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Metamaterial-based spectral filters and polarizers for compact spectrometers and polarimeters

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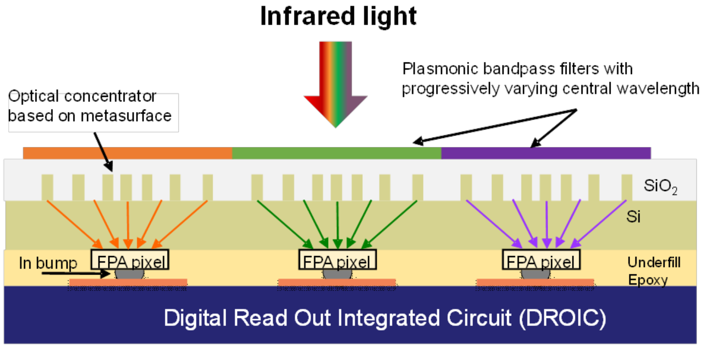
Tutorial Introduction

- Multispectral imaging and polarimetry are important tools for Earth and planetary observations providing a rich variety of information about the surface and atmospheric chemistry, as well as formation and evolution of planetary bodies. These instruments rely on separation of light into its wavelength and polarization components using complex optical elements such as gratings and polarization filters. These optical components are mounted into instruments and has to be aligned with the imaging arrays and optics. This adds to the size, mass and complexity of instruments, and increases the instrument cost. In contrast, on-chip solutions for filtering/polarization of light, which are integrated with imaging arrays, are highly compact and do not require separate mounting and alignment
- In this work, we designed and fabricated optical filters that can be integrated with imaging arrays. These plasmonic filters can simultaneously perform wavelength and polarization filtering in the wavelength range 3 – 5 μm
- These filters have the potential to enable new compact instruments, such as metasurfaced FPAs for multispectral imaging



Cross-section view of a metasurfaced FPA for multispectral imaging. The FPA consists of a metalens array, plasmonic filters and reduced-area pixels. Each metalens is optimized to efficiently focus at the design wavelength λ_n that matches the peak transmission wavelength of its corresponding plasmonic filter (depicted by orange, green and purple).

Problem Description

Spectrometers and more recently polarimeters have become essential instruments in Earth and planetary science as well as in astronomy. Spectrometry – wavelength separation of light – can be realized by using diffraction gratings or optical filters, or by creating a variable phase delay between parts of the optical beam as in Fourier Transform Infrared (FTIR) spectrometers. Polarimetry, which is the measurement of light polarization, is achieved with wire-grid polarizers and Wollaston prisms. **However, these optical components have to be inserted into the optical beam path, aligned and sometimes mechanically rotated, thereby increasing size, weight and complexity of the instruments**

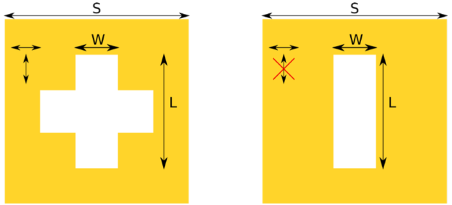
An alternative approach, which has a significantly smaller footprint, is to integrate spectral/polarization-selective optical elements with optical sensors such as focal plane arrays (FPAs). Various schemes for this type of compact instrument have been proposed in the past but their performance has been less than desirable. However, recent advances in subwavelength optics, in particular in metasurface-based flat optical components, as well as in plasmonics open new paths to develop ultra-compact filters and polarizers. **Metasurface-based components are expected to achieve better performance than traditional optical components when integrated with FPAs. More importantly, these integrated metasurface-based optical elements will combine the functionality of a polarizer and wavelength filtering into one component.**

Such integration allows for the development of compact spectrometers with simultaneous polarimetry capabilities that can be used on small satellites. For example, compact spectrometers operating in the spectral range of 2 - 5 μm can be deployed on a constellation of small satellites to provide global, around-the-clock fire monitoring and vegetation mapping. The added capability of measuring polarization will enable studies of aerosol content in the atmosphere as well as ice/water content in clouds. Both of these are important as they represent some of the largest unknowns in climate modelling to date.

Methodology

- Plasmonic filters make use of extraordinary optical transmission through subwavelength nanoholes, i.e. larger transmission than expected from the geometrical size of the holes
- The transmission through these nanoholes **is highly wavelength dependent** and is associated with the excitation of surface plasmons on the front and back of the filter metal film
  - By tailoring the size of the nanoholes, the periodicity of the hole lattice and by choosing the metal film and its surrounding environment, **the transmission amplitude and wavelength range can be changed** an this phenomenon can therefore be used to design bandpass filters
- By breaking the symmetry of the unit cell it is possible to make the filters polarization sensitive. In this work, we consider rectangular slits in a square-lattice array.
  - For a single slit, the length controls the wavelength of the transmitted light and the ratio between length and width determines the polarization discrimination

Cross-section view of the filter structure.

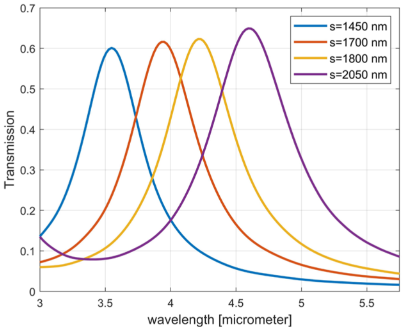


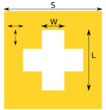
Top view of unpolarized (left) and polarized (right) filter

Results

- We have designed and simulated transmission filters with simultaneous wavelength and polarization selectivity

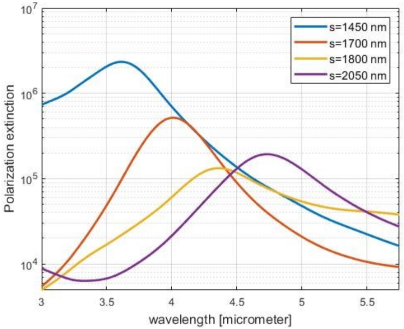
Unpolarized filters

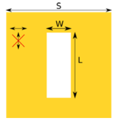




Transmission (all polarizations)

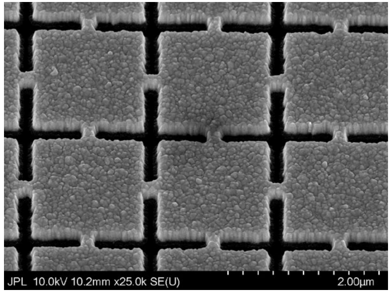
Polarized filters



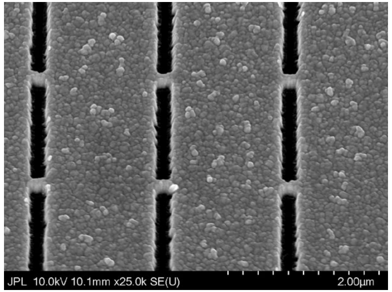


Transmission for accepted polarization is almost identical to transmission of the unpolarized filters.

- We have fabricated filters on gallium antimonide substrate using E-beam lithography and metal deposition



SEM images of filters that were fabricated on GaSb with a SiO_2 layer deposited on the surface. E-beam lithography was used to pattern resist, later used for lift-off of a Ti/Pt/Au metal layer.



- Next step will be integration of these filters with infrared detectors and testing performance of detector-filter hybrids

Publications and References

Design of High-Transmission Plasmonic Wavelength and Polarization Filters for Infrared Photodetectors, T. Wenger, A. Soibel, Virtual poster presentation at Metamaterials'2020. Accepted.