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Application of stencil masks for ion beam lithographic patterning

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ABSTRACT

The application of Au/Si_3N_4 stencil masks for the transfer of patterns using different MeV-ion beams with various substrates has been investigated. The techniques investigated were namely, conventional lithography with positive- and negative-tone resist polymers, oxygen ion-induced etching of PTFE and patterning using an etch-stop in silicon. We demonstrate that using different well-known microtechnology material-modification techniques, patterns can be transferred using stencil masks and broad ion beams to nanomachining scenarios. In the case of the etch-stop process; writing of 3D micropatterns with different height levels was achieved using a broad beam. The stencil masks were found to be durable with no obvious deterioration and well suited for exposure of large areas.

1. Introduction

The use of micro and nano structured stencil masks [1] in ion beam technology [2] allows the patterning of large sample areas while essentially maintaining the initial resolution of the mask. This parallel exposure approach has the important advantage that pattern writing is much faster compared to the pixel-by-pixel exposure in proton beam writing (PBW) [3] and the pattern element-by-pattern element in Programmable Proximity Aperture Lithography (PPAL) [4]. The stencil mask technique is essentially a masked ion implantation technique and as such can be used for micro- and nanopatterning using the whole range of high energy-ion induced materials modifications.

Recently, stencil masks have been used with low energy ions (1–3 keV, [2]) for patterning large areas. Here we have investigated the potential of stencil masks with broad beams of high energy ions to large area micro/nanomachining scenarios in different substrate materials.

2. Experimental

The first type (Type-1) of stencil mask [1] used for these experiments consists of a self-supporting 800 nm Au/500 nm Si_3N_4 membrane where the apertures penetrate right through the Au and Si_3N_4 layers. The second type (Type-2) has the same structure but the Si_3N_4 layer is continuous and only the Au layer is lithographically patterned. Fig. 1 presents scanning electron microscope (SEM) images of the Type-1 and Type-2 masks. The different types of materials patterned and the sample preparation are summarised in Table 1. The parameters for each irradiation were determined using the SRIM Monte Carlo code [5].

3. Results and discussion

Fig. 2 presents the SEM images of the patterns produced in negative and positive resist.

3.1. Negative resist

The SEM image in Fig. 2 shows that the pattern of the mask has been transferred to the negative resist polymer, which is a commercial SU8 [6]. In this case the energy and hence range of the ions has been selected so the ions are completely stopped in the Au/Si_3N_4 mask. The upper image in Fig. 2 shows the 250 nm wide central bar is faithfully reproduced. For higher energy ions, the Bragg peak lies within the resist layer which lead to degradation of the exposed pattern due to exposure of the surface layers in the masked-off areas.

3.2. Positive resist

As is the case of the negative resist (above), the pattern has been transferred to the resist polymer. Careful inspection of Fig. 2

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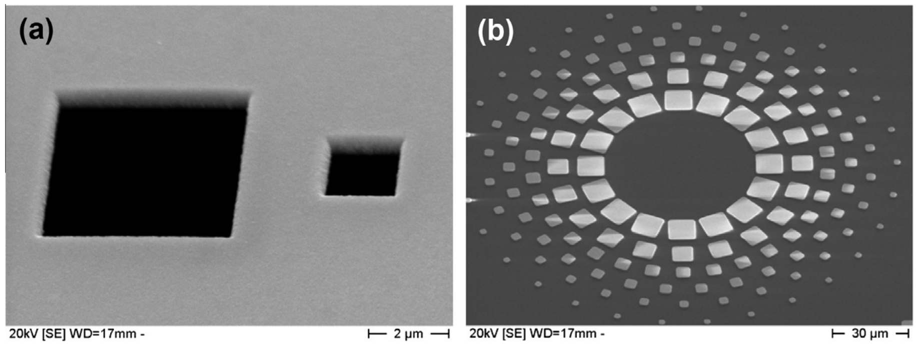

Fig. 1. (a) SEM image of a Type-1 mask with apertures. The visible part is the gold layer. (b) SEM image of Type-2 mask.

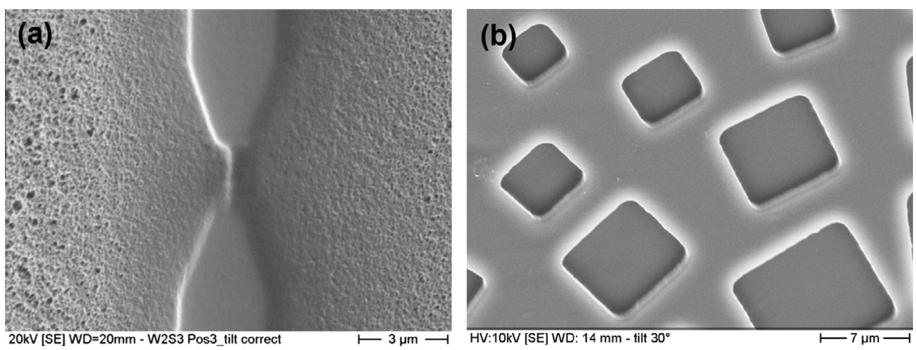

Fig. 2. SEM images of negative (GM 1030) and positive resist polymers after development. (a) Negative resist and (b) positive (PMMA) resist.

revealed the sidewalls where both straight and vertical. This was confirmed by optical confocal microscopy where the cross section of sidewalls was of the same size as the Abbe resolution limit. Moreover, small defects in the mask edges were faithfully reproduced down to at least the 1μm size.

3.3. PTFE dry-etching

Previously, some of us have reported direct etching of PTFE with an oxygen ion beam using a steel mesh mask [7]. The engraving effect is attributed to CF_2 chain scission under irradiation and recombination with implanted oxygen. This chemical reaction produces volatile CO_x, CF_x, HF gases which are removed by the surrounding vacuum. The advantage of using an oxygen beam is that it avoids the need for ion irradiation in an oxygen atmosphere [8]. Fig. 3 shows the pattern transferred using a Type-2 mask into PTFE by dry etching with an oxygen beam. The etch rate which depends on beam current was 1μms^{-1} for 40μAcm^{-2} beam current. The smallest square aperture (2 μm Fig. 1, bottom) is reproduced with a small rounding (~1 μm radius at the very surface). It can be clearly seen from Fig. 3 that the sidewalls are straight and smooth. Thus in-vacuum etching of PTFE with an oxygen beam is well suited for fabricating unsupported walls with large height to width aspect ratio. This is because of the absence of detrimental distortion from surface tension forces which are associated with liquid phase developers.

3.4. Implanted etch-stop in silicon

Fig. 4 presents images of the transferred Si microstructure patterns using $^{63}Cu^{2+}$ ions as an etch stop. This works by foreign chemical elements act to modify the etching rate. In particular, the implantation of $^{63}Cu^{2+}$ creates a copper-doped layer in silicon which produces a local *p–n* junction, identified by Greenwood in 1969 [9]. The electrostatic field generated by the junction reduces the electron diffusion. These electrons are therefore not available to react with the water molecules which strongly attenuates the creation of hydroxyl ions, which are required for the dissolution of silicon into Si $(OH)_4$. The SEM image (Fig. 4) shows that the pattern transfer into an etch-stop has been achieved and that some rounding of the side-walls has taken place; this may be advantageous for some applications such as stamps and moulds for nanoimprint and microinjection moulding applications. This rounding is not observed in the confocal microscope image presumably because the edge width is close to the resolution limit imposed by optical diffraction. The sharpness of the transferred pattern will be associated with the selectivity of the etching process and the

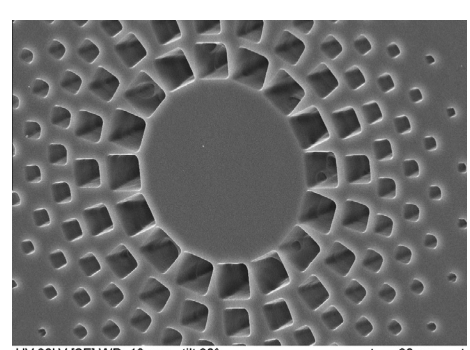

Fig. 3. SEM image of transferred pattern in PTFE using a Type-2 mask and 600 keV $^{16}O^{+}$ ions.