Extended Abstracts of the 1992 International Conference on Solid State Devices and Materials, Tsukuba, 1992, pp. 418-419 **PD2-L12**

Side Etch Control of n^+-Polysilicon with Nitrogen Added Chlorine Plasma

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n^+–polysilicon etching with both high anisotropy and high selectivity has been realized in our previous work[1)] by irradiating the nitrogen added chlorine plasma under a low ion energy condition using an ultraclean ECR etcher. In the present paper, mechanisms of the side etch of n^+–polysilicon with pure and nitrogen added chlorine plasmas are discussed. 1100 and 4500 Å thick n^+–polysilicon films with mask SiO_2 films were etched with nitrogen added (<20%) chlorine plasmas under a highly selective condition at 4 mTorr using an ultraclean ECR plasma etcher described previously.[2)] The lateral etch length was determined by cross sectional SEM observation.

Etching characteristics at a just plus ~10% over–etch point are shown in Fig. 1. The effects of the nitrogen addition on the side wall protection have been explained by a competitive adsorption and reaction scheme using an equation similar to Langmuir's adsorption isotherm (see Fig. 1),[3)]

$$\mathbf{Etch\ Rate} = A \cdot C_{Cl}^{\,x} \,/\, (\,1 + B \cdot C_N^{\,y}\,)^x \qquad (1)$$

where **A**, **B**, **x**(=4), and **y**(=4/3) are constants and C_{Cl} and C_N are concentrations of chlorine and nitrogen radicals, respectively. The time (t) dependence of the lateral etch length is shown in Fig. 2. The lateral etch for pure chlorine etching (○, ●) proceeds linearly with time and it is almost independent of the n^+–polysilicon thickness. On the other hand, the lateral etch for nitrogen added etching proceeds $\sim t^2$ initially, and then changes to the linear dependence similar to that for pure chlorine etching. Thinner films (■, ▲) are etched faster in the $\sim t^2$ region than thicker films (□, △) in the case of nitrogen added etching. The lateral etch for the ~19% nitrogen addition (△, ▲) is less than that for the ~10% nitrogen addition (□, ■). When nitrogen flows through the thin spacing between gate oxide and mask SiO_2 films, the flow equation in the molecular flow regime (mean free path >> spacing, see Fig. 3) can be applied:

$$C \,/\, (\,a\,b + \sigma\,) \cdot \partial^2 C_N \,/\, \partial \ell^2 = \partial C_N \,/\, \partial t \qquad (2)$$

where **C** is the conductance of nitrogen through the spacing, and **σ** the correction factor for adsorption of nitrogen onto SiO_2. Equation (2) is analogous to a diffusion equation with a diffusion coefficient of **C/(ab+σ)**. Moreover, the conductance decreases with increasing the lateral etch length

$$C \propto (\,a\,b^2 \,/\, \ell\,) \cdot K \qquad (3)$$

where **K** is a geometrical correction factor. Therefore, nitrogen flow through the spacing can be suppressed harder for longer ℓ. This, in combination with Eq. (1), results in an increase in the lateral etch rate. Only a weak dependence $C_N \propto \sim t^{-1/4}$ may give $\sim t^2$ dependence of the lateral etch, which can be easily expected from Eqs. (2) and (3). Moreover, the adsorption of nitrogen onto the SiO_2 in the spacing ($\sigma \neq 0$) is expected, because the lateral etch length ratio for the two thickness shown in Fig. 2 was deviated from that expected from the simple conductance calculation without adsorption. On the other hand, the linear dependence of the lateral etch (a constant etch rate) means that chlorine supply through the spacing is sufficient for etching, indicating that **C/(ab+σ)** for chlorine is large.

In conclusion, the $\sim t^2 \rightarrow \sim t^1$ dependence of the side etch was observed in nitrogen added chlorine etching, which can be explained by nitrogen deficiency in the competitive reaction due to decreasing conductance through the thin spacing in the molecular flow regime. This study was carried out at the Superclean Room of the Laboratory for Microelectronics, and partially supported by Grant-in-Aid for Scientific Research, Ministry of Education, Science, and Culture, Japan.

References

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3)T.Matsuura, et al, in ULSI Science and Technology/1991, p.236.

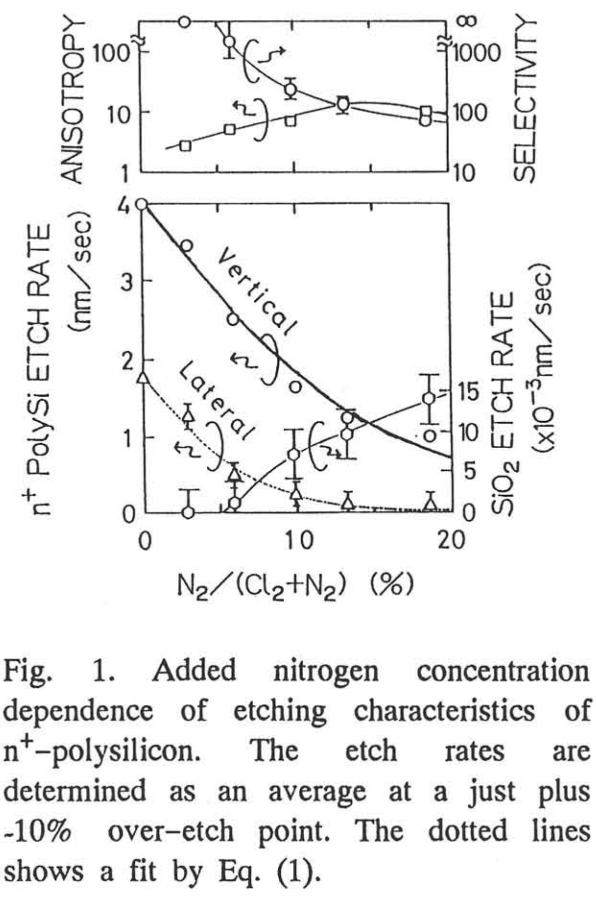

Fig. 1. Added nitrogen concentration dependence of etching characteristics of n$^+$-polysilicon. The etch rates are determined as an average at a just plus ~10% over-etch point. The dotted lines shows a fit by Eq. (1).

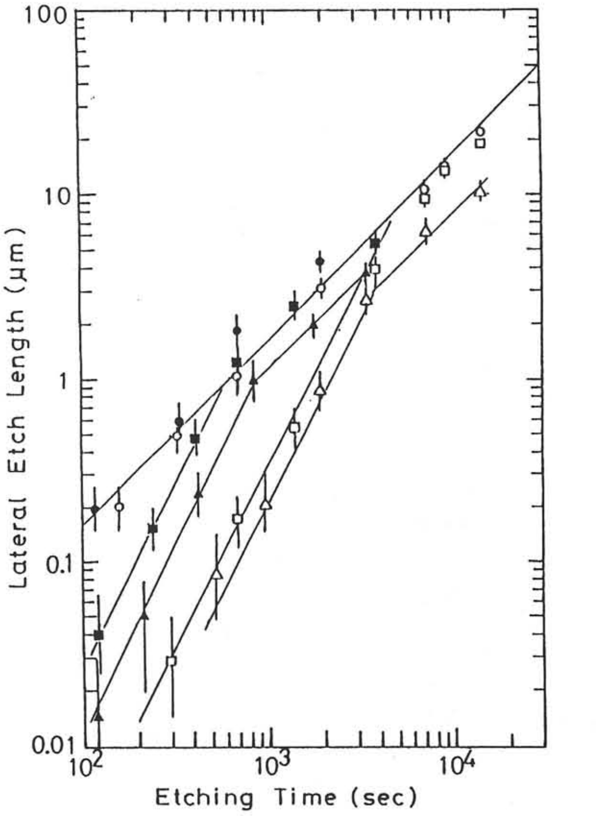

Fig. 2. Time dependence of lateral etch length of n$^+$-polysilicon for pure(○, ●), ~10%(□, ■) and ~19% (△, ▲) nitrogen added chlorine etching. Thickness of n$^+$-polysilicon is 1100 (●, ■, ▲) and 4500 Å (○, □, △).

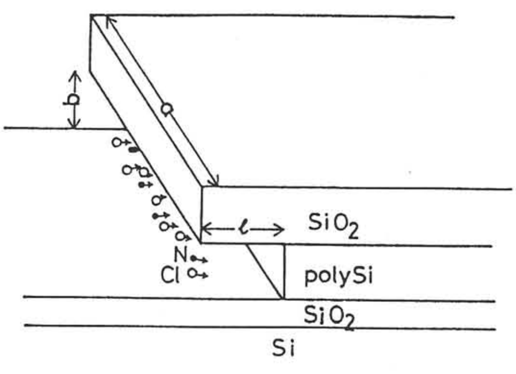

Fig. 3. Schematic of the side etch. Gas flow through the spacing between gate oxide and mask SiO_2 is in the molecular flow regime.