Fabrication of Dynamically Tunable Vanadium Dioxide Huygens Metasurfaces for Optical Modulation

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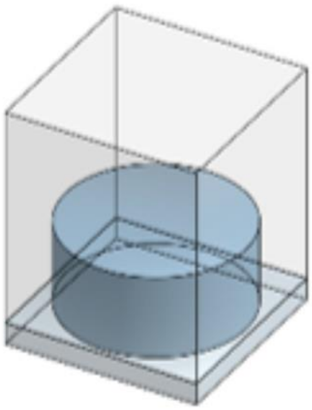
Abstract

Optical metasurfaces have emerged as potential candidates for next generation optical devices due to their ability to manipulate the amplitude, phase, wavenumber, and polarization of light[1]. They are two dimensional subwavelength structures which are engineered to abruptly impart a desired property shift to the impinging optical wavefront. Huygens metasurfaces comprise of an array of optical resonators where each resonator acts as a point source causing light to propagate in the forward direction. In our work, these metasurfaces are made using vanadium dioxide, which was chosen as a good candidate because it exhibits a reversible metal-insulator transition above 68^{o}C. Vanadium dioxide is known for its thermochromic property, making it a promising material for smart energy-saving windows[2]. In this report, we present a bottom-up fabrication process for vanadium dioxide metasurfaces useful for optical modulation at short wave infrared wavelengths (SWIR). Thin films of vanadium dioxide are fabricated using pulsed laser ablation of a vanadium pentoxide target on a quartz substrate. This is done using a KrF excimer laser while flowing oxygen gas into the vacuum chamber during ablation. Electron-sensitive resist (PMMA) is spun on the film and functions as a stencil for patterning using electron beam lithography. Different hard masks have been used to achieve etched features that closely match geometries designed using finite element analysis for specific behaviors. We present results of fabricated nanoantennas using fluorine- and chlorine-based etch processes. We propose that chlorine-based etch recipes are preferred in order to achieve good anisotropy and accurate nanoscale dimensions for optical device applications.

References

1. Nanfang Yu and Federico Capasso "Flat optics with designer metasurfaces" *Nature Materials*, Vol. 13 139-150 (2014)
2. Yuanyuan Cui, Yujie Ke, Chang Liu, Zhang Chen, Nign Wang, Liangmiao Zhang, Yang Zhou, Shancheng Wang, Yanfeng Gao, and Yi Long "Thermochromic VO_2 for Energy-Efficient Smart Windows" *Joule* Vol. 2 Issue 9, 1707-1746 (2018)

(A)



(B)

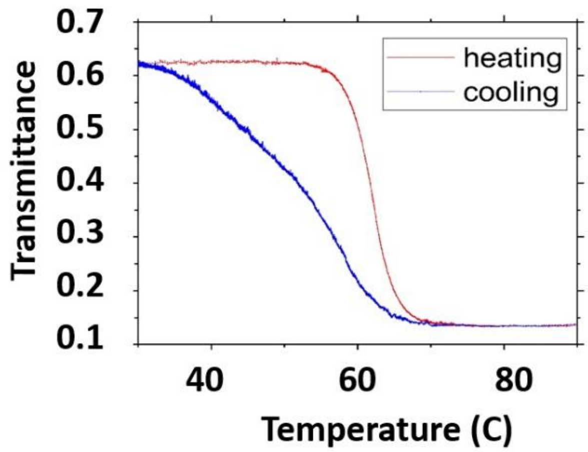
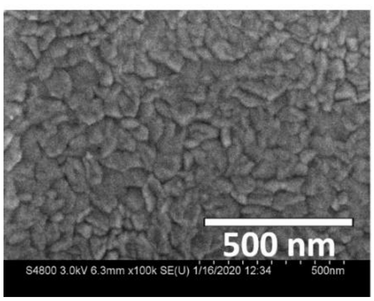


Fig. 1(A). Schematic of periodic unit cell of designed VO_2 Huygens metasurface showing the encapsulant (PDMS), nanoantenna (VO_2), and substrate (fused quartz) domains (from top to bottom) (B). Optical transmittance of VO_2 thin film at 1340 nm, fabricated using pulsed laser ablation.

(A)



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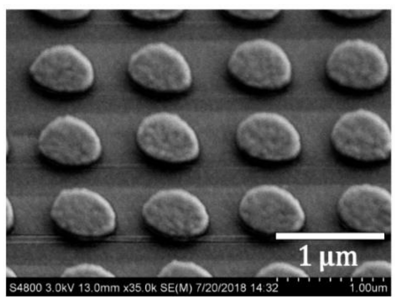

(C)

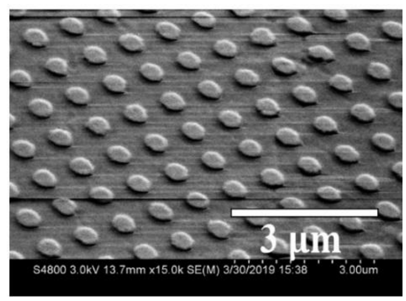

Fig. 2(A). Scanning electron micrograph of VO_2 thin film. (B). Scanning electron micrograph of VO_2 Huygens metasurface. Hard mask used here is Al_2O_3 (C). Electron micrograph of VO_2 Huygens metasurface. Hard mask used here is SiO_2.