Box 12: Stamps for Nanoimprint Lithography

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P-beam writing is a flexible direct write technique that is extremely suitable for rapid prototyping down to the nanometer level and therefore, in combination with electroplating, extremely suitable for the production of high quality masters for nanoimprintng. Direct write processes for a long time have been considered intrinsically slow and inefficient compared with masked processes for the mass production of large-area, high-density, low-dimensional structures. However, the increased technical complexities and predicted increased cost of producing feature sizes smaller than 100 nm has called into question the traditional role of masked processes as the universal method of mass production. Direct write processes therefore may have some distinct advantages when used in combination with nanoimprinting [1]. UV cured imprinting, employing a quartz stamp, has been successfully applied using step-and-flash imprint lithography. Here a photocurable prepolymer is cured and molded [2]. This technique has been mainly applied in semiconductor nanofabrication. Thermal nanoimprint lithography is a second form of nanoimprinting. Here either a Si or Ni mold is heated above the glass transition temperature of a polymer and pressed into the polymer to replicate features in the stamp [3]. Both these techniques have shown great success in low aspect ratio nanoimprinting. The p-beam written stamps have potential applications in all the developed technologies based on molds and stamps [1, 4, 5], such as template fabrication for single molecule electronics, nanophotonics, nanofluidics, biosensors, etc.

P-beam writing in combination with Ni electroplating has demonstrated the production of 3D Ni stamps [6]. Here we discuss the production of a high-quality, void-free, high aspect ratio metallic stamp of 100 nm width and 2 μm depth, using p-beam writing coupled with electroplating. P-beam writing exhibits the following features: (a) the ability to fabricate structures with smooth and vertical sidewalls, which is crucial to minimize pattern distortion during demolding in nanoimprint lithography; (b) the ability to fabricate high aspect ratio sub-100 nm features in a

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one-step process; and (c) since proton beam writing exhibits minimal proximity effects, it is ideally suited to produce features of high packing density. The fabrication of metallic stamps with these combined characteristics is very difficult to achieve with other lithography techniques such as focused ion beam (FIB), electron beam lithography (EBL), optical, or X-ray lithography.

Figure 1 shows a schematic representation of the process of stamp fabrication. This involves: (a) exposure of Si coated with PMMA, using p-beam writing; (b) deposition of a second metallization layer on the top surface which acts as a seed layer for the base of the stamp and development of the structures; (c) electroplating of the Ni stamp; and (d) nanoimprinting into a PMMA-coated Si wafer.

![Fig. 1 Schematic representation of the process stamp fabrication (a–c) and nanoimprinting (d) using proton beam writing](image)

The fabrication process starts in a similar way as described in Sect. 3.3 of the chapter “Proton Beam Writing: A New 3D Nanolithographic Technique.” The main difference is the fact that before resist coating a thin metallic seed layer for electrodeposition is applied (e.g., 20 nm Cr followed by 200 nm Au). In this example a layer of 2 μm PMMA was spin coated onto a wafer. In the CIBA facility a beam of 2 MeV protons was focused to a spot size of 60 × 90 nm² and magnetically scanned over an area of 50 × 50 μm². The test pattern, a precursor to a microfluidic lab-on-a-chip system, consisted of 100 nm parallel trenches connected to reservoirs of 50 μm (width) × 500 μm (length).

After resist exposure and development the Ni electroplating was carried out using a typical Ni sulfamate bath solution with a sodium-dodecyl-ether-sulphate wetting agent, without organic additives, using a Technotrans AG, RD.50 plating system. The deposition is carried out employing first a low current density of 0.4 A/dm² for the first 50 μm, and then a high current density of 4 A/dm² for the next 200 μm. The initial low plating current density produces less intrinsic stress in the high aspect ratio structures, and is also coupled with the highest hardness. After delamination, the stamps were cleaned in toluene at 40 °C for 30 min. Figure 2a shows two electron microscope photographs of the test stamp featuring Ni ridges of 100 nm width and 2 μm height.

To eliminate sidewall electroplating, thereby eliminating voids, two approaches have been explored: (1) deposition of the second metallization layer before proton beam patterning; this relies on the proton beam penetrating the second metallization layer without adverse effects; and (2) deposition of the second metallization