Optical Power-Handling Issues in Active Phase-Change Metasurfaces

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ABSTRACT

Phase-change materials can enable active control of optical metasurfaces; however, the effects of high-power sources on such devices are not yet well-studied. We present a model for the optical response of phase-change metasurfaces to high-power lasers and apply it to previous designs for a beam steerer and a lens.

Key words: active metasurface, high-power laser

1. INTRODUCTION

Metasurfaces are 2D arrays of sub-wavelength resonant elements (meta-atoms) that can control the phase, amplitude and/or polarization of incident light [1]. This allows precise control of the output wavefront, enabling metasurfaces to be used as perfect absorbers, beam steerers, polarisers, lenses and more [1,2]. If metasurfaces can be actively controlled, their possible applications are greatly expanded. One of the most promising active control mechanisms is the incorporation of chalcogenide phase-change materials (PCMs) into the metasurface design. PCMs are switched by heating, but the device will also be heated by the light it manipulates. If the source is sufficiently high-power, this creates the risk of unwanted switching of the PCM, which could adversely impact the optical response of the device. In this work, we explore the response of PCM metasurfaces to such high-power stimuli, considering in particular, (i) an active beam steerer that switches between anomalous and specular reflection, introduced in reference [2], and (ii) an active lens that controls numerical aperture introduced in reference [1]. These are illustrated schematically in figure 1.

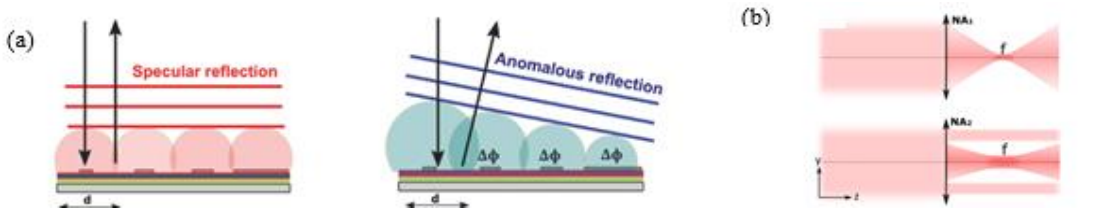

Figure 1. (a) Schematic representation of operation of PCM metasurface beam steerer (adapted with permission from [2]). (b) Schematic representation of operation of NA control lens (adapted with permission from [1]).

2. EXPERIMENTAL

We simulate the evolution of the temperature distribution in these metasurfaces under different laser intensities with the commercial finite element analysis package COMSOL Multiphysics. The relationship of maximum temperature to laser intensity for the beam steering metasurface is shown in Figure 2(a). We next combine the thermal model with a Gillespie Cellular Automata (GCA) crystallisation model, based on the work of reference [3], which divides the PCM region into cells to determine stochastically, based on crystal growth and nucleation rate equations, if each cell should experience crystal nucleation, growth or dissociation in each time step. Exemplar growth and nucleation rates, here for the PCM composition $Ge_2Sb_2Se_4Te_1$ (GSST) are plotted in figure 2(b), accompanied by simulated crystal distributions for heating at different temperatures.

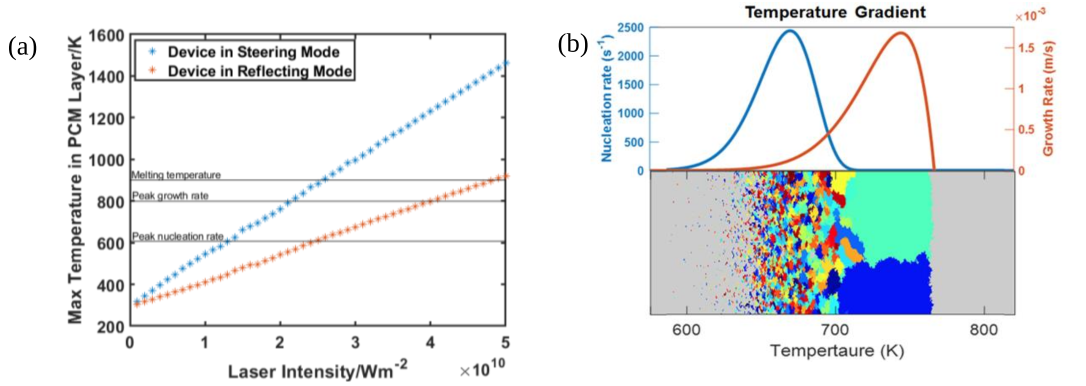

Figure 2. (a) Maximum temperature of PCM layer in the beam steering metasurface of [2] as a function of laser intensity. (b) Nucleation and growth rates for GSST, along with depiction of crystallization at different temperatures. Each colour is a different crystal grain.

3. RESULTS & DISCUSSION

Applying our approach to the beam steering metasurface, we find no significant change in optical performance for intensities up to 10^{10} Wm^{-2}, but at higher intensities unwanted crystallization occurs and degrades device performance, as shown in Figure 3(a). We then apply our approach to the active meta-lens. To save computation time, we first explore the responses of individual meta-atoms. High absorption in the crystalline state makes this state the limiting factor. For a 10 ns pulse of intensity 5×10^{10} Wm^{-2}, the cell is almost completely amorphised, as shown in figure 3(b).

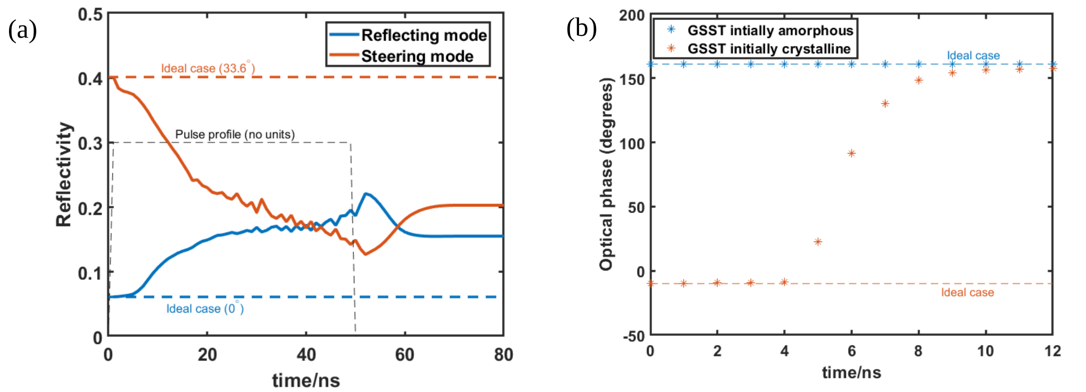

Figure 3. Time evolution of (a) the reflectivity into different diffraction orders when the beam steering metasurface from [2] is subject to a 50 ns pulse of peak intensity 5×10^{10} Wm^{-2}, and (b) the optical phase of crystalline lens unit cell from [1] subject to a 10 ns pulse of peak intensity 5×10^{10} Wm^{-2}.

4. CONCLUSIONS

We have developed a combined thermal and GCA crystallization model for the response of PCM metasurfaces to high-power laser illumination. Our work highlights the importance of studying the power-handling capabilities of PCM based metasurfaces for high-intensity laser applications.
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