Experimental verification of increased optical contrast in nanometer phase change films

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***Abstract* — The optoelectronic properties of phase change materials (PCMs) have been recently demonstrated for novel applications such as solid state nanodisplays. The thickness of the active PCM layer in particular is of critical importance. In this paper we verify experimentally this fundamental relationship between thickness and optical contrast. Our results show that further scaling into future 2D PCM materials, although counterintuitive, would benefit both the electrical and optoelectronic properties of such devices.**

Keywords — Nano Optoelectronics, Optical Nanodevices

Commercial re-writable optical storage discs utilize the remarkable and reversible optical refractive index of chalcogenide based phase change materials (PCM). This change in refractive index allows the storage of information on inexpensive plastic substrates [1] and even more interestingly has led recently to an emerging use in integrated photonic waveguides and circuits [2].

The difference in the refractive index between the amorphous and crystalline phases, in conjunction with an appropriate design of the thin film stack , ultimately dictates the performance of an optical thin film system, especially in the reflective mode. More recently, an entirely new optoelectronic framework based on electrically switched, optically active, ITO/$Ge_2Sb_2Te_5$/ITO/Pt films has been demonstrated [3]. In any such system, the optical contrast properties between the two phases are designed to be as high as possible. One advantage of a multilayer stack utilizing PCMs is that this optical contrast increases exponentially for ultra-thin (< 10 nm) PCM layers. This counterintuitive property has been shown through very simple optical transfer simulation techniques [4], and recently sparked renewed interest when thin metallic (i.e. absorptive) films were shown also to display these properties [5]. Extending this contrast enhancement to refractive-index-tunable and absorptive thin films, and confirming such enhancement experimentally would have important implications for the design of future solid state nanodisplays and optical storage systems [6], where a reduced volume of active phase change material would require considerably less energy to switch between phases [7]. In this paper we show experimental results that confirm these simulations, even approaching an incredible contrast ratio of 6000%.

A diagram of the optoelectronic multi-layered thin films used in this work can be found in Figure 1a. Sputter deposition is used to produce a variety of different stacks, starting from two solid targets of ITO and $Ge_2Sb_2Te_5$, on pre-cleaned SiO_2 substrates covered with a 100 nm Pt layer. Further details on the entire deposition process can be found in [3]. We start our investigation by depositing a series of films with various thickness of the ITO spacing layer and a constant 7 nm thickness for the active $Ge_2Sb_2Te_5$ layer. After each deposition, we cut the sample in half and place one part on a hot-plate at 200^o C for 3 minutes in order to achieve complete crystallization. The reflectivity of each pair of films is measured using a Lambda 1050 spectrometer (Perken Elmer, USA) and compared one against the other and for each wavelength using the standard equation $\Delta R_{\%} = \left(\frac{R_{crystal} - R_{amorphous}}{R_{amorphous}} \cdot 100\right)$. Figure 2 shows the measured reflectivity changes, when a 20 nm ITO / 7 nm GST / *t* nm ITO / Pt stack is crystallized upon heating (*t* being varied). The measurements are repeated for various thicknesses of the ITO spacer between 50 and 180 nanometers. Peaks revealing dramatic increases in reflectivity upon crystallization are shown at specific wavelengths based on the thickness of the ITO spacer, as initially simulated in [3]. We now move to demonstrate the correlation between reflectivity change and GST layer thickness. We sputter and compare a new series of films using a fixed ITO spacer thickness (150 nm) and increasing GST thickness in a manner similar to the previous experiments. Figure 3 shows the results from this second series. As one can see, the dramatic increase in reflectivity around 560 nm rapidly falls when the GST layer thickness is increased from 7 nm to 20 nm with $\Delta R_{\%}$ reaching values 6000% for the thinnest (7 nm) film. Comparing the reflectivity contrast obtained for different GST thicknesses at 560 nm, in Figure 3, one might extract an exponential dependence of the form $\Delta R_{\%} = 153 + 4.765 \cdot 10^5 e^{(-0.62 \cdot t)}$ where $\Delta R_{\%}$ is the change (in percentage) of reflectivity upon crystallization and t is the thickness of the active phase

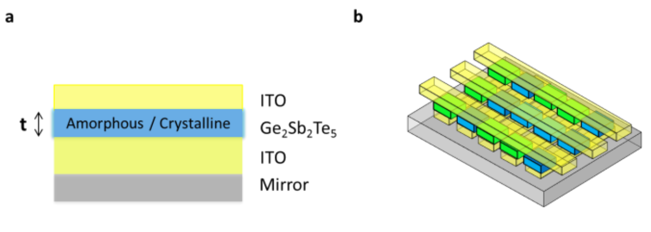

Figure 1 – **a** Diagram of the optoelectronic thin film stack used in this work. Various stacks with decreasing thickness (t) of the PCM layer have been prepared and their optical contrast performances evaluated. **b** The crossbar structure proposed for the realization of future PCM based nanodisplays.

change material in nanometers. Recent work on PCM scalability for memory applications has shown 1 nm, switchable, memory cells [8] which would correspond, in principle, to an astonishing $\Delta R_{\%}$ of 2.56 x 10^5, if one can

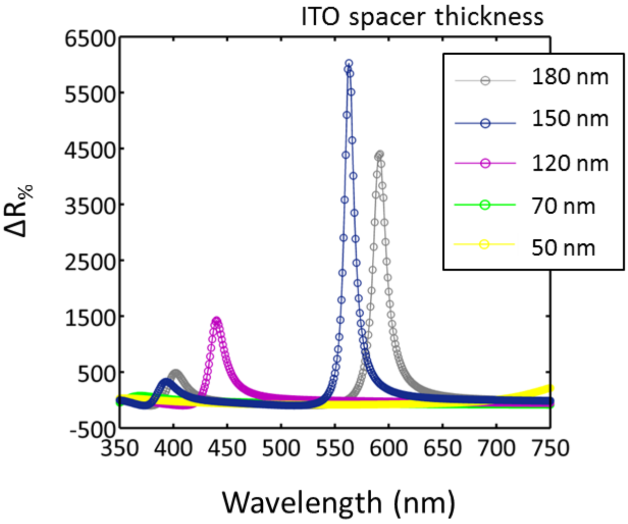

Figure 2 – Experimental verification of the reflectivity change in percentage when the GST in a thin-film stack comprising 20 nm ITO / 7 nm GST / ITO / 100 nm Pt / SiO2 is crystallized upon heating. The measurements are repeated for various thicknesses of the ITO spacer.

reliably deposit such thin materials and the above noted exponential dependence on contrast with film thickness were to hold. Even more importantly, a new generation of 2D phase change materials, as those proposed in [9], have the potential to enhance their performance even further. Interestingly, PCM memories exhibit increased performance and lower energy consumption when their active area is decreased to a few nanometers [7, 10], which is also extremely convenient for PCM based optoelectronic devices. The results shown here have the potential to spark a renewed interest into low-dimensional phase change materials for optical storage. Given that a lot of work on the reliability of thin films has been made in the context of electronic memories, it is likely that revisiting such storage by employing ultra-thin films might yield extremely high fidelity optical storage media [6, 11]. Such a technology would be directly applicable in current technology platforms (i.e. on a standard CD, DVD or Blu-Ray recording system).

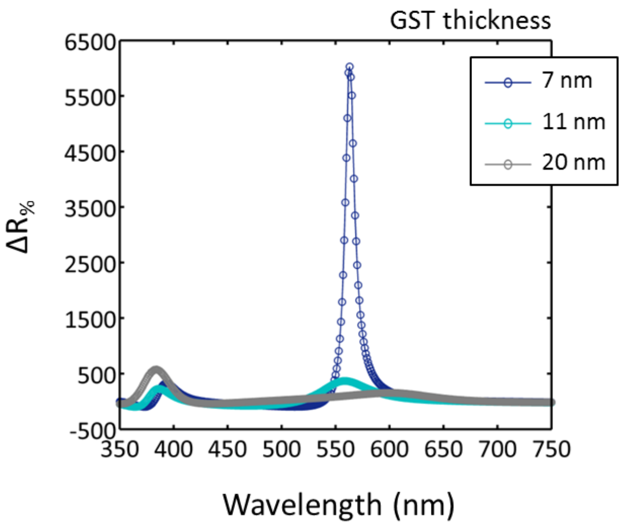

Figure 3 – Experimental measurements in thin-film stacks with 150 nm ITO spacer are studied with decreasing thickness of the GST layer. As the thickness of the phase change material decreases, a dramatic increase in the reflectivity change is observed (>6000%).

In conclusion we have experimentally verified how ultra-thin PCM thin film configurations demonstrate an exponential increase in optical contrast when the thickness of the active PCM layer is decreased to a few nanometers. Using an ultra-thin layer (7 nm) of $Ge_2Sb_2Te_5$ we demonstrated that the peaks in optical contrast are effectively tuned in wavelength by changing the thickness of the ITO spacing layer. These results have important implications for future PCM based optical and optoelectronic films and devices where a decrease in active volume corresponds to a decrease in energy necessary for a switching event. Further research into 2D phase change materials is therefore very topical and has highly relevant technological implications.

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