Controlled reactive HiPIMS – effective technique for low-temperature deposition of VO_2-based multilayer coatings for smart window applications

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1 Introduction

Vanadium dioxide (VO_2) is a technologically important thin film material of a high current world wide interest due to its reversible first-order thermochromic transition relatively near room temperature (approximately 68°C). Magnetron sputtering is probably the most important preparation technique of VO_2 films, and numerous deposition pathways have been reported in recent years. The research in this area is focused on (at least) the following three challenges. First, doping of VO_2 by other metals in order to decrease the transition temperature (T_{tr}) from 68 °C (bulk materials) or e.g. 50 °C (thin films) to the room temperature. Second, decreasing the deposition temperature (T_{dep}) of crystalline VO_2 at least below 300 °C, ideally without any substrate bias and without any crystalline interlayer, in order (i) to facilitate the large-scale production by reducing the energy consumption and minimizing problems with temperature uniformity over large substrate surfaces, (ii) to limit the diffusion of harmful elements from substrates such as soda-lime glass and (iii) to allow deposition on temperature-sensitive plastic substrates. Third, improving the luminous transmittance (T_{lum}) and the modulation of the solar transmittance (ΔT_{sol}) of the coatings by antireflection (AR) layers. (J. Houška et al. (2017))

2 Experimental details and Results

In this work, reactive HiPIMS with a pulsed O_2 flow control and to-substrate O_2 injection into a high-density plasma in front of the sputtered vanadium target was used for low-temperature (300°C) deposition of VO_2 films with a pronounced semiconductor-to-metal transition onto conventional soda-lime glass substrates without any substrate bias voltage and without any interlayer. The depositions were performed using an unbalanced magnetron with a planar target of 50 mm diameter in argon-oxygen gas mixtures at the argon pressure of 1 Pa. The deposition-averaged target power density was close to 13 Wcm^{-2} at a duty cycle of 1% with a peak target power density up to 5 $kWcm^{-2}$ during 50 µs voltage pulses. A high modulation of the transmittance at 2500 nm (between 51% and 8% at the film thickness of 88 nm) and the electrical resistivity (changed 350 times) was achieved for the VO_2 films synthesized at the controlled oscillations of the oxygen partial pressure around 15 mPa. Under these conditions, appropriate composition of the total ion flux and higher ion energies (up to 50 eV relative to

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ground potential) supported crystallization of the thermochromic phase (VO_2(R) during the deposition and VO_2(M1) at the room temperature). (Vlček et al. (2017))

Antireflection SiO_2 layers were deposited on the top of thermochromic VO_2 layer using mid-frequency (50 kHz, duty cycle of 50% and deposition-averaged target power density close to 8 Wcm^{-2}) bipolar dual magnetron sputtering onto the top of VO_2 layers at a surface temperature below 35°C in order to improve the optical and mechanical performance. We focus on the dependence of the luminous transmittance, T_{lum}, and the modulation of the solar transmittance, ΔT_{sol}, on the SiO_2 layer thickness. We show an improvement due to the SiO_2 overlayer of up to 16% (from 40.3% to 56.3%) for T_{lum} and up to 2.6% (from 7.7% to 10.3%) for ΔT_{sol}.

Tungsten doping of VO_2 layer allowed us to decrease transition temperature down to 20 °C (see Fig. 1), which is important condition for smart window applications. All these results are important for the design and low-temperature fabrication of high-performance durable thermochromic VO_2-based coatings for smart window applications.

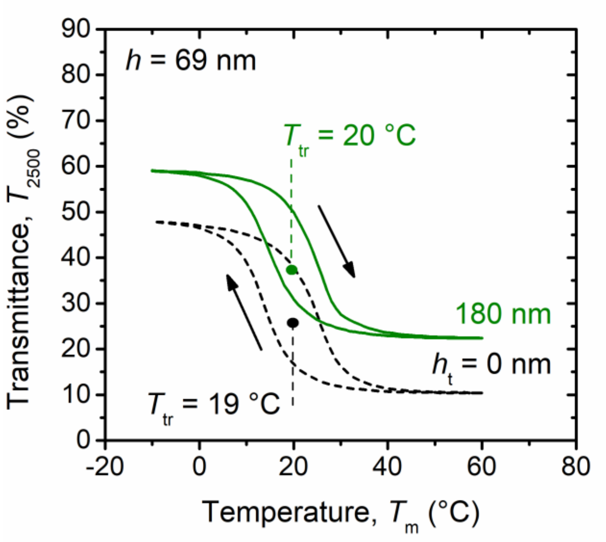

Figure 1: Transition temperatures, T_{tr}, determined from temperature dependence of the infrared transmittance (λ = 2500 nm) of soda-lime glass coated by 69 nm thick VO_2 film (black line) and the same film improved by 180 nm of antireflection layer (green line).

References

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