Electrical Controlled broadband Terahertz switch based on Vanadium Dioxide film

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***Abstract*—We propose and demonstrate an electrically controlled terahertz switch based on vanadium dioxide film. The switching mechanism is realized by triggering the insulator-metal transition of the film using bias electric fields. In our design, the switch is a two-terminal planar device driven by electrical field via interdigital electrode pairs. Experimental results show that the proposed device can act as a terahertz switch with a broad bandwidth and a high extinction ratio.**

I. INTRODUCTION

VANADIUM dioxide (VO_2) is an interesting electron material that exhibits a reversible metal-insulator phase transition (MIT) when it is triggered thermally, optically and Electrically.[1] Associated with this transition are a change of conductivity by several orders of magnitude, and significant changes of the optical properties at all wavelengths. VO_2 film plays an especially important role in the technologically relevant terahertz (THz) frequency regime because many materials inherently do not respond to THz radiation. VO_2 films, separately or integrated with resonant element (e.g. metamateirals), have already been used to switch and modulate THz wave.[2] However, almost all existed VO_2 based THz devices are thermally or optically controlled, which is incompatible with modern high-speed electronic systems.

In present work, we proposed and demonstrated an electrical controlled THz switch based on VO_2 film. The switch is a two-terminal device consists of 200nm VO_2 film on high-resistive silicon substrate and interdigital electrode pairs (IDE). It was found that by applying a relative low external electric field via the IDE, large modulation depth and broad bandwidth properties were simultaneously achieved. This new kind of switch is a potential tool for THz imaging, computing and telecommunication.

II. RESULTS

The THz switch was fabricated on a 0.47mm silicon substrate, which has a resistance more than 2000 Ω/cm thus is highly transparence to THz wave. A 200nm VO_2 film, followed by a 150nm Au film, was deposited on top of the Si by sputtering method. The Au film was then patterned by a conventional lift-off process to form the interdigital electrode pairs. All electrodes have an identical line width of 6μm and their separated from each other by a distance of 6μm, as indicated in Fig.1. By heating the VO_2 film to about 333K, a thermal MIT was clearly observed with a thermal hysteresis width (ΔH) of 8K and a huge resistivity drop about three orders in the amplitude. Due to the large crystal lattice mismatch and the formation of silicides or native oxide layers between VO_2 film and silicon substrate[3, 4], the properties of directly grown VO_2 is not optimal as compared with those fabricated with buffer layers[5, 6].

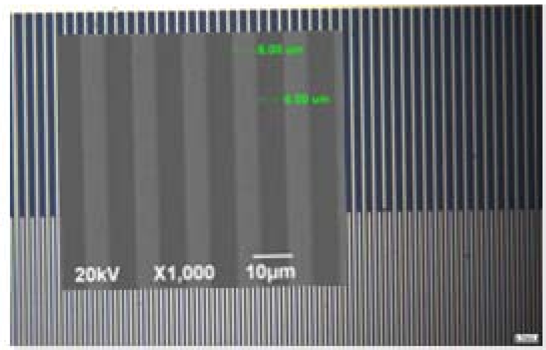

Fig.1 SEM image of the fabricated THz switch

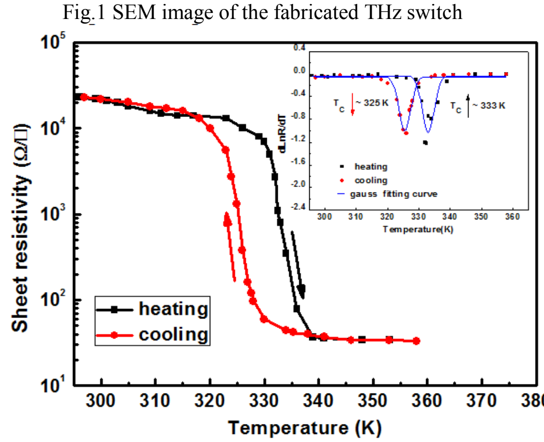

Fig.2 Resistivity versus temperature curves for VO2 thin film grown directly on Si. Inset is the Gaussian fitting of the differential curves of resistivity versus temperature.

To identify the thermal and electrical induced phase transition, another device with only a pair of electrodes on VO_2 film was prepared; we call it device-B thereafter. The two electrodes of devices-B is 1 mm wide and separated by a distance of 10μm. The I-V curves of device-B were measured under different temperature, as plotted in Fig.2. It is interesting to see that both thermal and electrical driven MIT were observed. At zero voltage, the current jump was observed at 333K, which is unambiguously a thermal triggered transition. At room temperature (~295K), an abrupt current jumps is also observed in the I-V curves when the bias voltage reaches a threshold value of 5.2V, indicating the occurrence of the electrical MIT of VO_2 films [6, 7]. When heating the device to 313K, the threshold value decreases to about 3.5V. Beyond 333K, no electrical MIT occurred since under that temperature the VO_2 has already metalized.

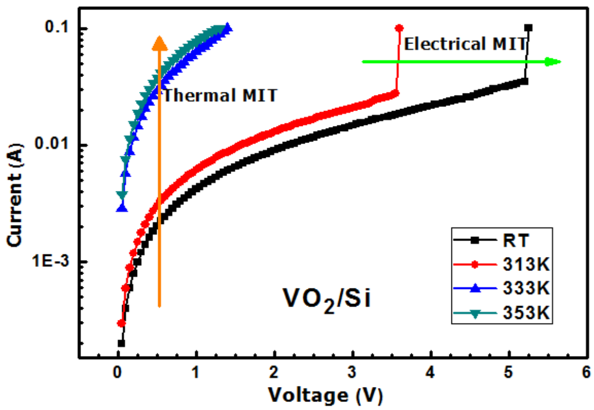

Fig.3 Current-Voltage (I-V) curves of device-B measured under different temperature.

As to the THz switch shown in Fig.1, a THz time domain spectroscopy (TDS) system was used to characterize the switching properties of the device by sweeping the voltage from 0 to 4 V. Fig. 4 shows the time trances for transmitted THz waves with respect to the applied voltage. When the voltage increases to 1.6V the THz transmission of the device begin to decrease. A sudden drop of the transmission was observed at a voltage of 2V, indicating an electrical driven MIT. As compared with device-B, the THz switch has a smaller threshold value due to the smaller space between the electrodes. The voltage dependence of the peak amplitude of the THz transmission indicates a high extinction ratio of 11dB. This switch is a broadband device which works from 0.2 to 2THz.

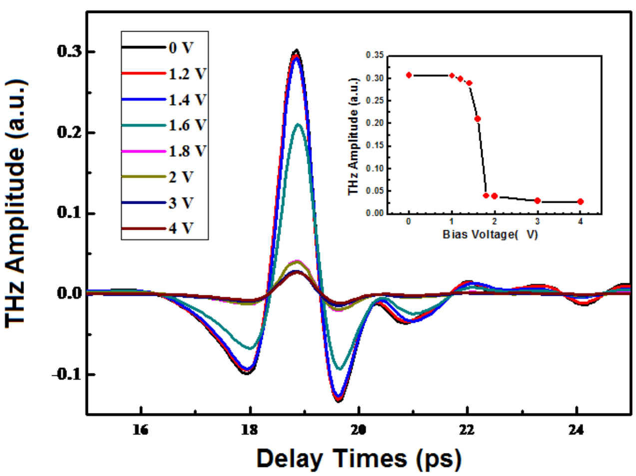

Fig.4. Time domain data for the switch at different applied voltages. Inset is the voltage dependence of the peak amplitude of the THz transmission.

The switch speed of device was measured at 340GHz carrier. In the measurement, a square-wave voltage altering between 0 to 4V was used to drive the switch and the modulated THz signal was detected by a VDI zero-bias Schottky diode intensity detector. The details of the set-up were described in our previous work [8]. The results indicated a 3dB operation bandwidth (fc) is ~20 kHz.

III. Summary

In present work we demonstrate an electrical driven THz switch based on VO_2 film, which is a broadband device works in the frequency range from 0.2-2THz and has a high extinction ratio of 11dB. This switch is vital for many applications in THz electronic systems.

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