Optical and electrical properties of phase change materials for high-speed optoelectronics

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Abstract: By doping $Ge_2Sb_2Te_5$ phase change material with tungsten, we produce material with improved electrical properties while simultaneously maintaining the optical contrast necessary for light modulation and switching.

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Spatial light modulation is a critical component of modern free-space optical devices for communications [1] and beam steering, LIDAR [2], and others. Currently, most of the work relies on Liquid Crystal on-Silicon (LCoS) or micromechanical adaptive mirrors (MEMS) for achieving the necessary control of light. These two techniques, while viable, generally rely on non-scalable fabrication techniques and suffer from limited reconfiguration speeds due to the nature of the underlying mechanism of light control. Phase-change materials (PCMs), such as germanium-antimony-tellurium (GST) offer an alternate path for high-speed light modulation [3]. PCMs generally alter their optical constants via an electronic, optical, or thermal stimulus, leading to a phase transition between a low-index amorphous state (index = 4.0) and a high-index crystalline state (index = 5.5). For spatial light modulators, the core idea (Fig. 1) is to implement an electrically actuated device where the refractive index of each individual pixels can be independently addressed as to affect a 0-π phase control on the incoming wavefront. Unfortunately, due to the high-impedance nature of the amorphous state coupled with the high contact resistance with metallic electrodes, electrical actuation a) is relatively slow and b) cannot rely on off-the-shelf radio-frequency (RF) components due to the incompatibility with standard 50Ω termination.

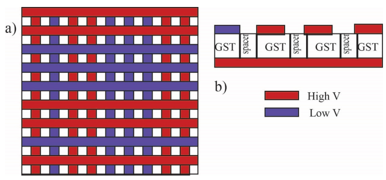

Fig. 1. Sample spatial-light modulator based on GST

Here, we show that it is possible, through doping the underlying GST thin film with tungsten, to simultaneously improve the electrical properties of GST while maintaining the necessary optical contrast for efficient light modulation devices. The idea is similar to the standard doping methods for silicon that reduce its resistivity by orders of magnitude by generating excess holes or electrons in the material. We choose tungsten (W) as the alloy material since a) we expect a transition metal to improve the conductivity and consequently reduce the resistance, b) it can be used as an effective electrode for actuating the pixels, and c) it has a close atomic radius to tellurium and can act as a substitutional active dopant. GST thin films are fabricated via magnetron sputtering with an independent cathode for co-sputtering tungsten into the film allowing for independent control over the percentage of tungsten introduced into the GST alloy. Once the W-doped GST film is deposited with varying doping percentages (~ 2 to $\sim 18\%$ [4], the electrical resistivity is measured using a four-point probe technique as a function of temperature/phase (amorphous vs crystalline). Figure 2 shows that for pure GST, phase transition (near 160 ^{o}C) is coupled with a large drop in resistivity, while, as tungsten is introduced, the electrical contrast between the two states is decreased, leading to a relatively low resistance value both in the amorphous and crystalline states of GST, as desired. The inset in Fig. 2 shows that even at the highest tungsten concentration, there is a strong transmission

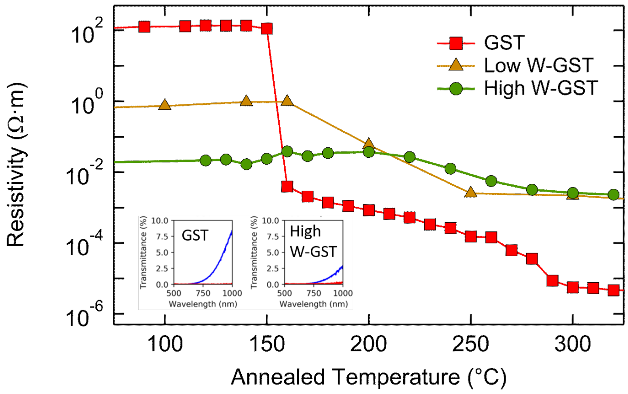

Fig. 2. Resistivity vs temperature for various W-GST alloys. Inset shows the maintenance of strong transmission contrast between the two states, indicating the preservation of the optical contrast even for very high tungsten doping leading to matched impedance in the amorphous/crystalline states.

contrast between the amorphous (blue) and crystalline (red) states for a wide range of wavelengths, indicating the preservation of the desirable optical properties of GST.

Critically, as Fig. 3 shows, the contact resistance, R_C, between W-GST and W contact electrodes - generally the true bottleneck in electrical actuation of PCMs - drops dramatically as tungsten is added to the alloy. Transmission line measurements (TLM), a technique used to extract contact resistance by measuring total resistance between contacts separated by varied distances reveal R_C drops by nearly 5 orders of magnitude.

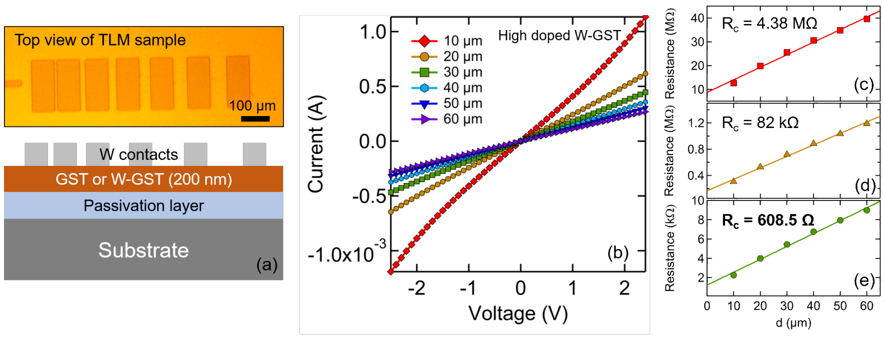

Fig. 3. (a) TLM structure for measuring contact resistance, (b) current vs voltage showing Ohmic contacts between tungsten-doped GST and tungsten electrodes (c-e) resistance vs electrode separation showing the dramatic reduction in contact resistance down to the few hundred Ω range.

This represents two major breakthroughs for using GST in optoelectronic applications: a) It will be relatively easy to impedance match GST-based pixels to high-speed electronic drivers, and b) the reconfiguration speed will increase significantly as the current passing through the GST pixel no longer needs to break through a very large impedance to achieve the phase transition. It is expected that this work will lead to high-speed electronically tunable spatial light modulators based on highly optimized GST-based phase-change materials.

References

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