# Fabrication of 3-dimensional Nanoimprint Stamps
# A comparison of 4 approaches using FIB

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Nanoimprint Lithography has the outstanding capability to fabricate 3-dimensional structures within one single process step. Conventional lithography including optical lithography, e-beam lithography and extreme UV (EUV) lithography require a radiation-sensitive polymer layer and cannot form 3-dimensional structures (except with special greyscale lithography). With NIL the fabrication of 3D-structures has repeatedly been demonstrated [1]. This makes NIL an facilitator for 3D microoptic, microfluidic and medical applications [2].
The main challenge with 3-dimensional NIL is the availability of 3-dimenional stamps. This work presents and compares 4 different approaches for producing 3-dimensional NIL-stamps utilizing a focused ion beam (FIB). A Zeiss Neon system was used either to directly remove material from a master blank or to pattern a hardmask layer containing the structure.
Physical milling of 3D structures was accomplished with a minimum feature size below 40 nm. Using the pixel-by-pixel removal of material complex structures such as shown in Fig 1 could be fabricated by physical milling.
Gas assisted milling of $SiO_2$ was explored using $XeF_2$ as etch gas. While being a pixel-by-pixel removal on $SiO_2$ featuring high process control and a high etch rate also spontaneous etching (e.g with Si) limits the usability of this process.
To overcome the obstacle of high processing time for large area stamps a hardmask patterning approach has been explored. The FIB is used as patterning tool while the structured hardmask is used to transfer the pattern in a subsequent dry etching of the entire stamp substrate to reach the desired depth of the structures. Additional hardmask layers such as Ta, AZO and Al were coated on the sample and patterned by FIB. The resulting surface roughness proved critical for the choice of the right hardmask. As alternative FIB implantation of Ga was used to generate an implantation hardmask. After RIE etching using dedicated etch gas mixtures a height of structures depending on the implantation dose could be achieved (Fig 3 and Fig 4).
The approaches were systematically compared regarding the smallest obtained feature size, the fabrication speed, and the surface roughness. The theoretical background are discussed and provide a deeper understanding of the underlying process of these 3D patterning approaches. With these FIB-based approaches complex 3-dimensional stamp structures (Fig 5) could be produced and used for fabricating an imprint (Fig.6) NIL replication The suitability of each approach for the fabrication of nanoelectronic and nanooptical devices will be discussed.

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[1] W. Wu, M. Hu, F. Suong Ou, Z. Li and R S.Williams, Nanotechnology 21 255502 (2010)
[2] M.Tormen, A. Carpentiero, E. Ferrari, D Cojoc ,ED.Fabrizio Nanotechnology 18(38), 18 2007)

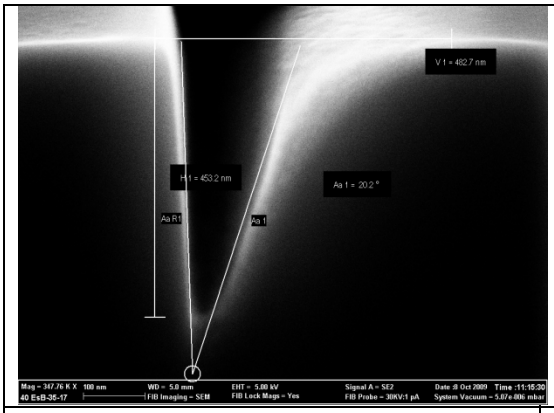

*Fig. 1.* Wedge-shaped structure in Si fabricated by direct milling.

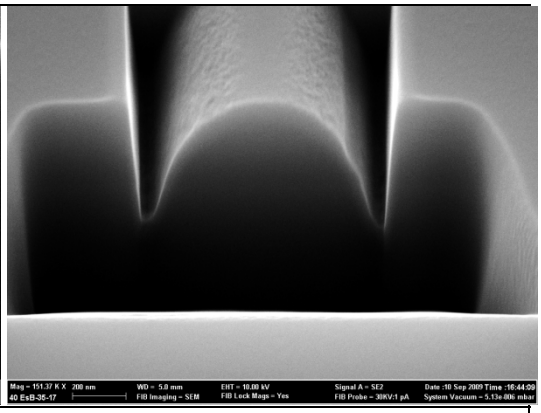

*Fig. 2.* Barrel-type structure in Si fabricated by direct milling.

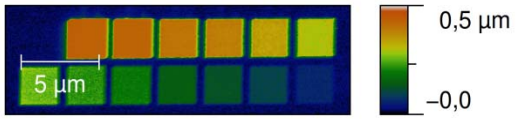


*Fig. 3.* 2D AFM image of square structures etched out by RIE after prevous exposure to different Ga implantation doses

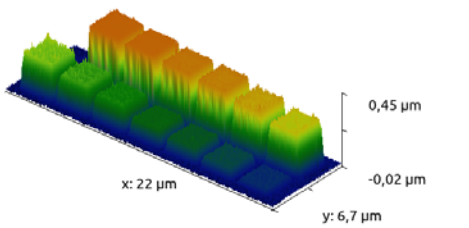


*Fig. 4.* 3D AFM image of square structures etched out by RIE after prevous exposure to different Ga implantation doses

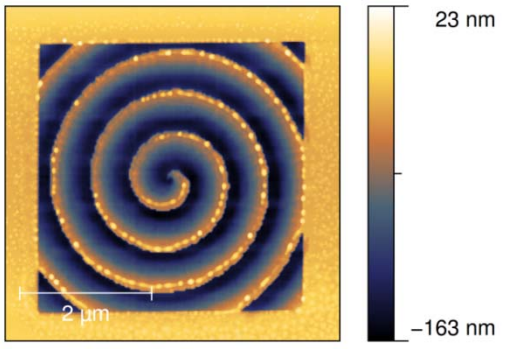


*Fig. 5* Complex 3dimensional spiral-shaped NIL-stamp structure used successfully for imprinting.

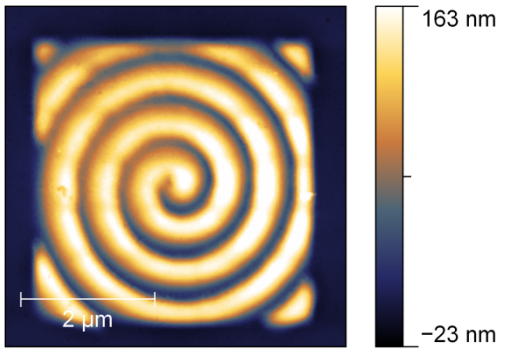


*Fig. 6* AFM image of imprint fabricated with stamp from Fig 5..