Isotropical Dry Etching of Silicon with High Rate and Planarized Surface by Using SF$_6$ Plasma

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SF$_6$ プラズマを用いた平坦な表面の得られるシリコンの高速等方性ドライエッチング

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Introduction

High rate isotropical dry etching of silicon without rugged surface is necessary for micro-machining applications. Planarized surface could be obtained by using conventional plasma of CF$_4$ and O$_2$ mixed gas with low etch rate. With high rate condition, however, it is difficult to obtain planarized surface.

In this letter, SF$_6$ gas that is expected not to produce any deposition films was examined for silicon dry etching. By using SF$_6$ and employing inductively coupled plasma that can perform high plasma density under low pressure, high rate isotropical dry etching of silicon with planarized surface could be obtained.

Experimental

Schematic diagram of dry etching system is shown in Fig. 1. Etching gas of SF$_6$ was fed to a sample chamber from the top side of a quartz tube at a pressure of 0.05 Torr. Gas flow rate was 10 sccm. RF power of 13.56 MHz was supplied to a six-turn helical coil with 130 mm diameter wound around the tube and glow discharge was performed. The quartz tube was attached on the sample chamber made of stainless steel. A silicon wafer for etching was placed on the stage at a distance of about 100 mm under the lower end of the coil to reduce incidence of ions in the plasma. The wafer surface was etched by down flow of reactive neutral species.

Etched depth and surface roughness ($R_m$) were measured by stylus method using 2 µm radius tip. Optical emission from the discharge region was fed to a multi-channel spectroscopy via optical fiber and emission spectrum (OES) in the range of 250 to 800 nm was measured. The gases in the sample chamber were introduced into a quadrupole mass spectrometer (QMS) to evaluate the formation of species ranging in mass number from 1 to 200.

Wafers of 10×10 mm$^2$ size which were cut from an (100) oriented single crystal silicon were used for etching sample. Patterned nega-type photo resist (OMR 83 made by Tokyo Ohka Kogyo Co., Ltd.) was used for etching mask. Natural oxide film on silicon surface was removed by dilute HF solution just before the sample was set into the vacuum chamber.

Results and Discussion

High intensity spectral lines of F atom were observed at a wave length region over 600 nm. Spectral lines of H and O which seem to be caused by adsorbed water were also observed.

As a result of mass spectra measurement, decomposition products of SF$_6$ such as F$\sim$SF$_5$ were detected in case of gas flow without glow discharge. After turning on the discharge, reaction products such as SiF$\sim$SiF$_3$ and SOF$\sim$SiF$_3$.
increased as decrease of decomposition products.

Etch rate and roughness of etched surface were examined as a function of pressure in the range of 0.02 to 0.15 Torr after 10 min etching. RF power was 100 W and SF$_6$ flow rate was 10 sccm. The etch rate attained maximum as about 0.7 μm/min at a pressure of 0.05 Torr. Etched surface could be regarded as a mirror surface with less than 0.05 μm R$_{max}$ under the condition of maximum etch rate. Both dependence of OES intensity of F atom and QMS intensity of 19F on pressure were similar to that of etch rate on pressure. As pointed out in conventional etching using CF$_4$ plasma, silicon is etched by reactive F atoms.

As a next attempt, etch rate and surface roughness was evaluated at 5, 10, 20 and 30 min. Etched depth increased linearly with stable rate until about 20 μm for 30 min. Although the etched surface for 5 min was rough, the etched surface longer than 10 min became more flat less than 0.05 μm R$_{max}$. Examples of the rough and the flat surfaces are shown in Fig. 2. In the sample etched for 5 min, there is fine ruggedness at the horizontal surface corresponds to open area of etching mask but no ruggedness existed at side walls which corresponds to the area under the mask. Therefore, the surface roughness seems to be caused by fine dotted deposition products which were formed only at the early stage of the etching. During the etching, the dotted products were removed and rugged silicon surface was planarized. The dotted deposition products seem to be some kinds of silicon oxide caused by adsorbed water by reason as follows. High intensity spectral lines of H and O were observed immediately after the discharge was turned on but they decreased drastically in about 30 s. In order to confirm the influence of residual H$_2$O, etching was carried out after high vacuum evacuation using turbo-molecular-pump instead of using conventional rotary pump. The results of conventional and high vacuum conditions are shown in Table 1. OES intensity of H line (656.8 nm) which was measured immediately after the discharge was turned on became much lower at high vacuum condition. Etch rate at high vacuum condition was as high as conventional, however etched surface was much more flat. Surface roughness of conventional condition was different slightly from the value in Fig. 2 because adsorbed H$_2$O amount was not reproducible completely. The result of high vacuum condition indicates that the dotted deposition products can be regarded as some kinds of silicon oxide caused by residual H$_2$O.

**Conclusion**

Isotropical dry etching using SF$_6$ inductively coupled plasma was examined for silicon wafer. It was found that high etching rate of 0.7 μm/min with mirror like surface less than 0.05 μm roughness could be obtained.

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**References**

