Focused Ion Beam: A Versatile Technique for the Fabrication of Nano-Devices

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Introduction

Nanostructures used in near field optics [1-3] material science [4, 5], and biological applications [6, 7] can easily be realised using Focused Ion Beam (FIB) technique. In this work three applications developed in our laboratories are presented in order to highlight the versatility of FIB technique. Sophisticated nanostructures can be written in a single step into substrates without any need of masks, stamps or other additional means and, most notably, FIB technique enables post-processing of prefabricated devices.

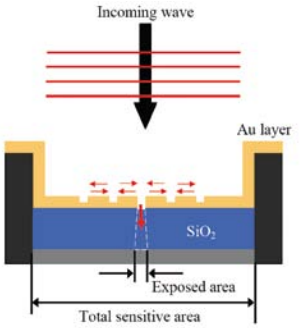

Fig. 1. Schematic illustration of the plasmonic effect leading to an enhanced transmission of the slit / groove structures. Surface plasmon polaritons are excited by the incoming light wave and reflected at the periodically arranged corrugations resulting in a plasmonic surface wave

Plasmonic Structures

10 years ago, with the article on the extraordinary optical transmission through sub-wavelength hole arrays in Nature [8], Ebbesen and his colleagues triggered a tremendous advancement in plasmonic research. Due to its suitability to write nanostructures with very high precision, FIB technique provides an ideal tool for the fabrication of plasmonic structures. Noble metals containing periodical structures exhibit surface-plasmon-enhanced transmission of light through subwavelength nanoholes. Such structures have been integrated in the pixels of a commercially available CCD camera with the objective of enhancement of the signal-to-noise ratio (SNR). Fig. 1 shows a schematic illustration of the plasmonic effect on a pixel modified using FIB technique. The optically active part of the CCD has been covered with a 250 nm thick opaque gold layer where periodical slit and groove structures have been engraved. The optically sensitive part of the detector is sensitive to ion implantation and, therefore, protected by a SiO_2 deposit located between the active and the gold layer. Impinging ions are absorbed by the protection layer. Fig. 2 displays a SEM image of an individual pixel modified using FIB technique. According to theoretical calculations values on the order of 5 for SNR improvement can be expected [9].

Nanodispenser (NADIS)

Precise deposition of individual liquid nanodroplets paves the way for many applications in the fields of bio- and nanotechnology. A nanodispenser (NADIS) has been developed using a standard AFM setup combined with a specially adapted cantilever. The principle of NADIS is schematically shown in Fig. 3. A microfluidic channel connecting a liquid reservoir with a nanoaperture is embedded in the NADIS cantilever. The cantilevers have been produced using standard microfabrication technique, whereas, the nanoaperture, shown in Fig. 3, has been fabricated using FIB technique [10]. Square and circular apertures with dimensions down to 80 nm have been drilled into the tip apex of the hollow cantilever, which nicely illustrates that FIB technique is, in contrast to standard fabrication methods, not limited to flat surfaces. Prior to the FIB treatment the cantilever tips have been gold coated in order to perform thiolisation of the perforated tips which ensures a hydrophobic confinement of the liquid in the vicinity of the aperture. As gold is easily removed by FIB milling, the apex of the tips have been protected with a carbon layer prior to the milling action in order to prevent gold removal due to dispersed ions close to the location where FIB milling takes place. Individual droplets with volumes down to 200 al have been deposited and, moreover, monolayers of PS-P2VP micelles have been locally modified by deposition of glycerol using NADIS technique [11].

Fig. 3. Conceptual drawing of the nanodispenser and SEM image of a modified tip

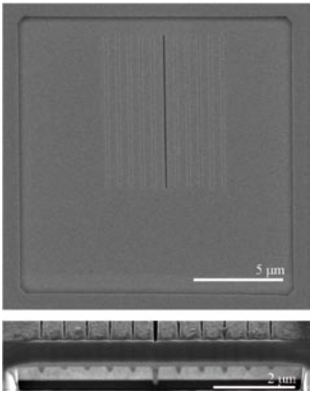

Fig. 2. SEM images showing top view and cross-section of a modified pixel. The structures have been realised using FIB technique

Stencil lithography

Stencil lithography is a shadow mask deposition technique enabling direct patterning with sub-micron resolution of diverse substrates, without any need of resist processing. It can be used for local material deposition [12], reactive ion etching [13], and ion implantation [14] on prefabricated substrates. A schematic illustration of metal deposition using stencil lithography is given in Fig. 4. The whole process includes 3 steps, namely, stencil fixation and alignment, metal deposition, and removal of the stencil.

Using stencil lithography structures down to a few tens of nm have been realised [12]. Stencil lithography requires the use of nanostructured membranes. The membranes have been fabricated using standard microfabrication techniques, whereas, the nanostructures have subsequently been added using FIB technique. Due to the flexibility of FIB technique individual chips can be post-

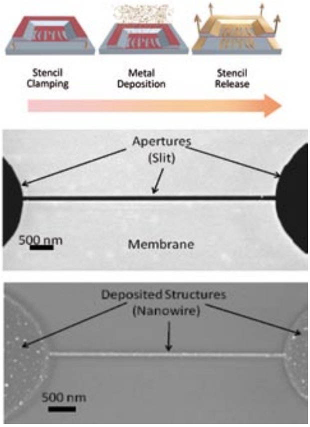

Fig. 4. The three main steps of stencil lithography: (1) clamping, (2) deposition, and (3) release. Al nanowires have been realised using a stencil containing nanoslits

processed and adapted to its specific need. Using this technique slits of widths down to 50 nm have been achieved in a 100 nm thick SiN membrane [15]. A nanostructured membrane used for local aluminium deposition and resulting nanowire are shown figure 4. Nanostencils can be cleaned and reused. This has successfully been demonstrated for twelve times using stencils shown in the presented example [13]. Furthermore, stencil lithography is well adapted for patterning polymer [13] and nonplanar substrates.

Conclusions

The realisation of new applications has successfully been demonstrated by local postprocessing of existing devices. Pixels of a CCD camera and SiN membranes of nanostencils have been modified. Moreover, apexes of 3-dimensional AFM tips have been adapted enabling the realisation a nanodispenser. The multiplicity of FIB technique and its importance in the field of nanofabrication has been illustrated on the basis of the presented applications.

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