X-ray Lithography for Lobster

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The goal of this research is to demonstrate the capability of deep x-ray lithography for producing densely packed high aspect ratio microstructures (DPHARMS) such as a lobster-eye optic. During our previous visits, we have addressed important problems such as stiction, development times, dimensional errors, surface roughness and sidewall slopes. From our in-depth studies, we have found that it is extremely difficult to produce DPHARMS with low surface roughness and low sidewall taper concurrently. We have found that exposure with a softer spectrum results in low surface roughness while exposure with a harder spectrum results in low sidewall taper. However, both of them depend strongly on exposure dose and development times (development threshold). Higher exposure dose would see a uniform distribution of dose and hence, low surface roughness. Higher development times would result in uniformity of development threshold along the resist height and hence, low sidewall taper.

In recent research we have carried out experiments to optimize the processing parameters such as the exposure spectrum, exposure dose, post-exposure bake and development times so as to minimize surface roughness and sidewall slopes and produce structures near the benchmark. Our numerical models suggest an optimal condition with harder spectrum, higher exposure dose, lower PEB time and higher development time. We designed a set of concordant experiments. A second goal of this research was to conduct nickel electroplating in the developed structures, remove SU-8 resist and measure the surface roughness of the nickel plated structures.

For the optimization study, initial experiments included deposition of Ti/Cu metal layer on glass slides. The thickness of the Ti layer was 20 nm and that of Cu layer was 50 nm. SU-8 was cast on this metal layer to achieve a thickness of 1.0 mm. The pre-bake time was selected to retain 5% of the solvent, which has been shown to provide good resolution in x-ray lithography. We used the same x-ray mask as in our previous experiments. The incident spectrum was made harder with, a peak at a photon energy of 12 keV, by using a 450 µm thick aluminum filter in the beamline. The bottom dose was increased from the standard dose of 25 J/cm^3 to 32 J/cm^3. The post-exposure bake time was 30 minutes at 65^{o}C. We overdeveloped the samples for 90 minutes instead of the normal development time of 70 minutes using megasonic agitation. This overdevelopment time would result in the same development threshold along the full resist height.

After the experiments, we detached the SU-8 columns using plastic tweezers and measured the width at the top, middle and bottom of the structures using a digital SEM and measured the sidewall roughness at the top, middle and bottom using an AFM. The resulting sidewall slopes from top-middle, middle-bottom and top-bottom are 0.15 ± 0.05, 0.3 ± 0.1 and 0.23 ± 0.03 µm/mm respectively compared to the -0.05 ± 0.05, -0.1 ± 0.05 and -0.07 ± 0.05 respectively obtained in a previous study. The resulting surface roughness at the top, middle and bottom was measured to be 7.0, 13.0 and 21.0 ± 5% nm rms compared to the 8.0, 38.0 and 43.0 ± 5% nm rms respectively obtained previously. This is a very good improvement in surface roughness without compromising sidewall slope and demonstrates that an optimization strategy as described is feasible. Another advantage of this optimization is that the dimensional error in this case is also reduced to -0.4% at the top due to higher exposure dose as compared to -1.2% using normal exposure dose. **This research has opened up a way for fabricating other devices requiring DPHARMS.**

The samples for nickel electroplating were prepared according to the optimized process parameters. Nickel electroplating was carried out at the micromachining lab of NSRRC as per standard procedure. After electroplating, the resist was removed by burning in a furnace at a temperature of 700^{o}C. We then cut the structure using pliers and measured the surface roughness. The rms surface roughness of the nickel structure was found to be 26 nm at the top and 58 nm at the bottom – much higher than that in the SU-8 structure (8 nm and 19 nm respectively). Further work needs to be done to optimize the plating parameters to obtain smooth nickel plated structures. Figure 1 shows an SEM image of the nickel grid after resist removal. Some SU-8 is still remaining along the wall of square holes as seen in the figure.

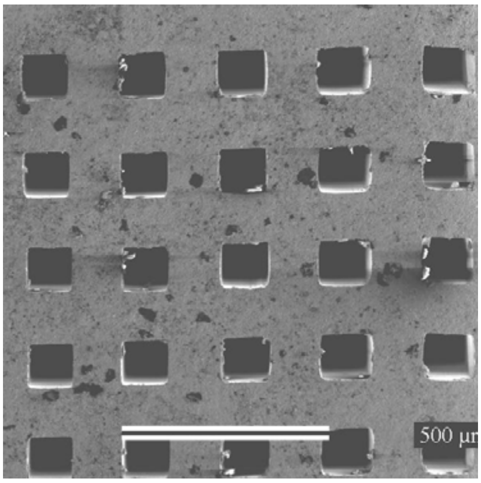

Figure 1. SEM image of a 1.5 mm thick nickel plated grid after resist removal. The square holes are 100 µm wide with a gap of 120 µm.