Optical Characterization of VO_2 Smart Materials using Spectroscopic Ellipsometry

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The development of new types of ultra-fast switches operating in the RF-microwave and optical domains is based on the use of a class of materials undergoing fast, reversible phase transitions from a semiconducting state to a metallic one (Semiconductor Metal Transition / SMT). An example of such a material is vanadium dioxide (VO_2).

VO_2 exhibits very fast SMT transition that can be triggered by different external excitations such as temperature change, optical excitation or charge injection. During the phase transition the electrical resistivity of the VO_2 thin film can decrease by several orders of magnitude. Optically the material is transparent in the semiconductor state and highly reflective in the metallic state for a large spectral range (from 1mm up to THz frequencies) (fig1). These remarkable properties can be exploited for optical micro mirrors, modulators, switches and microwave waveguides (see Ref. 1) to overcome the current problems encountered in communication systems (consumption, power handling, slow switching and integration).

This note describes how to characterize the optical properties of VO_2 as it changes phase, with the transition induced by a temperature change.

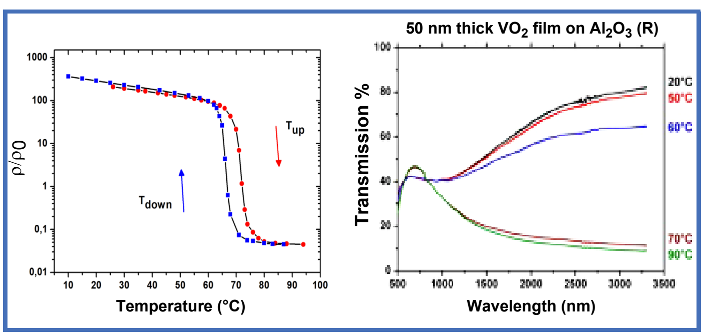


Fig.1: VO_2 SMT transition: electrical (left) and optical (right) properties

Experimental

A HORIBA Scientific UVISEL Spectroscopic Phase Modulated Ellipsometer with temperature cell has been used to characterize the optical properties VO_2 deposited on a sapphire substrate (fig.2&3). The change in the optical constants (n,k) at various temperatures is characteristic of the SMT exhibited by VO_2.

Ellipsometric measurements were performed at a range of temperatures from ambient to 90°C using an angle of incidence of 70° and spectral range 190-2100 nm.

Fig.2: UVISEL with temperature cell

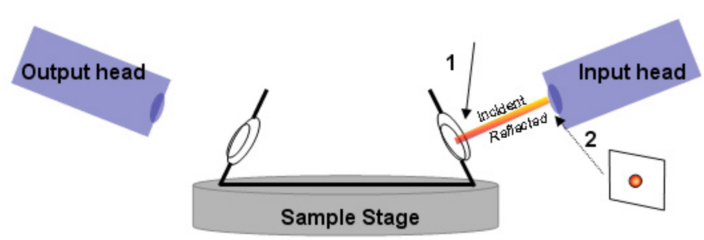


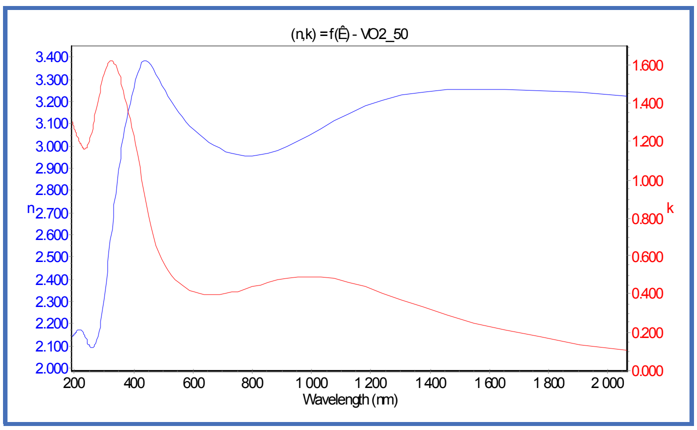
Fig.3: Schematic - positioning the temperature cell

Ellipsometric Modelling and Results

The model used to describe the sample is represented below.

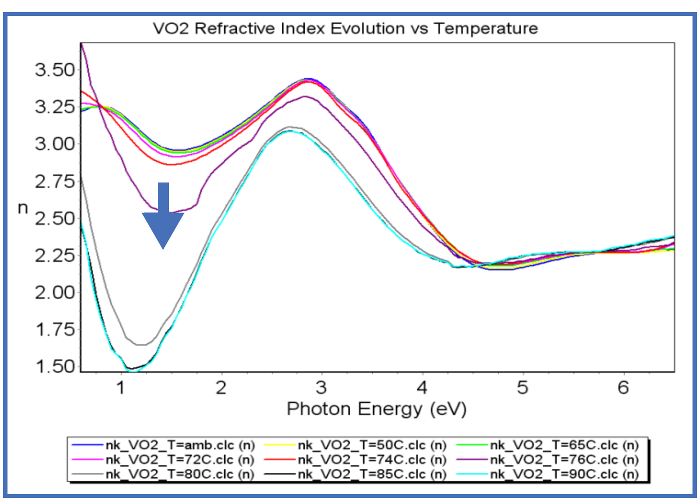
It shows a thin roughness layer (58 Å) at the surface of the VO_2 film that which improves the goodness of fit χ^2 parameter (from χ^2=1.3 to χ^2=0.2). As the sapphire is a transparent substrate the model includes automatic back-side correction. It also takes into account the anisotropy of the sapphire.

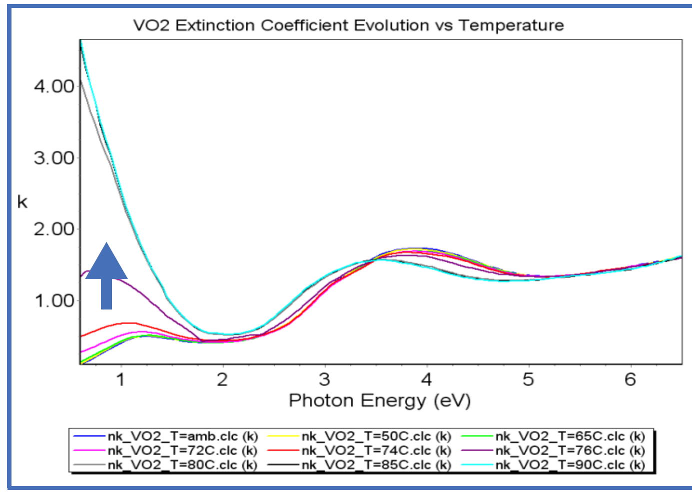
The optical constants of the VO_2 were determined using the **Tauc Lorentz dispersion formula** with multiple oscillators.



The two graphs below show how the optical constants change as a function of temperature from ambient to 90°C.

One can see that the refractive index decreases and **the extinction coefficient strongly increases in the near infra red** region. This behaviour is typical for **metals**.





Conclusion

A HORIBA Scientific spectroscopic ellipsometer equipped with a heating cell allows exploration of material properties as a function of temperature. It is well suited for the characterization of material transitions including thermal transition of polymers, semiconductor metal transition, band structure for compound alloys, thermal hysteresis of magnetic materials, etc…

Acknowledgements

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Ref.1: F. DUMAS-BOUCHIAT, C. CHAMPEAUX, A. CATHERINOT, J. GIVERNAUD, A. CRUNTEANU, P. BLONDY, ***RF Microwave Switches Based On Reversible Metal-Semiconductor Transition Properties Of VO_2 Thin Films: An Attractive Way To Realise Simple RF Microelectronic Devices***, Materials and Devices for Smart Systems III, Mat. Res. Soc. Symp. Proceedings Volume 1129, P. 275-286, 2009.