MASKLESS SUBMICRON MACHINING BY FOCUSED ION BEAMS

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The Focused Ion Beam (FIB) has been a valuable tool for those working at semiconductor industry. A FIB is capable of milling (machining) material as well as depositing material via the sputtering of ions. FIBs have been used to repair masks used in integrated circuit production, repair individual wires on integrated circuits, or even dope semiconductors. Microstructures of various geometries, including microtools (e.g., used for machining cantilevers for scanning probe microscopy), micro-springs, and micro-gears made from stainless steels, have been successfully fabricated using a FIB.

In the present research, the capability of using FIB for patterning/milling of microchannels is evaluated. Microchannel structures have been widely used for many MEMS devices, including micro heat pipes, sensors, and fluidic devices. Figure 1 shows an optical imagine of several patterns in a gold thin film milled by a FIB. The equipment used was the Nanofab 150 FIB facility. The arsenic 2+ ions were used as the source with a beam spot size of 50 nm. The patterning was conducted at a dwell time of 50 ms at a pixel spacing of 14.5 nm. The facility was operated at a voltage potential of 90 keV and a current of 5 pA.

The gold film was deposited by a high vacuum evaporation system with an ion-pumped glass belljar capable of ~ 10^{-6} torr. The gold was melted at to 1132 °C to attain a proper vapor pressure suitable for deposition. System pressures were monitored by ion and thermal conductivity gauges. The corresponding image by an atomic force microscope for the smallest pattern shown in Fig. 1 is depicted in Fig. 2.

The atomic force microscope was also used to quantify the relationships between the dimensional characteristics of the milled channels and the major operating parameters used in FIB milling and thin film deposition. Before FIB milling, the surface roughness of the thin films that were deposited at various speeds and substrate temperatures is first studied. At the substrate temperature equal to 25 °C, the typical arithmetic-mean surface-roughness (R_a) is 1.66 nm and showed no significant change for the deposition speed increasing from 0.02 to 0.06 nm/s. However, for the substrate temperature elevating from 25 °C to 360 °C, R_a increases more than five folds at 0.02-nm/s deposition rate. The dimensions of microchannels were also quantified. For substrates deposited at 0.02 nm/s rate at the room temperature, the depths of the FIB milled channels are 22 (4), 28 (5), and 37 (8) nm for the dwell time, respectively, at 10, 20, and 50 ms, while the corresponding mouth widths are 146 (21), 158 (21), and 189 (33) nm. The corresponding standard deviations are the numbers in parentheses.

In summary, as expected, the results show that the size of FIB milled micro-channels increases with dwell time. However, the size of certain features with respect to dwell time is not linear. As the dwell time is increased past 40 ms, the feature size does not significantly increase. This drop in sputter yield may be attributed to redeposition effects. As the micro-channel becomes deeper, it becomes harder for the ejected gold atoms to leave the vicinity of the ion beam, and some atoms deposit back to the surface. Finally future research directions on improving the FIB-milling recipe and on analyzing microchannel applications in MEMS and NEMS are also included.

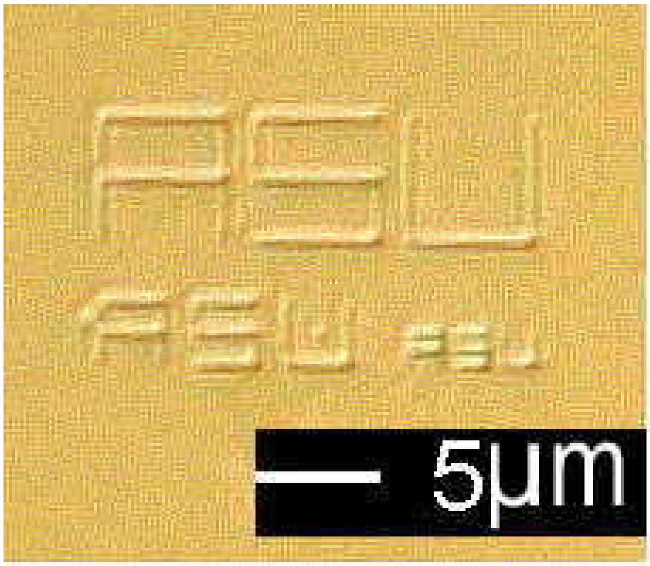

Fig. 1. Optical images of three patterns milled at 50-ms dwell time by FIB

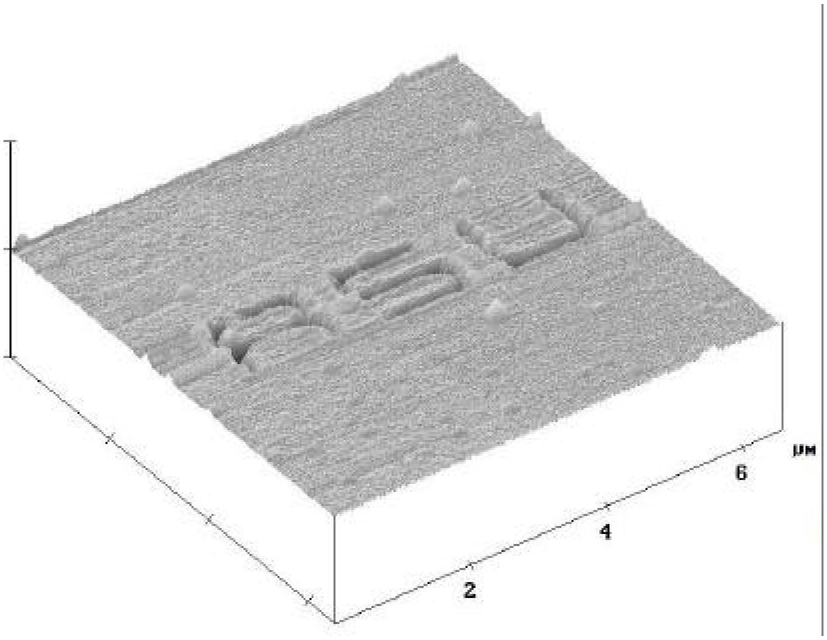

Fig. 2. Topography of FIB milled pattern by atomic force microscope (Each vertical division is 400 nm)