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Influence of deposition parameters on optical properties of silicon oxycarbide thin films

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ABSTRACT

On Si (1 0 0) and K9 glass, SiCO thin films were produced by radio-frequency sputtering with silicon oxycarbide target, respectively. And the influence of substrate temperature, working pressure and sputtering power on optical properties of SiCO thin films was studied. The optical properties of films were carried out through spectroscopic ellipsometer and UV/vis/IR spectrophotometer. Results showed that SiCO thin films presented excellent optical properties and exhibited a wide range of properties through a change of deposition parameters. Deposition rate and refractive index changed regularly with the variety of deposition parameters, while the dependence of these two properties to deposition parameters was opposite. Refractive index of SiCO ranges from 1.86 to 2.26 on Si (1 0 0), and 1.80 to 2.20 on K9 glass. With decreasing substrate temperature and sputtering power or increasing work pressure, the spectra transmittance was improved, and the average spectra transmittances were more than 80%.

1. Introduction

As one of glassy compound materials, silicon oxycarbide (SiCO) thin films have been of interest because of their preferred properties, such as excellent thermal stability, big energy band, big refractive index and high hardness. Therefore, SiCO thin films can be used as antireflection film, window material of silicon-based optoelectronic devices and solar cells [1–4]. So far, the methods to prepare SiCO include sol–gel, plasma enhanced chemical vapor deposition (PECVD), ion beam synthesis [5–9]. However, the operating temperatures of above techniques are required to high temperature (more than 1000 °C) [6–8], which leads to more defects in the interface of thin film and substrate, phase separation and crystallization. Furthermore, the SiCO materials fabricated by chemical means remained a significant organic character which limited their inorganic character and thermal stability [4]. In recent years, reactive radio-frequency (RF) magnetron sputtering was used to synthesize SiCO films at low temperatures without organic hydrocarbon precursors [3,4,9].

When using RF-magnetron sputtering technique to synthesize SiCO films, they were often fabricated by sputtering silicon carbide target or sputtering silicon target and carbon target together with oxygen flow. This paper described a different method to synthesize SiCO thin films by using RF-magnetron sputtering technique. The depositions were carried out by sputtering silicon oxycarbide target instead of oxygen flow. SiCO thin films were synthesized under different process parameters on Si (1 0 0) and K9 glass, respectively. The optical properties of the films were investigated by spectroscopic ellipsometer and UV/vis/IR spectrophotometer, and the influence of deposition parameters on optical properties of SiCO thin films was studied. The result showed that SiCO thin films presented excellent optical properties which depended on deposition parameters considerably. Deposition rate and refractive index changed regularly with the variety of deposition parameters, while the dependence of these two properties to deposition parameters was opposite. Refractive index of the films had a large changed region from 1.86 to 2.26 for the films on Si (1 0 0) and 1.80 to 2.20 for the ones on K9 glass. The transmission properties of SiCO films on K9 glass were very good and could be improved by decreasing substrate temperature and sputtering power or increasing work pressure.

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Table 1
Deposition parameters of SiCO films.

Samples		Substrate temperature (°C)	Work pressure (Pa)	Sputtering power (W)	Deposition time (min)
Si (1 0 0)	K9 Glass				
A1	A2	100	1	300	15
B1	B2	150	1	300	15
C1	C2	200	1	300	15
D1	D2	250	1	300	15
E1	E2	150	2	300	15
F1	F2	150	1	200	15
G1	G2	150	1	400	15

2. Experimental

The SiCO thin films were prepared on BK7 glass, namely, K9 glass in China, by RF magnetron sputtering with a sintered SiCO target. Argon gas (99.9% pure) was input into the chamber as the plasma and the working gas. The depositions were carried out under different substrate temperature, working pressure and sputtering power. The deposition time of all of films was 15 min. The specific deposition parameters of each sample were given in Table 1. The chamber was evacuated to 3×10^{-3} Pa before input argon gas in. The substrate was cleaned in acetone using an ultrasonic cleaner for 15 min previously in order to remove the organic matter on the substrate surface. Before deposition, 30 min sputtering was performed in order to clean the target surface.

After deposition, the thickness and optical constants of the films were achieved with different methods. Film thickness and refractive index (wavelength at 632.8 nm) of the films on Si (1 0 0) were measured by spectroscopic ellipsometer (Gaertner L116E, USA). Transmission spectra in the 250–2500 nm wavelength range of the depositions on K9 glass were tested by UV/vis/IR spectrophotometer (Lambda 900, USA). And film thickness and refractive index of the ones on K9 glass were achieved by a method which could determine optical constants of SiCO thin film only from transmission spectrum [10].

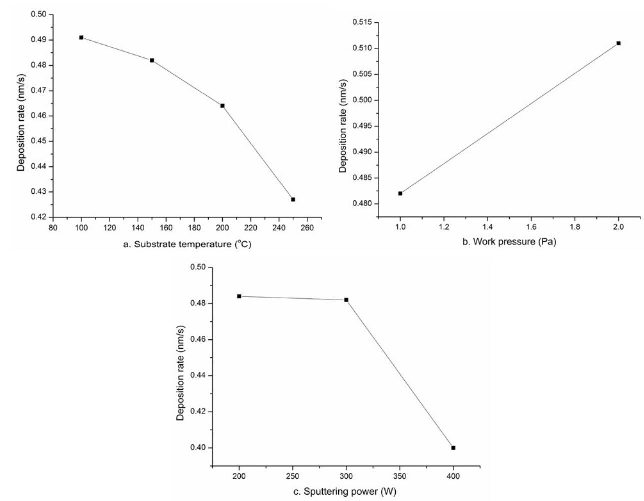

Fig. 1. Deposition rate of SiCO films on Si (1 0 0) under different deposition parameters. The data were listed in Table 2. Deposition rate decreased with the increasing of substrate temperature and sputtering power, while increased with the rise of work pressure.

3. Results and discussion

3.1. Optical properties of SiCO thin films on Si (1 0 0)

Film thickness of SiCO thin films on Si (1 0 0) measured by spectroscopic ellipsometer are listed in Table 2, and the corresponding deposition rates are also provided in this Table. Fig. 1 shows the relations of these deposition rates with different substrate temperature, working pressure and sputtering power respectively. It can be seen that deposition rate decreases with the increasing of substrate temperature and sputtering power, while increases with the rise of work pressure. These results are similar with the ones of other films prepared by magnetron sputtering technique except for the one gotten via varying sputtering power. As is well known, deposition rate increases with the increasing of sputtering power. While there is a different result for this method for preparing SiCO thin film mentioned in this work. It may have relation with the chemical structure change of the films while deposited under different sputtering power, and this hypothesis will be tested by using X-ray photoelectron spectroscopy in the further work.

Refractive index of SiCO thin films on Si (1 0 0) tested by spectroscopic ellipsometer are given in Table 2, and the relations of these refractive index with different substrate temperature, working pressure and sputtering power are shown in Fig. 2 respectively. The result shows that refractive index of SiCO thin films on Si (1 0 0) have a large changing region range from 1.86 to 2.26 and has a similar varying trend with the different deposition parameters on the whole. By the way, the large range of refractive index of the films also indicates that the chemical structure or component ratio of the film may have changed when deposition parameters varied.

3.2. Optical properties of SiCO thin films on K9 glass

Transmission spectra of SiCO thin films on K9 glass tested by Lambda 900 UV/vis/IR spectrophotometer in the 250–2500 nm wavelength range are given in Fig. 3. The films present excellent optical transmission and have strong dependence on deposition parameters. From Fig. 3a, it can be seen that the films with lower substrate temperature have better optical transmission properties in the low absorption region and transparent region. But there is no obvious red shift or blue shift on transmission spectrum, which indicates that substrate temperature has little influence on

Table 2
Thickness, deposition rate and refractive index of SiCO films on Si (1 0 0).

Samples	A1	B1	C1	D1	E1	F1	G1
Thickness (nm)	441.5	434.0	417.1	384.6	459.8	435.5	360.2
Deposition rate (nm/s)	0.491	0.482	0.464	0.427	0.511	0.484	0.400
Refractive index	1.99	2.20	2.18	2.26	2.22	1.86	2.24