VANADIUM DIOXIDE

ABSTRACT

Vanadium dioxide (VO_2) is a transition metal oxide recently used in plasmonics, metamaterials, and reconfigurable photonics. It shows a great change in its electrical and optical properties when is under the effect of an external stimuli allowing for ultra-compact devices with low power consumption.

Silicon (Si) provides the most promising platform for photonic integration, ensuring CMOS (Complementary Metal Oxide Semiconductor) fabrication compatibility and making possible the mass production of cost-effective devices. During the last decades, photonic technology based on the Silicon on Insulator (SOI) platform has shown a great evolution, developing different sorts of high performance optical devices. Nevertheless, Si is reaching its performance limits due to the constant enhancement of the device requirements. Therefore, the limitations of Si motivate a search for new materials to make hybrid structures mixing the properties of the Si with the properties of the incorporated materials.

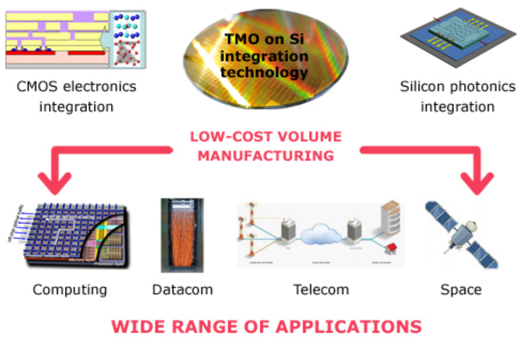

Fig. 1. The combination of TMOs with the Silicon platform mix the characteristics of both technologies allowing for new applications in a wide range of fields. Silicon platform ensures CMOS compatibility and low cost volume manufacturing while the TMOs provide tunability in its electrical and optical properties.

In this way, the hybrid technology can overcome the limits of the Si technology and develop new devices trying to exceed the performance metrics of its counterparts electronic devices. Hence, hybrid technology compatible with CMOS fabrication techniques might be the best option for producing high-performance devices. It will provide a broadband performance, faster operating speed and energy efficient optical response with wavelength-scale device dimensions. Materials like germanium and graphene have been widely integrated in the SOI platform and recently certain transition metal oxides (TMOs) are under study. TMOs have attracted a considerable interest in different fields like matter physics, chemistry and several fields of engineering due to their unique properties. Due to their electrical capabilities, TMOs have been considered for oxide electronics in different ways; for elements of non-volatile memory, FETs based on materials with semiconductor to metal transition, sensors, devices for signal processing etc. In addition, their integration in the silicon platform makes possible to take advantage of its tunable optical characteristics. Nowadays, several applications in fields like computing, datacom, telecom or space are being developed combining the properties of the TMOs with the Silicon platform and allowing a total CMOS compatibility. Figure 1 shows the wide range of applications for the TMOs on Si technology.

Among these TMOs, vanadium dioxide (VO_2) is one of the most disruptive candidates. It is known as a "smart" material because its optical and electrical properties can be controlled and tuned by an external signal (electric field, focused optical excitation, temperature variation, strain or pressure).

These changes in the properties of the material are because VO_2 has an insulator to metal transition (SMT) which provides a change in resistivity of several orders of magnitude and large changes in the absorption and refractive index. At room temperature, VO_2 is in the insulating phase and has a monoclinic structure with high transparency in the infrared spectrum. After inducing the SMT, VO_2 changes to the metallic state, having a tetragonal structure with absorbing and reflecting properties. Figure 2(a) shows a scheme of the change in the resistance due to the SMT induced in the VO_2 and the crystal structure for both states. The measured refractive index as function of the wavelength for both states is shown in Figure 2(b) for a VO_2 film with a thickness of 65nm.

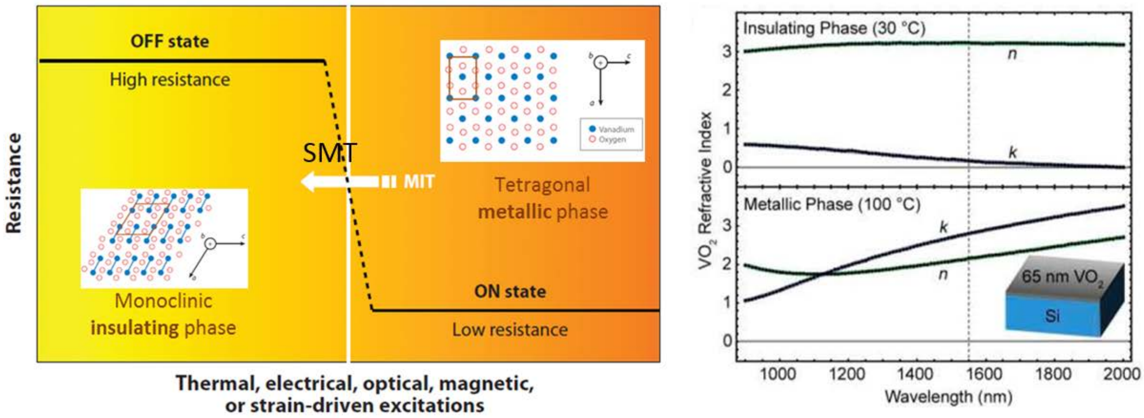

Fig. 2. (a) The SMT changes the VO_2 from the OFF state (insulating state, monoclinic structure and high resistance) to the ON state (metallic state, tetragonal structure and low resistance) [3]. This transition also causes a huge change in the refractive index of the material between its two states. (b) For 1.55µm, the refractive index changes from a value of 3.21+0.17i in the insulating state to a value of 2.15+2.79i in the metallic state [4].

VO_2 is thermodynamically stable and its transition temperature (around 70ºC) is very close to room temperature. Reaching the transition temperature, a change of conductivity around 4-5 orders of magnitude is accomplished. Furthermore, the most substantial optical contrast between the semiconducting and metallic states occurs near 1.5µm, making VO_2 particularly attractive for applications in optical communications. Optical switching at room temperature has also been recently demonstrated [5]. Table 1 summarizes the VO_2 properties at optical wavelengths and the enhanced capabilities offered to the silicon platform.

Material unique properties at 1550nm optical wavelengths	Key enhanced capabilities offered to the silicon platform
• Metal-insulator transition induced thermally, electrically or optically. • Ultra large change of the complex refractive index. • Ultra-fast time response. • Bistable performance via phase transition triggering.	• Ultra small footprint. • Ultra-low power consumption. • Very low insertion losses. • Electro-optical bistable performance for non-volatile photonic devices.

Table. 1. VO_2 has disruptive properties at optical wavelengths which provide enhanced capabilities like ultra-small footprint and ultra-low power consumption to the silicon platform.

These unique properties allow VO_2 films to be used for building high performance components for a broad range of optical applications like modulation, polarization control, switching, filtering, sensing, detection etc. Figure 3 shows some examples of different devices based on the hybrid VO_2-Si technology.

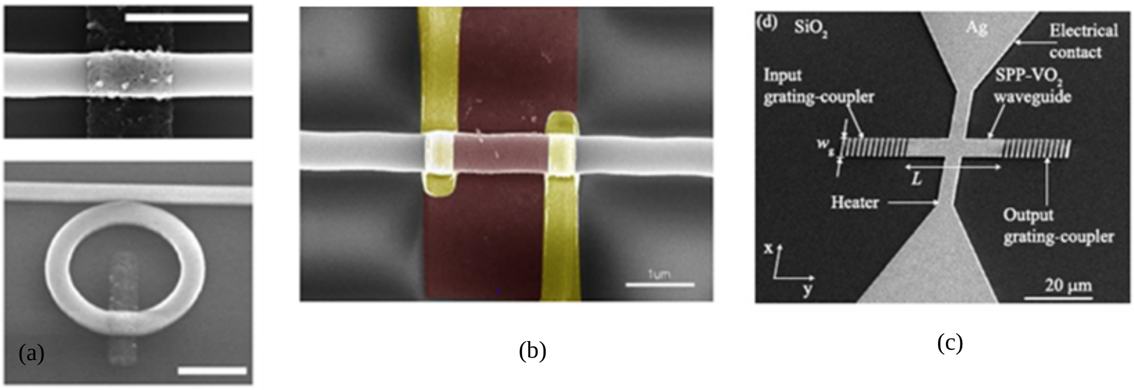

Fig. 3. (a) SEM pictures of an absorber and an electro-optical resonator based on hybrid VO_2-Si technology [6]. (b) Electro-absorption modulator controlled by the SMT of a thin VO_2 film deposited over a silicon waveguide [7]. (c) Ultra compact optical switch based in the combination of plasmonic and VO_2-Si technologies [8].

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