Improvement of Bonding Strength in Room Temperature Wafer Bonding using Surface Smoothing by Ne Beam

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Wafer direct bonding is a powerful technology for heterogeneous integration of ICs, micro electro-mechanical systems (MEMS) and so on. In the bonding process of these devices, high-temperature annealing is generally required [1]. However, the high temperature process often causes degradation of sensitive devices. Therefore, we have developed a surface activated room temperature bonding. The bonding process is based on inter-atomic bonds formation between two sufficiently clean and smooth surfaces [2]. The specimens are typically bonded in a vacuum after removal of surface contaminant layers using accelerated inert gas beam, as shown in Fig.1. Ar fast atom beam (FAB) has been used in the method. In this report, we examined applicability of Ne and Xe FAB as the inert gas beam for surface activation.

4 inch double side polished (100) Si wafer surfaces were used. FAB 104 (Atom Tech Ltd.) beam sources in a room temperature wafer bonding apparatus (MWB-12-ST : Mitsubishi Heavy Industries) were used for etching. Applied voltage and plasma current were about 1.8 kV and 100 mA, respectively. After FAB etching, the surfaces were bonded with an applied load of about 0.4 MPa in vacuum. The crack opening method [3] was used to measure the bonding energy.

With Ne and Ar FABs etching for 60 s, strong bonding comparable to the bulk strength was obtained. On the other hand, the bonding was weak in the case of Xe FAB etching. To explore the reason of this weak bonding, surfaces etched by each FABs were measured by Atomic Force Microscope (AFM). By Xe FAB etching for 600 s, 30 nm etching depth, the surface roughness increased from 0.18 to 1.37 nm rms. It is supposed that this degradation of the surface roughness resulted in the weak bonding. On the other hand, by Ar FAB for 600 s, 30 nm etching depth, the surface roughness increased only up to 0.33 nm rms. Surprisingly, the surface etched by Ne FAB kept the surface roughness of 0.18 nm rms even after etching for 1200 s, 30 nm etching depth.

From these results we examined the possibility of the surface smoothing by Ne beam. Ne FAB was irradiated to the rough surface produced by Xe FAB. Figure 2(a) shows an AFM image of the Si surface irradiated by Xe FAB for 1 min. Figure 2(b) and (c) show AFM images of the Si surface after subsequent Ne FAB irradiation for 3min and 20 min. Figure 3 shows the surface roughness change depending on the Ne FAB irradiation. Surface roughness of Xe beam irradiated surface was decreased from 0.40 down to 0.17 nm rms by Ne FAB irradiation for 20 min. Figure 4 shows the bonding energy depending on Ne FAB irradiation time. Without Ne beam irradiation, bonding between Xe beam irradiated rough Si surfaces was weak. The bonding energy increased by Ne FAB irradiation. With Ne FAB irradiation more than 5 min, bonding strength equivalent to the bulk materials was achieved. We concluded that the smoothing by Ne beam is applicable to the improvement of bonding energy for rough Si surface.

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References

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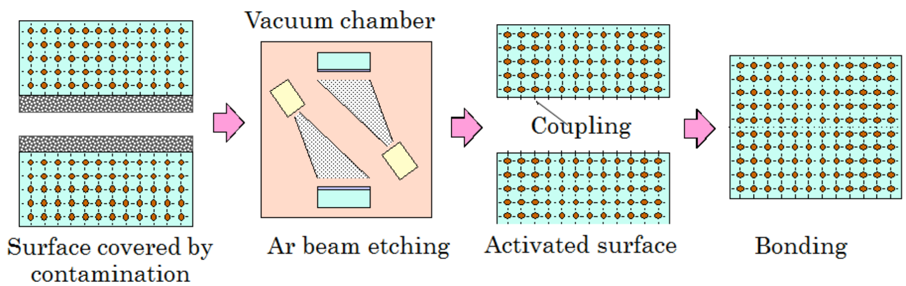
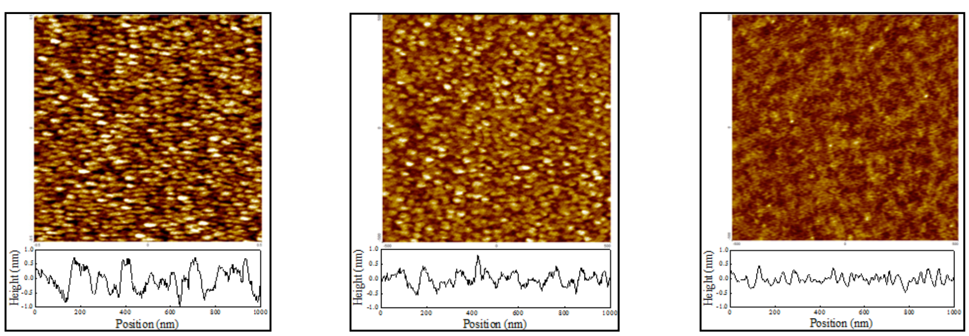


Figure 1: Conventional surface activated bonding at room temperature



(a) The rough surface produced by Xe beam *(b) After Ne FAB irradiation for 3 min* *(c) After Ne FAB irradiation for 20 min*

Figure 2: Surface morphology change by Ne FAB irradiation

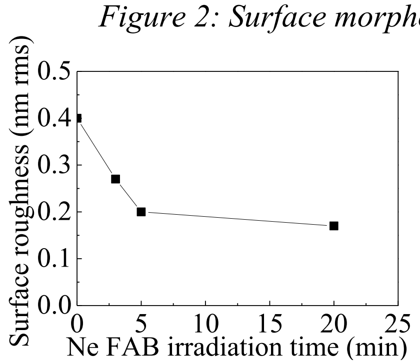


Figure 3: Surface roughness change by Ne FAB irradiation time

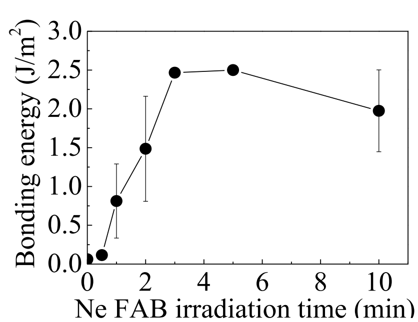


Figure 4: Surface energy change by Ne FAB irradiation time