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Brent L. Danner
Air Force Institute of Technology

Ronald A. Coutu Jr.
Marquette University, ronald.coutu@marquette.edu

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Characterizing Metal-Insulator-Transition (MIT) Phase Change Materials (PCM) for RF and DC Micro-switching Elements

Brent L. Danner and Ronald A. Coutu, Jr.*

Air Force Institute of Technology (AFIT), 2950 Hobson Way, Wright-Patterson AFB, OH 45433, USA

Abstract

Metal-insulator transition (MIT) phase-change materials (PCM) are material compounds that have the ability to be either conductors or insulators depending on external stimuli. A micromachined test structure for applying external electric fields across MIT wire segments was designed and fabricated. Using this novel test structure, Germanium Telluride (GeTe) and Vanadium Oxide (VO_x) were successfully transitioned from a conductor to an insulator. The resistivity of the GeTe wire segments increased three to five orders of magnitude with ~40V applied to the parallel plates of the test structure. The VO_x wires exhibited an order of magnitude transition in resistivity with ~20V applied. Characterization of both RF and DC switching performance of these MIT wire segments was completed and GeTe and VO_x appear to be viable materials for micro-switching.

Keywords: Metal Insulator Transition Materials (MIT), Phase Change Materials (PCM), Germanium Telluride (GeTe), Vanadium Oxide (VO_x)

1. Introduction

The ability to control the flow of current in a wire without using a mechanical component provides the possibility for more robust switching capability. This paper reports the significant change in resistivity of GeTe and VO_x in the presence of external stimuli. In an ambient environment VO_2 is an insulator with a

* Corresponding author. Tel.: 1-937-255-3636 ext 7230
E-mail address:Ronald.coutu@afit.edu

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monoclinic crystalline phase [1]. When thermally or electrically activated, it becomes a conductor with a tetragonal crystalline phase [1]. This transition can be used to control the flow of current through different wire segments, acting as a micro-switch. Bouyge *et al.* began using VO_2 in reconfigurable microwave systems and were able to create a variable resistivity of three to five orders of magnitude using an electric field across the VO_2 wire segment [2]. The conditions under which GeTe is deposited have a significant role in its switching ability. Polycrystalline GeTe is naturally a conductor, but resistivity of the film increases when an external stimulus is applied [3]. When deposited as an amorphous film, GeTe can be transitioned from an insulator to a conductor using thermal stimulus.

2. Design

A micromachined test structure was designed to test the varying resistivity of MIT materials in the presence of an electric field. In order to transition the material, parallel wire segments were placed on each side of the MIT wire. By placing a bias across the parallel segments, an electric field can be generated across the material. The first order magnitude of these electric fields was calculated using

$$E = \frac{V}{D}, \tag{1}$$

where V is the voltage applied across the parallel wires and D is the distance between the plates. DC test structures, shown in Figure 1, were created with 80 µm and 100 µm gaps between the wires. Using a digital multimeter, the resistance across the MIT wire was measured while varying the electric field strength. The measured resistance is then used to calculate the resistivity of the wire segment using

$$R = \frac{\rho L}{A}, \tag{2}$$

where R is the resistance, L is the length of the MIT wire, A is the cross-sectional area of the wire, and ρ is the resistivity of the material. By measuring the resistance while varying the voltage applied to the parallel plates, the transition of the MIT material was observed. While an electric field across any material will have some impact on the resistivity, the drastic variance in the resistivity that MIT materials exhibit makes them unique.

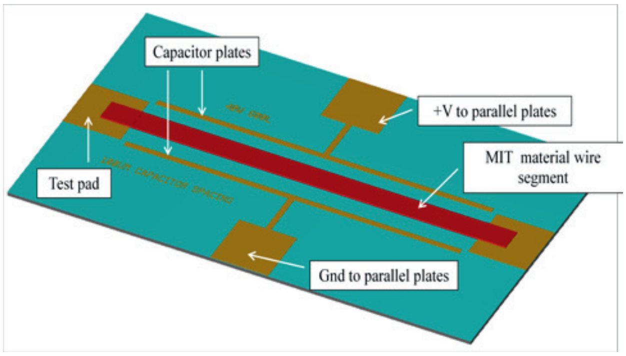


Figure 1. Test structure design for MIT materials.

3. Fabrication

A series of test structures were designed and fabricated in order to measure the changing resistivity across MIT materials in the presence of external stimuli. Samples were prepared on the native oxide of Si substrates. The VO_x devices were created using RF sputtering to deposit 200 nm of vanadium (V). The samples were then patterned using liftoff and placed in the O_2 plasma asher to be oxidized. In order to make baseline resistance measurements, several samples were fabricated with pure vanadium. Gold test pads were then evaporated on top of the MIT wires for testing purposes. Samples were fabricated in a similar manner to measure the varying resistivity of GeTe wire segments. Figure 2 shows a finished test structure with a GeTe wire segment between the gold parallel plate capacitor.

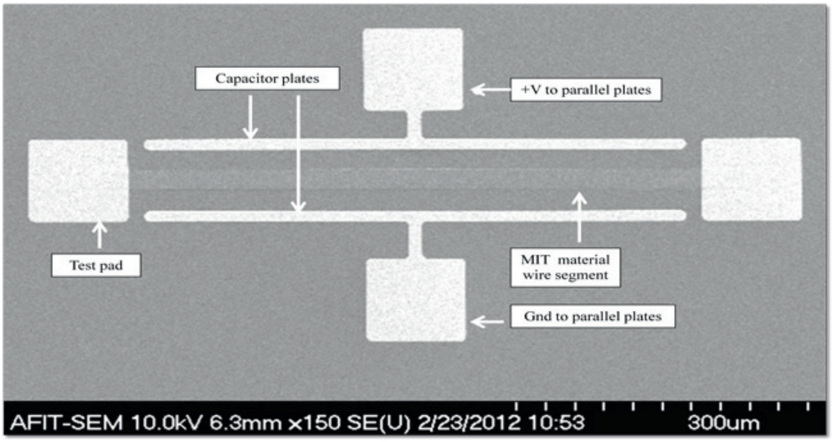
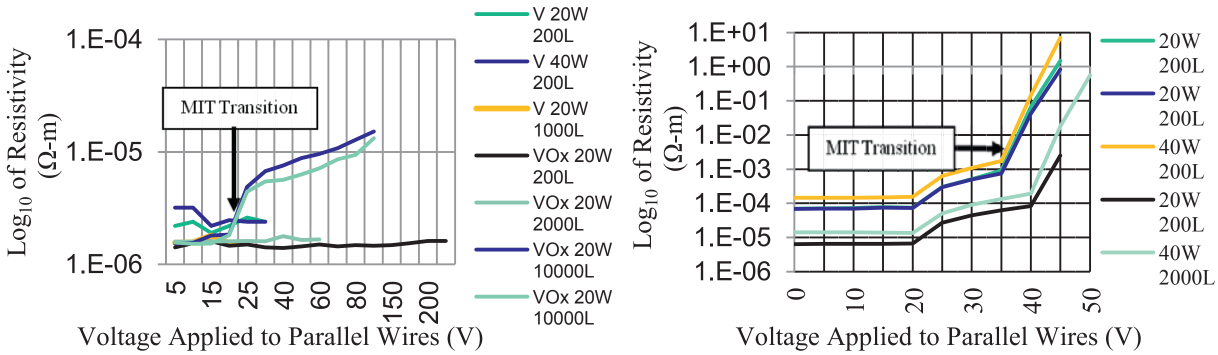


Figure 2. Scanning electron microscope (SEM) image of a MIT test structure with a GeTe wire segment.

4. Testing

The DC testing was done by probing the gold test pads at the ends of the MIT wire segment and measuring the resistance across it. While measuring the resistance, the voltage across the parallel wires was slowly increased, creating a stronger electric field across the material. The VO_x wire segments were tested using voltages on the parallel wires from 0 to 200 V. The shorter wires saw minimal changes in their resistivity that closely mirrored that of the baseline vanadium samples. This is attributed to only the surface of the wire being oxidized to a transition phase of vanadium oxide in the plasma asher. Therefore, in the presence of the electric field stimulus, only a small fraction of the material went through the metal insulator transition. The resistivity across the 10,000 µm VO_x wire segments increased an order of magnitude when a 20 V bias was applied across the parallel wires. The large length of the wire

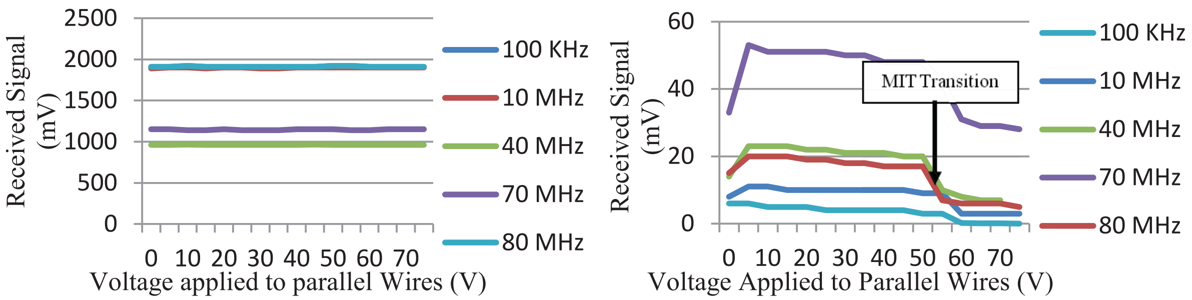


(a) (b)

Figure 3. Resistivity change in the presence of an electric field, (a) V and VO_x, (b) GeTe.

allowed for a greater area to be oxidized therefore creating more VO_x in a transition phase. Figure 3 shows the transition in the V, VO_x, and GeTe wire segments. The GeTe wire segments were successfully transitioned from a conductor to an insulator. In various wire lengths and widths, three to five orders of magnitude increase in resistivity was achieved in the presence of an electric field. Figure 3b shows the transition occurring when 37 V to 45 V are applied to the parallel wires. When the electric field stimulus was removed, the material transitioned back to its initial state. This quick transition between states is necessary in order to use MIT materials as micro-switching components.

RF testing was done by placing a waveform generator on one end of the wire segment and a spectrum analyzer on the receiving end of the wire. Different frequencies were tested while biasing an electric field across the MIT material. A significant transition in the received power across the wire was seen in the GeTe samples when 55 V were applied to the parallel wires. At certain frequencies, the electric field nearly eliminated the signal through the MIT material. The VO_x samples saw no change in received power at any frequencies, as shown in Figure 4a.



(a) (b)

Figure 4. The RF signal sampled across the MIT wire segment in the presence of an electric field, (a) VO_x, (b) GeTe.

5. Conclusion

In this paper we presented the initial results of our experimental testing to characterize the transitional ability of GeTe and VO_x. The GeTe samples were successfully transitioned during both RF and DC tests. From our results, GeTe presents the characteristics necessary to serve as a micro-switching component. Further testing using the micro fabricated test structures will be done on other phases of VO_x, as well other MIT materials.

Acknowledgements

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