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Development of Diamond-like Carbon Film as Passivation Layers for Power Transistors

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Because of the novel characteristics such as chemical stability, hardness, electrical resistivity and thermal conductivity, diamond-like carbon (DLC) film is a suitable material for the passivation layers. For this purpose, using the PECVD, DLC films were synthesized at room temperature. The adhesion and the hardness of the DLC films deposited on Si and SiO_2 substrate were measured. The resistivity of 5.3×10^{8} $\Omega\cdot$cm was measured by automatic spreading resistance probe analysis method. The thermal conductivities of different DLC films were measured and compared with that of phospho silicate glass (PSG) film which is commonly used as passivation layers. The thermal conductivity of DLC film was improved by increasing hydrogen flow rate up to 90 sccm and was better than that of PSG film. The patterning techniques of the DLC film were developed using the RIE and the lift-off method to form 5 μm line. Finally, the thermal characteristics of the power transistor with the DLC film as passivation layer was analyzed.

Key words : Diamond-like carbon, Passivation, Thermal conductivity, Patterning, Power transistor, Stability, Breakdown voltage

I. Introduction

Because of its outstanding thermal conductivity, Diamond-Like Carbon (DLC) film is highly expected to be used as the passivation layer of power transistors, enhancing its performance by outletting heat produced at the surface of transistor.[1] In addition to the above characteristic, DLC film shows high hardness, chemical inertness, high electrical resistivity, and good surface smoothness. These characteristics can lead to the application as passivation layers. But it was found difficult for DLC films to be applied to semiconductor devices because of the limitation in patterning techniques.

In this paper, DLC films were sythesized by the PECVD method and used as passivation layers for power transistors. By varying methane and hydrogen gas ratio, films having high resistivity, adhesive strength, and thermal conductivity were deposited. Depending on the composition condition of the gases, the thermal conductivity could be improved. Through the lift-off and the RIE method,[2] the patterning techniques were developed. By Applying DLC films as the passivation layers for power transistors, the performance of device was enhanced by its novel thermal conductivity.

II. Experimental Procedure and Results

DLC films were synthesized by using the Plasma Enhanced Chemical Vapor Deposition (PECVD) method with react gases, methane and hydrogen. In synthesis, the flow rate of methane gas was fixed at 20 sccm and the flow rate of hydrogen gas was varied in conditions 20, 40, 60, 90, 120, 150 sccm. As hydrogen flow rate increased; the deposition rate reduced from 20 to 7 nm/min. The adhesive strength of DLC films to Si, Al and SiO_2 was measured by scratch test. In comparison with Phospho Silicate Glass (PSG) which is commonly used as passivation layers, DLC films showed better adhesive characteristics. The resistivity of the synthesized DLC films was measured about 5.3×10^{8} $\Omega\cdot$cm.

To investigate the thermal conductivity of DLC films,[3,4] it was tested and compared with that of PSG films. Figure 1 shows the schematic of device which is fabricated to measure the relative thermal conductivity. For the thermal insulating substrate, corning 7059 glasses with low thermal conductivity were used. Onto each of those glasses, DLC60 (methane : hydrogen=20 : 60), DLC90 (20 : 90), and PSG films were deposited. Then nichrome was deposited by sputtering. A heat source and heat resistors were formed. After the heat source was turned on, the resistance of heat resistor was changed and the change rate was proportional to thermal conductivity of DLC and PSG films. The relative thermal conductivity was inferred from the changes in the resistance of Ni-Cr resistor. Figure 2 shows the measured thermal conduction characteristics of DLC and PSG films. The thermal conductivity of DLC film was improved by in-

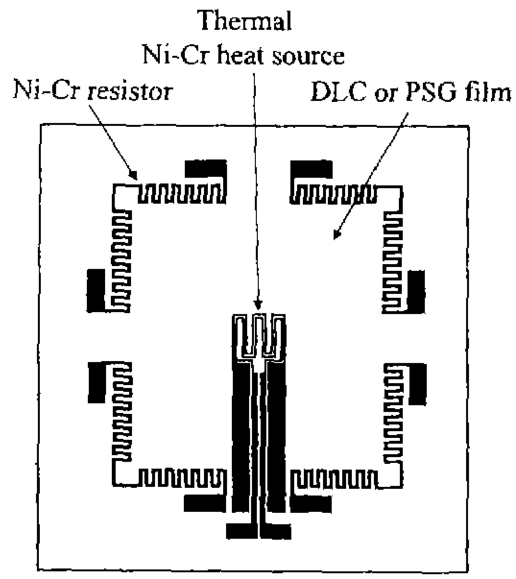

Fig. 1. Schematic structure for measuring thermal conduction characteristic of DLC film.

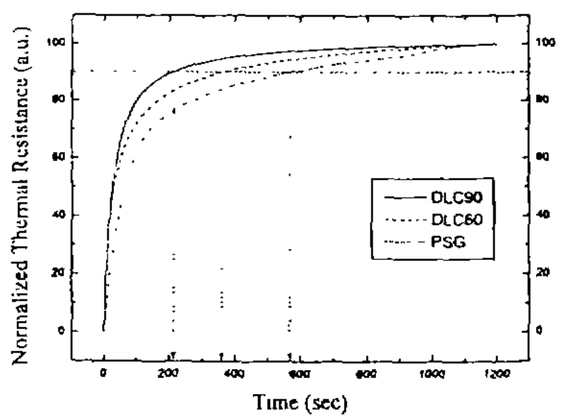

Fig. 2. Thermal conduction characteristics of DLC and PSG films.

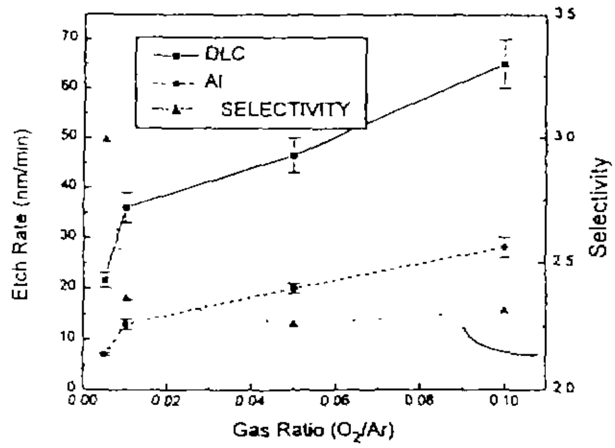

Fig. 3. Etch rates of DLC film and Al layer depending on O_2/Ar gas flow rate by RIE method.

Fig. 4. SEM image of the 5 μm pattern of DLC film by RIE method.

creasing hydrogen flow rate up to 90 sccm and was better than that of PSG film. As setting 90% of final resistor value standard, the resistance of DLC film reached to saturation level 1.5~2.7 times faster than that of the PSG film.

In this experiment, considering the fact that the normal wet etch process nearly can not be used for the patterning of DLC films because of its chemical inertness, the patterning techniques using the lift-off method and the Reactive Ion Etching (RIE) method are suggested. Because DLC films can be synthesized in room temperature, the thermal effect to photoresist, when synthesizing films, was almost neglibible. By using the lift-off method 8 μm patterns could be achieved successfully.

In the dry etch process, the RIE method was chosen. O_2 gas was used as react gas and Ar as inert gas was added to stabilize plasma. Aluminium was utilized as mask layers. The etch rate of aluminium and DLC films were investigated varying flow rate of O_2 gas from 1 to 20 sccm, while fixing Ar gas flow rate at 200 sccm (Figure 3). The DLC films had the etch rate 2,5~3 times higher than that of aluminum, and the selectivity increased as the gas flow rate of O_2 decreased. Figure 4 shows a 5 μm pattern of the DLC film by the RIE method using aluminium as mask layer.

For analyzing DLC films as passivation layers for power transistors, npn BJT transistors with the DLC films (DLC90, DLC120) were fabricated. The thermal characteristics of these transistors were compared with that of the transistor without passivation layers. The operation voltage between emitter and collector was varied from 0 V to 20 V and base current from 0.2 mA to 0.8 mA. The transistor was kept in operation for 20 minutes and the thermal stability of device was investigated. From the results (Figure 5), the current change was 4.3% for the case without any passivation layers, 2.1% for the DLC90, 1.45% for DLC120. It could be inferred that the stability of device was improved by the high thermal conductivity of DLC passivation layers. Also, the DLC film with higher hydrogen flow rate showed better thermal charac-

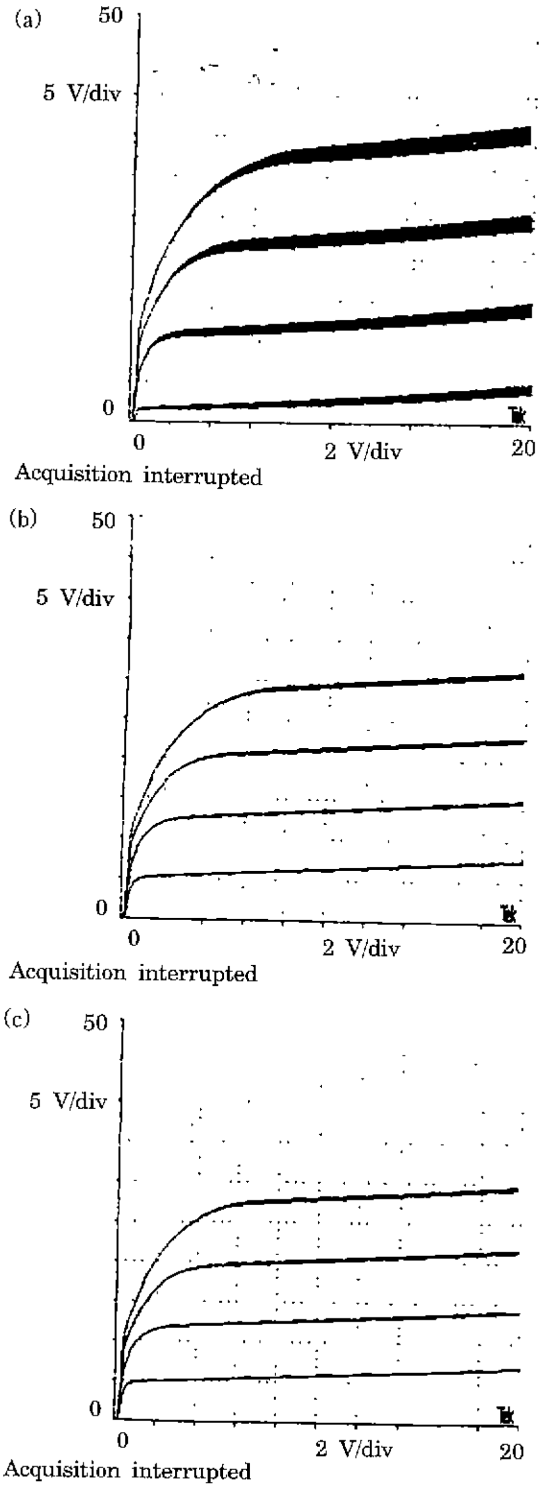

Fig. 5. Long-term stability of power transistors (a) without passivation (b) with DLC 90 film (c) with DLC 120 film.

teristic.

The breakdown voltage characteristic of each transistor by increasing bias voltage between emitter and collector is shown in Figure 6. For the transistor with no passivation layers, breakdown was occurred at 70 V while the transistors with DLC passivation layers performed stably even at 100 V.

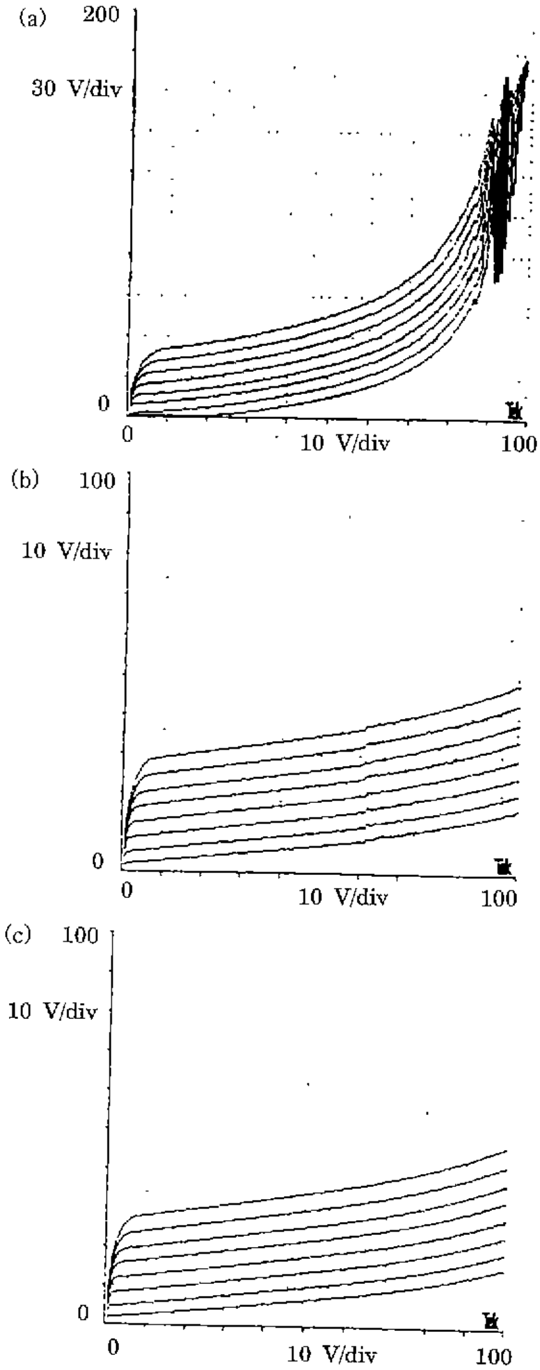

Fig. 6. Breakdown voltage characteristics of power transisters (a) without passivation (b) with DLC 90 film (c) with DLC 120 film.

III. Summary

DLC films were synthesized by using the PECVD method and their characteristics were investigated. Films with novel characteristics such as electrical resistivity, adhesion, and hardness were produced. The thermal conductivity of the DLC films was higher than that of PSG films. Also it was confirmed that the increase of the flow rate of hydrogen gas which is used in synthesis enhances the thermal conductivity. The patterning techniques of DLC films were developed. 8 μm patterns and 5 μm patterns were achieved by the lift-off method and the RIE method, respectively. Finally power transistor with DLC films as passivation layers was fabricated. Due to the outstanding thermal conduction characteristics of DLC films, the heat generated at the surface of transistor was effectively dissipated. This made the operation of power transistor stabilized and the breackdown voltage enhanced.

Acknowledgement

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