

Active plasmonics based on phase change materials

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Abstract- Phase change materials are suggested as a means to attenuate surface plasmon polariton waves. In particular, the transmitted power was attenuated by 7 dB using the prototypical phase change material Ge₂Sb₂Te₅.

Keywords- Phase Change; plasmonics; Modulation; Nanophotonics

I. INTRODUCTION

The surface plasmon resonance is the collective oscillation of charge at the interface between two materials with dielectric constants of opposite sign. Usually, the resonant frequency of this interfacial charge occurs at visible or near infra-red frequencies. The surface plasmon polariton (SPP), is a guided wave of the electronic charge that is able to propagate at the interface between the two materials. The propagation constant of the surface plasmon at the boundary of a semi-infinite dielectric and a metal is given by expression (1).

$$\beta = k \sqrt{\frac{\epsilon_m n_s^2}{\epsilon_m + n_s^2}} \quad (1)$$

where k is the wavenumber of the metal, ϵ_m the dielectric constant of the metal ($\epsilon_m = \epsilon'_m + i\epsilon''_m$) and n_s is the refractive index of the dielectric. The SPP wave is guided when $\epsilon_m < -n_s^2$ [1]. It follows that modulation of the SPP is possible by changing the refractive index of the dielectric such that in one state the $\epsilon_m < -n_s^2$ and in the other state $\epsilon_m \approx -n_s^2$.

Phase change data storage materials, which are usually based on chalcogenide materials, exhibit large changes in refractive index when switched between their covalent and resonant bonding states [2-3]. The prototypical phase change material Ge₂Sb₂Te₅ (GST), for instance, can be switched with a 20 fs laser pulse [4] from a refractive of $n \approx 6.5 + i1.4$ to $n \approx 4.0 + i0.1$ [6]. Furthermore, for this particular type of material the structural phase can be switched back and forth 10^9 times [6] yet is stable at stable at temperatures below 85 °C for periods of years [5]. The most recent phase change material research, however, has concentrated on its use in electrical phase change random access memory (PCRAM)- a technology which due to the phase change material's short switching time [5], cycleability [5] and scalability [7] is a strong candidate to replace FLASH memory. Individual bits are written to the phase change memory cell using electrical Joule heating to induce the phase change. The electrical resistivity changes by several orders of magnitude and can thus be read electrically.

In the case of GST, the large change in optical properties is attributed to a change in the local atomic coordination of the Ge atoms. In one state the Ge atoms are predominantly octahedrally coordinated by Sb and Te atoms [9] with p-orbital bonds aligned with adjacent molecular units [3]. The p-orbital electrons are effectively delocalized between atoms leading to a high polarisability and consequently, a large refractive index. In the other state, the p-orbital alignment is lost and a substantially lower refractive index is observed [2,3,9]. The energy necessary to change the bonding state of all the atoms in the phase change material (PCM) scales with its volume thus PCMs are well suited to nano scale switching applications such as nanophotonic modulators and memories.

Generally, the losses of SPP waves restrict their useful transmission range to just a few hundred microns [10]. However, even with these high losses SPP waves do hold some promise for novel memory and processing concepts where a high density of phase change memory cells are located within the useful range of the SPP wave. Research in this field is still in its early stages with most of the most prominent work employing the different solid-solid phase transitions of Gallium [11]. However, basing the plasmonic phase change technologies around chalcogenide materials has the added advantage of allowing the phase change to be detected using the change in optical and electrical properties thus allowing hybrid photo-electronic devices, which might find use in future computing technologies. Herein, the potential of plasmonic modulation via a thermally induced phase transition in GST is discussed.

II. EXPERIMENTS

The samples were prepared on silica glass substrates (200 μm) with the following structure: a Ti seed layer (30 nm), a gold layer (60 nm), a silica layer (190 nm) and finally the GST layer. The Ti and gold layers were deposited by thermal evaporation whilst the silica layer was deposited from an SiO₂ target in an Argon atmosphere of 0.25 Pa. The GST layer was formed by sequentially depositing 0.5 nm thick GeTe and Sb₂Te₃ layers in an argon atmosphere or 0.5 Pa. The input and output gratings were fabricated in the resultant structure by focussed ion beam milling. The grating line width was 0.2 μm whilst the pitch was 1.025 μm . Output gratings, of the same structure, were milled at distances varying from between 200 μm and 40 μm from the input grating. A schematic of the resultant structure is given in figure 1. The GST was deposited in a covalently bonded state but focussing 800 nm laser light through a 0.4 NA compound objective, with a optical power of ~40 mW at the sample surface, changed the material to its resonantly bonded state. Finally, prior to measurement, a thin

Poly(methyl methacrylate) film was deposited on the sample surface.

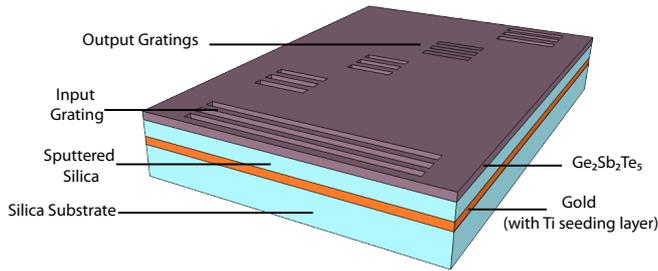


Figure 1: Schematic of the sample used to measure the transmission of surface plasmons polaritons dependence on the bonding state of $\text{Ge}_2\text{Sb}_2\text{Te}_5$.

SPP waves were excited at the sputtered silica - gold interface by illuminating the input grating with focussed 1550 nm laser light. The light scattered from the output grating was collected in transmission mode using a plasmon leakage microscope. A full description of the set-up can be found in [12]. A CCD camera was used to collect images of the scattered light with 16 bit resolution. Measurement of the scattered light was performed by integrating the intensity measured by the camera across the area of each output grating. A typical image is shown in figure 2.

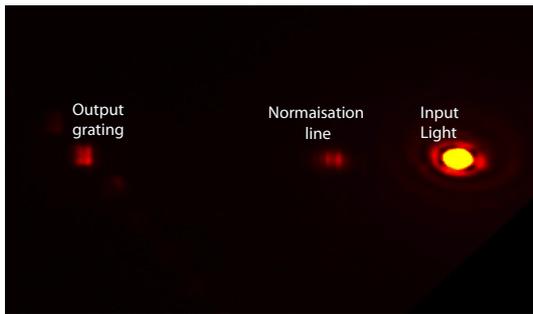


Figure 2: A typical image collected for the transmission of a surface plasmon through using a covalently bonded $\text{Ge}_2\text{Sb}_2\text{Te}_5$ layer.

III. CONSLUSIONS

The linear attenuation coefficient, α , of the SPP wave significantly increased from $0.01 \mu\text{m}^{-1}$ for covalently bonded GST to $0.04 \mu\text{m}^{-1}$ for resonantly bonded GST; the difference in transmitted intensity of the SPP was approximately 7 dB. Although 7 dB is quite a small change in transmitted power, it is believed that the combination of new phase change materials and a novel sample design will yield useful switchable plasmonic modulators and memory devices that will find new applications in hybrid electro-photonics computing.

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