Silicon nanostructures with negatively tapered profile by ICP-RIE

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Depending on the application, a good control of the silicon etch profile is a key requirement for a successful process. Most of the research efforts on Si plasma etching have been focused on the obtaining of perfectly vertical sidewalls with high aspect ratio structures [1,2]. However, only few studies in the literature were reported regarding the means of obtaining structures with negatively tapered profile [3-5] which can be used for many applications such as water and oil repelling surfaces, Si nanowires for single electron or multi-gate transistors, or for lateral re-entrant AFM tips fabrication.

Previous work in our group demonstrated the obtaining of Si nanostructures with a very large positively tapered profile by increasing the gas flow ratio of C_4F_8/SF_6 [6]. However, by gradually decreasing the gas flow ratio, we obtained an undercut profile (i.e. positively tapered or curved profile after mask removal) due to insufficient sidewall passivation by C_4F_8 and isotropic etching by SF_6, rather than a negatively tapered profile.

In this work, after extensive etching parameter fine tuning, Si structures with a negatively tapered profile (8-10°) have been achieved. The influence of the plasma etching parameters, especially the RF power and C_4F_8/SF_6 gas flow ratio, on the etching rate and sidewall angle had been studied using Cr as mask that was fabricated by standard electron beam lithography and liftoff. The plasma etching was carried out using an Oxford 380 ICP-RIE, with the total gas flow fixed at 60 sccm, ICP power 1200 W, pressure 25 mTorr, and time 10 min. These results were demonstrated on different structures sizes of diameter 500 nm, 700 nm, and 1.2 μm.

The effect of the RF power was studied at a fixed gas flow of C_4F_8/SF_6=40/20. The Si etch rate remains almost constant at 280 nm/min for RF powers between 45 W and 120 W, with the sidewall taper angle decreasing considerably from 3.06° at 45 W to -2.2° at 60 W, then to saturate at approximately -3° between 80 W to 120 W. Thus tuning the RF power alone didn't give a large negative taper angle (-8 to -10°). Figure 1 showed the silicon structure obtained at RF power of 120 W with taper angle of -3.63°.

Then we studied the effect of gas flow ratio at different fixed RF power. At optimal RF power of 60 W, increase of SF_6 from 20% ($C4F_8/SF_6$=48/12) to 40% (C_4F_8/SF_6=36/24) increased the etching rate from 128 nm/min to 558 nm/min, and decreased the taper angle considerably from 4.46° to -9.79° (see Figure 2). Figure 3 shows examples of unique structures etched at 60 W RF power and different SF_6 gas flows.

[1] C. K. Chung, H. C. Lu, and T. H. Jaw, *Microsystem Technologies*, 6, 106-108 (2002).
[2] C. Con, J. Zhang, and B. Cui, *Nanotechnology,* 25, 175301 (2014).
[3] P. Harvey-Collard, A. Jaouad, D. Drouin, and M. Pioro-Ladrière, *Microelectron. Eng.,* 110, 408-413 (2013).
[4] A. Susarrey-Arce, A. G. Marın, S. Schlautmann, L. Lefferts, J. G. E. Gardeniers, and A. van Houselt, J. *Micromech. Microeng*. 23, 025004 (2013).
[5] G. Dahlen, M. Osborn, N. Okulan, W. Foreman, A. Chand, and J. Foucher, *J. Vac. Sci. Technol. B,* 23, 2297 (2005).
[6] F. Saffih, C. Con, A. Alshammari, M. Yavuz, and B. Cui. *J. Vac. Sci. Technol. B,* 32, 06FI04 (2014).

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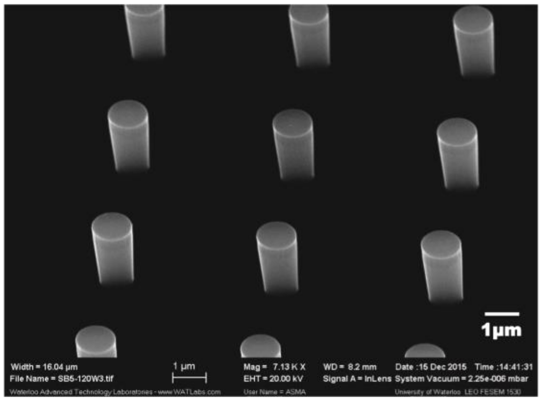

Figure 1. SEM image of Si structures obtained at 33% of SF_6 (C_4F_8/SF_6=40/20) and RF power of 120 W, showing a negative taper angle of -3.63°.

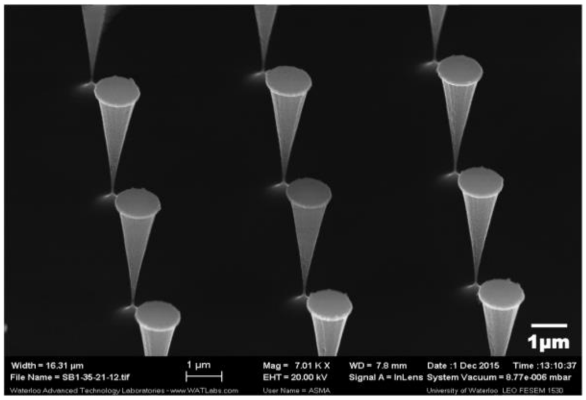

Figure 2. SEM image of Si structures obtained at 40% of SF_6 and RF power of 60 W, showing a large taper angle of -9.7°.

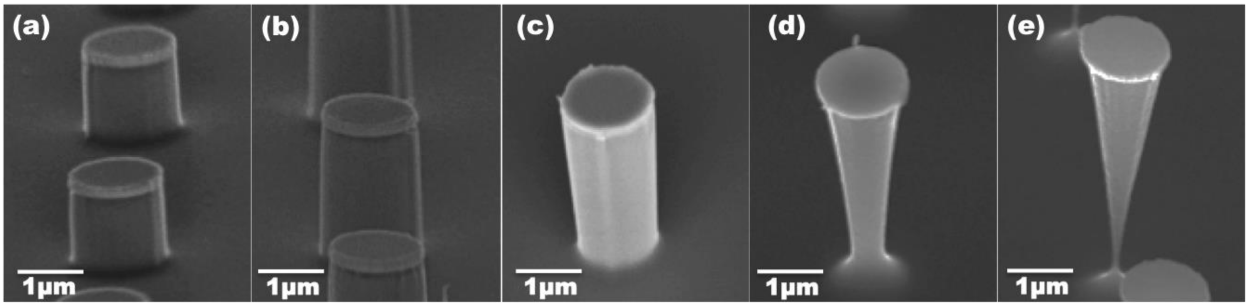

Figure 3. SEM images of Si structures (Cr mask still on) as a function of SF_6 gas flow percentage in the C_4F_8/SF_6 mixture with respective taper angles: (a) 25% of SF_6 (4.4°), (b) 30% of SF_6 (3°), (c) 33% of SF_6 (-4.6°), (d) 38% of SF_6 (-8.5°), and (e) 40% of SF_6 (-9.7°).