Continuously Tunable Vanadium Dioxide Metasurfaces for Active Optical Wavefront Control

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Vanadium dioxide (VO_2) is a notable thermochromic material that undergoes a reversible metal-insulator transition at a critical temperature around 68°C[1]. Because of its unique optical and resistivity properties, VO_2 is desirable for applications in many areas including sensors[2] and smart windows[3], but particularly in our work for metasurfaces. Huygens dielectric metasurfaces are useful in optical devices for their ability to modulate the behavior and properties of light.

In this work, VO_2 thin films are grown on quartz substrates using RF magnetron sputtering and ex situ annealing. The tube-furnace post-deposition annealing step in inert atmosphere is used to reduce the oxygen-vanadium mole ratio suitable for fabrication of tunable nanophotonic devices.

To increase the yield and reduce annealing time, rapid thermal processing (RTP) was used as an alternative method to tube-furnace annealing. Gas flow rate, annealing temperature, and annealing time were varied towards achieving VO_2 thin films. Obtaining the exact stoichiometry is challenging due to the many vanadium oxides that exist. Annealing at 600°C for 300 seconds in a 97%/3% argon/hydrogen gas mixture yielded a thin film with a critical temperature of 63°C and a reversible transition. Optical transmittance and ellipsometric measurements were done to determine the phase transition behavior and optical constants of the films.

From the tube-furnace annealed thin films, VO_2 dielectric nanoantenna arrays are fabricated using a RAITH VOYAGER 100 electron beam lithography tool and a reactive ion etching tool. Highly directional etching suitable for optimal device performance is challenging with VO_2 due to mask selection and the non-volatile nature of vanadium chlorides. Here, vanadium dioxide metasurfaces are etched using Cl_2 and Ar at 700 W and rf bias power of 250 W at 7 mTorr. These VO_2 metasurfaces are then characterized to measure their continuous phase and amplitude modulation ability in the near-infrared. Results from these metasurfaces suggest potential success for fabrication using RTP thin films with better efficiency.

References:

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2. Brett Kruger, Arash Joushaghani, and Joyce K. S. Poon "Design of Electrically Driven Hybrid Vanadium Dioxide (VO_2) Plasmonic Switches" *Optics Express*, Vol. 20 (2012)
3. Yanfeng Gaoab et al. "Nanoceramic VO2 Thermochromic Smart Glass: A Review on Progress in Solution Processing" *Nano Energy*, Vol. 1 Issue 2 (2012)

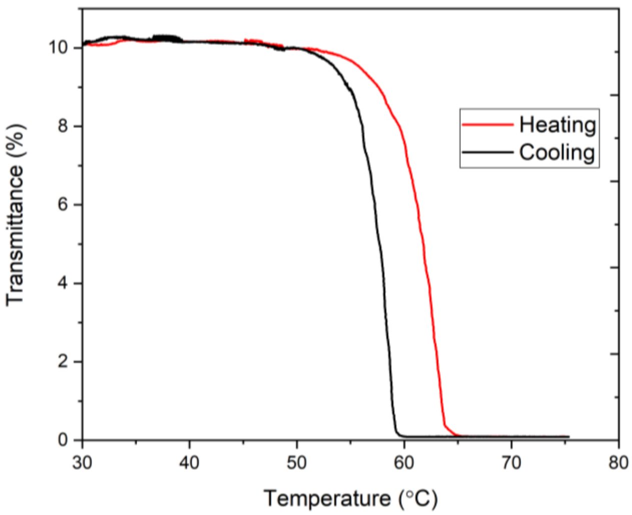

Figure 1: Hysteresis behavior in optical transmittance of a VO_2 thin film fabricated by sputtering and RTP

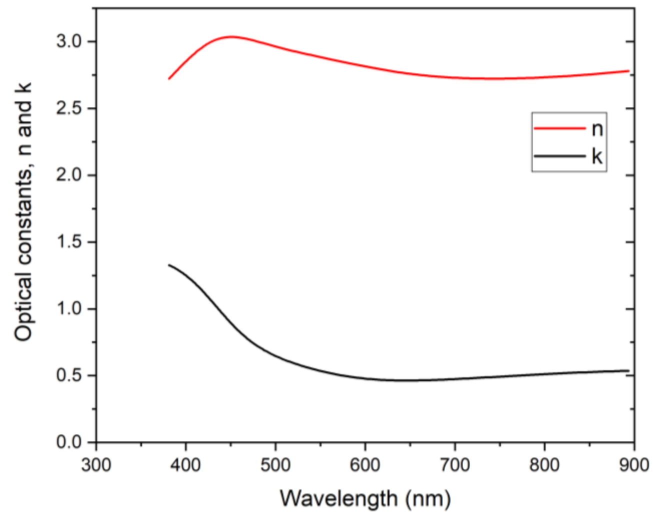

Figure 2: Spectral optical constants for VO_2 on fused quartz, fabricated with sputtering and RTP, and measured at 21°C in the insulating phase

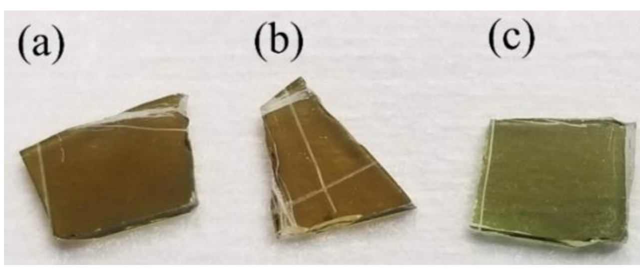

Figure 3: VO_x on fused quartz fabricated with sputtering and RTP-annealing at 350°C for (a) 300 seconds in nitrogen, (b) 420 seconds in nitrogen, (c) 420 seconds in a 95%/5% argon/hydrogen gas mixture

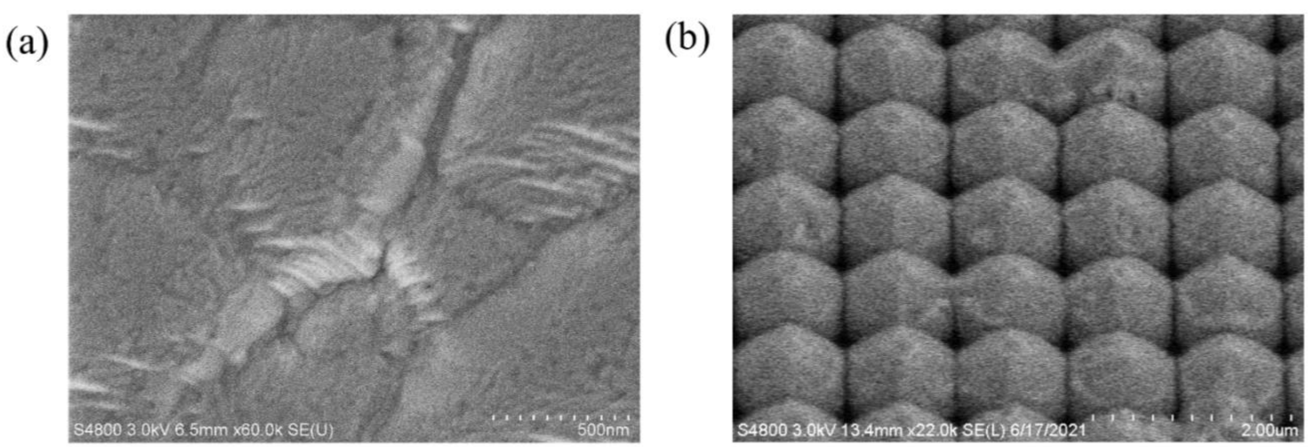

Figure 4: Scanning electron micrograph of (a) an RTP-annealed VO_2 thin film on fused quartz and (b) a VO_2 Huygens metasurface etched with Cl_2/Ar from a tube-furnace annealed VO_2 thin film