Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp567-568

Generation Mechanism of Photoemission-assisted Plasma on SiO_2(350 nm)/Si Substrate

Toshiteru Kaga[1], Shuichi Ogawa[1, 2], Hideaki Hozumi[1], Haruki Sumi[1], Motonobu Sato[2, 3], Mizuhisa Nihei[2, 3] and Yuji Takakuwa[1, 2]

[1] Tohoku Univ., 2-1-1Katahira, Aoba-ku, Sendai, Miyagi 980-8577, Japan
Phone: +81-22-217-5367 Fax: +81-22-217-5405 E-mail: kaga@mail.tagen.tohoku.ac.jp
[2] CREST・JST, Sanbansho bldg., 5 Sanban-cho, Chiyoda-ku, Tokyo 102-0075, Japan
[3] Fujitsu Ltd., 10-1 Morinosato-Wakamiya, Atsugi 243-0197, Japan

1. Introduction

Photoemission-assisted plasma chemical vapor deposition (CVD), which is one of the direct current discharge plasma CVD method combined with the UV irradiation, has been proposed for depositing diamond and DLC films [1]. In this plasma process, photoelectrons emitted from the substrate due to UV light irradiation are accelerated to decompose gases, so that the resultant plasma can be locally generated only above the substrate, enabling us to achieve high growth rate at low power consumption without no significant undesirable deposition of carbon onto the chamber walls and electrodes. To grow multi-layer graphene for the LSI interconnection by means of this process, we have to generate the photoemission-assisted plasma on thick SiO_2 layers used as interlayer dielectric films.

In this study, therefore, we investigated the generation mechanism of photoemission-assisted plasma on a SiO_2(350 nm)/Si substrate by measuring the discharge current versus bias voltage (I-V) characteristics as a function of Ar pressure. Our discussion is focused on the transmission process of UV light through a gas phase and SiO_2(350 nm) layer, and the escape process of photoelectrons through the SiO_2(350 nm) layer.

2. Experiment

The measurement of I-V characteristic was performed using a photoelectron-assisted plasma CVD apparatus designed for the 3-inch size wafer. Figure 1 (a) shows a block diagram of this apparatus which is equipped with facilities of UV light irradiation, sample heating, gas inlet and evacuation in addition to the DC power supplies and digital multimeter (DMM) for the I-V characteristic measurement. A Xe excimer lamp (USHIO, UER20H-172A: 172 nm) was employed as a UV light source. As shown in Fig. 1(a), the sample was negatively biased to accelerate photoelectrons emitted from the sample surface. The electrode applied positive potential has large openings enough for UV light to reach the surface by more than 90%.

The details of a sample heating part are given in Fig. 1(b). In this study, 3-inch SiO_2(350 nm)/Si wafers were used. The sample was mounted on a Mo holder placed on a vacuum hot plat made of SUS304, and fixed by a quarts retainer, making it possible to electrically bias only the sample surface against the electrode. Due to the photoemission-assisted plasma confinement condition of UV irradiation and bias voltage for the acceleration of photoelectrons, the photoemission-assisted plasma can be generated just above an opening area of the retainer as demonstrated in Fig. 1(c).

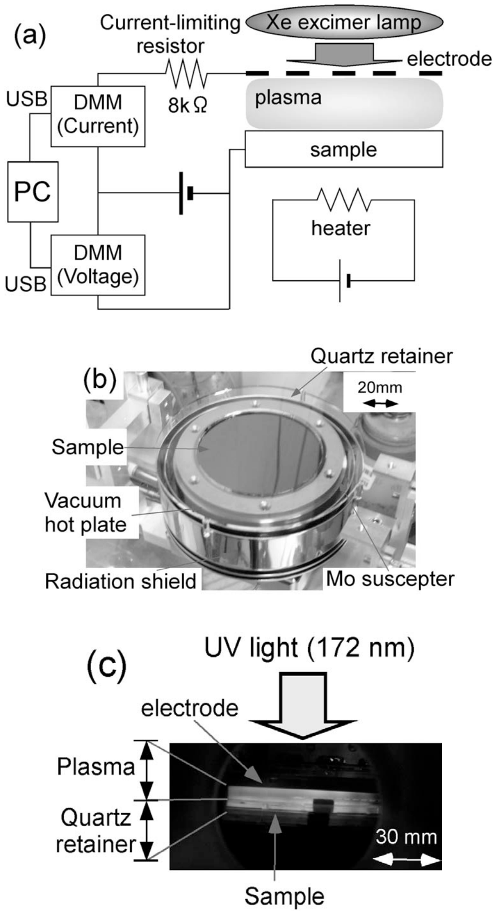

Fig. 1 (a) Block diagram of a photoelectron-assisted plasma CVD apparatus. (b) Photograph of a vacuum hot plate for 3-inch size substrates. (c) Photograph of a photoemission-assisted plasma appearing just above 3-inch Si wafer.

To avoid changing the surface chemical condition of a substrate by CVD growth during the course of I-V characteristic measurement, pure Ar of 99.9999% was employed as a source gas. Since non-doped Si substrates for SiO_2 growth were used, the sample was annealed at 200℃ to keep it electrically conductive. The sample bias voltage and

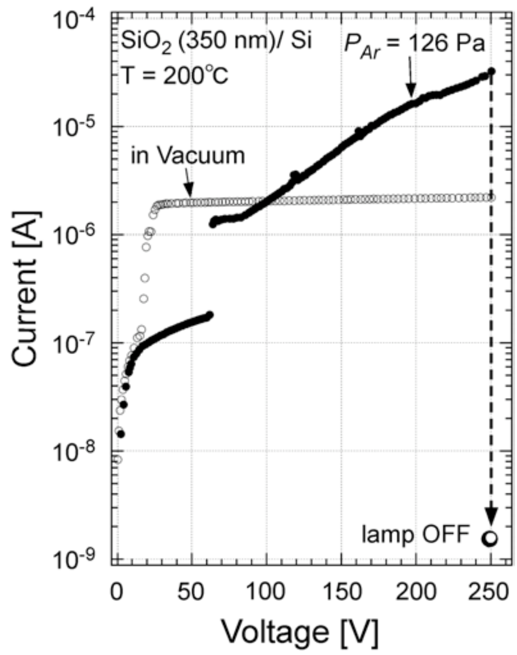

Fig. 2 Discharge current versus bias voltage (I-V) characteristic of photoemission-assisted plasma on SiO_2(350 nm)/Si substrate at an Ar pressure of 126 Pa (close circle) compared with that in vacuum (open circle).

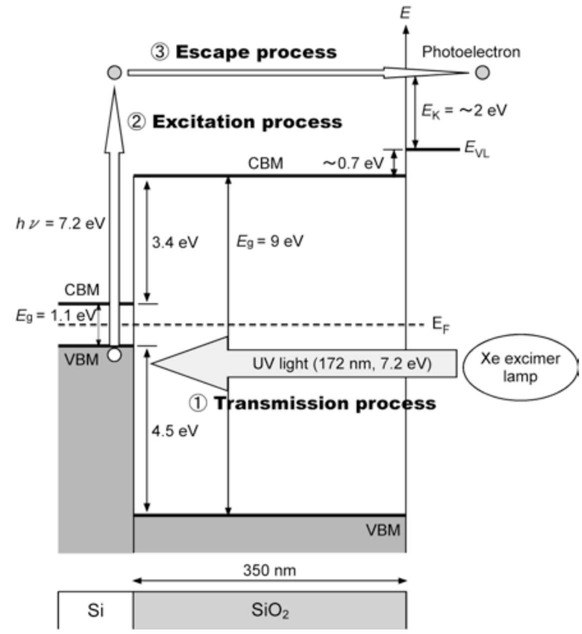

Fig. 3 Energy band diagram of SiO_2(350nm)/Si surface for no sample bias voltage. The photoemission mechanism is divided into three processes; ① UV light transmission process, ② photoelectron excitation process and ③ photoelectron escape process.

Ar pressure were changed in the region of 0-250 V and 50-5000 Pa, respectively.

3. Result and discussion

In vacuum, the current increases rapidly up to 30 V and then is almost constant as ~2×10^{-6} A independent of bias voltage, while it decreases down to ~10^{-9}A as shown in Fig. 2. It is noteworthy that photoelectrons can be emitted from the SiO_2(350 nm)/Si substrate with the current level of 10^{-6} A that is almost the same as for a metallic TaN surface. This finding has a great important meaning for generating the photoemission-assisted plasma above SiO_2 surface. This is because photoemission-assisted plasma could be effectively generated according to its principle [1] if a number of photoelectrons are sufficiently emitted from the substrate.

Next we consider the photoemission mechanism from the SiO_2(350 nm)/Si substrate in terms of the energy band diagram in Fig. 3. Since the energy band gap of SiO_2 is 9 eV, there is no significant photoabsorption of UV light ($h\nu$ = 7.2 eV) from Xe excimer lamp, so that the UV light can transmit through the SiO_2 film without absorption (process ① in Fig. 3), even though it is as thick as 350 nm. When UV light reaches the SiO_2/Si interface, valence electrons of Si can be easily excited to empty states (process ② in Fig. 3). Such photoelectrons can surmount the barrier height in conduction band minimum (CBM) between Si and SiO_2 (3.4 eV). When the bias voltage is applied between the substrate and electrode, the excited photoelectrons are accelerated to go through the SiO_2 film and then escape from its surface (process ③ in Fig. 3). Here, it should be noted that the electron holes are not exist in the valence band of SiO_2 because of no UV absorption in SiO_2. As a result, there is no recombination of photoelectrons during the course of escape. In addition, there is no inelastic scattering of them due to the energy band gap of SiO_2 larger than the kinetic energies of photoelectrons. Consequently most of the photoelectrons can escape from the SiO_2 surface, leading to a large photoelectron current of ~10^{-6} A. Based on this mechanism, it is possible to emit photoelectrons for rather thick SiO_2 film grown on Si substrate. However it is difficult to apply this plasma for the quarts plates with no Si substrate. Anyway, this result is of practical importance to grow multi-layer graphene on the interlayer SiO_2 film by the photoemission-assisted plasma CVD process.

Under Ar atmosphere at 128 Pa, the discharge current is smaller than that in vacuum between 0 to 60 V. However, it increases rapidly at 63V and then increases exponentially as shown in Fig. 2. Thus photoemission-assisted plasma can be generated the SiO_2(350 nm)/Si substrate. In fact, we have succeeded to grow the multi-layer graphene on SiO_2(350 nm) film with Ar-diluted CH_4 gas[2].

4. Conclusions

We have succeeded to generate the photoemission-assisted plasma on a SiO_2(350 nm)/Si substrate with pure Ar gas. The generation mechanism of photoemission-assisted plasma on the SiO_2(350 nm)/Si surface was discussed using the I-V characteristics.

References

[1] Y. Takakuwa: Patent GB2406173 (2006).

[2] S. Ogawa, H. Sumi, A. Saikubo, E. Ikenaga, M. Sato, M. Nihei and Y. Takakuwa, *Extended Abstracts of 2009 International Conference on Solid State Devices and Materials* (2009).