Nanofabrication of 4 nm Si nanowires by high resolution e-beam lithography for high sensitive gas sensors

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Owing to their large surface-to-volume ratios, one-dimensional (1D) nanostructures have been regarded as one of the best candidates for bio-sensors with high sensitivity. Typical biochemical and gas nano-sensors have reached to the milestone of several ten nanometers nanowires (NWs) as schematically depicted in figure 1. In pursuing high sensitivity, one of the efforts is to generate ultrafine conducting Si wires by state-of-art electron beam lithography combined with delicate dry etch processes. However, when the line width is further reduced below 10 nm, a number of new barriers comes to hinder the advance of this technology. For example, line edge roughness is one of the key issues to be solved.

This paper reports our recent progress in replicating sub-4 nm silicon nanowires by electron beam lithography with JEOL6300FS and reactive ion etch (RIE) with a SAMCO etcher. Positive tone hydrogen silsesquioxane (HSQ) was selected for this ultra high resolution patterning thanks to the advantages of the HSQ line-width faithfully reflects the e-beam spot size. Furthermore, the line edge roughness (LER) of HSQ is incredibly small, leaving a large space for further improving the line-width control. The EBL process was first optimized by a numerical Monte Carlo simulation using BEAMER delivered by GenlSys Ltd. As narrow as 4 nm linewidth was calculated. Using the simulation result as the guide, high resolution EBL was carried out and as narrow as 5-7 nm line widths of HSQ have been achieved. Masked by the replicated HSQ lines, silicon on insulator (SOI) was etched in fluorine based plasma to fabricate sub-4 nm silicon nanowires, using the erosion of on the line edges in the plasma etch. The characterizations of electronic sensing by the fabricated SOI narrow wire sensors are still under the way. This work is approaching the limit of EBL for ultra fine conducting lines as chemical biosensors with high sensitivity.

By summary, in this work, as narrow as 5 nm HSQ lines were successfully replicated by EBL. Using the lines as etching masks, as narrow as 4 nm silicon wires becomes feasible. It is believed that such narrow conducting Si wires will certainly start a new age in this area.

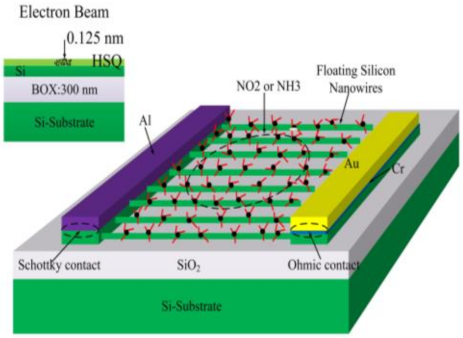

Figure 1: Schematic of the sub-4 nm nanowire-based gas sensor and the diagram of Monte Carlo simulation.

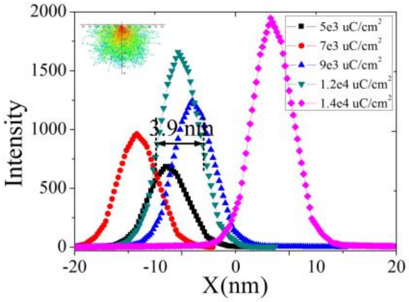

Figure 2: The Monte Carlo simulation results with various dose from 5000 to 14000 μC/cm^2. This picture shows the charges distribution simulated by BEAMER. Clearly, well defined 3.9 nm HSQ line as the full width at half height (FWHH) can be achieved by the beam spot of 2 nm. The simulation parameter was at 100 Kev with 2 nm spot size, and the think of HSQ on SOI substrate was 10 nm.

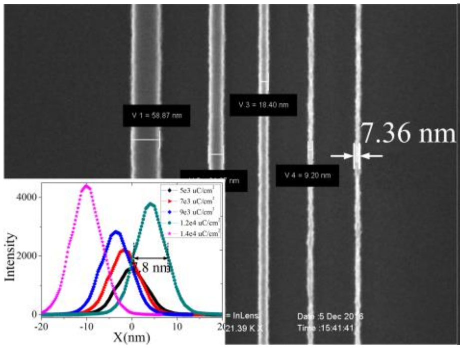

Figure 3: Our initial results of EBL on 25 nm HSQ. As narrow as 7.36 nm HSQ has been achieved on SOI substrate. The exposure was at 100KeV with 7 nm spot size. The line-width of HSQ was matching with the simulation result of 7.8 nm FWHH.

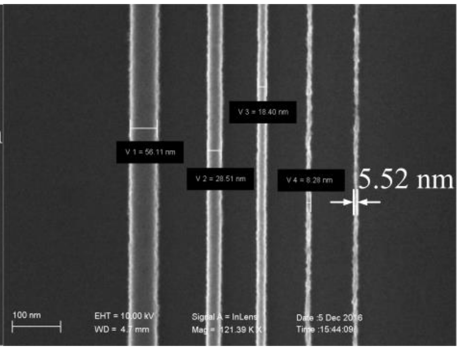

Figure 4: The 5.52 nm HSQ line was successfully achieved with 20 nm HSQ on SOI substrated and the exposure at 100Kev and the spot size at 7 nm.