Characterization of Phase Change Materials for Radio Frequency Applications

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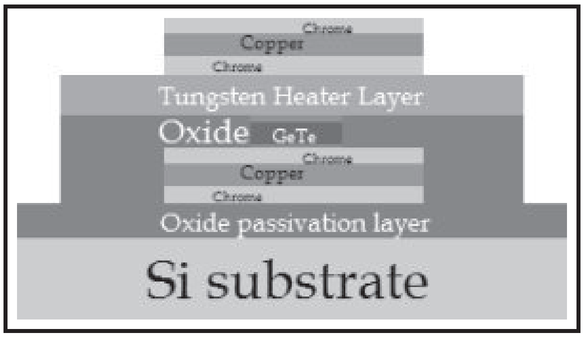

Figure 1: Cross-sectional schematic of device structure.

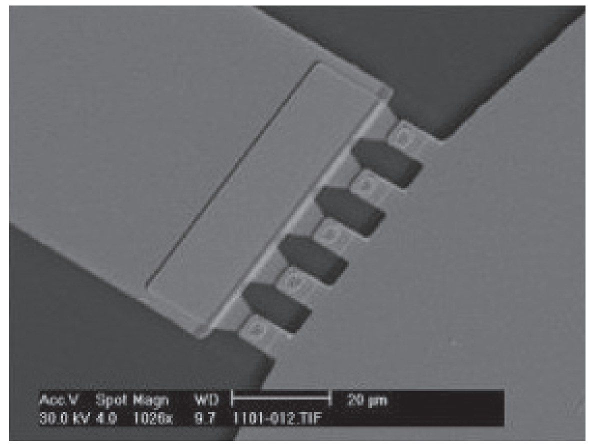

Figure 2: SEM image of a device with five 2 × 2 µm² vias.

Abstract:

Phase change materials are a class of compounds that can alter states between crystalline and amorphous when specific heating conditions are applied to them. Due to fast switching speed, long life cycles, and potential for high-density integration, these materials are currently being investigated for use in non-volatile memory applications [1, 2]. The focus of this project was to characterize a specific phase change material, $Ge_{50}Te_{50}$, to determine its possible capabilities for radio frequency (RF) applications. This material was chosen for use in RF switches due to its low crystalline state resistance and a high OFF/ON resistance ratio. The method of characterization was to fabricate simple ohmic switches and then apply voltages or currents with different pulse shapes and durations in order to obtain the phase transitions. The goals of this project were to optimize the switch design and fabrication method to achieve a low ON resistance and high OFF/ON resistance ratio, and to optimize the biasing conditions to obtain repeatable and reliable phase transitions. An extension of the project was investigating the effects of direct heating versus indirect heating. If the switches are successful, this material can be incorporated to design more advanced passive elements such as filters, phase shifters, and antennas.

Introduction:

Previous work has been reported on the use of phase change materials from GeSbTe (GST) compounds in non-volatile memory applications. There has been a recent report on the application of $Ge_{50}Te_{50}$ in switchable inductors [3].

The larger scope of this project included characterizing the $Ge_{50}Te_{50}$ material using simple ohmic switches, then moving on to the characterization of more complicated designs, such as filters, to determine the overall use of the material in radio frequency applications.

The goals of this internship were to develop fabrication processes for implementing phase change switches (aka phase change vias). Materials in the stack were deliberately chosen, the specific thickness for the different layers was determined, and the etch times and recipes were optimized through fabrication of several test wafers and characterization steps. Once the optimal design was determined, the devices were fabricated and direct heating measurement techniques were employed to transition the vias.

Experimental Procedure:

The switches were fabricated on silicon wafers. All liftoff molds and etch guides were created using photolithography. In order to isolate the devices from the silicon, wafers were passivated with a 2 μm thick silicon dioxide layer deposited by plasma-enhanced chemical vapor deposition (PECVD). Then the bottom electrode was deposited in an evaporator. The bottom electrode consisted of three layers, 300 Å NiCr, 5000 Å Cu, and 300 Å NiCr. After liftoff, 3000 Å of oxide was deposited using PECVD, and then etched to form an insulation layer on top of the tips of the electrodes, with a via directly over the electrode. The 100 nm $Ge_{50}Te_{50}$ layer, with 50 Å Ti adhesion layer and 100 Å Ti overcoat layer, was deposited on this via by sputtering. $Ge_{50}Te_{50}$ liftoff was completed, and then a heater layer of 2500 Å of W was deposited using sputtering. Liftoff of the heater layer was completed, and then the top electrode was deposited. The top electrode also consisted of three layers, 200 Å NiCr, 3000 Å Cu, and 200 Å NiCr. After liftoff of the top electrode, the devices were complete.

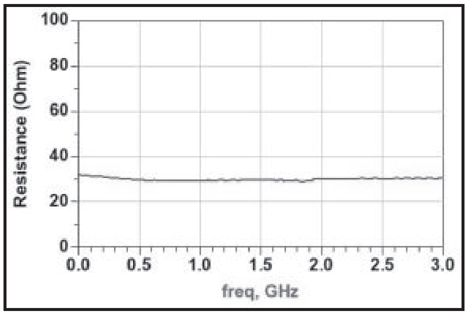

Figure 3: Crystalline resistance of the device shown in Figure 2.

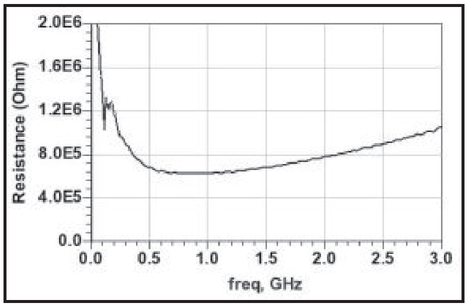

Figure 4: Amorphous resistance of the device shown in Figure 2.

Characterization results reported here were obtained using phase change vias with a tungsten layer in the stack, as discussed earlier. Repeatable phase transitions were obtained. The crystallization pulse was 200 μs with a rise and fall time of 200 μs, and amplitude of 1 V. The crystalline resistance was 100-300 Ω; however, the resistance of the electrodes alone was measured to be around 75 Ω, yielding an ON resistance of ~30 Ω for the phase change layer (see Figure 3). The pulse to amorphize was 2 μs with a rise and fall time of 5 ns and amplitude of 2.5 V. However, the amorphization was easily obtained with several different pulses of different durations with amplitudes of 1.5 V or higher. The amorphous resistance was 800 kΩ -1 MΩ (see Figure 4).

While this OFF resistance is higher than previous work [1], and the OFF/ON resistance ratio is between 10^4 and 10^5, the ON resistance could still be improved upon.

Given these results, $Ge_{50}Te_{50}$ has good potential for use in RF applications.

Future Work:

While basic characterization of the material was completed during this internship, there remain many variations to be explored.

Further investigation could be conducted into the effect of various sputter pressures and powers on the $Ge_{50}Te_{50}$ material. Different thicknesses of $Ge_{50}Te_{50}$ for the via could have effects on the phase change conditions and should be further characterized. Also, the variations between direct and indirect heating should be examined.

This summer research has shown that $Ge_{50}Te_{50}$ is a promising candidate for RF switching applications and can be used in tunable inductors, capacitors, and advanced devices such as antennas, phase shifters, and filters.

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[2] Ryu, Sang-ouk, "Characterization of $Ge_{22}Sb_{22}Te_{56}$ and Sb-Excess $Ge_{15}Sb_{47}Te_{38}$ Chalcogenide Thin Films for Phase-Change Memory Applications," J. of Electronic Materials, Volume 37, No. 4 (2008).

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