Thickness and temperature dependency of variation of dielectric functions of phase-change VO_2 film

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Abstract

In this paper, temperature- and thickness-dependent variation of dielectric functions of VO_2 film deposited by pulsed-laser deposition is characterized at both insulating and metallic phases by ellipsometry.

I. Introduction

Vanadium dioxide (VO_2) is a representative phase-change material which exhibits drastic changes in thermal, electronic, electric, and optical properties around the critical temperature [1, 2]. In particular, there have been much interest in VO_2 film paid by optics and photonics communities for various smart and active applications [3, 4]. However, as growth and characterization of polycrystalline VO_2 film is challenging and not preferable for conventional optical applications, properties of thick VO_2 film with thickness over 100 nm have been rarely studied [5]. In this paper, we fabricate and characterize phase-change thick VO_2 film at both insulating and metallic phases by scanning electron microscopy (SEM) and optical spectroscopic ellipsometry (SE). Hence, temperature and thickness dependences of the dielectric functions are analyzed.

II. Experimental Results

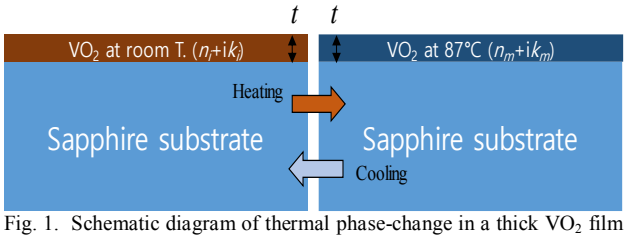

Fig. 1. Schematic diagram of thermal phase-change in a thick VO_2 film (t = 261 nm). n_i and n_m correspond to real parts of complex refractive indices at the insulating and metallic phases, respectively. On the other hand, k_i and k_m correspond to imaginary parts of complex refractive indices at the insulating and metallic phases, respectively.

First of all, we fabricated a thick phase-change VO_2 film [See Fig. 1.] on a transparent sapphire substrate with conventional pulsed-laser deposition (PLD) method using a KrF excimer laser with the wavelength of 248 nm [3].

Ahead of SE for investigation of refractive index spectra at both phases, approximate thickness was characterized by SEM as shown in Fig. 2(a).

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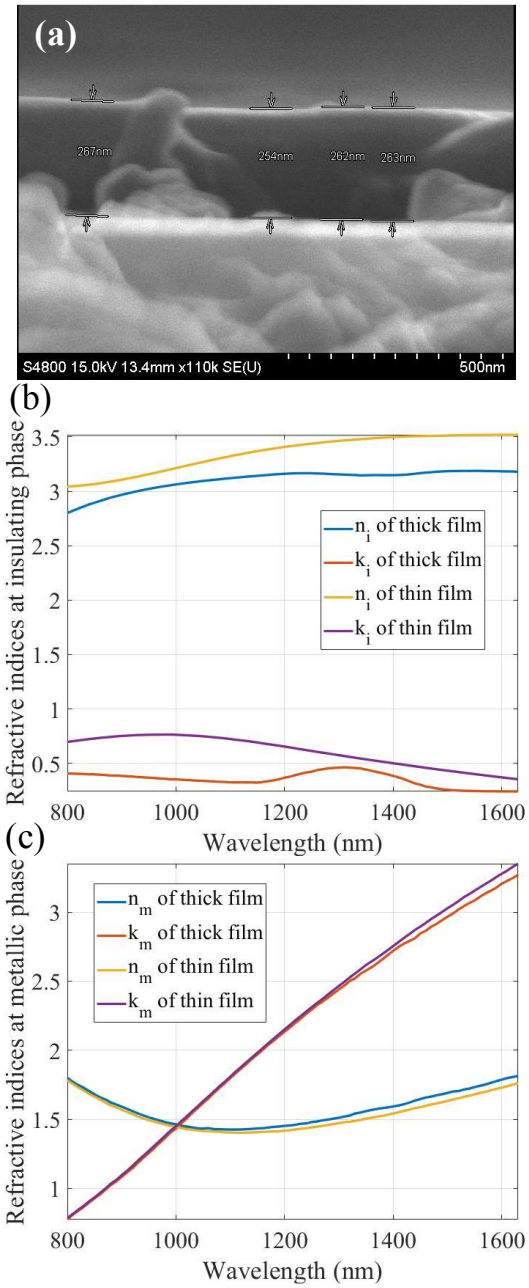

Fig. 2. (a) SEM image of cross-sectional view of the thick VO_2 film on a sapphire substrate. Spectra of VO_2 refractive indices of thick and thin films at (b) the insulating and (c) metallic phases, respectively. The thick film data were measured by SE and fitted according to Kramers-Kronig relations. The thin film data were cited from Ref. [6].

Finally, we conducted SE measurement using temperature-controlled variable-angle ellipsometer (V-VASE, J. A. Woollam) in the wavelength range from 800 to 1630 nm. The SE measurements were done at 25 and 87 ºC for data at the insulating and metallic phases, respectively. With effective medium approximation for consideration of surface roughness and effective thickness of the thick VO_2 layer, measured raw data have been precisely fitted according to theoretical Kramers-Kronig relations as shown in Figs. 2(b) and 2(c).

Figs. 2(b) and 2(c) show interesting variation characteristic of VO_2 film depending on thickness and temperature. It is shown that increased thickness of VO_2 film made by PLD method resulted in clear decrease of n_i and k_i at the room temperature. On the other hand, there have been negligible changes in dielectric function according to thickness increase above the critical temperature. It means that dielectric function of VO_2 film deposited by PLD method is sensitive to the thickness at the insulating phase rather than metallic phase.

III. CONCLUSIONS

Thickness- and temperature-dependent variations of dielectric functions of VO_2 film in the near-infrared band are experimentally studied. The authors expect that the work would be fruitful for various optical applications including compact active optical elements.

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