3D nano patterning using local Ga implantation and subsequent RIE etch

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3D patterning on the micro scale using laser writers or electron beam lithography (EBL) is a state of the art technology but 3D patterning on the nano scale is still a challenging task. EBL, the method of choice for 2D mask writing is hardly usable for direct 3D patterning on the nano scale due to proximity effects. The most popular workaround, namely multilevel patterning is a good option if only a few height levels are required but it cannot provide real 3D patterns with 10 or more height levels since the cost of such a pattern becomes excessive. Recently Henry et al.[1] showed that the local implantation of Ga into Si and subsequent reactive ion etching (RIE) can be employed to fabricate 3D patterns.

In this paper we report on an in deep analysis of this patterning technique with emphasis on 3D nano scale patterning. The technique promises to provide higher resolutions for 3D patterns than EBL due to the absence of the proximity effect while still being significantly faster than other 3D nano patterning methods such as FIB milling or FIB gas assisted etching (GAE).

In order to find the optimum implantation parameters in terms of speed and efficiency we have investigated the impact of the scanning parameters on the implanted Ga quantity for a wide range of Ga-doses and scanning parameters. For this purpose we employ energy dispersive X-ray spectroscopy (EDX) measurements. Fig. 1 exemplifies our results for the impact of the acceleration voltage on the implantable Ga-quantity. We find that the highest useful implantation dose is highly dependent on the acceleration voltage. For 30kV it should not exceed 300pC/µm².

We have studied the effect of the implanted Ga during RIE etching and the impact of various gas compositions during RIE. We find that depending on the employed etch gas composition the etch stop effect of the implanted Ga can either be maximized or completely suppressed. Also the dependence of the etch depth from the implanted Ga quantity can be linearized or optimized for a certain 3D pattern by fine tuning the etch parameters.

Using the gained knowledge we demonstrate the 3D patterning capability of our optimized process and investigate the achievable resolution. We find that our process is capable of manufacturing complex 3D objects as shown in fig. 2 and patterns with lateral resolutions down to 50 nm half pitch (HP) as shown in fig. 3. The process is expected to allow patterning of at least 6µm²/s when an average coverage of 50%, an etch depth of 300nm and a HP resolution better than 100nm is assumed.

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[1] M D Henry, M J Shearn, B Chim, A Scherer, Nanotechnology **21** (2010)

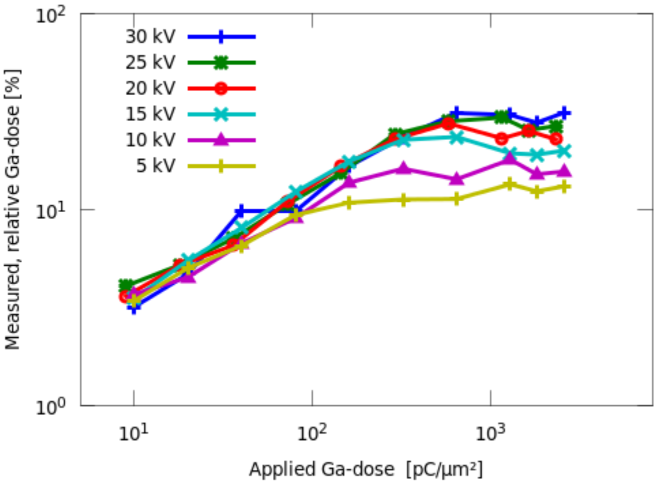

Figure 1: Impact of the acceleration voltage on the implantable Ga quantity: Ga was implanted on 2.5x2.5µm² quadratic areas. The beam current was set to 10pA for all areas, while the acceleration voltage and the exposure time were varied. The relative Ga quantity was measured by EDX and is given in percent of the total measured counts.

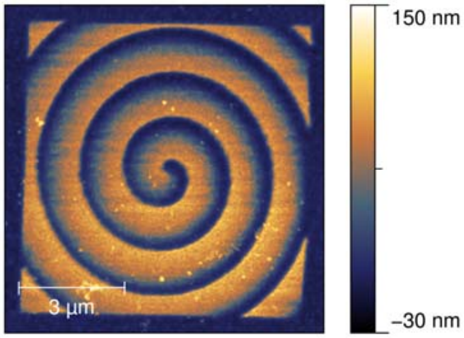

Figure 2: 3D spiral: Atomic force microscope (AFM) image of a spiral created by implantation based on a 10 level gray scale image and subsequent RIE etching using an optimized process. The inhomogeneity of the pattern in the higher part of the image is due to limitations imposed by the employed scan generator.

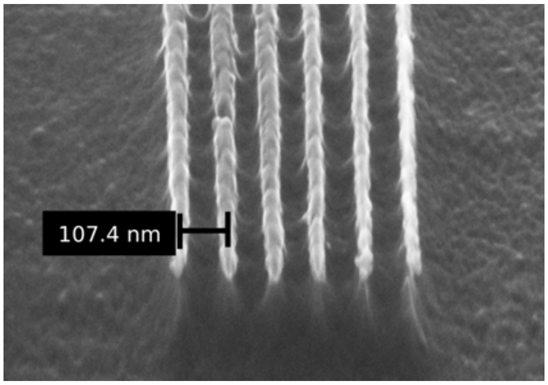

Figure 3: 50 nm half pitch lines/spaces: Scanning electron microscope (SEM) image of an implanted and etched lines/spaces pattern with 50 nm half pitch.