A Reprogrammable Photonic Meta-platform

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Abstract: We present an all-solid, reprogrammable meta-platform, which can be rapidly (re)programmed into nearly arbitrary photonic devices by writing/erasing patterns on it. The writing is performed with a low-power laser, and the erasing utilizes global cooling.

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1. Introduction

Conventional photonic devices are limited by their fixed functionalities after fabrication. As such, tunable and reprogrammable photonic devices have been widely pursued for dynamic functionality, just as successful examples in other fields like field-programmable gate arrays (FPGA) [1]. In situ reprogramming is necessary to realize optical reconfigurable systems as well as time-resolved observation of photonic phenomena. Previous attempts at realizing reprogrammability used micro/nano-mechanical metamaterials [2], liquid crystals [3] or amorphous-crystalline phase transition materials [4], which are limited in terms of functionality, pixel density, efficiency, fabrication/reconfiguration cost or high working temperature (>600 ^oC). It is much desired to utilize phase-transition materials to reprogram photonic elements in a fast, scalable, cost-effective, and lithography-free way at or near room temperature.

Here, we demonstrate an all-solid, reprogrammable meta-platform for photonic applications, on which arbitrary photonic devices can be rapidly and repeatedly written and erased for real-time manipulation of light waves. Different patterns can be written and erased on the same meta-platform successively. The writing is performed with a low-power laser and the entire process stays below 90 ^oC. The meta-platform opens possibilities where photonic elements can be field-programmed to deliver complex functionalities.

2. Experiment

The meta-platform is realized using the hysteretic metal-insulator phase transition (MIT) of polycrystalline vanadium dioxide (VO_2) films. VO_2 undergoes a temperature-driven, reversible transition from the insulating (I) to metallic (M) phase when heated above its transition temperature (T_c = 68 ^oC) [5]. These two phases differ drastically in their relative dielectric constant (-35 + 119 i Vs. 4.9 near the operation wavelength of 10.6 μm in this work) [6]. To fabricate meta-platforms, VO_2 films were deposited onto double-side polished, undoped silicon substrates in a DC magnetron sputtering system using a high-purity vanadium metal target. Note that the thickness of the VO_2 film used is only 200 nm and the probe beam wavelength is 10.6 μm, forming a wavelength-thickness-ratio as high as 53.

Fig. 1a shows the schematic of a meta-platform being micro-patterned with a focused laser beam. As illustrated in Fig. 1b, we first globally heat the VO_2 film from room temperature (cooler than Point A) to T_c (Point B), and the entire film is still in the I phase. Subsequently, a laser is focused onto the film to locally heat the VO_2 to the M phase (Point C). When the laser is turned off or moves to other regions, the laser-heated region will still stay in the M phase (Point D) owing to the hysteresis [7]. Hence a non-volatile M-phase pattern is written onto the I-phase film. The pattern can be easily erased by reducing the global temperature of the entire film beyond the hysteresis (e.g., to Point A). Upon re-heating to Point B, the film is reset and ready for re-writing a new pattern in the same region. This process is illustrated in Fig. 1c. As such, nearly arbitrary patterns of the M phase can be written, erased, and rewritten onto the I-phase film, hence forming a reprogrammable meta-platform. In this work, a continuous-wave laser at 532 nm wavelength integrated in a direct laser writing system was used for the laser writing. The global temperature was controlled by a heating stage.

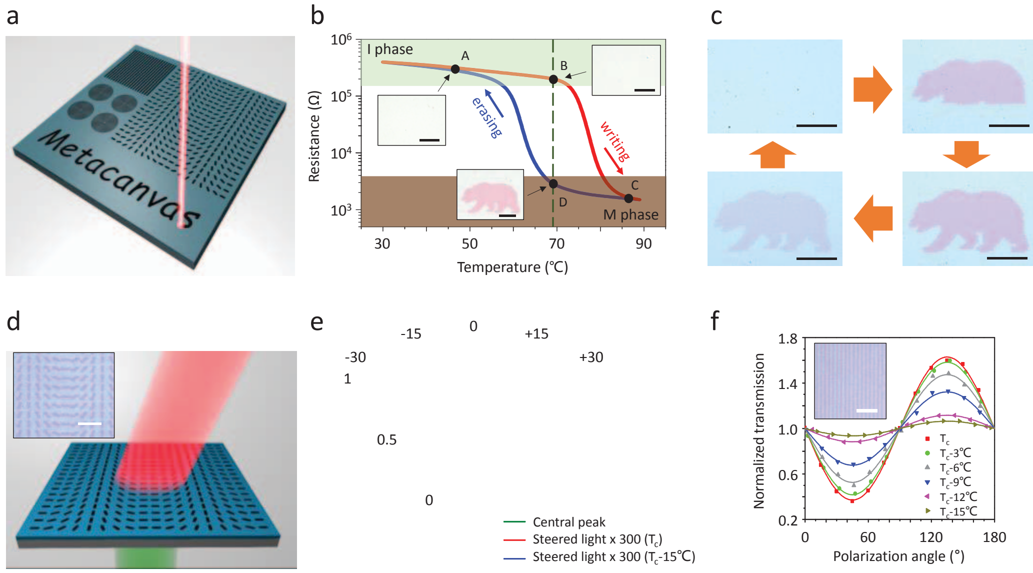

Fig. 1. (a) Schematic of laser writing different patterns on a meta-platform. (b) Temperature-dependent resistance of a VO_2 film, where the transition temperature (T_c) is denoted by a vertical dashed line. Inset A and B: un-patterned VO_2 film (all in the I phase). Inset D: the VO_2 film (global temperature kept at T_c) is laser-written with a pattern of a bear in the M phase. (c) Optical images from writing and erasing process on the meta-platform: a pattern of a bear (M-phase) is written onto an I-phase VO_2 film, then erased by decreasing the global temperature. (d) Schematic of a meta-platform programmed as a beam steerer. Inset: optical image of the beam steering phase array written on the meta-platform. (e) Normalized, measured light intensity as a function of the propagation direction angle. (f) Evolution of the normalized, polarization-dependent light transmission from a meta-platform programmed as a linear polarizer as temperature is decreased from T_c to T_c-15 °C. Inset: optical image of the linear polarizer written on the meta-platform. Scale bar is 100 μm in (b) and (c), and 10 μm in (d) and (f).

Fig. 1d shows the meta-platform programmed for beam steering. The designed metasurface is written onto the meta-platform, which steers the input light beam as well as changes the handedness of the steered beam [8]. In the experiment, a steered beam was indeed observed along the designed direction (Fig. 1e). As we erased the metasurface pattern on the meta-platform by decreasing the global temperature, the steered beam vanished. We also experimentally characterized the meta-platform programmed as a wire-grid linear polarizer (Fig. 2f). The polarization ratio of this linear polarizer is maximized and equal to 4.5 at T_c, and gradually decreases to about 1 at T_c-15 °C when the pattern is nearly completely erased.

3. Conclusion

In conclusion, we have exploited the VO_2 phase transition to attain real-time reconfigurability and reprogrammability of photonic devices, and achieved a reprogrammable meta-platform for full light manipulation in both space and time dimensions. The meta-platform technology can be further applied for more advanced applications, including building dynamic optical systems without moving parts, where a wide range of functionalities can be customized in situ by repeatedly programming and coding the meta-platforms.

4. References

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