Helium Ion Beam Milling for Chiral Nanostructures

PMMA resist as a viable target material for ion beam milling

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Chiral 3 dimensional nanostructures have widely gained interest in physics due to their optical and electronical properties, such as circular dichroism, plasmonics and electrical Magneto Chiral Anisotropy (eMChA). To obtain these structures, various methods have been applied, from bottom up methods like chemically induced growth, self assembly and shadowing based deposition, to top down processes such as gray scale or imprint lithography.

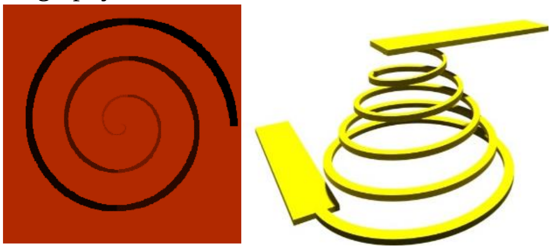

Figure 1: Schematics of the device layout, a chiral conical spiral. Left: a schematic of the resist surface after milling of the structure into the surface. Right: a schematic of a metal wire without the supporting PMMA.

Traditional lithographical processes combining an exposure with a subsequent wet chemical development such as optical lithography and electron beam lithography are commonly used for manufacturing of nanostructures. However, in order to minimize feature sizes, in recent years focused ion beam lithography has been widely studied as an alternative [1]. The structures were either written and conventionally developed, or directly milled using the sputtering caused by the beam. However, the milling into surfaces is depending on the beam used and often limited to particular materials such as graphene or gold.

Here we want to report on work applying direct writing Helium Ion beam Milling (HIBM) to obtain chiral 3 dimensional structures in a polymethyl-methacrylate (PMMA) layer.

The structure that is carved into the PMMA layer follows a conical spiral by applying higher ion counts per area for lower lying parts. In Figure 1, the schematic of the 3 dimensional structure is shown. Left is a schematic of the resist after milling, right is a schematic of a wire deposited into the milled structure without the supporting PMMA. The possible wire materials can be freely chosen from any material used in typical deposition processes, which includes most metals, semimetals and semiconductors.

The results from milling are depicted in Figure 2, which shows an AFM image of a milling into PMMA. Notably, the milling has not, as has been seen by others [2], any re-deposition edges, which would give a "volcano-like" structure.

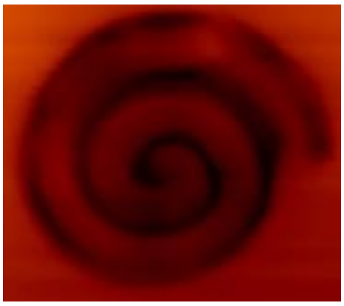

Figure 2: HIM milled structure in PMMA. Total structure size 1 µm, dose 1×10^{16} ions/cm^2, maximum depth 100 nm.

To estimate the milling under the assumption of sputtering, SRIM simulations are taken into considerations.

The proposed mechanism for the milling process may be, rather than a removal of the solid material as is the case for metallic layers like gold, be due to a breaking of chemical bonds within the polymer followed by removal of the gaseous elements through the vacuum. In this case, there may be a significant deviation between the observed milling rate and the rate simulated by SRIM.

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[2] H. Wang et al, Journal of Vacuum Science & Technology B, Nanotechnology and Microelectronics: Materials, Processing, Measurement, and Phenomena 36, 011603 (2018)
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