Pixel level demonstration of phase change material based spatial light modulation

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Abstract: We present an advancement towards high speed (sub μs) phase change material based spatial light modulators by electrically addressing single pixels with high-speed optical monitoring at 1550nm light.

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1. Introduction

Optical devices used to manipulate light can be as simple as a lens or as complexly engineered as a spatial light modulator (SLM). Most modern tunable modulation devices used for reconfigurable photonics rely on liquid crystal (LC) based SLMs which are extremely limited by their time response (∼60 Hz refresh rate). For instance, phase only SLM response times are dependent on the LC material, LC film thickness, applied voltages and temperature, and at best perform at millisecond time scales. On the contrary, phase change materials are excellent candidates for replacing LCs as the active medium in SLM pixels due to their ability to switch between an amorphous or crystalline in 1μs or less [1]. As a result of pronounced lattice distortions/displacements, enhanced refractive index contrasts in the infrared regime are obtain, making this emerging technology suitable for ultra-thin optical phase tuning devices. Two drawback of commonly used $Ge_2Sb_2Te_5$ (GST) pixels is that a) electrically addressing micron sized pixels requires high voltages and consequently is not realizable in a simple lateral configuration (as opposed to complex cross-bar geometry), b) consequently, most demonstrations have relied on lossy auxiliary microheaters (leading to very high energy consumption on the scale of microjoules per pixel operation). One possible solution is in doping the GST to modify its conductivity while simultaneously preserving its desirable optical properties [2].

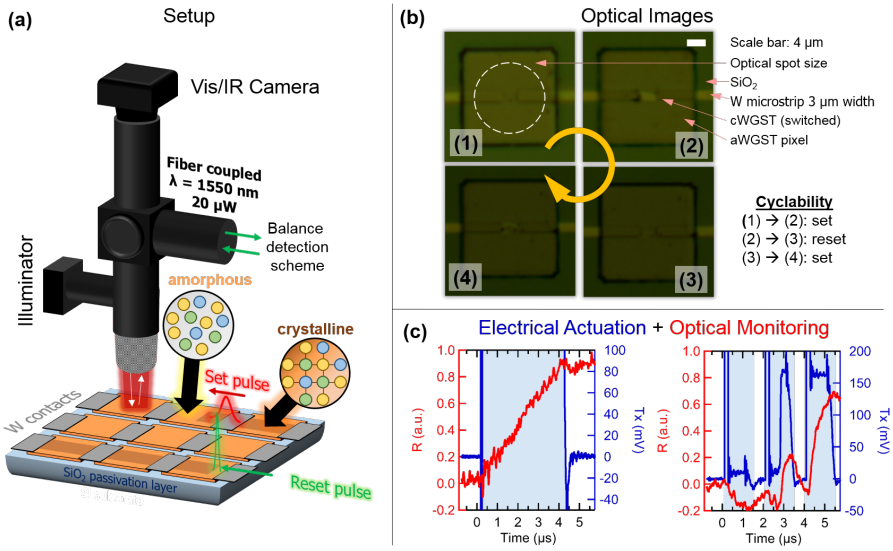

Fig. 1. (a) Optical setup, (b 1-4), Optical images of the GST pixel as it is cycled between its amorphous and crystalline states. c) Time dynamics of the electrical transmission (blue) and optical reflectivity (red) for both single high voltage pulse (left) and low-voltage burst (right).

Recently, we have demonstrated optical actuation in bulk thin film GST using nanosecond optical pulses [3]. In this work, we demonstrate similar high speed optical time dynamics via electrical actuation of co-sputtered W-GST alloy and show truly reversible single pixel operation with scalable lateral electrode configuration.

2. Experiment

Single microsecond pulses (or less) are generated and amplified (30V-50V) using a high-speed probe and is transmitted through a set of W contacts that are electrically connected through a 25 μm^2 GST-W pixel. More details on the GST-W material structural, thermal, electrical and optical material properties are reported here [4]. In our scheme, impedance matching to an RF pulse generator is optimized by reducing the electrical contrast between the GST states through tungsten doping, while preserving the difference in refractive indices at 1550 nm - as desired for spatial light modulation. Light from a telecom laser is split through an 50:50 splitter and sent via a circulator (port $1 \rightarrow 2$ of circulator) to one input of a compound microscope (Fig. 1a) and focused unto the GST-W optical pixel. The reflection/modulated light back propagates through the microscope through the $2 \rightarrow 3$ port of the circulator and on to one arm of a high speed balance detector where the second arm is fed directly from the initial 50:50 splitter. By matching the signal in both arms pre-phase change, our system is only sensitive to the changes in reflectivity and yields a high signal-to-noise ratio. Additionally, our thin film devices were designed to maximize the difference in reflected light ($\sim 40\%$) from the aWGST and the cWGST for maximum modulation contrast. The stack included a WGST (340nm) sandwiched between a sputtered SiO_2(10nm) capping layer and plasma enhanced chemically vapor deposition SiO_2 passivisation layer mounted on a Si substrate.

Figure 1-b shows the GST pixel upon switching from/to the amorphous to/from the crystalline state through a complete cycle. The pixel is defined by the $3\mu m$ x$3\mu m$ square space between the two metal bar electrodes (with the rest of the 10x10 μm GST square unaffected by the change). The starting point (1) is in the amorphous state. Upon sending a voltage pulse, the GST transitions to the crystalline state (2) with the entire $3\mu m$x3 μm pixel switching to higher reflectivity. A shorter, higher voltage pulse switches the GST back to the amorphous state (3), and the next cycle of crystallization is started in (4). Figure 1-c shows the time dynamics as recorded via the optical monitor described above. The left side of 1-c shows how a single, high voltage pulse can switch the GST pixel fully to its stable crystalline state (corresponding to b-2) in few microseconds, which is a much faster time scale than traditional liquid crystal SLM pixels are capable of, and shows the potential of W-GST as a viable material for spatial light modulation applications.

Interestingly, our scheme of in-situ optical monitoring allows us to investigate other regimes of operation for GST pixels, such as the volatile and partial crystallization regime (1-c, right). In that regime, multiple pulses are required to fully transition the pixel to its final non-volatile crystalline state. Through a burst of 3 pulses, we can explore nucleation (1st pulse), volatile phase transition (2nd pulse), and non-volatile crystallization (3rd pulse). This shows the power of in-situ optical monitoring as means of studying the fundamental physics of phase change dynamics of GST-based devices in the optical domain.

As a conclusion, we have demonstrated pixel-level electrically actuated light modulation via tungsten doped GST, and developed a system for high-speed in-situ monitoring. This experiment opens the path towards future, high-speed optical light modulators based on phase-change materials.

References

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