Fabrication of Vanadium Dioxide Resistors on Fully-released Polyimide Thin Films for High Strain Studies

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Vanadium dioxide (VO_2) is a promising material that is well known for its phase change properties, i.e. a reversible insulator-to-metal transition (IMT) near room temperature (more precisely ≈ 68°C) [1]. Across the transition, many of its physical properties undergo an abrupt variation notably its electrical resistance, optical absorption or Young's modulus [2]. The transition of the material between its monoclinic (M1) and rutile (R) phases can be triggered by electrical, thermal or mechanical stimulation [2]. Additionally, vanadium dioxide has been identified for its outstanding gage factor (GF) with authors reporting values from 259 [3] to 534 [4] at a strain level below 0.1%. These results position VO_2 devices as promising candidates for strain sensing with sensitivity beyond silicon (GF ≈120) [5].

This work presents a novel fabrication scheme based on [6] that allows the integration of VO_2 resistors on fully-released polyimide thin film for high strain studies ($\varepsilon > 0.1\%$). The proposed fabrication process, shown in Fig. 1, follows a conventional top-down approach and allows the integration of high-performance VO_2 devices on a flexible substrate. The main processing steps include: (i) the deposition of vanadium dioxide on a Si substrate via reactive sputtering off a vanadium target, (ii) RIE patterning of the VO_2 thin film, (iii) metallization by thermal evaporation and lift-off of chromium and gold, (iv) spin coating and patterning of HDMicroChemical PI2545 and finally (v) XeF_2 etch of the Si substrate and thin film transfer onto a four-point-bending (4P-bending) setup to conduct strain studies.

Fig. 2 shows the as-fabricated resistors. The final stack is made of a 2.5 µm-thick polyimide (PI) layer, 50 nm-thick PECVD SiO_2, 100 nm-thick VO_2, 200 nm-thick Cr/Au contact and a final layer of 50 nm-thick thermal SiO_2. A macroscopic picture of the PI film transferred on office tape is visible in Fig. 2a. Fig. 2b shows a microscopic picture of a complete VO_2 resistor from the same film and Fig. 2c presents the grains forming the VO_2 thin film. Fig. 3a shows the Raman spectrum of the patterned VO_2 thin film to prove its stoichiometry. Finally, Fig. 3b. shows a typical IV characteristic over successive IMTs of one of the fabricated resistors on the polyimide film. Colors from dark to light blue represent the first and last transitions, respectively. As can be seen in the figure, the device showcases a voltage-driven IMT that settles in the sub-five-volts region after a few transitions due to electroforming [7]. This IMT proves that the transfer of the VO_2 devices to the released thin PI film did not hinder the material properties. The success of this fabrication process paves the way to new experimental studies of the material under high strain. The proposed process will allow us to study multiple properties of highly-strained VO_2 resistors including the linearity of the gage factor, the mechanical limits of polycrystalline-VO_2 devices or the impact of strain on the transition temperature or voltage.

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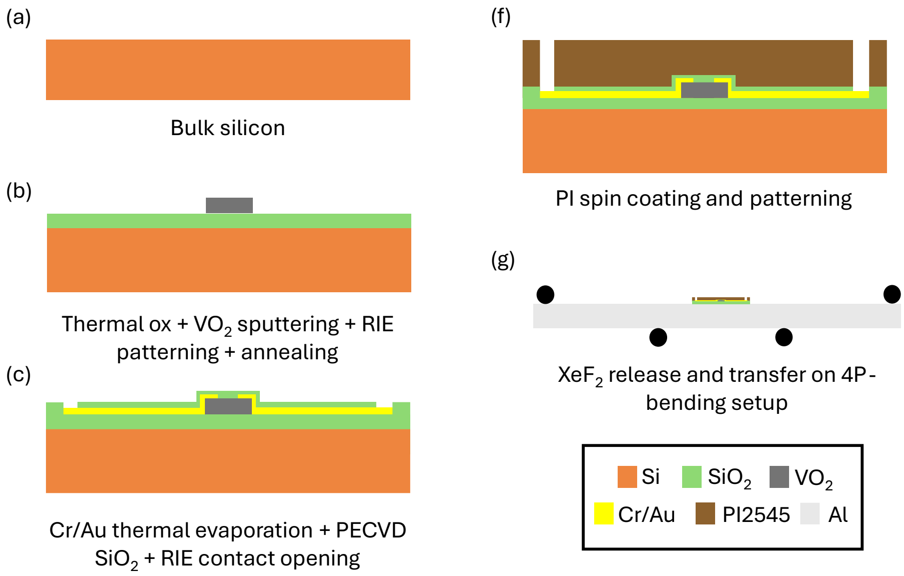

Figure 1. Fabrication process of VO_2 resistors on polyimide thin film for high strain studies

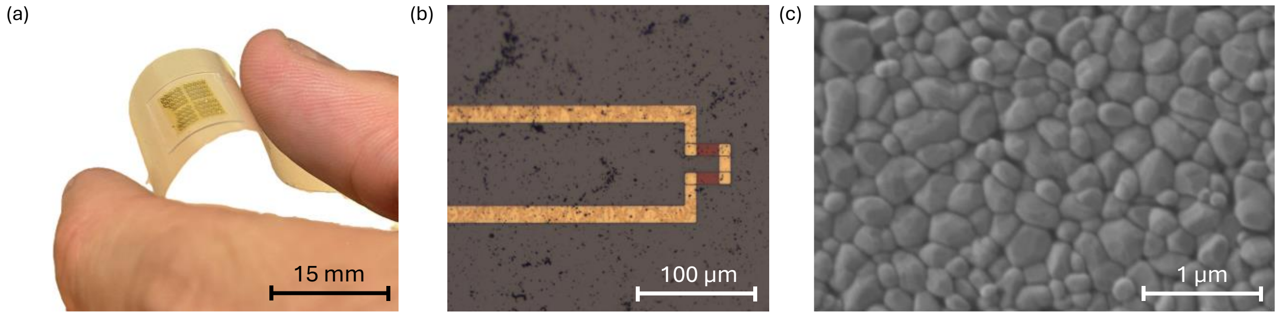

Figure 2. (a) Photography of the fully-released polyimide thin film with VO_2 resistors. (b) Microscopic picture of a VO_2 resistor on a fully-released polyimide thin film. (c) SEM photography of the polycrystalline patterned VO_2 film.

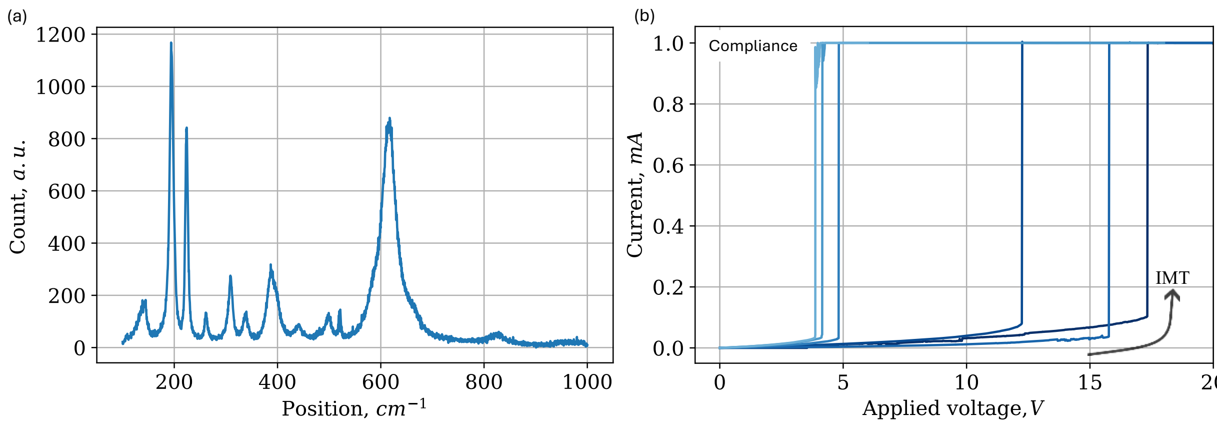

Figure 3. Raman spectrum of the deposited and patterned VO_2 film. (b) IV measurement of a VO_2 resistor on a fully-released polyimide thin film. Colors from dark to light blue indicate the order of the IMT measurement from first to last, respectively.