Plasma Etching of Silicon Nitride with High Selectivity over Silicon Oxide and Silicon in Fluorine Containing Plasmas

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Silicon nitride (Si_3N_4) is widely used in microfabrication processes as a dielectric and mask material. In CMOS technology, removal of Si_3N_4 film is a critical step as it represents a possible source of device damages. Possible overetch in the nitride processing may result in damages of a thin oxide and an underlying Si substrate through imperfections of the oxide. Thus high selectivity of Si_3N_4 etching over both Si and SiO_2 is strongly desired.

For plasma etching of Si_3N_4, usually gases containing fluorine are used. Several approaches to solve the problem of the etch selectivity have been analyzed. The use of gases promoting formation of polymer films on the surfaces was shown to favor the selectivity. In this case, the surface fluorination and subsequent material removal competes with the polymer formation on surfaces. The thickness of a steady-state polymer film depends essentially on a substrate material, so that under certain conditions it is possible to slow down or even stop completely the etching of Si. However, it is unlikely to obtain high Si_3N_4/SiO_2 selectivity using solely polymerization as it is an essential step for most known SiO_2 etch processes, which promotes the oxygen removal from oxide in the form of CO or CO_2.

Another approach is to use chemical dry etching (CDE) of Si_3N_4 with mixtures rich in O_2/N_2 [1]. In contrast to RIE, the synergistic effect of ion bombardment, which is known to enhance etching strongly, is not available in CDE. Instead, material removal occurs through purely chemical interactions occurring at the processed surface. In this case, the etching selectivity may be improved considerably by a proper choice of etching gases and reaction intermediates. In the lack of ion bombardment, etching of certain materials, which requires high activation energies, can be suppressed.

Our objective was to optimize Si_3N_4 etching using a RIE etcher. We were looking for plasma conditions providing not only an adequate surface chemistry but lower DC bias values as well. The results of Si_3N_4, SiO_2 and Si etching in fluorine-containing mixtures (CF_4/H_2, $CF_4/O_2/N_2$, $SF_6/O_2/N_2$, $SF_6/CH_4/N_2$ and $SF_6/CH_4/N_2/O_2$) are presented. The use of multi-component gas mixtures is essential as etching conditions for three different materials should be considered and optimized. For suppression of silicon etching, addition of gases promoting considerable oxidation and/or polymerization of the Si surface is necessary. The best results in terms of both etching selectivity and Si_3N_4 etch rate have been achieved with $SF_6/CH_4/N_2/O_2$ mixtures. Increasing gradually the O_2 content in the mixture, it was possible to improve strongly the Si_3N_4/Si selectivity without affecting the Si_3N_4/SiO_2 etch rates ratio, see Fig.1. A special attention was paid to the problem of plasma-induced structural damages. Results of the after-etch surface roughness measurements made by AFM are presented in Table1. Higher roughness was observed for oxygen-free plasmas. It is interesting to note that the processed surfaces become much smoother as soon as the etch front passes through the nitride and reaches the underlying oxide layer, see Table 1.

[1] B. E. E. Kastenmeier, P. J. Matsuo, G. S. Oehrlein, J. Vac. Sci. Technol. A 17 (6), 3179 (1999).

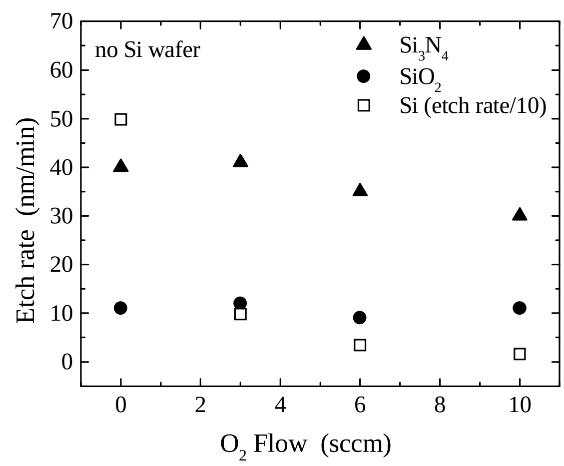

Fig. 1: Etch rates vs. O_2 flow in a $SF_6/CH_4/N_2/O_2$ plasma. Process conditions: RF power 50 W, SF_6 and CH_4 flow =10 sccm, N_2 flow 20 sccm, gas pressure 150 mTorr. Note the fast fall of the Si etch rate with small oxygen additions.

Gas mixture, sccm	*P*, W	*p*, mTor	U_{sb}, V	*t* , min	*R*A, nm	*R*B, nm
$15CF_4/10H_2$	75	40	550	3	12.0	2.0
$15CF_4/30O_2/30N_2$	50	150	319	4	0.8	0.5
$10SF_6/30O_2/30N_2$	75	150	162	5	3.3	1.6
$10SF_6/5CH_4/20N_2$	75	40	267	4,5	12.7	1.0
$5SF_6/20CH_4/20N_2$	50	150	89	3	3.1	2.7
$5SF_6/20CH_4/20N_2/5O_2$	50	150	122	5	-	0.5

Table 1: Surface roughness after plasma etching using different gas mixtures. Two kinds of samples were etched under the same conditions: A) a thick (500 nm) silicon nitride film, and B) a thin (100 nm) silicon nitride film, both deposited over a silicon oxide layers. Etching time in all processes was chosen to have the etch depth of about 110-120 nm, in order to reach the oxide surface for the samples B.

P - RF power, p – gas pressure, U_{sb} – DC self-bias, t – process time, RA and RB– rms surface roughness after etching for samples A and B, respectively.

Note the higher roughness obtained for the oxygen-free processes, and a strong difference between samples A (nitride surface) and B (oxide surface) for these processes.