

PROPERTIES OF THE SiC/Si STRUCTURE PREPARED BY RAPID THERMAL ANNEALING OF AMORPHOUS HYDROGENATED CARBON LAYERS DEPOSITED ON CRYSTALLINE SILICON

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We investigated the SiC interface layer formation by the rapid thermal annealing (RTA) of a-C:H/c-Si (p-type) structures at 800, 1000 and 1200 °C for 3 minutes. The a-C:H layers, about 120 nm thick, were deposited by HF PECVD from methanol at a substrate temperature of 340°C. The creation of a SiC interface layer was established by Raman spectroscopy. I-V and C-V measurements showed the presence of a heterojunction.

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1. Introduction

Silicon carbide (SiC) layers are widely used in modern electronics. Its high thermal conductivity, wide energy bandgap and high breakdown electric field make silicon carbide a candidate of choice for high temperature, high speed, high frequency and high-power electronics. Ellison *et al.* [1] used a High Temperature Chemical Vapour Deposition reactor to grow SiC at 2100-2300°C using SiH₄ and C₂H₄ as reactants. The development of this technique is given in [2,3]. Several growth parameters have been suggested to influence the quality and properties of the SiC films [4-9]. The electrical characteristics of a rectifying polycrystalline Si/SiC heterostructure have also been investigated [10]

In this work we report the preparation of nanolayer SiC films by the Rapid Thermal Annealing (RTA) of carbon films on silicon substrates. The samples were investigated by Raman spectroscopy, capacitance-voltage (C-V) and current-voltage (I-V) measurements.

2. Experimental details

Amorphous hydrogenated carbon (a-C:H) layers were deposited on p-type crystalline silicon substrates by the h.f. plasma decomposition (at 27 MHz) of methanol (CH₃OH) vapour at a 340°C substrate temperature and 10 Pa pressure. During deposition, the DC self-bias voltage of the h.f. electrode was maintained in the range 650-750 V. A plasma reactor with a parallel electrode configuration was used. The samples were submitted to RTA treatment in the temperature range 800 to 1200 °C, for 15 to 300 sec, at a pressure of 6.6×10^{-3} Pa. The structures were investigated by Raman spectroscopy, C-V and I-V measurements. Both sides of the Al contacts were deposited by RF sputtering. The top Al contacts had diameters of 6×10^{-2} cm.

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3. Results and discussion

During the plasma decomposition process of the CH_3OH vapours, oxygen and carbon atoms and different C-H radicals are created in the plasma bulk. The oxygen atoms influence the a-C:H structure, because a $\text{C} + \text{O} = \text{CO}$ (reverse) reaction occurs on the layer surface during the deposition process. The graphite bonded carbon atoms react with O atoms more intensely than the diamond bonded ones. This is a reason for more detail structural investigation of the plasma deposited carbon layers from methanol.

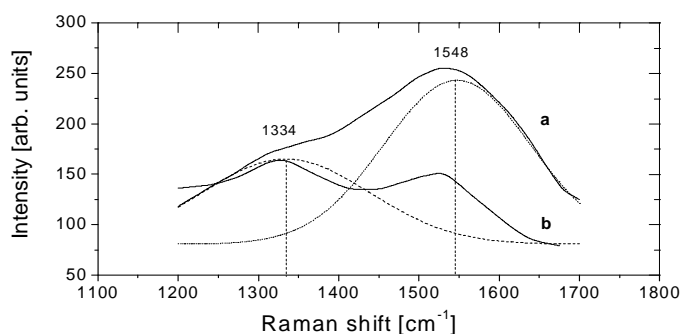


Fig. 1. Raman spectra of a 300 nm thick a-C:H layer. (a) as deposited; (b) after 1 hour temperature treatment in N_2 ambient at 1150°C .

The Raman spectrum of the 300 nm a-C:H layer is shown in Fig. 1a. The broad peak can be considered as a sum of two peaks with maxima around 1334 and 1548 cm^{-1} . The first of these corresponds to diamond bonded carbon atoms [1], while the position of the second is significantly displaced with respect to the band at 1580 cm^{-1} related to graphite bonded carbon atoms. This indicates that the structure of the a-C:H layer is complicated, and cannot be considered in terms of a diamond and graphite bonded carbon atoms only. The position of the peak at 1548 cm^{-1} depends on the number of diamond bonded carbon atoms and C-H bonds. Fig. 1b shows the Raman spectrum of the same layer measured after one-hour treatment at 1150°C in N_2 ambient. It can be seen that the peak at 1548 cm^{-1} is transformed into one at 1515 cm^{-1} , which corresponds to diamond-like carbon (DLC) [1]. The peak at 1334 cm^{-1} is more clearly pronounced, and its area becomes comparable with that of the peak at 1515 cm^{-1} . Hence, the high temperature treatment leads to structural changes resulting in an increase in the fraction of the diamond phase.

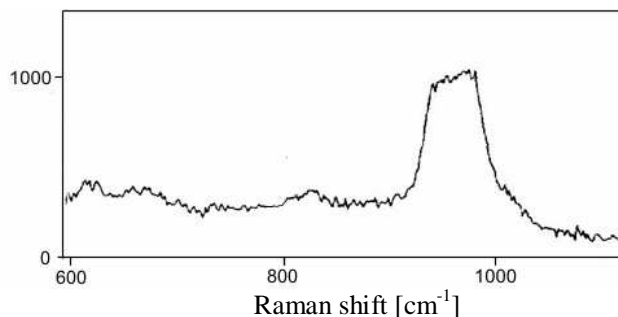


Fig. 2. Raman spectra of thin (5 nm) a-C:H layer after 3 minutes RTA at 800°C .

Also, after high-temperature treatment of the a-C:H/c-Si structure, a thin SiC interface region is created at the carbon-silicon boundary. Fig. 2 shows a Raman spectrum of a 5 nm carbon layers after 3-minutes RTA in vacuum at 800°C . The spectrum has a relatively broad but clearly pronounced maximum at about 1000 cm^{-1} , as is typical for 15R, 4H and 3C SiC polytypes [11].

C-V and I-V measurements of the a-C:H/c-Si (p-type) structure (with a 120 nm carbon layer thickness) were performed before temperature treatment, after 5 min O_2 treatment at 800°C and after

3 minutes RTA at 800, 1000 and 1200 °C. As can be seen from Fig. 3 (curves *a* and *c*), the c-Si interface surface region of the structures is in a depletion mode at zero voltage before RTA

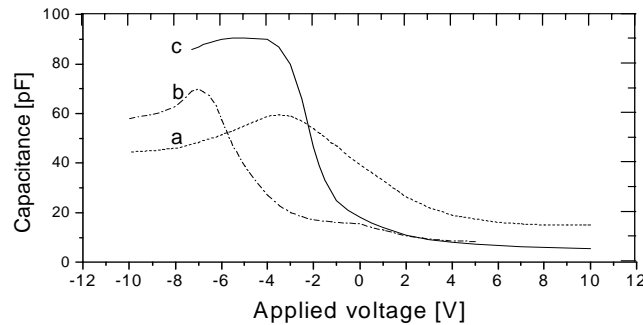


Fig. 3. Dependence of the capacitance on the applied voltage for various a-C:H/c-Si (p-type) structures: (a) as deposited (a-C:H layer thickness 120 nm); (b) after 3 minutes RTA at 800 °C in vacuum; (c) after 5 minutes treatment at 800 °C in O₂ ambient.

treatment and after 5 min O₂ treatment at 800 °C. The capacitance of the structure does not reach a minimum value when the applied voltage is increased. This behaviour is similar to that of a p-n junction. In our case, these C-V dependences correspond to those of a DLC/c-Si heterojunction. Fig. 3 does not show the C-V curves corresponding to RTA treated structures at 1000 and 1200 °C, because their dependences were similar to that shown. The presence of an interface SiC nanolayer between the DLC and the c-Si substrate leads to a decrease of the interface state density, because the slope of the C-V dependence increases and simultaneously the C-V curve displacement from the y-axis decreases after the high-temperature treatment in O₂ ambient and RTA at 1000 °C and 1200 °C. Therefore, an a-C:H/c-Si heterojunction is created in these processes.

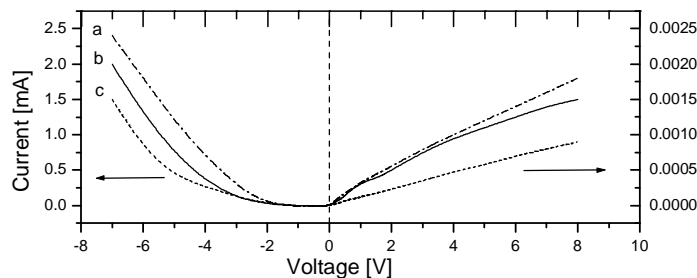


Fig. 4. I-V dependences of the a-C:H/c-Si (p-type) structures measured after RTA at different temperatures, of (a) 1000 °C; (b) 1200 °C; and (c) 800 °C. The forward direction corresponds to negative voltages.

After a 3 minutes RTA treatment at 800 °C (curve *b*), the structure is in an inversion mode at voltages in the -1 to 0 V range, because the value of the capacitance is constant. Therefore, an induced c-Si p-n junction at the a-C:H/c-Si interface occurs at these voltages. From this point of view, at negative voltage the behaviour of the structure is similar to that of a MIS (metal-insulator-semiconductor) structure. For this RTA treatment, positively charged states are created in the bulk of the a-C:H layer (perhaps the H-concentration in the layer bulk decreases, and this increases the concentration of defect states).

Fig. 4 shows the I-V dependences of structures measured after RTA treatment at 800, 1000 and 1200 °C. The reverse currents for all structures are relatively high (10^{-6} to 10^{-7} A) because a c-Si interface region with electron-dominated conductivity exists (as can be seen from the C-V dependences in Fig. 3). This region collects electrons from an area much larger than that of the electrodes. At the same time, the current in the forward direction is relatively low, due to the large serial resistance of the diamond like carbon layer, which is a wide band gap semiconductor. This also leads to a large voltage drop (approximately 2 V) across the structure in this direction.

The structure prepared by the 1000 °C RTA process has the lowest voltage drop and the largest current in the forward direction. From this point of view, 1000 °C is an optimal temperature for the formation of a SiC/c-Si hetero-junction by RTA treatment of the a-C:H/C-Si structure. Using XPS analysis, it has been established [12] that 1200 °C furnace treatment of the a-C:H/c-Si structure creates a SiC region with optimal stoichiometry.

4. Conclusions

High temperature (1150 °C) furnace treatment of a-C:H layers deposited by plasma deposition from methanol in an N₂ ambient leads to structural changes resulting in an increase in the fraction of the diamond phase.

After high temperature treatment (800 to 1200 °C) of the a-C:H/c-Si structure, a thin SiC interface layer is created.

After a 3 minute RTA process at 800 °C, positively charged states are created in the a-C:H layer bulk. It is assumed that the H-concentration in the layer bulk decreases, leading to an increase of the defect state density. At the same time, an induced p-n junction in the interface c-Si region exists at negative voltages in -1 to 0 V region.

The structure treated under a 1000 °C RTA process has the lowest voltage drop and the largest current in the forward direction. Therefore, 1000 °C is an optimal temperature for the formation of a SiC/c-Si hetero-junction by RTA treatment of an a-C:H/C-Si structure.

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