Metamaterial Spectrometer: A Low SWaP, Robust, High Performance Hyperspectral Sensor for Land and Atmospheric Remote Sensing

CNF Project Number: 2661-18

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Primary Source(s) of Research Funding: NASA

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Primary CNF Tools Used: DWL2000 photomask writer, ASML stepper, JEOL 9500 e-beam lithography, AJA sputter, Oxford PECVD, SC4500 evaporators, Oxford Cobra etcher, Oxford 81 etcher, Trion etcher, CMP, SEM, Woolam ellipsometer, DISCO dicing saw

Abstract:

Since 2003, Phoebus Optoelectronics has enabled custom R&D solutions in the fields of Plasmonics, Metamaterials, Antennas, and Sensors. We work closely with our customers throughout device development, from prototype realization to small volume manufacturing. Our R&D portfolio spans the spectral ranges of visible light, infrared, terahertz, and microwave radiation, for applications in high resolution infrared imaging systems, wavelength and polarization filtering, tunable optical components, beam forming and steering, solar cells and renewable energy devices, and chemical and biological toxin sensors. Our agile team makes extensive use of the resources at the CNF for our nano/micro fabrication and testing, to provide cost efficiency and rapid turnaround. In the present report, we discuss the ongoing development of a metamaterial-based hyperspectral imaging filter.

Summary of Research:

Phoebus uses the resources of the CNF to fabricate plasmonic chips patterned with a metamaterial surface to enable Extraordinary Optical Transmission (EOT), a phenomenon unique to metastructures in which light is transmitted through apertures much smaller than the incident wavelength, at anomalously large intensities relative to the predictions of conventional aperture theory. EOT was first observed by T.W. Ebbesen in 1998 [1]. Since its founding in 2003, Phoebus has successfully harnessed EOT by incorporating metasurfaces into devices used to perform light filtering [2-3], photon sorting [4-5], polarimetric detection [6], high speed optical detection [7], and most recently, in our SPR plasmonic sensor chips [8].

Examples of metastructured optical devices previously fabricated by Phoebus at CNF are shown in Figures 1-3. In our first-generation IR polarimeter (Figure 1), which is currently commercially available, each pixel has four arrays of wires oriented at 0°, 45°, 90°, and 135° to each other. Each array is capable of acting as a graded index lens, to focus and collimate transmitted light. At the same time, the phase delay produced by the four arrays together allow the pixel as a whole to behave as a polarizer to control the phase of the light. A higher magnification image of a typical array (Figure 2) illustrates the high aspect ratios and smooth sidewalls which are essential for the high-quality performance of our metasurface structures. A second generation of this design, which was fabricated by electron beam lithography and tailored to operate at a shorter wavelength, is shown in Figure 3.

In our current project, we are developing a hyperspectral imaging system, shown schematically in Figure 4. Our technology (Figure 4b) uses a metasurface to precisely target very narrow spectral bands of interest, enabling a significant reduction in the size and number of optical components relative to current state-of-the-art imaging systems (Figure 4a), which in turn will enable integration of our high-performance sensor onto weight-sensitive platforms (ie. satellites) far more readily than existing systems. The goal of our initial application is to detect and image trace gases in the Earth's atmosphere in the midwave infrared (MWIR) region, with a reduction to adjacent channel latency of less than 10 ms. In planned future research, the overall metasurface technology can be easily adapted to other spectral ranges, from the visible to the microwave, by substituting appropriate materials (most of which can be deposited in the CNF), and scaling feature sizes of the metastructures in proportion to the desired wavelength of imaging. Thus, our versatile Metamaterial Spectrometer technology is expected to be applicable to a much broader range of imaging and sensing applications.

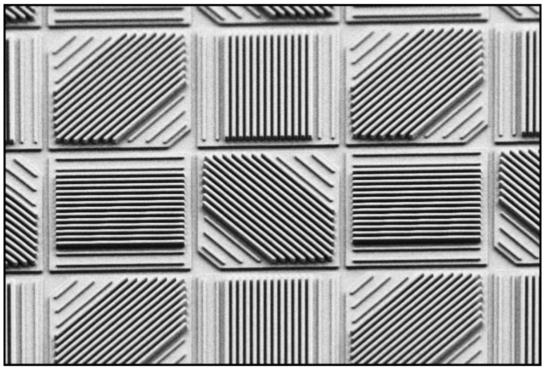

Figure 1: SEM image of metasurface-based IR polarimeter, currently commercially available from Phoebus, and initially developed at CNF using the ASML DUV stepper.

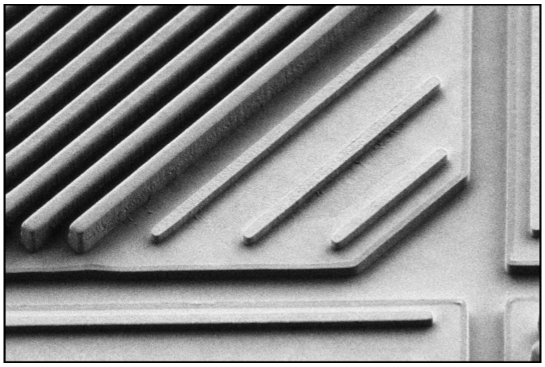

Figure 2: A single sub-pixel at higher magnification. These high aspect ratio features with smooth sidewalls were fabricated at CNF using the ASML DUV stepper and dry etch tools.

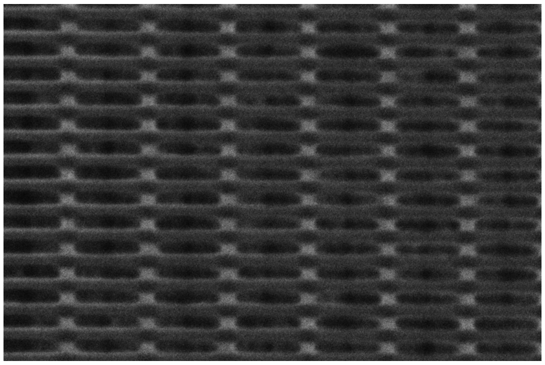

Figure 3: SEM image of another focusing polarimeter device developed by Phoebus at CNF, fabricated using the JEOL 9500 e-beam lithography system.

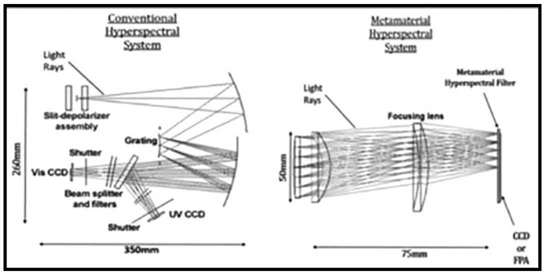

Figure 4: Phoebus's Metamaterial Spectrometer (MS) technology eliminates much of the size and weight of current hyperspectral spectrometer technologies.

References:

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