Effect of oxygen plasma cleaning on non-switching pseudo-Bosch etching of high aspect ratio silicon pillars

Aixi Pan, Ferhat Aydinoglu, Bo Cui
Department of Electrical and Computer Engineering, University of Waterloo
200 University Ave. West, Waterloo, ON, N2L 3G1, Canada
a22pan@edu.uwaterloo.ca

Dry etching of silicon is widely used in nanostructure fabrication, as it works better than wet etching due to high anisotropy and selectivity[1]. The long-term goal of dry etching is to obtain nanostructures with high aspect ratio and high etching rate at the same time[2], so non-switching pseudo-Bosch recipe was introduced to this area[345]. Two gases are used in this process. The first one is SF_6 to etch silicon, and the second one is C_4F_8 to deposit a chemically inert passivation layer. However, one of the challenges in non-switching pseudo-Bosch process is the formation of contaminations such as excess passivation residues and silicon fragments produced during the process that will influence the etching rate and profile of structures[6]. In order to obtain high aspect ratio structures with high etching rate, an advanced process is required.

In this work, the etching process is divided into many discontinuous steps/cycles, with cleaning steps using oxygen plasma inserted in-between these etching steps. Oxygen plasma can effectively remove the contaminations without significant attack of silicon and chromium mask[7]. In the experiment, e-beam lithography and lift-off of chromium was performed for forming the hard mask, then non-switching pseudo-Bosch process was carried out. We prepared eight samples with different combinations of etching step and cleaning step as shown in Table 1. The total etching time in every combination is fixed at 2400 seconds. In the etching step, the gas flow ratio of C_4F_8 and SF_6 is 42/18, with ICP power 1200W, RF power 20W, pressure 10 mTorr; and in the cleaning step, the O_2 gas flow is 20 sccm, with ICP power 1200W, RF power 20W, pressure 10 mTorr. All samples were first cleaned with 60 sec oxygen plasma before the real etching started.

Etched pillars are presented in Figure 1 and the detailed information is shown in Table 2. From sample (a) to (f), the results show that more frequent cleaning gave higher etching rate and aspect ratio. However, too frequent cleaning (sample g and h) led to worse result, such as lower etching rate likely due to excess surface oxidation by oxygen plasma knowing that oxide is harder to etch than silicon, and too much lateral etching causing mask falling off likely due to the excess removal of sidewall passivation layer.

In summary, an optimized number of oxygen plasma cleaning steps inserted to the non-switching pseudo-Bosch process can help to reduce polymer contamination, leading to higher etching rate and higher aspect ratio structures at no cost.

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Sample/Process	O2 Cleaning(sec)	# of Cycle	Etching step(sec)	Oxygen step(sec)
Sample (a)	60	1	2400	60
Sample (b)	60	4	600	30
Sample (c)	60	8	300	20
Sample(d)	60	13	180	10
Sample (e)	60	20	120	10
Sample (f)	60	40	60	10
Sample (g)	60	80	30	10
Sample (h)	60	160	15	5

Table 1. The combinations of different etching steps and oxygen cleaning steps.

	Pillar height(µm)	Average pillar base diameter(µm)	Aspect ratio
Sample (a)	5.41	1.088	4.973
Sample (b)	7.04	1.380	5.105
Sample (c)	8.13	1.211	6.716
Sample(d)	8.63	1.409	6.131
Sample (e)	8.01	1.121	7.164
Sample (f)	9.33	1.275	7.321
Sample (g)	6.35	1.097	5.795
Sample (h)	4.42	-	-

Table 2. The detailed size/shape information for sample (a) to (h).

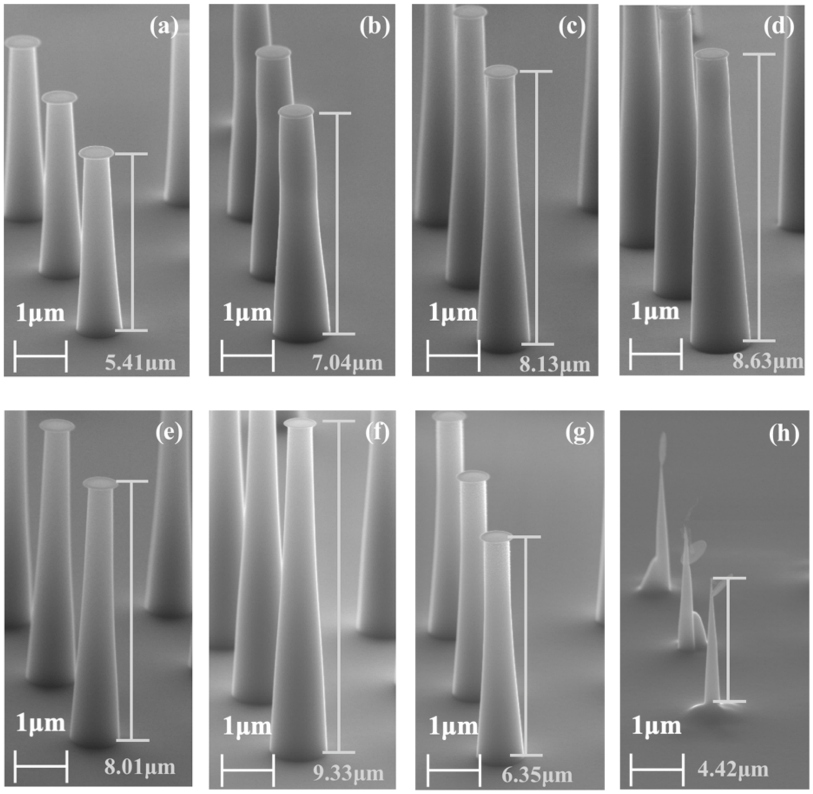

Figure 1. SEM images of silicon pillars etched using steps shown in Table 1.