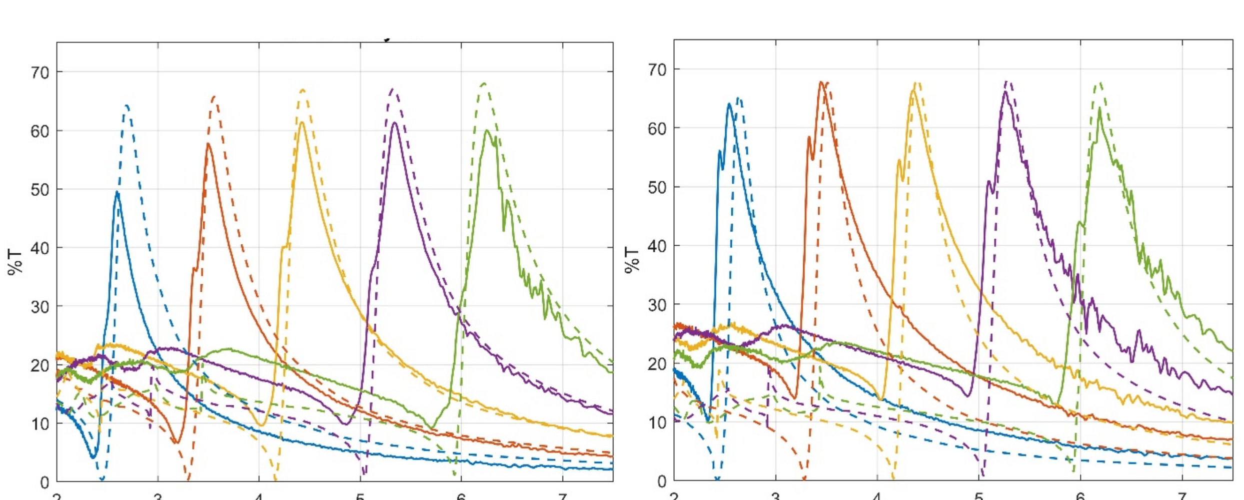

Figure 3. Simulated (dashed) and measured (solid) transmission curves for a gold array (left) and silver array (right).

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
www.nasa.gov

Clearance Number: CL#
Poster Number: RPC#

Publications:

PI/Task Mgr. Contact Information:

Email: Alexander.Soibel@jpl.nasa.gov