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Development and evaluation of the novel FAB gun

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Abstract

Argon fast atom beam (FAB) gun is used as a neutral atom beam irradiation source for surface activated bonding (SAB). Since SAB does not require any heat treatments, stress due to difference in thermal expansion coefficients does not occur, and the bonding between not only the same material but also different materials is realizable. However, the conventional FAB gun can be used for only short time because carbon abrasion powders are generated from the worn part of the inside walls of the gun due to argon ion sputtering. We developed the novel FAB gun applied magnetic fields and new position of the anodes in the gun to control the motion of the argon ions and reduce the sputtering. The design concept is that the magnetic fields guide both argon ions and electrons to the irradiation port of the gun and the argon atoms for the irradiation increased. In this study, we investigated the influence of the positions of the magnetic fields and the anodes on the plasma generation, the argon irradiation and the sputtering. With the novel FAB gun, the stable plasma is generated in the vicinity of the irradiation port, and the maximum irradiation amount is 3 times in comparison with the conventional design. Less sputtering of the inside walls of the gun was observed after the irradiation for more than thousands of minutes, while the sputtering with the conventional gun is more observed at the same condition.

Fast atom beam (FAB), Surface activated bonding (SAB), Room-temperature bonding, non-heat treatment, sputtering, abrasion

1. Introduction

Composite substrates improve heat conduction [1,2], ferroelectricity, ferromagnetism [3,4] and the like by directly bonding the support substrate and the functional layer. In order to produce this composite substrate, a bonding method called SAB is used [5, 6, 7]. In other bonding methods such as anodic bonding [8, 9] and diffusion bonding [10, 11, 12], it is necessary to heat treat. Therefore, distortion and stress are generated, and large damage is given to the device. However, SAB enables bonding by removing contaminants on the bonding surfaces by FAB irradiation and bringing activated surfaces into contact with each other [13, 14]. Since SAB can be performed at room temperature, bonding of dissimilar materials and high precision alignment are possible, additionally, it can be said that bonding is highly efficient [1, 13, 16].

The irradiation source of FAB that removes contaminants on the substrate surface is called FAB gun. Argon plasma is generated inside the FAB gun and irradiated as neutral atoms [17, 18]. Therefore, sputtering by argon ions is constantly performed inside the FAB gun, and the inner carbon walls are worn out. After repetitive operation, carbon abrasion powders generated from the worn parts adhere to the substrate surfaces, voids are generated at the bonding interface, and the bonding strength decreases. Therefore, it is necessary to frequently replace the FAB gun with a short life, and the bonding efficiency is poor.

In this research, based on the above, we aimed to develop a novel FAB gun that solves the problem of that the conventional FAB gun is short life. In this paper, we examine reducing the wear area of the inner wall of the FAB gun and increasing the irradiation amount of the argon atoms in order to extend the life of the FAB gun. Performance evaluation of the novel FAB gun developed based on this concept was carried out. Oxide film removal tests were carried out to evaluate the removal performance and the inner wall of the novel type FAB gun was observed after long-term use for lifespan evaluation.

2. Idea and development of novel FAB gun

In this study, we aimed to develop the novel FAB gun that realizes long life by applying magnetic fields inside the gun and changing the anodes arrangement. By applying a magnetic field, argon ions, which caused wear inside the conventional FAB gun, are guided to the irradiation port, and wear area of the inner wall caused by sputtering are decreased. Argon ions, which caused wear inside the conventional FAB gun, are guided.

In addition, the anode arrangement was changed in order to increase the irradiation amount of argon atoms. In the conventional FAB gun, most of the generated argon ions do not fly to the irradiation port but come to collision with the inner wall. In this study, we developed the novel FAB gun having the structure shown in the figure 1. It is expected that the novel FAB gun can reduce the wear area of the inner wall and greatly increase the irradiation amount of argon atoms.

3. Experiments

Argon FAB was irradiated for 1 hour to Si substrates having 1 μm oxide layer on the surface with the novel FAB gun to evaluate the removal performance of the gun. The removal depth of the oxide film on the Si substrate after the irradiation experiment were evaluated. We masked on a part of the Si substrate and defined the removal depth of the oxide film in that portion as zero. In addition, the irradiation experiment was carried out in a vacuum chamber, and the Si substrate with the oxide film was placed to face the irradiation port of the FAB

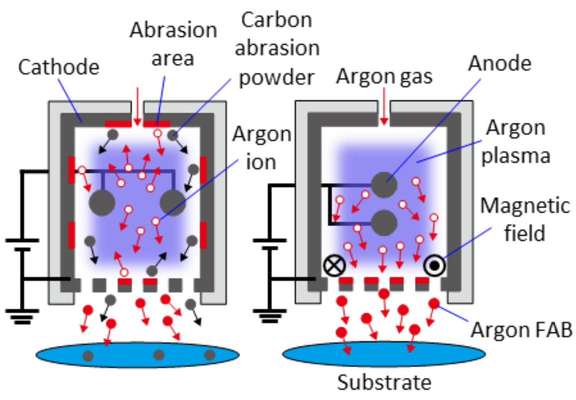

Figure 1. Schematic illustration of the inside of the conventional FAB gun (left) and the novel FAB gun (right).

gun. An observation window is provided on the side of the chamber, and the stability of the plasma can always be observed. We also examined the life of the novel FAB gun by observing the wear state of the inner wall of the gun after irradiation experiments.

4. Results and discussions

In this study, in order to perform evaluation of the novel FAB gun and to optimize structure of the gun in the future, the following parameters were defined, and irradiation experiments were carried out. While, as a result of experiment with the conventional FAB gun, maximum etching rate was 50 nm/h.

4.1. Position of magnetic field and anodes

The position of the magnetic field, which are near the irradiation port, opposite side, and the centre, the distance between anodes were changed to three levels, respectively, and a total of nine irradiation experiments were conducted. The results show that the irradiation amount increases as the position of the magnetic field is close to the irradiation port and as the distance between the anodes is narrowed. The plasma was observed in the vicinity of the irradiation port for all position of the magnetic field, and the plasma generation at the opposite side, when the opposite magnetic field was applied. It is considered that the magnetic field affects not only the motion of argon ions but also the plasma generation.

Regarding the distance between anodes, it seems to be due to the generation principle of plasma. Between the anode and the cathode, plasma is generated, and argon ions are accelerated. Thus, it is considered that a large amount of high energy argon ions is generated, and the removal amount of the oxide film is increased as the distance between the anode and the cathode is enough, or as the distance between the anodes is narrower.

Figure 2 shows the distribution of oxide film removal depth obtained when the maximum etching rate is the best among the 9 conditions. At this time, maximum etching rate up to 150.7 nm/h was achieved. This is about three times more than that of the conventional FAB gun (50 nm/h).

4.2. Evaluation of the lifetime of the novel FAB gun

In order to evaluate the lifetime of the novel FAB gun, the surfaces of the cathodes, which was the inner wall of the FAB gun, was observed after 5200 minutes irradiation experiments. The result showed that abrasion and presence of abrasion powder were not clearly confirmed. Although the lifetime of the conventional FAB gun was hundreds of minutes, it can be said that the lifetime of the novel FAB gun was more than five times longer than that of the conventional.

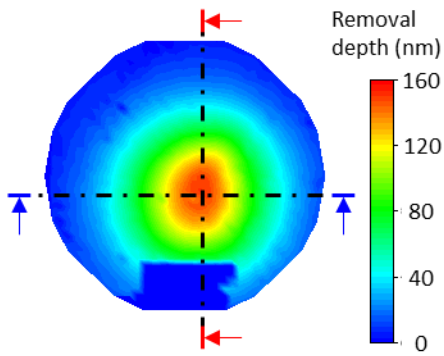

Figure 2. Distribution of removal depth of oxide film on Si substrate

5. Conclusions

In this study, we developed the novel FAB gun that solved the problem of that the conventional FAB gun was short life and evaluated the removal performance and the lifetime. For the novel FAB gun, it was expected to reduce the wear area and increase the irradiation amount by applying magnetic fields and arranging the anodes differently from the conventional FAB gun. We conducted irradiation experiments with the novel FAB gun and the Si substrates having the oxide film on the surfaces. The results showed that we achieved the maximum etching rate about 3 times higher than that of the conventional FAB gun. Also, abrasion was not clearly on the cathodes even after use for more than 5 times longer than the lifetime of the conventional FAB gun. From the above, the novel FAB gun indicated the possibility of achieving longer life as expected.

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