Free-Space optical switching of GST phase-change thin films via 1550 nm light

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Free-Space optical switching of GST phase-change thin films via 1550 nm light

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Abstract: We experimentally demonstrate free-space phase change of Germanium Antimony Telluride (GST), switching between the amorphous and hexagonal crystalline states utilizing telecom-band laser pulses.
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Phase change materials (PCMs) alter their optical, dielectric, and electrical properties using external excitations in the form of optical or thermal stimuli [1]. The change in properties is due to a non-volatile and reversible phase transition (reconfiguration) between the amorphous and crystalline states through a melt and solidification cycle [2]. The different phases of germanium-antimony-telluride phase change materials are achieved by controlling not only the energy of the stimulus, but also the cooling time of the material. If the GST is heated beyond its melting point (approximately 600 °C) and the quench time is fast enough (single to sub ns) the material will not have time to organize into the crystalline structure and will end up in the amorphous state. If the temperature doesn't reach the melting point, but reaches a certain temperature threshold for the crystallization, and is not allowed to cool quickly enough, the material is able to organize into a crystalline state as it cools [3]. While optical phase control via thermo-optical heating is a standard practice through blue-UV lasers, 1550 nm control would be desirable for telecommunications-band applications, such as spatial-light modulation and chip-scale reconfiguration [4]. In this work, we show a complete a phase-change and reversal via free-space telecom-band light.

Our GST samples were grown on a silicon substrate via RF sputtering and characterized with Ellipsometry measurements at multiple annealed temperatures (Fig. 1). A distinct difference can be seen between the different phases of the GST. The first happening around 140 degrees Celsius (the fcc state) and the second around 200 degrees Celsius (the hcp state). This is similar to earlier reports [3,5]. These measurements also show that the absorption at 1550 nm is much higher for the hcp state than either the fcc or amorphous states. This phenomenon can be used to help control the power needed for the phase change [6,7].

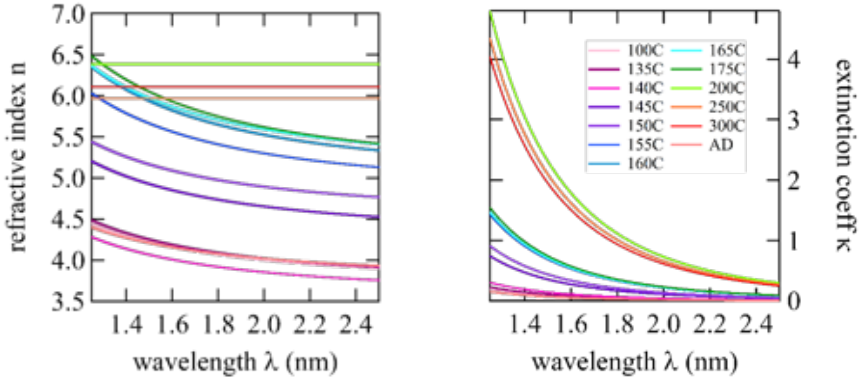

Fig 1: Ellipsometry measurements of the n and k of sputtered GST thin films as a function of temperature.

In our setup (Fig. 2) , a CW 1550 nm, fiber coupled laser runs through a polarization controller and into an electro-optical modulator. The modulator is controlled by an arbitrary waveform generator (AWG). The signal out is then split into two paths, one going to an oscilloscope, in order to monitor the pulse shape and power, and the other

going into an Erbium Doped Fiber Amplifier (EDFA). The output of the EDFA is sent to a collimator and then sent to a compound microscope where it is focused onto the sample.

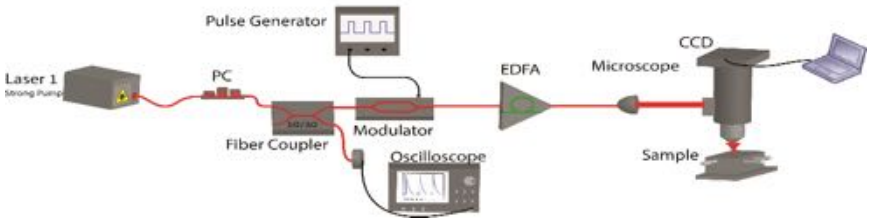

Fig. 1: Experimental setup

The amorphous to crystalline change is achieved by a 200 ns pulse, with a 50 ns fall edge, a peak power of 19.43 W and a fluence of approximately 22.67 J/cm^2. The crystalline to amorphous switch is achieved with a 8 ns pulse, with a 4 ns fall edge, peak power of 250 W, and an approximate fluence of 13.33 J/cm^2. The spot size for both lasers is approximately 4.5 μm in diameter. The change is detected by imaging through white light: As the crystalline phase is more absorptive/metallic, it will reflect more of the light to the camera.

In order to achieve greater contrast between the crystalline and amorphous phases in the visible wavelength range, an attempt was made to fabricate an anti-reflection coating on top of the GST. Both Zinc Sulfide (ZnS) and Indium Tin Oxide (ITO) were used as possible low-loss coatings of appropriate index. The ZnS was highly promising, but more work needs to be done to figure out the ideal thickness for the layer and its effect on thermal dissipation. The ITO was found to have too low of a damage threshold and was ablated before any change in the phase of the GST was noticed. As a first step, GST was tested without any top-level coating.

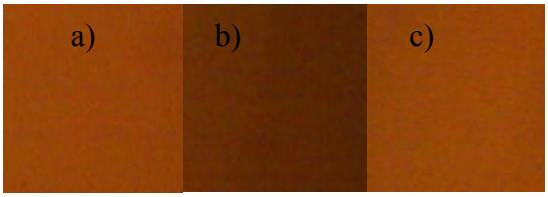

Fig 3: GST pixel through the cycle: a) Crystalline, b) Amorphous and c) Back to crystalline.

The results of the laser induced phase reconfiguration/change are shown in Fig. 3. With the small spot size, it is easy to control the size and shape of the reconfigured region. One pixel (~20 μmx20μm) is shown here. The pixel is optically reconfigured from a) crystalline to b) amorphous and c) back to crystalline without any loss in material quality. While the time dynamics in this experiment indicate that ~ 200 ns is necessary for the complete reconfiguration cycle – much faster than what is possible via liquid crystal spatial light modulators – we have observed promising indications that it is possible to complete the cycle within < 10 ns with appropriate shaping of the excitation pulse, making this technique a viable method for free-space optical reconfiguration and spatial light modulation applications.

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