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Enhanced transmittance of sapphire by silicon oxynitride thin films annealed at high temperatures

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ABSTRACT

Silicon oxynitride (SiON) and SiO_2 thin films attracted considerable attention for various applications such as anti-reflection coatings and surface passivation layers. In this report, we present the enhancement of sapphire optical transmittance by over-layer deposition of the amorphous SiON by RF magnetron sputtering, and investigation on changes in microstructure and transmittance upon high-temperature annealing ~1373 K. A thin layer of nanocrystalline SiO_2 was formed at the sapphire/film interface induced by the annealing. Remarkably, the XPS spectra revealed that the silicon-nitrogen bonds disappear in the annealed films to form a non-stoichiometric silicon oxide (SiO_x) phase. The films showed high visible transmittance ~92%, which is comparable to that of soda-lime glass due to a significant reduction in the refractive index 1.41 of the films after annealing at 1373 K.

1. Introduction

In recent years, with the rapid development of opto-electronic technology, sapphire substrates are widely used for various opto-electronic applications over the glass substrates because of its significant hardness [1], scratch resistance and thermal stability [2], corrosion resistance [3], and excellent optical performance [4]. It is well known that the optical transmittance of the thin film should be guaranteed in most of the wide variety of opto-electronic applications. Despite, the sapphire exhibits a very low visible transmittance (~84%) than that of soda-lime glass (~91%), which is essential to upgrade [5,6]. Typically, low refractive antireflection coatings are desirable to improve the transmittance. Silicon oxynitride has been well known for the transparent amorphous film since it exhibits low absorbance and adjustable refractive index from 2.1 to 1.47 [7]. By carefully adjusting the refractive index, surface microstructure and thickness of the film, sapphire transmittance could be possibly improved. SiO_2 thin films can be synthesized in different ways, such as sputtering and Chemical Vapor Deposition (CVD) [8]. Despite, SiO_x porous structure can be obtained through the silicon oxynitride coatings by rapid thermal annealing >973 K. Several researchers studied on the heat treatment dependent changes in optical properties of the SiO_x coatings [9,10]. However, due to the coexistence of different phases and compositions upon annealing, the structure and the formation of SiO_xN_y with the role of oxygen content in changing the optical properties are still unclear. As the fact that both the SiO_xN_y and SiO_x layers were used as a substitute emitter layer for nc-Si and a-Si hetero-junction solar cells due to their less parasitic absorption caused by the larger band gap [11], investigation of the optical properties of such materials is of great interest. It is also known that the change in silicon oxynitride composition consents to tune the optical properties which are important in a wide variety of industrial applications [12,13]. In this work, SiO_x thin films were obtained by annealing the silicon oxynitride (SiO_xN_y) films deposited by magnetron sputtering. In this report, the primary concern is to increase the sapphire transmittance and to investigate the influence of the high-temperature annealing of non-stoichiometric SiON films on phase change, refractive index, and optical transmittance.

2. Experimental details

The SiO_xN_y films were deposited on single crystal sapphire substrates by RF magnetron sputtering at room temperature. Metallic Silicon (2 in. diameter, 99.99% pure) target with a sputtering power 250 W, and Ar and N_2 mixture (50 sccm each) were used for thin film deposition. Prior to deposition, the deposition chamber was evacuated to a base pressure 2.0×10^{-6} Pa and pre-sputtered for a few minutes. The deposited SiO_xN_y films were annealed at 1373 K in air ambient for 1 h. Surface microstructure and

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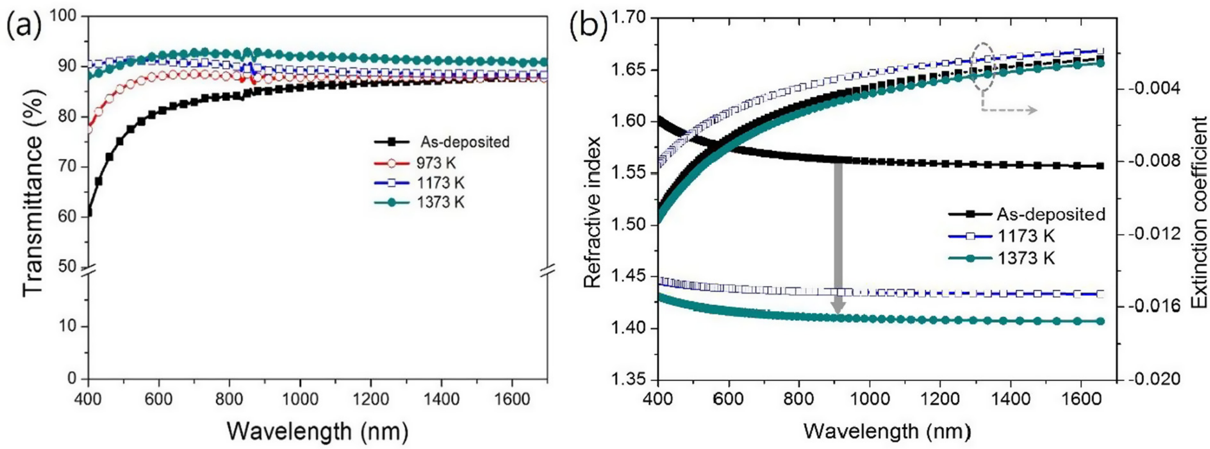

Fig. 1. (a) Optical transmittance, (b) refractive index and extinction coefficient of the as-deposited and annealed SiO_xN_y films.

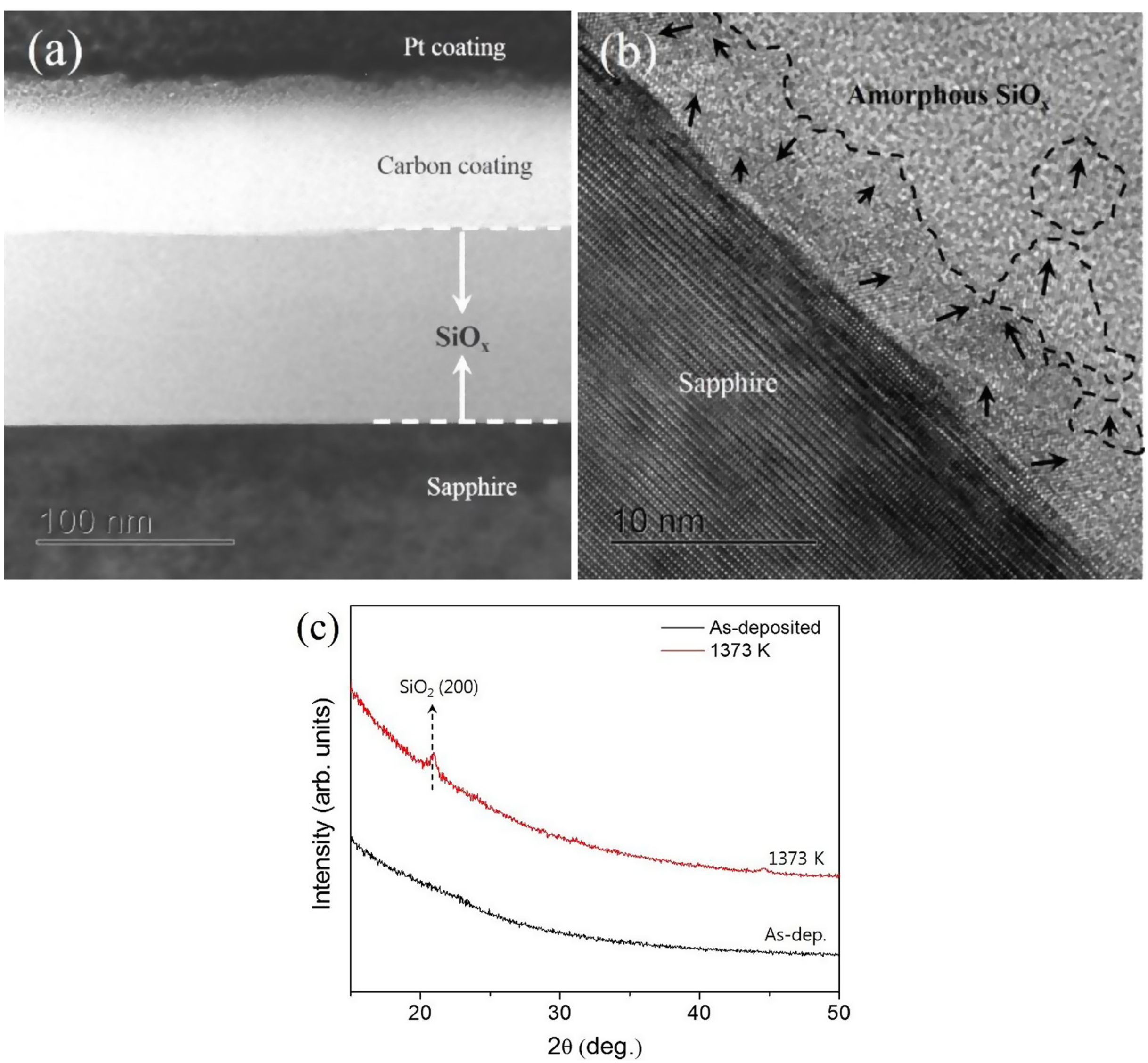

Fig. 2. HR-TEM images (a, b) and X-ray diffraction results (c) of the films annealed at 1373 K.

topography of the films were observed by FE-SEM (TESCAN MIRAH) and AFM (XE-70; Park systems). HR-TEM (Tecnai G2 F20) was used to observe the nanostructure of the annealed films. The surface chemical analysis was performed by the XPS (MultilLab, ESCA 2000) with Al Kα radiation for investigating the bond structure of the films. SIMS was used to investigate the depth

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