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Elimination of Curvature in Microelectromechanical-System Membrane

T. Sakata, K. Yamaguchi, N. Nemoto, M. Usui, F. Sassa, K. Ono, K. Takagahara, K. Kuwabara, J. Kodate, and Y. Jin
NTT Microsystem Integration Laboratories
3-1, Morinosato Wakamiya, Atsugi-shi, Kanagawa Pref., 243-0198 Japan
sakata.tomomi@lab.ntt.co.jp

The SOI (silicon-on-insulator)-based MEMS (micro electro-mechanical systems) are attracting a great deal of interest from the viewpoints of increasing fabrication accuracy, process simplicity, and device performance [1]. The recent rapid performance advances of MEMS devices, which frequently require nanometer-scale control of movable-membrane shape, have focused attention on the problem of the membrane deformation in microfabrication [2]. In optical MEMS devices, which frequently employ a free-standing membrane structure to reflect or diffract light, the out-of-plane deformation sensitively causes critical degradation of optical characteristics, such as coupling loss and crosstalk. Therefore, the deformation must be small in comparison to the optical wavelength of interest to avoid compromising device performance. This paper presents a process in which the curvature in the membrane structure can be eliminated by annealing and describes the mechanism involved.

In MEMS device fabrication, oxygen plasma exposure is often used to ash off an organic sacrificial layer and clean the surface. However, the process often cause the oxidization of the silicon membrane surface, which results in unexpected movement of the membrane due to the charge accumulated in the oxidized surface. Therefore, the oxidized surface has to be removed to prevent from such charge drift. Argon plasma exposure is usually used for this purpose, as shown in Fig. 1. In this process, we measured the shape of membrane with 4.5-μm thickness with white-light microscope-based interferometer (NewView™ 200; Zygo). The obtained shape is out-of-plane deformation, which is derived from the compressive stress in the membrane, and the curvature, ρ, was -3.4 m^{-1}, a value larger than before exposure, -1.0 m^{-1}. To suppress the curvature enhanced by argon plasma exposure, we examined an annealing treatment. Figure 2 shows the relationship between the curvature and annealing time at 500 °C in nitrogen ambient. The curvature decreased with annealing time, and after a two-hour annealing it saturated, ρ_∞ = -0.6 m^{-1}, which is slightly smaller than that of before argon plasma exposure. This difference might be related to the compressive stress due to the oxide layer. To investigate the difference in the surface state before and after annealing, we carried out a total-reflection X-ray fluorescence (TXRF) analysis. Figure 3 shows that there is argon on silicon surface before annealing and that there is no argon after it. This indicates that argon is implanted into the crystal lattice of silicon by argon plasma exposure and that there is a correlation between the curvature and implanted argon. Figure 4 shows the relationship between implanted argon concentration, obtained from the peak intensity in TXRF spectra, and the curvature change with the saturated one ($\Delta\rho = \rho_\infty - \rho$). It is found that there is a linear relationship between them. These results mean that curvature change of membrane increases in response of the argon concentration, and that the desorption of implanted argon by annealing causes the decrease of membrane curvature.

In summary, we clarified the relationship between curvature change in membrane and implanted argon concentration and demonstrated the elimination of curvature by annealing.

References

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[2] T. G. Bifano, et al., J. MEMS., **11** (2002) p.592.

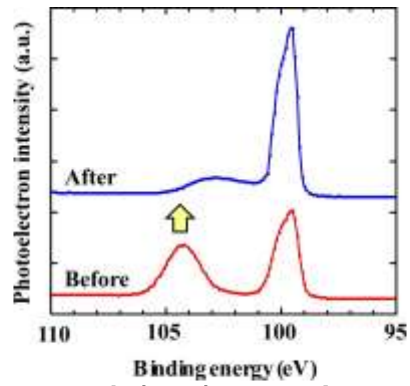

Fig. 1. XPS spectra before/after argon plasma exposure.

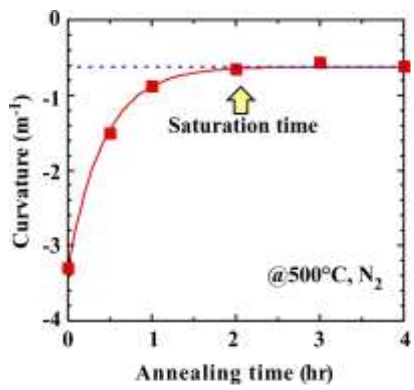

Fig. 2. Relationship between membrane curvature and annealing time.

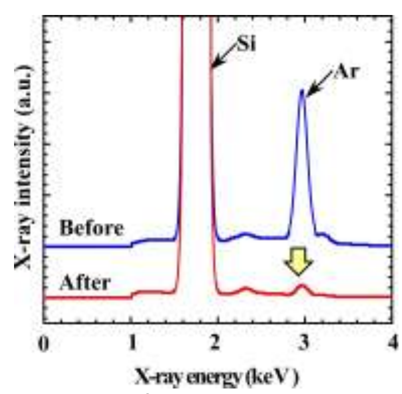

Fig. 3. TXRF spectra of argon-plasma-exposed Si surface before/after annealing.

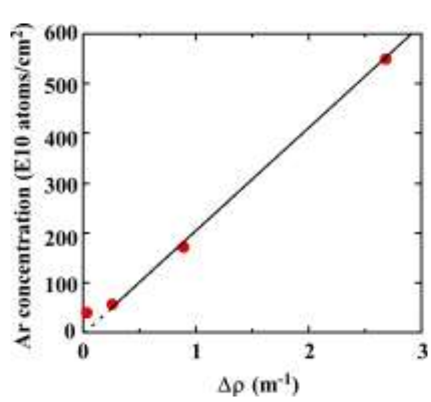

Fig. 4. Relationship between $\Delta\rho$ and implanted argon concentration.