Vanadium Dioxide for Selector Applications

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Vanadium dioxide is likely the most studied material showing a metal to insulator transition (MIT). At the transition temperature (T_C), the resistivity of the VO_2 changes abruptly by up to 4 orders of magnitude. At the same temperature, a structural transition takes place and the material changes from a low temperature monoclinic structure to a high temperature rutile phase. We are assessing how VO_2 and the abrupt change in resistivity can be used in two-terminal devices for selector applications.

Selectors serve the role of limiting the leakage current through unaddressed memory cells in non-volatile memory arrays. They are considered to be the largest hurdle for the introduction of multilayer high-density memory arrays. Because of space limitations, the selectors have to be two-terminal devices and diodes are the devices most studied for this application [1]. Selectors have to provide large current density ~10^6A/cm^2 and high endurance to cycling. Moreover, in order to enable increasing the number of memory cells in an array, the selectors need to show large on/off current ratios.

We describe here two types of selector devices with VO_2. One type uses the metal to insulator transition which in two terminal devices can be induced by Joule heating. The second type of devices described is oxide diodes with VO_2 and TiO_2. While there are many n doped semiconducting oxides (TiO_2 is one such example), there are very few oxides which are p type. VO_2 has been reported to be either p or n doped depending on the material deposition conditions. VO_2 has also been reported to have a high electron affinity/work function (~5.2eV) [2] and relatively high conductivity, which could contribute to the rectifying behavior.

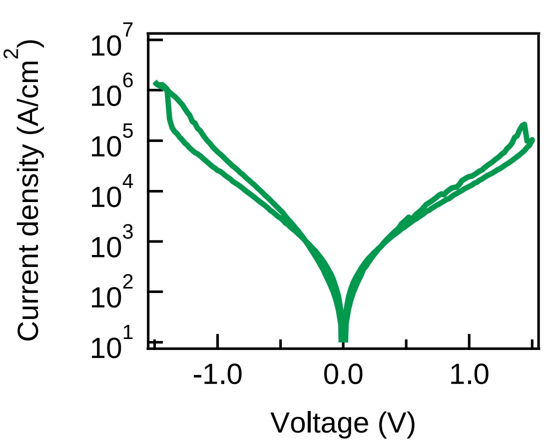

Fig.1: Current density vs voltage bias in a 60×60nm^2 device with 8nm VO_2 between TiN electrodes.

We fabricate and investigate two terminal devices in a cross-bar geometry with a patterned and planarized TiN bottom electrode. On the bottom electrode either VO_2 [3] or VO_2 and TiO_2 [4] are deposited via the atomic layer deposition (ALD) method. The as deposited VO_2 is amorphous and a crystallization anneal is performed. The top electrode, patterned via dry etching, is also made of TiN. The devices have been fabricated on 300mm wafers in the imec CMOS cleanroom. The devices vary in size between 40×40nm^2 and 10×10µm^2.

Devices with only VO_2 show a current density higher than 10^6A/cm^2 at 1.5V and nearly symmetric I-V characteristics (Fig. 1). Volatile switching is observed and is consistent with a Joule heating induced MIT. The onset of the MIT contributes to increasing the on/off current ratio, which is about 200 when estimated at 1.5 vs. 0.8V. Pulsed measurements show device turn-on time shorter than 10ns.

Devices with VO_2 and TiO_2 show rectifying behavior (Fig. 2) and a relatively high current density of ~10^5A/cm^2 in forward bias. The diode ideality factor is lower than 2.3, better than all other oxide diodes reported until now. Even though the VO_2 likely undergoes an MIT when the ambient temperature surpasses the transition temperature, the rectifying behavior is still present, suggesting that the large work function of VO_2 plays a large role in the observed asymmetric I-V characteristic.

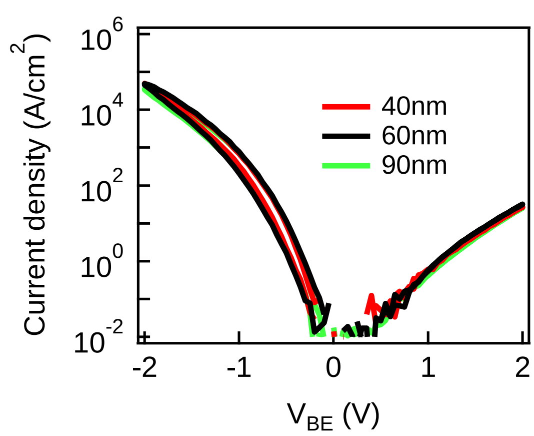

Fig. 2: Current density vs. voltage bias in 40×40nm^2, 60×60nm^2 and 90×90nm^2 diodes with 8nm VO_2 and 4nm TiO_2 and TiN electrodes. The devices show rectification.

The oxide diodes have response times faster than 10ns and endurance better that 10^9 cycles. The high stability of the diodes is also confirmed in constant voltage stress measurements. To our knowledge, this is the best endurance observed in oxide diodes.

In addition to device characteristics we will discuss how material properties need to be further tuned to fulfill the requirements for selectors.

The fast response time, high endurance and high current density make the VO_2 two-terminal devices very promising for selector applications.

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