Industrial applications of micro/nanofabrication at Singapore Synchrotron Light Source

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Abstract. SSLS (Singapore Synchrotron Light Source) has set up a complete one-stop shop for micro/nanofabrication in the framework of the LIGA process. It is dubbed LiMiNT for Lithography for Micro and Nanotechnology and allows complete prototyping using the integral cycle of the LIGA process for producing micro/nanostructures from mask design/fabrication over X-ray lithography to electroplating in Ni, Cu, or Au, and, finally, hot embossing in a wide variety of plastics as one of the capabilities to cover a wide range of application fields and to go into higher volume production. The process chain also includes plasma cleaning and sputtering as well as substrate preparation processes including metal buffer layers, plating bases, and spin coating, polishing, and dicing. Furthermore, metrology using scanning electron microscopy (SEM), optical profilometry, and optical microscopy is available. LiMiNT is run as a research lab as well as a foundry. In this paper, several industrial applications will be presented, in which LiMiNT functions as a foundry to provide external customers the micro/nano fabrication services. These services include the fabrication of optical or X-ray masks, of micro/nano structures from polymers or from metals and of moulds for hot embossing or injection moulding.

1. Introduction

SSLS (Singapore Synchrotron Light Source) has set up a complete one-stop shop for micro/nanofabrication in the framework of the LIGA process. It is dubbed LiMiNT for Lithography for Micro and Nanotechnology. Fully operational since 2003 [1], its equipment allows complete prototyping using the integral cycle of the LIGA process for producing micro/nanostructures from mask writing via either laser direct writing or e beam lithography over X-ray irradiation, development, to electroplating in Ni, Cu, or Au, and, finally, hot embossing in a wide variety of plastics as one of the capabilities to cover a wide range of application fields and to go into higher volume production. The process chain also includes plasma cleaning and sputtering as well as substrate preparation processes including metal buffer layers, plating bases, and spin coating, polishing, and dicing. Furthermore, metrology using scanning electron microscopy (SEM), optical profilometry, and optical microscopy is available (figure 1).

LiMiNT is run as a research lab as well as a foundry. An overview on the research and service in micro/nanofabrication at the Singapore Synchrotron Light Source may be found in [2]. The LIGA
process has been established based on the use of SU-8 negative tone resist in X-ray lithography. As a foundry, LiMiNT provides services which include the fabrication of optical or X-ray masks, of micro/nano structures from polymers or from metals, and of mould inserts for hot embossing or injection moulding. X-ray lithography and the hot embossing process can also be provided to customers. In this paper, several industrial applications will be presented, in which LiMiNT functions as a foundry to provide external customers the micro/nano fabrication services.

2. Services from LiMiNT as a micro/nanofabrication foundry

SSLS is providing all process steps for prototyping of micro- and nanodevices, starting from pattern design, over mask fabrication, lithography, electroforming to plastic moulding. As the LiMiNT facility includes deep X-ray lithography in its portfolio, SSLS becomes a unique micro- and nanotechnology lab in South East Asia. The deep and straight penetration of X-rays through resist materials allows the fabrication of microstructures with very high aspect ratios (LIGA technology [3]). The LiMiNT beamline provides, at the sample, a useful spectral flux which covers a bandwidth from 2 keV to 10 keV. SU-8 resist is preferred because of the relatively soft X-ray spectrum.

2.1. Fabrication of high aspect ratio SU-8 honeycomb microstructures

The fabrication of high aspect ratio honeycomb microstructures from SU-8 photo resist for a customer is described in the following.

The requirement from the industrial customer is to fabricate the honeycomb microstructures to the following specifications

| Specification                  | Value         |
|-------------------------------|---------------|
| Height of honeycomb           | 400 μm        |
| Width across flats            | 50 μm         |
| Wall thickness                | 10 μm         |
| Size of one pad               | circular area of Ø12 mm |
The fabrication of the required honeycomb microstructures comprises the process steps of mask layout design, optical mask fabrication, X-ray mask fabrication, substrate preparation, X-ray exposure, resist development and metrology. AutoCAD is used in the mask layout design. The pattern area is usually inscribed in an 80 mm diameter circle. An array of 4 x 4 moulds is designed in the mask layout, which results in a total of 16 moulds on one 100 mm diameter Si wafer. The optical mask fabrication is carried out all in-house, including pattern generation, resist development, chromium etching and resist removal. Pattern generation is made through Heidelberg Instruments DWL 66 direct-write laser system with 4 µm resolution. The X-ray mask was fabricated via a cost-effective method [4],[5] in which a 100 mm diameter graphite wafer of 200 µm thickness was used as membrane material and SU-8 resist was applied on the graphite wafer to achieve a 30 µm resist layer. The pattern of the optical mask was transferred to the SU-8 resist layer by UV exposure using a Karl Suss MA8 contact mask aligner. Post exposure bake and development were followed by an electroplating process to deposit 20 µm gold into the SU-8 mould as absorber. The X-ray resist used by SSLS is SU-8 photoresist. A Ti/Au plating base was deposited on a 100 mm diameter Si wafer and SU-8 resist was applied on the wafer by spin coating to obtain the required thickness. X-ray exposures were performed at the LiMiNT beamline of SSLS. This beamline operates using an Oxford Danfysik scanner which was designed for 4-inch masks complying with the NIST-standard. When an X-ray exposure is underway, the mask and sample are scanned vertically. The substrate is water-cooled and the ambient pressure of exposure is typically 100 mbar He. The exposed sample was put into an oven for post exposure bake, a process required for fully cross-linking of the exposed SU-8. After post exposure bake, the sample was developed using SU-8 developer. The detailed process of SU-8 based X-ray lithography/LIGA may be found in reference [6], [7], [8] and [9]. After SU-8 resist development, the sample was ready (figure 2a) to dice into 16 final products: 15mm x 15mm Si chips with 12 mm SU-8 honeycomb microstructures. The SEM image in figure 2b shows the 400 µm SU-8 honeycomb microstructures.

![4 x4 array of honeycomb microstructures](image1.png) ![SEM of honeycomb microstructures](image2.png)

**Figure 2.** SU-8 honeycomb microstructures fabricated by X-ray lithography at SSLS

### 2.2. Fabrication of high aspect ratio nickel hot embossing mould insert

The fabrication of a high aspect ratio nickel hot embossing mould insert for a group of customers is a joint effort by SSLS and MiniFab Pty Ltd [10]. The mask layout includes the designs of different microstructures from different customers, so it was called multi-project wafer (MPW). The same process steps for optical and X-ray mask fabrications were involved as mentioned in 2.1. The finished optical and X-ray masks are shown in figure 3.
For the fabrication of the metal mould for hot embossing or injection molding, there are two process routes to form the base of the mould insert. One is to use a thick metal plate as the base on top of which the microstructures are plated. An alternative is to form the base of the mould insert through overplating. In the present application, the first option was selected using a 2 mm thick nickel plate as the base of the mould insert and plating the microstructures on top (figure 4).

2.3. Fabrication of nickel moulds for injection moulding

A nickel injection mould featuring with micro channels of 2 μm wide and deep, was fabricated. The channels had to be equally distributed on a ring having 25.4 mm inside diameter and 35 mm outside. The process starts with preparing a Si wafer with a Ti/Au plating base onto which a 2 μm thick photo resist was applied by spin coating and prebaked. Using the Heidelberg Instruments DWL 66 direct-write laser system with a resolution of 0.8 μm, 2 μm wide micro channels were directly written into the photo resist at a pitch of 4 μm. After development, nickel was electroplated to form the mould for the channels and, by overplating, the base of the mould insert (figure 5a). For injection moulding, a chamber or a space ring is needed to give the moulded plastic parts the required thickness. To fabricate the chamber, a second LIGA process using aligned X-ray exposure was carried out on top of the completed mould insert shown in figure 5a. The finished injection mould is shown in figure 5b, the SEM image in figure 5c shows the 2 μm wide and deep micro channels.
3. Summary and conclusions

Micro/nano fabrication activities at SSLS include both research programs and industrial applications. Three application examples with industrial background were presented. In application example 1, thick and high aspect ratio polymer (SU-8) microstructures were fabricated by X-ray lithography; in example 2, high aspect ratio metal nickel microstructures were produced by LIGA process on a thick nickel plate to make hot embossing moulds; in example 3, nickel injection moulds with 2 micrometer feature size were fabricated by combining laser/X-ray lithography and electroplating process. All these applications exploit and utilize the unique characteristics of X-ray lithography/LIGA process. The products of these applications are difficult or impossible to produce with the same quality by using precision machining or other microfabrication methods. The LiMINT facility at SSLS can function as a foundry to provide customers with micro/nano fabrication services including the fabrication of optical or X-ray masks; the fabrication of micro/nano structures from polymers or from metals and the fabrication of hot embossing mould inserts or injection moulds. In addition, X-ray lithography and hot embossing process can also be provided to users.

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