Sidewall Protection by Nitrogen in Anisotropic Etching of P-doped Poly-$Si_{1-x}Ge_x$

Hang-Sup Cho, Shinobu Takehiro, Masao Sakuraba and Junichi Murota*

Laboratory for Electronic Intelligent Systems, Research Institute of Electrical Communication, Tohoku University
2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan
*Corresponding Author: Tel&Fax: +81-22-217-5548
E-mail: murota@riec.tohoku.ac.jp

Polycrystalline(poly)-$Si_{1-x}Ge_x$ has become attractive as a gate electrode material of MOS devices to replace poly-Si, because it is possible to control the threshold voltage by variation of work function with Ge fraction (1). For application of poly-$Si_{1-x}Ge_x$ to MOS gate, highly anisotropic etching of poly-$Si_{1-x}Ge_x$ is required. In our previous works, it has been found that the sidewall etching of P-doped poly-Si was suppressed by the N_2 addition and highly anisotropic etching was performed, as shown in **Fig. 1** (2). In the present work, etching characteristics of P-doped poly-$Si_{1-x}Ge_x$ in $Cl_2/N_2/SiCl_4$ plasma are investigated, and the sidewall protection by nitrogen is discussed.

The dry etching of P-doped poly-$Si_{1-x}Ge_x$ was carried out using an electron-cyclotron-resonance (ECR) plasma etching apparatus. The total pressure of gases supplied to reactor chamber was 0.28 Pa, and the microwave power to generate plasma was 350W. A 400 nm-thick P-doped poly-$Si_{0.4}Ge_{0.6}$ film (P concentration: $1\times10^{20}cm^{-3}$) was grown at 550°C on the thermally oxidized Si wafer by ultraclean low-pressure CVD using a SiH_4-GeH_4-PH_3-H_2 gas mixture (3). After an 80 nm-thick SiO_2 mask was formed by CVD at 350°C, photolithography and wet etching, dry etching of P-doped poly-$Si_{1-x}Ge_x$ was performed. To investigate the effect of radical reaction on the sidewall etching, radical dominant etching was also examined using a shutter above the wafer (4). N and Si atom amount on the etched surface was evaluated by XPS.

Cross-sectional SEM images of P-doped poly-$Si_{0.4}Ge_{0.6}$ after the dry etching are shown in **Fig. 2**. It is found that, with addition of both N_2 and $SiCl_4$, the sidewall etching becomes smaller than that with N_2 addition. $SiCl_4/(SiCl_4+Cl_2)$ ratio dependence of the vertical and horizontal etch rates is shown in **Fig. 3**. In the case without N_2 addition, both the etch rates scarcely change with increasing $SiCl_4/(SiCl_4+Cl_2)$ ratio. In the case with N_2 addition, both the etch rates tend to decrease and the anisotropy becomes larger with increasing $SiCl_4/(SiCl_4+Cl_2)$ ratio. XPS spectra of Si*2p* and N*1s* for P-doped poly-$Si_{0.4}Ge_{0.6}$ after the radical dominant etching are shown in **Fig. 4**. With N_2 addition, Si*2p* peak with the chemical shift and N1s peak are observed, indicating the formation of the Si-N bond on the etched surface. On the other hand, with addition of both $SiCl_4$ and N_2, the intensities of Si*2p* and N*1s* peak drastically increase compared with either $SiCl_4$ or N_2 addition. It is considered that an ultrathin Si nitride film is formed on the surface by reaction of $SiCl_4$ and N_2 under the radical dominant etching. From these results, it is suggested that highly anisotropic etching of P-doped poly-$Si_{1-x}Ge_x$ is achieved by the protective Si nitride formation on the sidewall.

References

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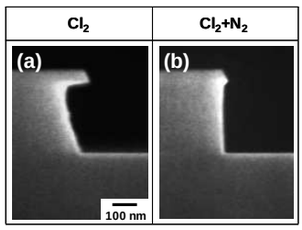

Fig. 1. Cross-sectional SEM images of P-doped poly-Si at 10% over etching (P concentration: $8\times10^{20}cm^{-3}$). The flow ratio of added N_2 to Cl_2 is 10%.

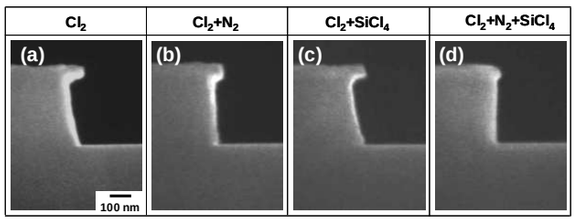

Fig. 2. Cross-sectional SEM images of P-doped poly-$Si_{0.4}Ge_{0.6}$ at 10% over etching. The flow ratio of added $SiCl_4$ and N_2 to Cl_2 is (b) 3%N_2, (c) 9%$SiCl_4$, and (d) 20%N_2+9%$SiCl_4$, respectively.

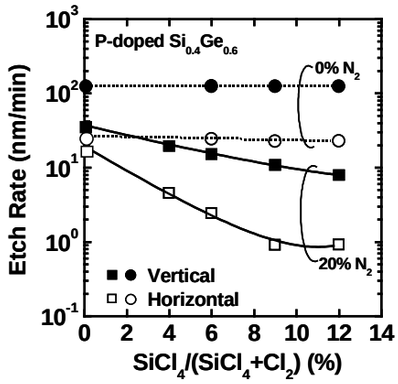

Fig. 3. $SiCl_4/(SiCl_4+Cl_2)$ ratio dependence of the etch rate with addition of $SiCl_4$ and N_2 for P-doped poly-$Si_{0.4}Ge_{0.6}$. The flow ratio of added N_2 to $SiCl_4+Cl_2$ is 0% and 20%.

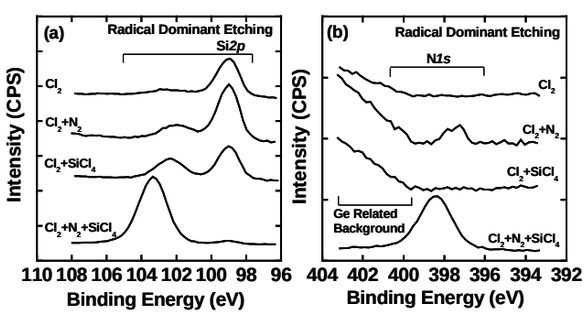

Fig. 4. XPS spectra of Si*2p* (a) and N*1s* (b) for P-doped poly-$Si_{0.4}Ge_{0.6}$ after the radical dominant etching. The flow ratio of added $SiCl_4$ and N_2 to Cl_2 is 9% and 20%, respectively.