Sub-10nm Resolution after Lift-Off Using HSQ/PMMA Double Layer Resist

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Hydrogen silesquioxan (HSQ) is a well-investigated negative tone inorganic resist [1,2] which is known for its capabilities for high resolution electron beam lithography (EBL) and its stability against dry etching [3]. These properties make HSQ first choice to act as hard mask to transfer patterns by dry etching into the underlying material. Unfortunately, finally removing the HSQ mask in a wet solution requires HF containing etchants [4], which is not suitable for all samples, especially glass or those covered by silicon dioxide. In these cases it is more convenient to use a process where – at the end – the HSQ mask can be simply lifted off from the sample by using an additional layer underneath the HSQ which is easy removable in a compatible solvent.

For working on silicon dioxide covered or silicon substrates we developed an EBL process utilizing a layer of poly-methyl-methacrylate (PMMA) as sacrificial layer beneath the HSQ. Such a process was already described by Yang et al. in 2008 with a resolution limit of 50 nm wide lines with 100 nm spacing [5]. Here we modified the process and pushed this idea to sub-10 nm resolution.

The whole process is depicted in Fig. 1 and consists of two times spin coating interrupted by a pre application bake at 160 °C using a hotplate to prevent resist intermixing. The sacrificial layer is a 80 nm thick PMMA 950k layer and covered by the 30 nm thick HSQ film. After coating, the sample is transferred into a Jeol JBX6300FS system and is exposed with 6 mC/cm² using 100 kV, followed by the development of the HSQ top layer in Microposit MF322 for 60 s. To stop the development the sample is rinsed 60 s with deionized water. In contrast to Yang et al. [5] who used pure oxygen plasma, we used an oxygen / argon plasma (1:1) to remove the PMMA in the areas of developed HSQ. By this we reduce the etching rate for the PMMA layer. Afterwards 10 nm metal is deposited on the sample by thermal evaporation. Finally, using n-ethylpyrrolidone (NEP), the PMMA layer is attacked and removed with the HSQ mask and the on-top lying metal.

As visible in the scanning electron microscope image (Fig. 2) of a processed metal pattern, we were able to improve the resolution down to the sub-10 nm regime. The resulting structures consist of 100 nm squares with a gap smaller than 10 nm covering a 100 µm times 100 µm field. Fig. 3 emphasizes the large area uniformity. There is a slight grid distortion of the pattern on small scale which results from the deformation of the HSQ mask (c.f., Fig. 2). This might be due to the partly missing contact of the HSQ mask with the substrate. Further optimizing the PMMA layer thickness, baking and developing parameters might reduce this effect.

Already at this stage, our process is straightforwardly applicable to fabricate patterns that mimic thin metal films at the percolation threshold where metal grains are close to fully cover the substrate. Due to the nm vicinity of the grains, such films reveal interesting optical properties. Artificially patterned quasi-films as the one shown in Fig. 3 offer by-design tunable parameters that allow to investigate and optimize such optical properties.

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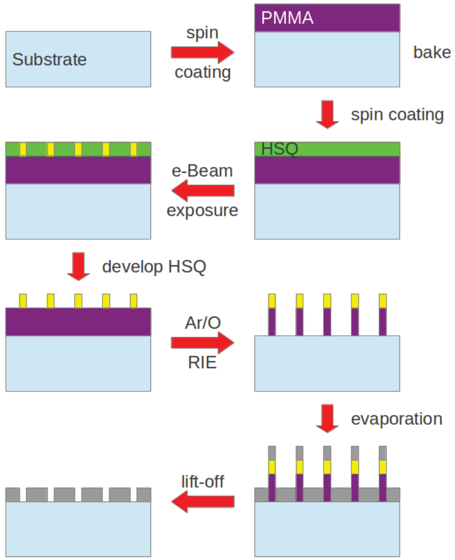

Fig.1: Schematical depiction of the process flow, including all performed steps.

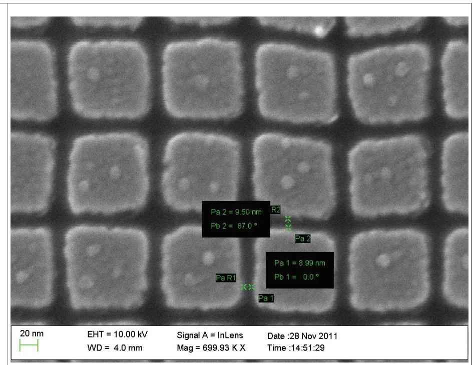

Fig.2: SEM micrograph showing 100 nm gold squares separated by less than 10 nm.

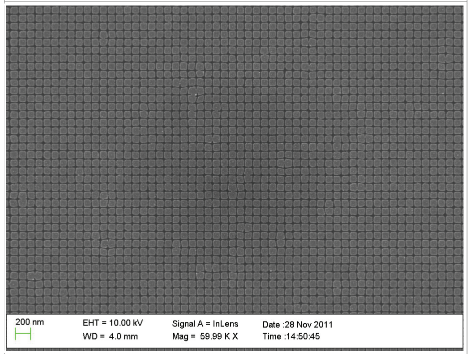

Fig.3: Overview of a larger area of the structure in fig.2 emphasizing the uniformity of the patterning.