Characteristics of Low-k Film Deposited by Plasma-Enhanced CVD Using a Liquid BCB Source

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Abstract

Characteristics of organic film deposited by plasma-enhanced CVD at low temperature below 250 °C using a liquid source of BCB were investigated and compared with standard spin-coated BCB. Uniform thin organic film was successfully deposited on 3-inch wafer with thickness uniformity of 3%. Dielectric constant, breakdown voltage, and moisture absorption of the film deposited by CVD are similar to spin-coated BCB. It was found from FT-IR measurement, however, that the film deposited by CVD has fewer Si atoms than spin-coated BCB and therefore it can be etched by RIE using only O_2 gas. The step-coverage of the film deposited by CVD is conformal and considered advantageous for ultra-fine structures.

INTRODUCTION

BCB is widely used in ultra-high-speed ICs and three-dimensional monolithic microwave ICs using compound semiconductor as an interlayer dielectric material because of its low dielectric constant, low moisture absorption, and low process temperature [1] - [2]. The standard method of preparing BCB film comprises spin coating and curing, which provides thick film easily [3]. However, with this method, it is very difficult to deposit thin film below 1 μm with accurate thickness control on a substrate with steps. This problem has made it difficult to apply BCB to ultra-fine structures. To solve this problem, we have investigated the plasma-enhanced CVD technique using BCB. This technique was first studied for Cu dual-damascene interconnects by Kawahara et al. [4]. However, their technique is not suitable for compound semiconductor devices because of its high process temperature. In this paper, we investigate the characteristics of organic film deposited by plasma-enhanced CVD at low temperature below 250 °C using a liquid BCB source (p-BCB) and compare p-BCB with standard spin-coated BCB (sc-BCB).

EXPERIMENTAL

In this work, we used a conventional parallel-plate-type plasma-enhanced CVD system for TEOS. As a liquid source, BCB resins for spin coating were used. BCB resins were heated at 80 °C and vaporized resins were supplied to the reactive chamber without carrier gases. For the deposition, pressure was 80 Pa, gas flow was 10 sccm, and power was 150 W. About 0.3-μm-thick films were deposited at temperatures ranging from 100 to 250 °C. After deposition, these films were cured at 220 °C for 1 h in N_2 ambient. For comparison with p-BCB, about 1-μm-thick BCB film was deposited by standard spin coating and curing.

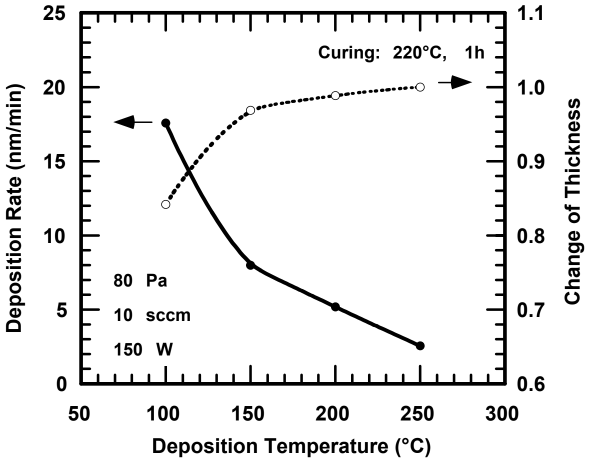

Fig. 1. Dependence of deposition rate and change of thickness by curing on deposition temperature.

RESULTS AND DISCUSSION

Figure 1 shows the dependence of the deposition rate on the deposition temperature. The deposition rate increases as the temperature decreases. Figure 1 also shows the dependence of the change of thickness by curing on the deposition temperature. The change of thickness increases as the deposition temperature decreases. The change of film deposited at 100 °C is larger than that of sc-BCB, which is about 10%. Furthermore, for the film deposited at 100 °C, blister-like bubbles were observed after curing. The film deposited at 100 °C is thought to include much solvent. On the other hand, for the film deposited at 150 °C, there were no blister-like bubbles and uniformity of the thickness was about 3% in the film deposited on 3-inch.

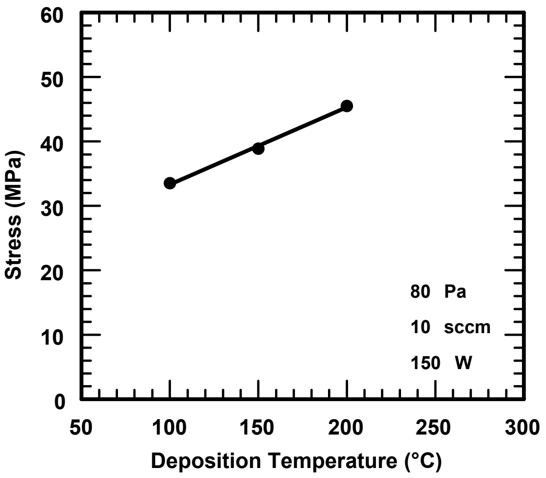

Fig. 2. Dependence of the stress of cured film on the deposition temperature.

Film stresses impact both the fabrication and long-term reliability of ICs. Figure 2 shows the dependence of the stress of cured film on the deposition temperature. These stresses were tensile. The stress increases as the temperature increases. However, the values are similar to those for sc-BCB.

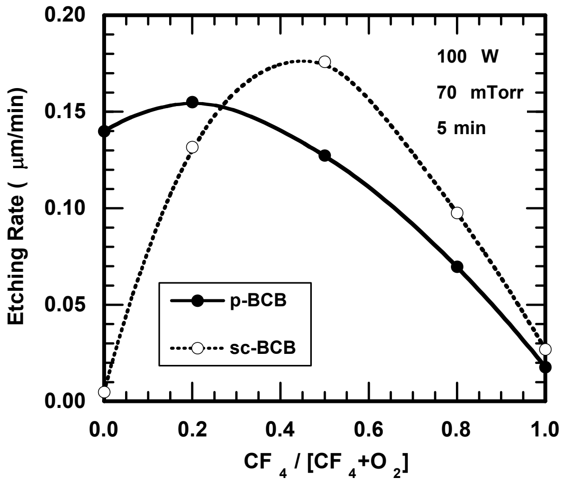

Fig. 3. Etching rate as a function of the CF_4/O_2 gas ratio.

BCB cannot be etched by RIE using only O_2 gas because of its Si content. Etching of BCB thus requires a CF_4/O_2 or SF_6/O_2 mixture. Figure 3 shows the etching rate as a function of the CF_4/O_2 gas ratio. For the RIE, pressure was 70 mTorr, total gas flow was 50 sccm, and power was 100 W. For sc-BCB, the highest etching rate was obtained with CF_4 content of 50%. On the other hand, for p-BCB, the highest etching rate was obtained with CF_4 content of 20%, and p-BCB could be etched sufficiently in only O_2 plasma. This suggests that p-BCB has significantly fewer Si atoms than sc-BCB.

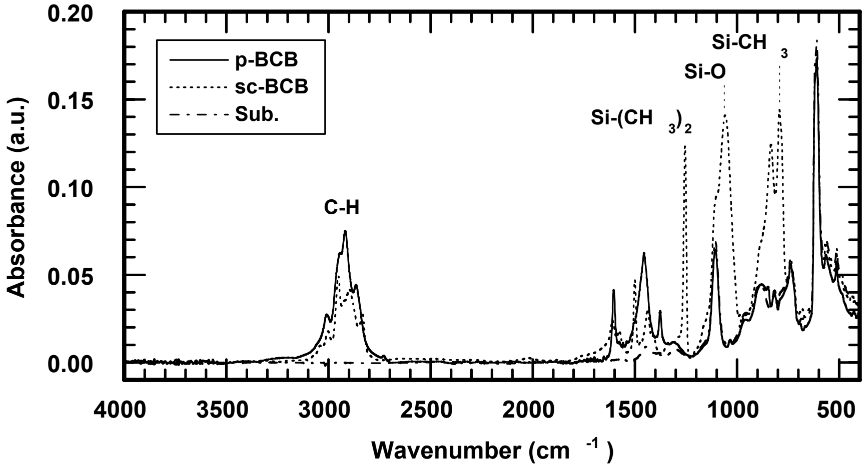

Fig. 4. FT-IR spectra of sc-BCB film and p-BCB film after curing.

The chemical composition of p-BCB was monitored by FT-IR spectroscopy. In p-BCB films deposited at temperatures from 100 to 200 °C, there were no differences in the spectra. Moreover, the spectra did not change after curing. Figure 4 shows FT-IR spectra of a sc-BCB film and a p-BCB film, which were deposited on Si substrate and cured. The spectra of the Si substrate are also shown in Fig. 4. The most noticeable point is that there are not any peaks related to Si (Si-O, $Si-CH_3$) in the p-BCB film. This indicates that p-BCB has significantly fewer Si atoms than sc-BCB.

The electrical properties of p-BCB film were investigated by capacitance measurements at a frequency of 1 MHz and by I-V measurements. Figure 5 shows the dielectric constant as a function of the deposition temperature. In the temperature rang of 100 to 200 °C, the dielectric constant is almost constant at 2.7, which is the same as the value for sc-BCB.

Figure 6 shows the leakage current density as a function of the electric field. In the electric field below 1 MV/cm, the leakage current density of p-BCB films is lower than that of sc-BCB film. For samples deposited at 100 and 150 °C, the electric field at $1\text{x}10^{-6}$ A/cm^{2} is about 3 MV/cm, which is the same as the value reported for sc-BCB [3].

The moisture absorption of film has a very large effect on the IC fabrication process and reliability. It is well known that the dielectric constant increases as the moisture content in the film increases. Figure 7 shows the change of the dielectric constant of films kept in air with a relative humidity of about 60% as a function of the time after baking at 150 °C for 1 h. It also shows the result for polyimide, which has higher moisture absorption than BCB [5]. For polyimide, the dielectric constant increases as the time increases and the change is in excess of 8% after 350 h. On the other hand, for p-BCB and sc-BCB, the change is very small, about 0.5% after 500 h. This indicates that p-BCB has as the same low moisture absorption as sc-BCB.

Figure 8 is a cross-sectional SEM image of 0.3-μm-thick BCB film deposited at 150 °C on GaAs substrate with a 1.5-μm step. The step is covered successfully by the thin BCB film.

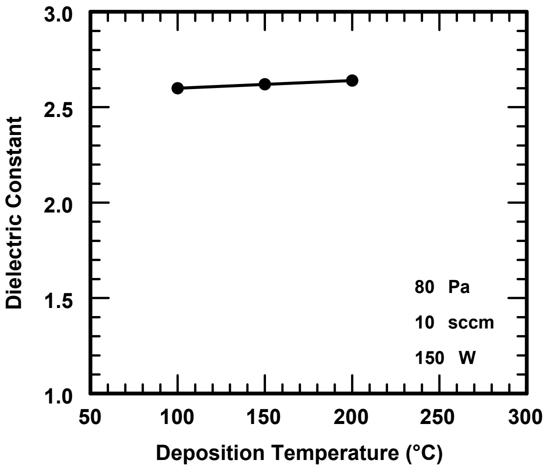

Fig. 5. Dielectric constant as a function of the deposition temperature.

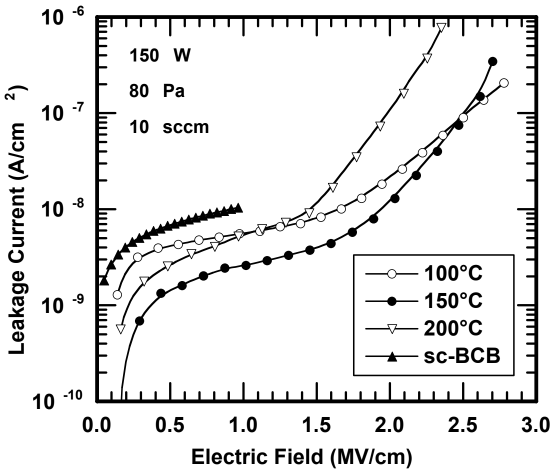

Fig. 6. Leakage current density as a function of the electric field.

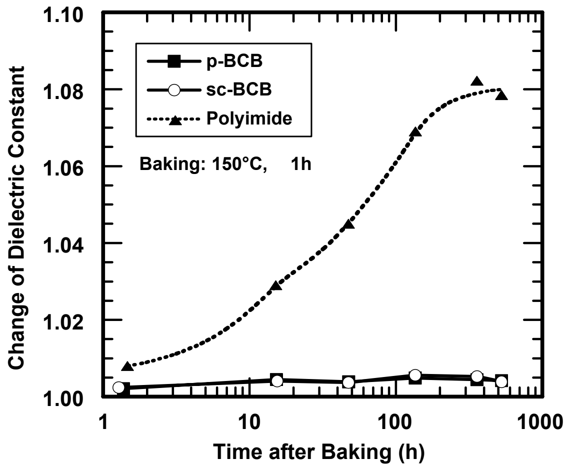

Fig. 7. Change of the dielectric constant of the films kept in air with a relative humidity of about 60% as a function of the time after baking.

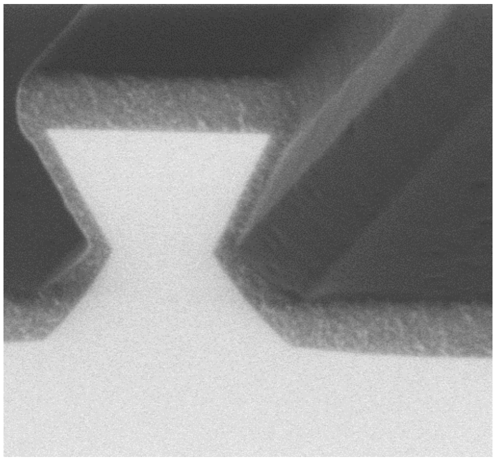

Fig. 8. Cross-sectional SEM image of 0.3-μm-thick BCB film on GaAs substrate with a 1.5-μm step.

The results of this investigation are summarized in Table I.

TABLE I

PROPERTIES OF p-BCB DEPOSITED AT 150 °C AND sc-BCB

	p-BCB	sc-BCB
Dielectric Constant (@1MHz)	2.7	2.7
Breakdown Voltage (MV/cm)	~ 3	> 1
Stress (MPa)	39	25
Change of Dielectric Constant (@25°C, 60% R.H.)	0.5%	0.6%
Etching Rate of O_2-RIE (µm/min)	0.140	0.005

CONCLUSION

We have investigated plasma-enhanced CVD at low temperature using a liquid BCB source to deposit thin BCB film below 1 µm with accurate thickness control. The film retains the advantages of spin-coated BCB, such as a low dielectric constant, low moisture absorption, and high breakdown field strength, even though the chemical composition is newly synthesized.

These results indicate that organic film deposited by CVD using BCB has sufficient properties for application as a thin insulator film for ultra-high-speed devices and ICs.

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ACRONYMS

BCB: benzocyclobutene
CVD: chemical vapor deposition
FT-IR: Fourier transform infrared
IC: integrated circuit
RIE: reactive ion etching
SEM: secondary electron micrograph
TEOS: tetraethoxysilane