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Resistive Switching in V_2O_3 Thin Films Induced by Current Sweeps and Voltage Pulses

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Abstract
We report electrical properties of V_2O_3 microbridges at temperatures close to the metal-insulator transition. A volatile resistance switching is evident as a sudden jump in the resistance of the device when continuously sweeping the current. A much less pronounced non-volatile resistance change towards the metallic state is observed after the current sweep is performed. In the case of the non-volatile change the resistance of the insulating state can only be recovered by thermal cycling. Similar results are obtained when applying voltage pulses.

1. Introduction

The metal-insulator transition (MIT) in transition metal oxides has been the subject of numerous research works in the field of condensed matter physics. Besides the interest due to the intriguing behavior due to electron correlations, much attention has been given to these materials due to their potential for novel electronic applications such as memory devices and field effect transistors among others. In V_2O_3 the first order transition from insulator to metal when increasing the temperature above 150K is accompanied by a structural and a magnetic phase transition [1]. Although the transition temperature of V_2O_3 is too low to be appropriate for applications, it can still be used as a model system to study the MIT.

The MIT can also be triggered by magnetic or electric field, light and strain [2]. From the applications point of view, the electrical triggering is one of the most desirable. However, for many materials it has been suggested that the MIT induced by electric field is not a pure electronic effect, but rather a result of Joule heating or movement of oxygen vacancies [3-5]. In ref. [3], low temperature scanning electron microscopy indicates that the formation of electro-thermal domains causes the electrical breakdown of V_2O_3 microbridges.

To investigate the influence of Joule heating on the MIT in V_2O_3 microbridges triggered by an electric field, electrical measurements were performed using both DC and pulsed voltage methods. In both cases, a volatile and a non-volatile resistance switch can be induced.

2. Experimental

A 35 nm thick film of V_2O_3 was grown on a 2" Al_2O_3 wafer using molecular beam epitaxy (MBE). Vanadium was evaporated using an electron-gun while molecular oxygen was introduced in the MBE chamber during the deposition. X-Ray Diffraction confirms the good crystalline quality of the film and Atomic Force Microscopy measurements shows a surface roughness of ~1nm.

V_2O_3 bridges of micrometer size (microbridges) with Au electrodes were fabricated using a combination of photolithographic process, lift-off and reactive ion etching. Microbridges with different lengths (l) and widths (w) were fabricated, ranging from 200 μm to 1 μm for each dimension (see inset of Fig. 1). Electrical measurements at different temperatures were performed using a cryogenic probe station.

3. Results and discussion

All fabricated microbridges show a MIT at T~170 K evident as a change of around two orders of magnitude in resistance (measured by the 4-point method) and a hysteresis between cooling and warming curves (see Fig. 1). No clear relation between the transition temperature and the size of the microbridges is observed.

Voltage-current (VI) characteristics were measured at fixed temperatures across the MIT for all microbridges. As an example, the VI curves for a microbridge of 100x1 μm^2 (wxl) at temperatures between 120 K and 200 K are shown in Fig.

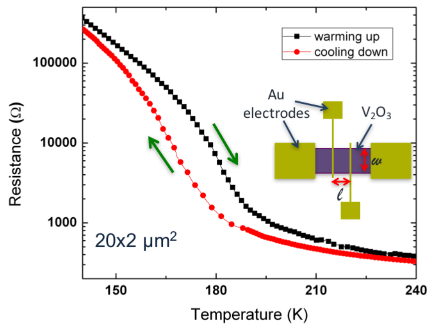

Fig. 1 Resistance vs temperature of a 20x2 μm^2 microbridge.

2. At intermediate temperatures (~145K to ~165 K) the VIs show a sudden change in voltage and a large hysteresis between increasing and decreasing current sweeps. This change from a high to a low resistance value is volatile since the voltage (and therefore the resistance) goes back to the starting value when the current is decreased. The volatile resistance change, $\Delta R_{volatile}$, is defined as the ratio between the high and low resistance values (R=V/I). This volatile resistance switching have been associated with the electro-thermal breakdown of the devices. At higher temperatures, the hysteresis persists although the voltage changes smoothly with current (see Fig. 2(b)). These different regimes in the VIs have been observed in the devices with w ranging from 200 μm to 10 μm and with l = 1 μm and 2 μm. The absence of the intermediate temperature regime in devices longer than 2 μm is related with the fact that in those cases the electric field (and

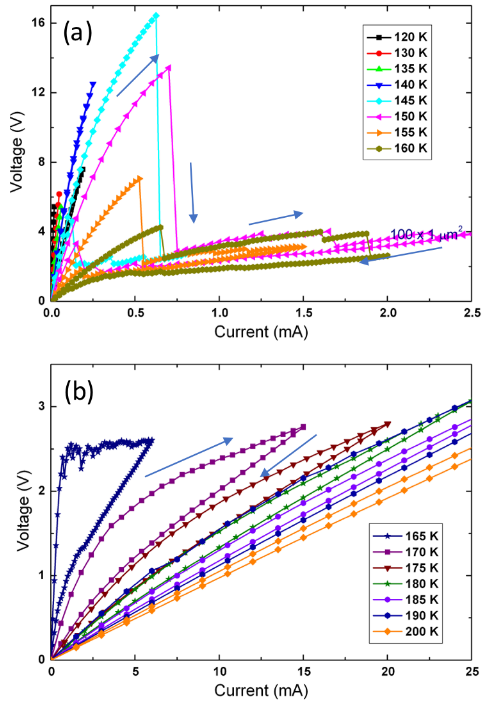

Fig. 2 Resistance switching of a 100x1μm^2 bridge induced by current sweep: Voltage vs current at different temperatures. The arrows indicate the direction of current sweep.

therefore the Joule heating) is not sufficiently large to induce the resistance switch.

In the high temperature regime where the VIs are continuous but hysteretic, there is a gradual change in behaviour as the temperature is changed. Remarkably, at T = 165K the voltage remains nearly constant for currents above ~1mA for the increasing-current curve. This is in agreement with the predictions of the theoretical model presented in [3].

Besides the volatile resistance switch, a non-volatile change is also observed at the measurement temperature, T_M, as described below. The 4-point resistance of the microbridge decreases after a current sweep has been performed. However, this low resistance state can only be switched back to the original value by performing a thermal cycling (i.e. the temperature is decreased until the device is in the insulating state and then increased back to T_M). The non-volatile change is measured as the resistance ratio before and after the current sweep, R_{before}/R_{after}. Ratios between 1.5 and 3.1 are observed depending on T_M and the dimensions of the microbridges. This non-volatile resistance switch is caused by the heating induced during the current sweep. The change in temperature induced by the current sweep performed at 145 K in the 100x1 μm^2 microbridge is estimated to be of around 15K.

Similar resistance switching behaviour has been observed when applying a voltage pulse instead of applying current sweeps as described above. In Fig. 3 the volatile resistance switching of a device of 100x1 μm^2 is shown. In this case, the applied voltage pulse has a magnitude of 11V, a duration of 2 µs and a rise time of 2 µs.

In Table I we summarize the resulting R_{before}/R_{after} and $\Delta R_{volatile}$ for different voltage pulse durations and compared with the results from current sweeps for a 20x1 μm^2 microbridge.

Table I Resistance changes in the 20x1 μm^2 microbridge at 160K

Control parameter	Pulse width	R_{before}/R_{after}	$\Delta R_{volatile}$
I sweep	-	1.60	3.54
Voltage pulse	2 µs	2.77	9.44
	1 µs	3.98	9.69
	500 ns	2.70	21.4
	100 ns	2.47	28.4
	60 ns	2.68	29.1
	20 ns	1.88	111

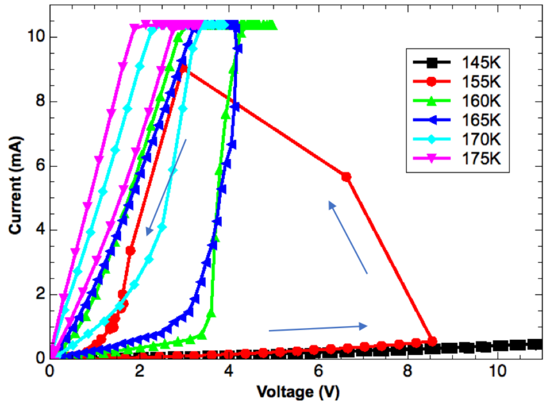

Fig. 3 Resistance switching of a 100x1μm^2 bridge induced by a voltage pulse: Current vs voltage at fixed temperatures between 145K and 175K

4. Conclusions

Volatile and non-volatile resistance switching has been observed in microbridges of V_2O_3. In both cases, the results indicate that the main mechanism for the observed resistive switching is dominated by Joule heating in agreement with literature. Larger volatile resistance changes have been observed when using voltage pulses indicating that this protocol can be more effective for memory applications.

Acknowledgements

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