

Controlled reactive HiPIMS – effective technique for low-temperature (300°C) synthesis of VO₂ films with semiconductor-to-metal transition

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1 Introduction

Vanadium dioxide (VO₂) is the most interesting thermochromic material due to its reversible phase transition from semiconducting IR transparent state (monoclinic structure) to metallic IR reflective state (tetragonal structure) at around 68 °C. A high IR transmittance modulation makes the VO₂-based films a suitable candidate for optical switching applications, such as self-tunable infrared filters, temperature sensing devices and “smart” windows regulating the solar transmission. Current drawbacks limiting the application potential of the VO₂ films include high deposition temperatures (> 400 °C) of the films and the necessity to use a substrate bias potential in the case of their magnetron sputter deposition (J. Houska et al. (2016)).

2 Experimental details and Results

Reactive High power impulse magnetron sputtering (HiPIMS) with a feed-back pulsed reactive gas (oxygen) flow control and an optimized location of the oxygen gas inlets in front of the target and their orientation toward the substrate made it possible to form crystalline thermochromic VO₂ films at very high values of the maximum target power density of up to 5 kWcm⁻² in a pulse. The thermochromic VO₂ films (85 - 88 nm thick) were deposited onto floating conventional soda lime-glass substrates without any Na-diffusion barrier layer and nucleation-promoting “seed” layer at the temperature of ≤ 300 °C. Note that using the floating potential improves the application potential of the films due to a simplified deposition process and a decreased ion-induced compressive stress. The depositions were performed using a strongly unbalanced magnetron with an indirectly water-cooled planar vanadium target (50.6 mm in diameter) in argon-oxygen gas mixtures at the argon pressure of 1 Pa. The duty cycle was set to a constant value of 1%, the voltage pulse durations were between 40 μs and 100 μs, and the corresponding repetition frequencies were between 250 Hz and 100 Hz. The deposition-averaged target power density was approximately 13 Wcm⁻². The target-to-substrate distance was 145 mm. The phase composition of the VO₂ films was determined by grazing-incidence X-ray diffraction. The semiconductor-to-metal transition of the films was investigated by temperature-dependent transmittance and electrical resistivity measurement

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using a spectrophotometer and a four-point probe, respectively. Both analyzing systems were equipped with custom-designed heat cells to control the measurement temperature of the samples from 25 °C to 100 °C. The time-averaged energy distributions of positive ions were measured with an energy-resolved mass spectrometer placed at the substrate position. The ion energy distributions with increased fractions of high-energy ions (measured at substrate position) were extended up to 50 eV relative to ground potential. The VO₂ film prepared at the voltage pulse duration 50 μs exhibited an optical transmittance of about 40 % in the visible region and a large drop in the infrared transmittance ($\lambda = 2500$ nm) from 51% to 8% and in the electrical resistivity from $5.3 \times 10^{-3} \Omega\text{m}$ to $1.5 \times 10^{-5} \Omega\text{m}$ after the phase transition, its transition temperatures $T_{tr} = 56$ °C and 57 °C were lower than for the bulk VO₂ ($T_{tr} = 68$ °C) (Fig. 1).

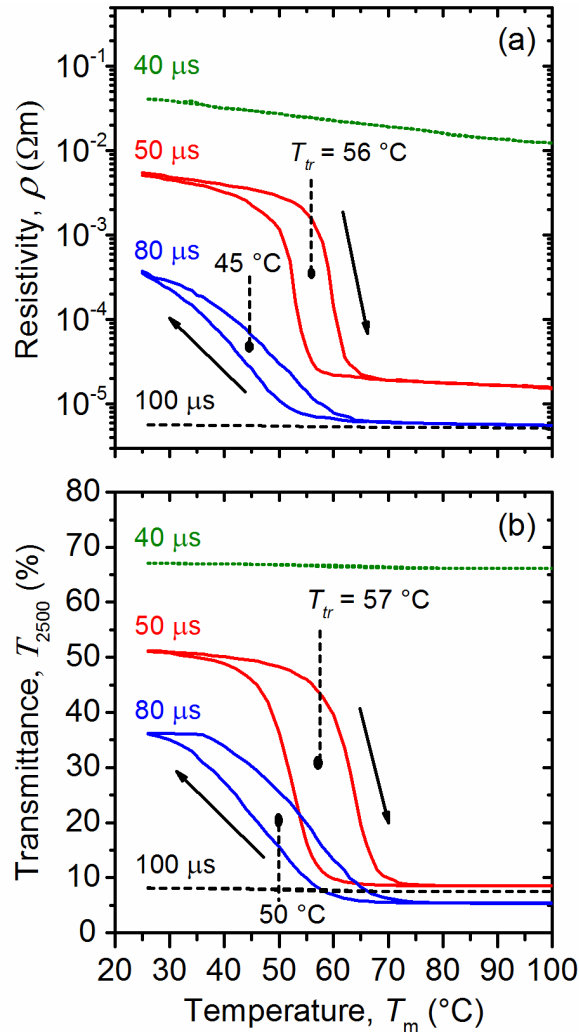


Figure 1: Temperature dependence of the electrical resistivity and infrared transmittance ($\lambda = 2500$ nm) of soda-lime glass coated by 85-88 nm thick films prepared at HiPIMS voltage pulse durations of 40, 50, 80 and 100 μs and the determined transition temperatures, T_{tr}

References

- Houska, J., Kolenaty, D., Rezek, J., Vlcek, J., (2016) Characterization of thermochromic VO₂ (prepared at 250°C) in a wide temperature range by spectroscopic ellipsometry, *J. Applied Surface Science*, ISSN 0169-4332