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Silicon films deposited on flexible substrate by hot-wire chemical-vapor deposition

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ABSTRACT

Silicon film was deposited on a novel flexible polymer, cyclic olefin copolymer (COC), by using hot-wire chemical-vapor deposition at a low substrate temperature and increasing hydrogen-dilution ratios (D_H: 0%–95%). The crystallinity of the silicon film coated on a COC substrate increased, changing from amorphous to microcrystalline, accompanying the rising hydrogen-dilution ratio. The surface morphology of the deposited silicon film varied according to the hydrogen-dilution ratio, with roughness values of the silicon film increasing from 4.20 to 6.51 nm. This study examined the effect of hydrogen-dilution ratios on the crystallinity, surface roughness, and optical-absorption properties of silicon films.

1. Introduction

Microcrystalline silicon (μc-Si) is a two-phase material in which crystalline regions are embedded in an amorphous matrix. Because the optical absorption of μc-Si is superior to that of crystalline silicon, μc-Si film has received considerable attention in recent years. In addition, in contrast to amorphous silicon, μc-Si has stable transport properties that are not influenced by light degradation [1]. Hot-wire chemical-vapor deposition (HW-CVD) technology has been considered favorably as an alternative deposition method for hydrogenated amorphous silicon [2,3] and μc-Si [4] because it can achieve higher deposition rates [3] and improved film stability [5].

Cyclic olefin copolymer (COC) was used as flexible substrate in this study. A COC substrate is an amorphous engineering thermoplastic, used in many optical and electrical applications [6,7] because of its high optical transparency, low dispersion rate, and low water-vapor transmission rate (WVTR). The WVTR of different polymer substrates are shown in Fig. 1. Four types of polymer material were compared: polycarbonate (PC) and poly(ethylene terephthalate) (PET) substrates, and COC and annealed-COC films. The WVTR of annealed-COC films was superior to that of unannealed COC because the dipole moments of the polymer chain in the sample tended to rearrange themselves to the preferred orientation and because molecular well-packing phenomena occurred after the thermal treatment. However, the surface was smooth after annealing, with the surface roughness reaching 1.31 nm [7]. The WVTR of the pure PC and PET substrates were extremely high because of their higher water absorption [8]. The lower WVTR of the flexible substrate could avert postoxidation of the silicon film when the silicon film was used to manufacture an electronic device. Inorganic films, such as SiN_x [9], SiO_2 [10], and Al_2O_3 [11], were deposited on flexible substrate as a barrier layer to reduce the WVTR and oxygen transmission rate (OTR). The WVTR and OTR for a flexible electronic device were kept as low as possible to avoid postoxidation.

In this study, a series of silicon films was deposited on a COC surface with different hydrogen-dilution ratios by using HW-CVD. The crystallinity, surface roughness, and optical-absorption properties of silicon films with different hydrogen-dilution ratios are discussed in this article.

2. Experiments

COC pellets were melted at 230 °C by using a hot-press machine. After the hot-press process, the COC films were annealed at 210 °C for 2 h in a vacuum environment. The silicon films were deposited

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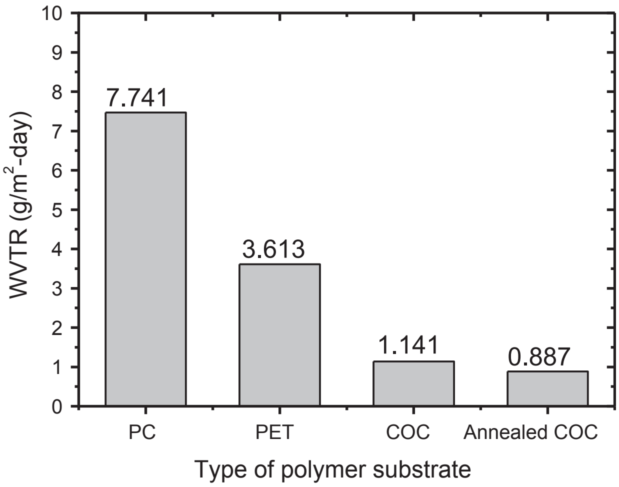

Fig. 1. Water vapor transmission rates of different polymer substrates.

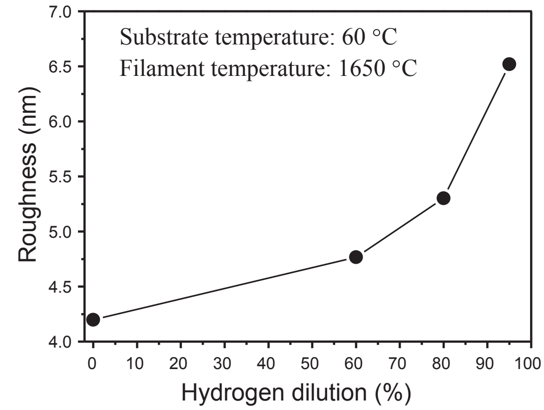

Fig. 4. Roughness of coated silicon films on COC substrates with different hydrogen-dilution ratios.

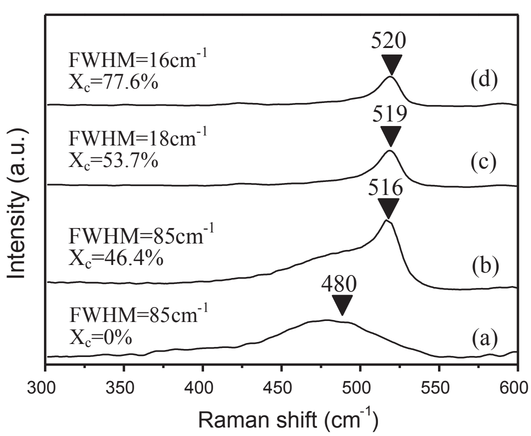

Fig. 2. Raman spectra for silicon film deposited on COC substrates with (a) 0%, (b) 80%, (c) 90%, and (d) 95% hydrogen-dilution ratios.

on the COC substrate by using HW-CVD at a low-substrate temperature of 60 °C. Different ratios of silane (SiH_4) gas and hydrogen (H_2) were used during the deposition. The different hydrogen-dilution ratios (D_H) were defined as $D_H = [H_2]/[SiH_4 + H_2]$ in this study. A tungsten filament was employed as the heating source and was heated to 1650 °C. The distance from the heating source to the sample substrate was 5 cm. The crystallinity of the silicon film at different hydrogen-dilution ratios was calculated according to Raman spectra. A 632.8 nm He–Ne laser was used in the Raman spectrometer, and the power of the incident beam was set below 50 mW to avoid thermally induced crystallization. The surface morphology of the silicon film, with different hydrogen-dilution ratios deposited on the COC substrate, was monitored using atomic force microscopy, and the scanning area was 1×1 μm in a tapping mode. The microstructure of the silicon film was observed using a scanning electron microscope (SEM) with cross-section and plane views.

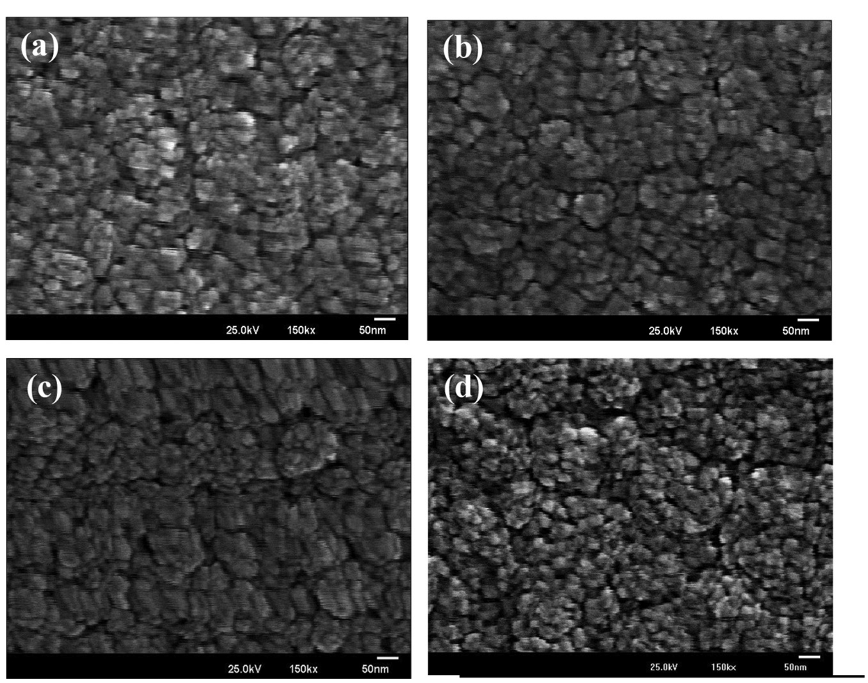

Fig. 3. SEM plan-view images of silicon film deposited on COC substrates with (a) 0%, (b) 60%, (c) 80%, and (d) 95% hydrogen-dilution ratios.