SWITCHABLE OPTICAL PROPERTIES ON VO_X:AL_2O_3 NANOCOMPOSITE THIN FILMS PREPARED BY PLD

S. Nuñez-Sanchez, R.Serna, M. Jiménez de Castro,
Instituto de Optica (CSIC), Serrano 121, 28006, Madrid, Spain
AK. Petford-Long,
Argonne National Laboratory , Bldg 212, 9700 S Cass Avenue, IL 60439, USA
J.F. Morhanghe,
Université Pierre et Marie Curie-Paris 6, UMR 7588, INSP, Paris, F-75005 France ; CNRS, UMR 7588, INSP, Paris, F-75005 France
nusa66@io.cfmac.csic.es

The development of optoelectronic systems needs new functional materials and techniques that can be used to obtain active photonic devices. Dielectrics functionalized by embedding nanoparticles in a transparent host are especially suited for optical applications. Among the proposed materials the vanadium oxides are a promising choice since they show a semiconductor to metal transition leading to a large absorption enhancement near the phase transition temperature that can be used for optical switching. This has attracted the research on nanocomposite systems containing vanadium oxide nanoparticles, and indeed the production of a switchable reflectivity device in a VO_2-SiO_2 composite surface layer prepared by ion beam and thermal processing has been very recently demonstrated [1].

In the present work we study VO_X nanoparticles embedded in a dielectric (Al_2O_3) thin film structure that will allow a simple implementation in waveguide configuration, thus rendering possible its application in integrated optical circuits. The multilayered VO_X nanocomposite thin films were produced by Alternate Pulsed Laser Deposition (a-PLD). This technique offers the possibility of obtaining artificially structured thin films in which the nanoparticle size and the separation between nanoparticle layers can be controlled in the nanometer range. The thin films have been grown on Si and glass substrates in vacuum by alternate ablation of the V and Al_2O_3 targets, as a result a multilayer structure with embedded nanoparticles separated by 15 nm of amorphous Al_2O_3 has been produced (Figure 1). Samples with different V content have been prepared by changing the number of laser pulses on the metal target. The transmission electron microscopy (TEM) images show the presence of 5 nm diameter crystalline nanoparticles with fcc structure, indicating that they are formed by VO_X (Figure 2). The Raman spectra show two broad bands at 200 cm^{-1} and at 460 cm^{-1} that are also consistent with the presence of VO_x compounds with a nanocrystalline structure (Figure 3).

The spectral response and the temperature dependence of the optical behaviour in the IR range of these films have been studied. The infrared spectra [900-1600 nm] show an enhanced absorption phase at the high temperature. The samples show an optical transmission hysteresis loop as a function of temperature (Figure 4), which has often been observed in vanadium oxides [1, 2, 3]. The observed transmission changes around 1% in the heating/cooling process are in good agreement with the 10% change observed in earlier works for 100 nm diameter particles [2]. The analysis of the optical transmission measurements and Raman spectra are consistent with nanoparticles having a [O]/[V] ratio in the 1.75-2.5 range. Therefore the PLD technique seems a suitable method to obtain VO_X nanoparticles with different oxidation states embedded in a dielectric matrix.

The results indicate that, during the vacuum PLD, vanadium is oxidized thus forming VO_X nanoparticles. The V oxidation may happen during Al_2O_3 deposition due to the high kinetic energy of the Al_2O_3 species generated in the ablation process. The experimental parameters affecting vanadium oxidation are now being investigated to control the nanoparticle composition.

References:

[1] R. Lopez et al, Applied Physics Letters, **85** (2004), 1410
[2] EE. Chain, Applied Optics, **30** (1991), 19
[3] D.P. Parlow et al, Journal Applied Physics, 70 (1), 1991.

Figures:

STRUCTURE & MORPHOLOGY

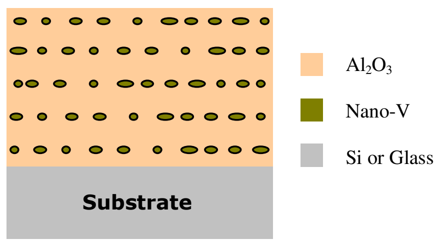

Figure 1. Scheme of the sample structure. The nanoparticle layers are separated by 15 nm of Al_2O_3.

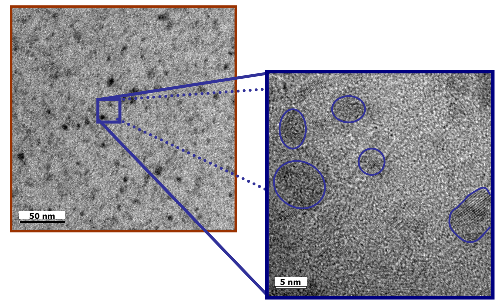

Figure 2. TEM images show crystalline nanoparticles on the amorphous aluminium oxide (Al_2O_3) background

RAMAN SPECTRA

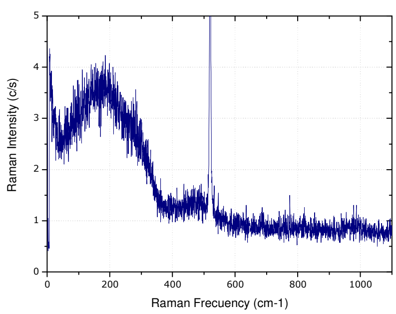

Figure 3.- Raman spectrum for the sample with $[V]=1.7\cdot10^{15}$ cm^{-2}. The sharp peak at 520 cm^{-1} is due to the Si substrate.

OPTICAL SWITCHING

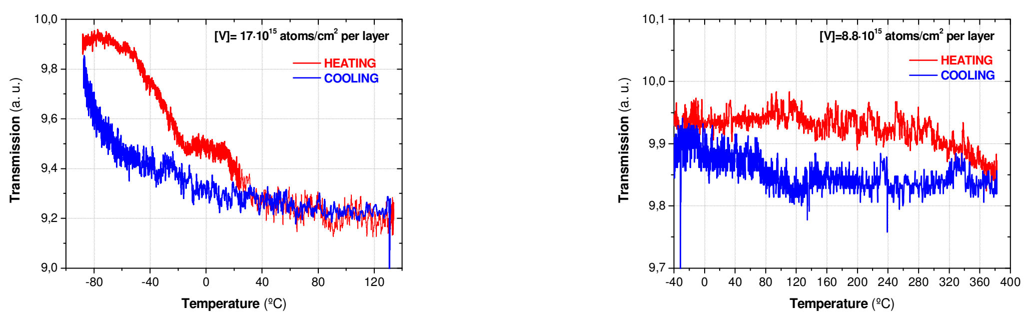

Figure 4. Temperature dependence of the optical transmission at 1.2 µm for samples with $[V]=1.7\cdot10^{15}$ cm^{-2} and $[V]=8.8\cdot10^{15}$ cm^{-2} per layer. The different transition temperatures observed for each sample are associated to different oxide compounds, probably V_4O_7 and V_2O_5 respectively.