Effects of focused ion beam dwell time on Nano fabrication

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Introduction

Focused ion beam (FIB) systems are widely used as a versatile tool for nanofabrication prototyping, device modification and ion beam lithography [1]. However, there are still many unexplored effects in FIB milling using Ga^+ due to the FIB beam and its halo, particularly at low total dose. Generally, dwell time plays an important role as it controls the time of continuous ion implantation at each milled pixel. It is known that the beam profile changes with beam current [2] but how this affects the milling is not well known. In this study the effect of varying beam current and pixel dwell time on milling was investigated for fixed total dose. The effects were analyzed using AFM and Raman Spectroscopy.

Theory

Ion implantation

The 30 keV simulation of ion implantations were carried out using SRIM software. Figure 1 shows longitudinal and lateral projection of ion implantations. [3]

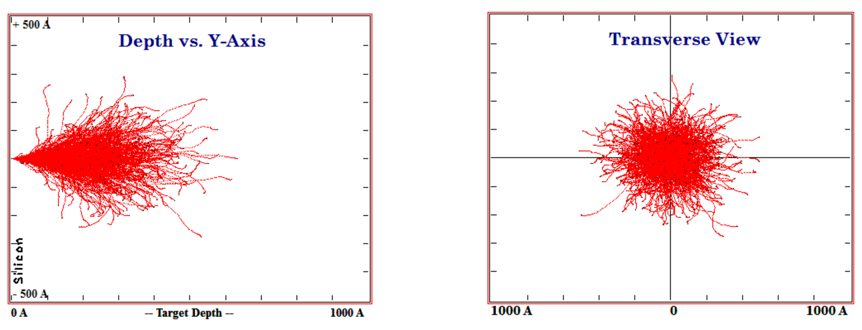

Figure 1. Ion implantation trajectories of Ga in Si

Sputtering Yield (P. Sigmund)

Number of atoms removed per incident ion (atom/ions) calculated as follows:

$$\alpha = 0.13\left(\frac{M_t}{M_i}\right) + 0.15$$

$$Y(E) = \frac{0.042\ \alpha\ S_n(E)}{U}$$

Nuclear cross section and energy function

Sublimation energy

Experiments

The micromilling of Si has been carried out by using focused ion beam (FIB) with Ga^+ as liquid metal ion source (LMIS). In this experiment the ions have been accelerated to 30 keV and currents from 100 pA to 1000 pA were applied. The milling was performed with three different dwell times of 0.1 µs, 1 µs and 10 µs for doses of 10^{17} ions/cm^2. The sputter yield was analyzed by means of Atomic Force Microscopy for the different currents and dwell times. Also the structure of Si was investigated through Raman spectroscopy for the milled features. Figure 2 shows a typical 3d image from AFM measurements.

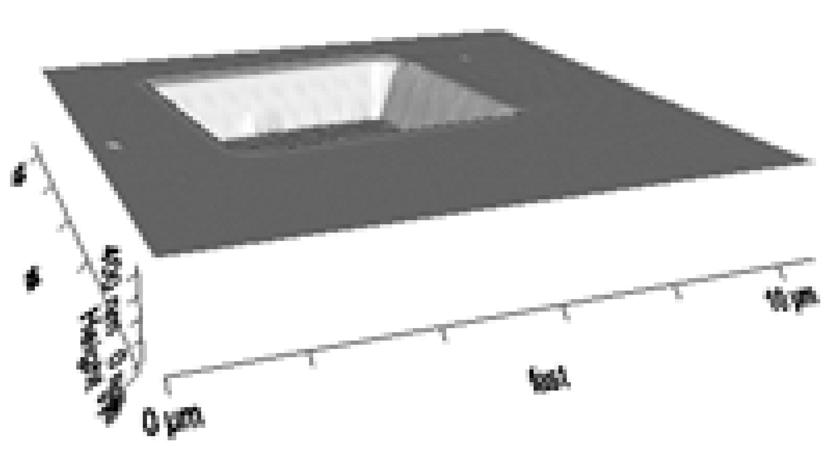

Figure 2. 3d AFM measurements for surface topography

Results and discussions

AFM results show that as dwell time increases for a given current at fixed dose, the sputtering yield is increased (Figure 3). This can be due to the following reason. By increasing the dwell time more ion implantation occurs and therefore there is increased lateral spreading of ions inside the substrate which have lower mean stopping range. As the beam moves to the next pixel, it is harder for arriving ions to penetrate deeper into the substrate due to the presence of the previously implanted Gallium. Therefore the ions dissipate their energy closer to the surface causing more sputtering of the substrate and thus increasing the sputtering yield. Future practical experimentation is planned to verify this hypothesis.

It has been observed from the Raman measurements that increasing the dwell time would increase the ratio between crystalline silicon and amorphous silicon at all currents studied. This indicates less damage for higher dwell times (Figure 4). As described above, this is due to lower ion implantation mean stopping range for longer dwell times due to tail region, resulting in a shallower region of damage by implanted ions.

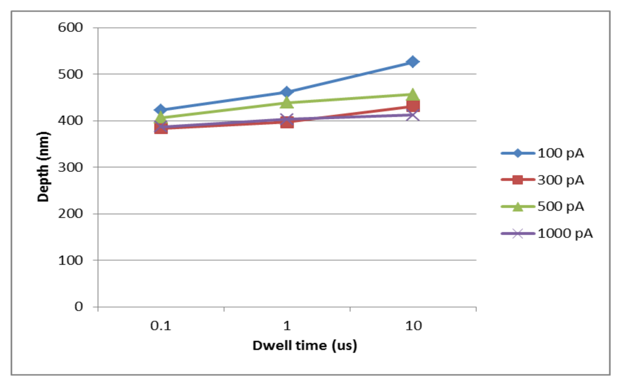

Figure 3. Milling depth at different milling currents at chosen dwell time

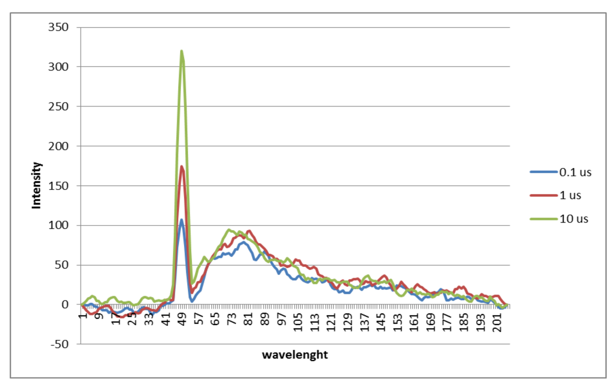

Figure 4. Raman measurements at 100 pA for three different dwell time at dose of 10^{17} ions/cm^2. (similar behavior were found for other beam currents)

Conclusion

In this study we investigate the effect of dwell time on sputtering yield and substrate damage. It was shown by increasing the dwell time the sputtering is increased for all the milling currents. Also increasing current would cause less damage to substrate for corresponding doses.

Acknowledgement

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References

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