Mechanism producing bowed profiles in the etching of low-k organic films

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Current ULSIs employ Cu metallization and low-k film to reduce the RC delay. In order to protect the environment and save energy, ASET is trying to develop new integration with ultralow-k film interlayer and a non-PFC dry etching process for these materials. Although a plasma process with a mixture of nitrogen and hydrogen is commonly used to etch organic low-k films, the etching mechanism is not well understood. In this study, we investigated this mechanism, with a special focus on the phenomenon of bowing in ultrasmall contact holes.

Figure 1shows how the profiles of holes etched with NH_3 NLD plasma depend on their diameter for two etching conditions: a high etching rate and a low etching rate. For holes more than 0.2 µm in diameter, the side walls are vertical; but for holes smaller than that, the profile is bowed, regardless of the etching rate. Even though the plasma density and ion energy are much higher for the high etching rate, the phenomenon of bowing appears just as for the low etching rate. This demonstrates that bowing is not related to the number of radicals or the ion energy, and strongly suggests that the main factor is the deposition of etch products on the side walls.

To confirm this supposition, a surface analysis of hole walls was carried out using micro AES. The samples were etched by two processes: one using N_2 plus H_2 and the other using NH_3; and the etching time was varied to yield partial etching (70%) and overetching (150%). Overetched holes were found to exhibit marked bowing. Figure 2 shows the analysis scheme. Observations were made at three points in the holes, which were either 0.15 µm or 0.5 µm in diameter, and also at points out of the holes to obtain information on the surface of unetched film. Peaks for C, Si, and N signals were obtained from the observations. Figure 3 shows the results; the Si and N peaks were divided by the C peak to remove sampling noise. For both etching processes, it is clear that narrow holes and overetched holes have less N than wide holes or partially etched holes. That demonstrates that bowing arises when there is insufficient deposition of N compounds. On the other hand, overetching produces much more Si on the side wall than partial etching. Moreover, the Si signal from overetched holes shows the presence unoxidized Si, while that from partially etched holes shows the presence of oxidized Si. That is, the oxygen contained in the SiO_2 mask or underlayer probably affects the deposition of N compounds on the side walls of holes.

To verify this inference, oxygen-free samples were etched under different conditions, namely, with a N-rich or a H-rich gas mixture. Figure 4 shows cross-sectional SEM images of the etched samples. For the N-rich process, the excess deposition of N compounds causes a tapered profile at the top of the hole and bowing in the middle, which results in a bottleneck shape. Although the N-rich process produces less bowing, the bottleneck is larger. In SiN mask samples, top of holes have a greater tendency to taper. Further analysis by micro AES shows that lower regions of holes have less N signal even in the both mask samples, moreover, SiO_2 mask sample has half amount of N signal than that of SiN mask sample. This obviously proves that bowed profiles are caused from luck of N compound deposition. We believe that positive control of the ion energy and the N_2/H_2 flow rate ratio during the etching processing can reduce the bowing and that holes with good profiles can be formed.

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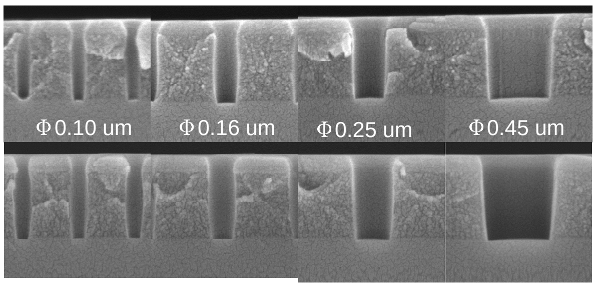

Fig. 1 Etch profile dependence on the hole diameter in the cases of different etch condition (upper high rate, lower low etch rate).

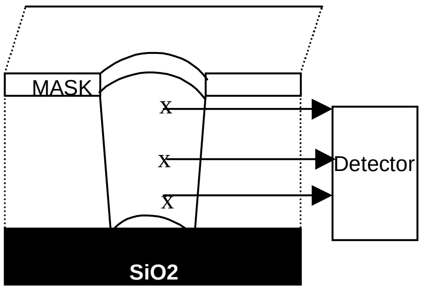

Fig. 2 Scheme of hole-wall analysis by u-AES

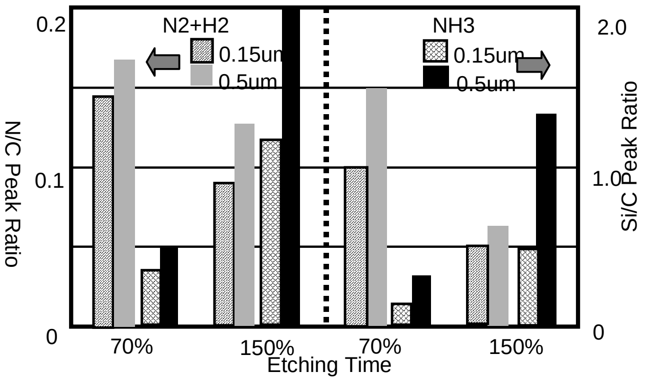

Fig.3 Result of the calculation

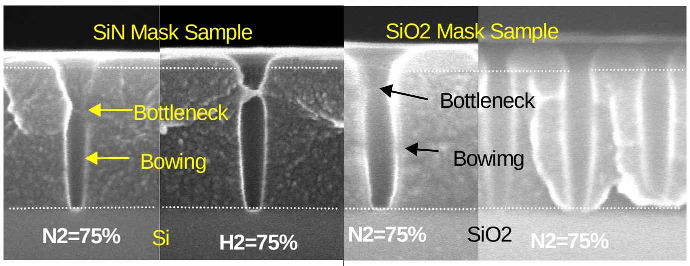

Fig. 4 Cross sectional view of SEM of 0.1um diameter holes etched under another gas mixture conditions