Cryogenic processes for advanced material plasma etching

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Cryogenic etching of silicon was first introduced in the end of the 80ies by a Japanese team [1]. The standard cryogenic process consists in using a low pressure plasma mixture of SF_6 and O_2 interacting with a silicon substrate cooled down to a low temperature of typically -100℃. In the presence of oxygen, a SiO_xF_y passivation layer forms and remains stable at low temperature preventing lateral etching of sidewalls. This passivation layer desorbs when the wafer is warmed back up to ambient temperature [2]. This effect provides clean sidewalls of the microstructures after etching.

Some dedicated experiments were performed to clarify the involved mechanisms in the passivation formation and desorption [3]. SiF_4 by-products can play an important role in the formation of the SiO_xF_y film. Two different mechanisms were evidenced and will be presented at the conference. We showed that oxygen and fluorine diffusion during the wafer warm up leads to the formation of SiF_4 volatile compounds, correlated with the desorption of the passivation layer [4].

These characterization experiments allowed us to develop the so-called STiGer process [5]. It consists in alternating passivation and etching steps, like in the well-known Bosch process [6]. However, in the STiGer process, SiF_4/O_2 plasma is used instead of C_4F_8 plasma for the passivation steps. But the SiO_xF_y layer forms only when the wafer is cooled to a very low temperature. In the STiGer process, there is no deposition on the reactor walls, because they remain at ambient temperature. As a consequence, it is not necessary to clean them regularly after each etching process like in the Bosch process. Compared to the standard cryoetching, the STiGer process is also more robust and provides more reproducible profiles [7].

Cryogenic etching processes in SF_6 and SF_6/C_4F_8 plasmas were successfully applied to porous organosilicate glasses. Such materials are low-k candidates for advanced interconnects. Their integration is very challenging because of plasma induced damage. These two chemistries have demonstrated a promising capability of significantly reducing the damage caused by plasma etching. Desorbed species were analyzed during the wafer warm-up from cryogenic to room temperature by in situ mass spectrometry. An equivalent damage layer (EDL) was evaluated by ex-situ Fourier transform infrared (FTIR) spectroscopy and in situ ellipsometry. Anisotropic profiles were obtained using both chemistries. The selectivity is enhanced using SF_6/C_4F_8 process at low temperature. [8]

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