Fabrication of 3D structure by double-angled etching with reactive gas cluster injection

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3D multilayer lever structure were fabricated by double-angled (±45º) etching with reactive gas cluster injection process. It is expected that the angled anisotropic etching process with reactive gas cluster injection will enable the creation of unprecedented structures for use in MEMSs or photonic crystals.

1. Introduction
For through-silicon via (TSV) or microelectromechanical systems (MEMSs) processing, anisotropic etching with high speed, high selectivity, and high precision is required. Plasma processes have generally been used for anisotropic etching [1], but the charge-up damage and mask etching by the irradiation with energetic ions from plasma still remain issues of concern [2,3]. Plasma-less, low-temperature dry processing with XeF₂ can avoid the damage caused by irradiation with energetic ions, but the process performs isotropic etching [4]. The reactive gas cluster injection process is a unique etching method that uses a neutral cluster beam, i.e. with un-ionized clusters. A gas cluster is an aggregate of 100–50,000 atoms or molecules, and when it bombards a local area, high-density energy deposition and multiple-collision processes occur simultaneously [5]. Accelerated cluster ions have been used in conventional cluster beam processes [6–8]; however, in the cluster injection process, neutral cluster beams of the highly reactive ClF₃ gas are used for Si etching. The ClF₃ gas is highly reactive with Si [9]. The kinetic energy of the neutral cluster beams is extremely low and its value is actually close to that of the thermal energy. Moreover, the divergence of the neutral cluster beams is low because there is no space charge effect. Therefore, the reactive gas cluster injection process can achieve anisotropic etching with high speed, high selectivity, high precision, and low damage [10–12]. Angled pattern etching with low damage can also be realized by this process. These characteristics indicate that a reactive gas cluster injection process can be applied to the fabrication of new types of MEMSs and photonic crystals.

2. Experimental
Figure 1 shows a schematic diagram of the ClF₃–Ar neutral cluster injection system for angled etching. For the formation of cluster beams, an adiabatic expansion of a high-pressure gas through a nozzle was performed. A ClF₃–Ar gas mixture was used as the source gas. The volume ratio of ClF₃ in the source gas was 3–9% and the source gas was at room temperature. The ClF₃–Ar gas mixture was fed into a conical nozzle in the pressure ($P₀$) range of 0.5–9 MPa. The orifice diameter of the conical nozzle was 0.05–0.1 mm. The pressure in the process chamber ($P_s$) was less than 10 Pa during the irradiation with the ClF₃–Ar neutral cluster. The incident angle of the cluster beam was 45 degree from normal to the sample surface and the target distance ($L_t$) between the nozzle and the sample was 13–70 mm.

Fig. 1 Schematic diagram of the ClF₃–Ar neutral cluster injection system for angled etching.
3. Results and discussion

SEM images of ClF₃–Ar cluster double-angled (±45°) etching (Lt = 70 mm) applied with scanning (18 × 18 mm²) to form three dimensional (3D) multilayer lever structure on a substrate coated with a 110-nm-thick Al mask are shown in Fig. 2. The Al mask was formed by the lift-off process. The volume ratio of ClF₃ in the source gas was 9%. The width, length, and intervals of the lever patterns were 10, 100, and 20 μm, respectively. The first angled etching time was 40 min and the second angled etching time was 40 min. The reactive gas cluster injection process can achieve a high etching selectivity of Si against the Al mask. The high-precision anisotropic etching with high aspect ratio was realized and 3D multilayer lever structure was fabricated. These results show that various 3D structures can be fabricated through multiple etchings with varying angles and directions. It is expected that the angled anisotropic etching process with reactive gas cluster injection will enable the creation of unprecedented structures for use in MEMSs or photonic crystals.

4. Summary

A reactive gas cluster injection system for angled etching was constructed and 3D multilayer lever structure were fabricated with double-angled (±45°) etching.

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