Process characterization of inductively coupled plasma etched silicon nanopillars by micro-Raman

G. M. Laws, A. Handugan, T. Eschrich, P. Boland, C. Sinclair, and S. Myhajlenko
Center for Solid State Electronics Research, Arizona State University, Tempe, AZ 85287, USA

C. Poweleit and J. Menendez
Department of Physics, College of Liberal Arts and Sciences, Arizona State University, Tempe, AZ 85287, USA

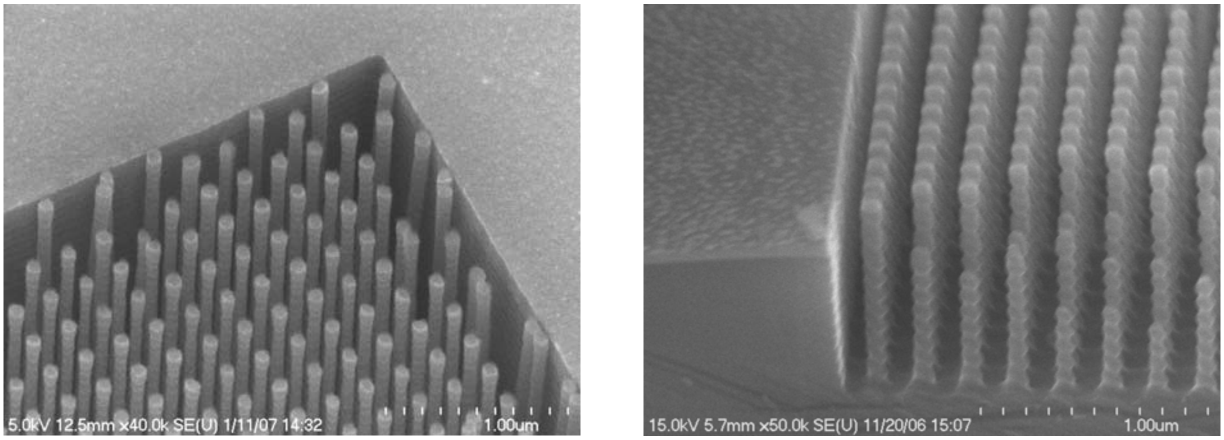
The attributes and application of silicon nanopillars have been extensively investigated over the past decade or so. A promising recent development is the vertically integrated nanowire field effect transistor that offers continued downscaling opportunities for future CMOS-related integrated circuits[1]. Nanowire-based transistor performance is thought to be strongly influenced by surface roughness viz. additional scattering and quantum interference effects[2]. Many challenges remain in order to fully implement nanostructures into mainstream semiconductor technology such as, characterizing the impact of semiconductor processing on the properties of individual and nanopillar arrays.

To this end, a conventional top-down fabrication procedure using electron beam lithography incorporating cold development and advanced reactive ion etching protocols was used to fabricate an array of silicon nanopillars with scalloped and smoothed sidewalls. High density nanopillar fabrication using plasma etch processes presents a number of challenges[3]. An inductively coupled plasma advanced silicon etcher was optimized to produce nanopillars with diameters ranging from 50 nm to 100 nm with aspect ratios up to 20:1, see Fig.1. However, due to the inherent "scalloped" nature of the etched profile produced by the BOSCH process, the nanopillar sidewalls have an undulating appearance. To address the scalloping, a plasma-based technique has been developed to both smooth and reduce the overall diameter of the nanopillar. This has the potential of improving the electrical properties of the structure and enhancing the quantum effects. An example of plasma smoothing of the nanopillars is depicted in Fig.2.

In order to characterize the properties of the nanopillars and the effects of processing we have investigated the use of micro-Raman. Recent work suggests this optical technique has promise since it is sensitive to the lattice microstructure[4]. Preliminary Raman measurements comparing bulk and nanopillar structures are shown in Fig.3. The results suggest a correlation between the Raman signal and the attributes of the as-etched pillars. For example, in comparing the nanopillar region with the bulk silicon, the spectral linewidth has increased and a low energy shoulder has appeared in the 510 cm^{-1} region consistent with expectations of reduced dimensionality.

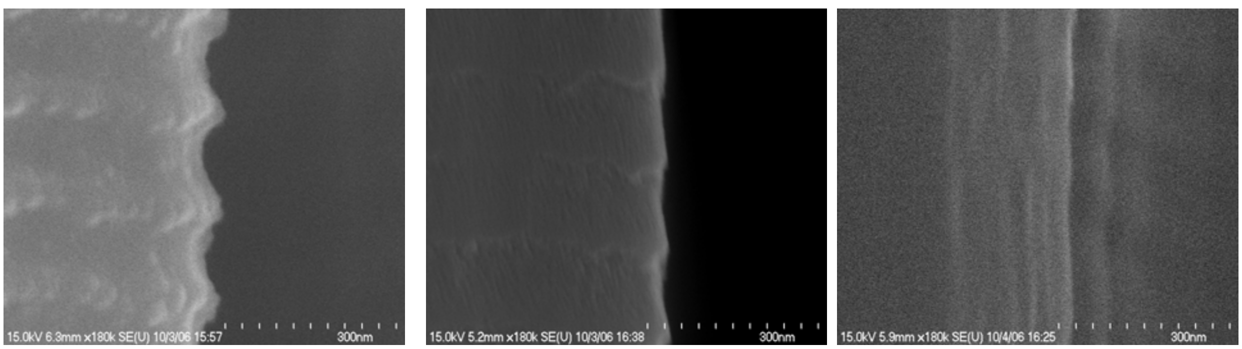
We will present further details of the plasma smoothing process and the application of the micro-Raman technique to nanopillar characterization viz. as-etched and plasma smoothed structures.

1. J. Goldberger, A.I. Hochbaum, R. Fan and P. Yang, Nanoletters, 6(5), 973 (2006).
2. D. Basu, M.J. Gilbert and S.K. Banerjee, J.Vac.Sci. Technol., B24(5), 2424 (2006).
3. Selin H.G. Teo, A.Q. Liu, J. Singh and M.B. Yu, J.Vac.Sci.Technol., B22(6), 2640 (2004)
4. C. Ji, E.A. Guiliants and W.A. Anderson, Proc. 29th IEEE Photovoltaic Specialists, 1314 (2002).



(a) (b)

Fig.1: FESEM top view (a) and cross-section (b) of as-etched silicon nanopillar array.



(a) (b) (c)

Fig.2: FESEM cross-sections of as-etched silicon pillars with scalloping (a), compared with plasma-smoothed pillars after 10 cycles (b), and 20 cycles (c).

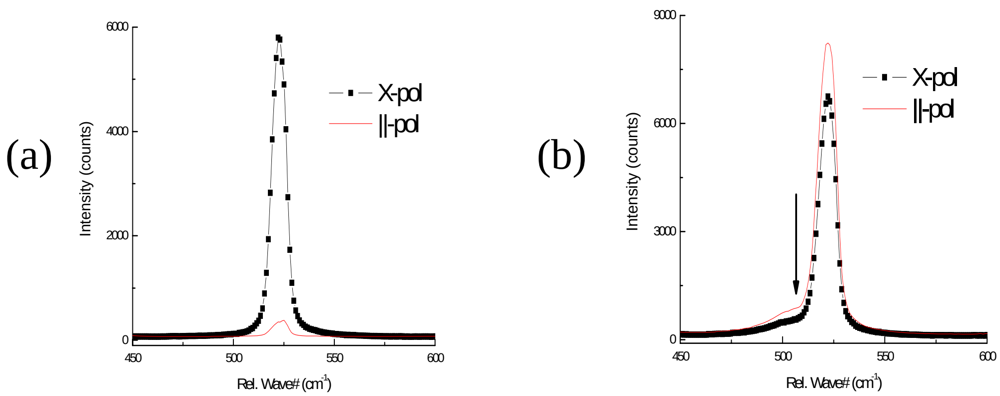


Fig.3:(a) micro-Raman of the bulk Si outside the nano-pillar region, X-polarization [z(x,y)z'] (squares + line) has a 15 times intensity increase over the ||-pol [z(x,x)z'] (line) and (b) micro-Raman of the nanopillar region, X-polarization [z(x,y)z'] (squares + line) is 0.8 less than the ||-pol [z(x,x)z'] (line).