Fabrication of nano-gap using high and low energy electron-beam lithography

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Nanotechnology has reached a level to offer various devices with narrow-gap that have applications ranging from NEMS [1] to Bio-MEMS [2], as well as application in SERS imaging [3], bio/ molecular electronics [4] etc. For a device to function properly, one needs to fabricate narrow-gap structures with high degree of reproducibility.

Fabricating narrow-gap structures is challenging and researchers have demonstrated a wide range of methods to produce structures with a gap in nano-meter range, which include electron-beam lithography (EBL) [5], electron-beam induced deposition [6], focused ion beam (FIB) lithography [4,7], etc. Some other alternate methods, such as mechanical break junction [8], electrochemical deposition [9], electromigration methods [10], photolithography by a post-annealing process [11] etc, are also used to fabricate narrow-gap structures.

Though EBL is a high resolution and reproducible process, proximity effect caused by backscattered electrons greatly limit the attainable gap size. One way to eliminate the proximity effect is to carry out EBL on thin electron-transparent silicon nitride membrane that has achieved a gap in gold down to 3 nm [12], yet membrane is extremely fragile.

In this paper, we propose to fabricate nano-gap using an optimized two-step exposure technique. As shown in Figure 1, we first used high energy (20 keV) exposure to define the nano-gap between two thin lines, knowing that proximity effect is negligible for isolated sparse pattern. Then we defined the large pad structure (could be used as electrode) using low energy (2.5 keV) exposure. Proximity effect will be very significant for such large microscale features, but the lateral backscattering range is small (100-200 nm) for this low energy, and thus the proximity exposure at the middle of the gap would be low if the two pads are separated by >100-200 nm. Therefore, with accurate alignment between the two exposures, a nano-gap between two large pads can be attained when the wide gap region is filled with a pair of thin lines having a nano-gap in-between.

In the experiment, thin PMMA resist (~ 30 nm) was spun on Si wafer. After the exposures at the high and low electron energies, the sample is developed in methyl isobutyl ketone (MBIK): IPA (1:3) for 20 sec at room temperature. Alternately, it can be developed at low temperature (-20 ^{o}C) for 30 Sec. To get a high resolution SEM image, a thin layer (~10 nm) of Cr has been deposited.

As a quick proof of concept, Figure 2 shows the gap fabricated between two thin lines and two large pads exposed at various electron energies, indicating a nano-gap down to 45 nm was achieved when exposed at two electron energies. Note that the pad here is much larger than the bow-tie structure for plasmonics, leading to much greater challenge for nano-gap fabrication. Nano-gap below 20 nm between two large pads is expected with considerable further process optimization.

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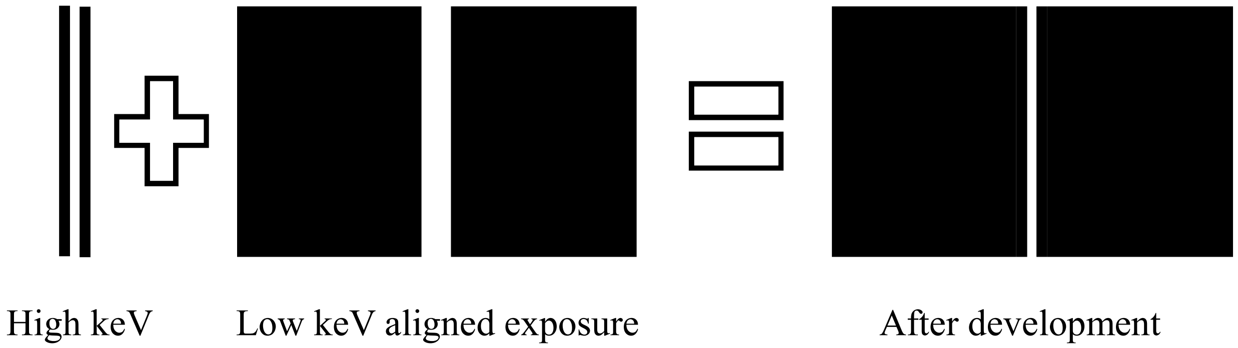

Figure 1. Schematic to show the working principle of high and low energy exposure for the fabrication of nano-gap.

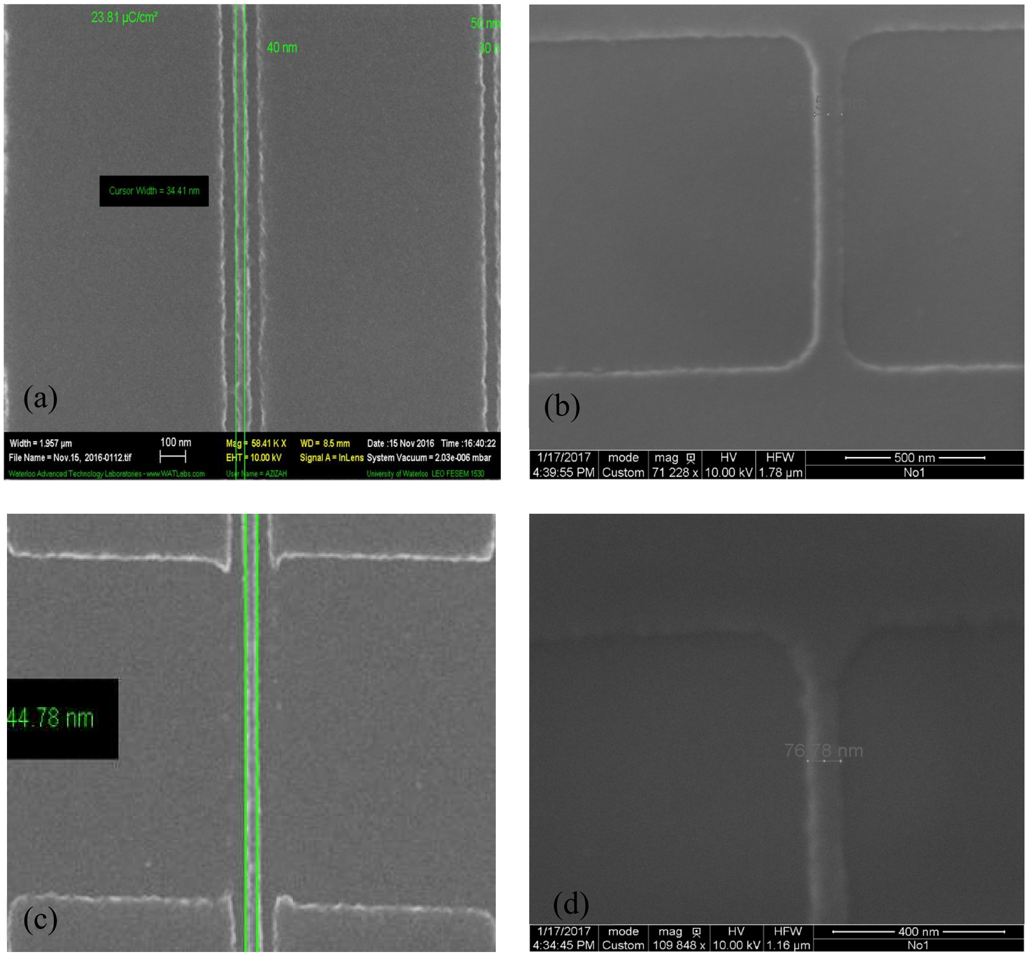

Figure 2. SEM images of (a) 34 nm gap between two lines exposed at 20 keV; (b) 96 nm gap between two large pads exposed at 2.5 keV; (c) 45 nm gap between two large pads exposed at 20 and 2.5 keV following the step shown in Figure 1; (d) For comparison, down to 77 nm gap was obtained when exposed at a single energy of 20 keV.