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Nickel Injection Mould Fabrication via Proton Beam Writing and UV Lithography

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Abstract. For applications of injection mould fabrication in the field of MEMS, proton beam writing (PBW) and UV lithography are combined to manufacture 2 mm thick Ni moulds with sub-10 µm fine features in 10 µm deep fluidic channels. PBW is capable of writing micro and nano features with straight and smooth sidewalls with sub-10 nm RMS roughness, while UV lithography has the advantage of large area structuring through a mask. A newly developed positive resist maP1275 hv is presented in combination with PBW and UV lithography for Ni injection mould fabrication. Fine micro pillars with straight and smooth sidewalls have been achieved by PBW and linked with UV lithography into a microfluidic channel. The new resist is successfully removed after electroplating without compromising the Ni mould.

Introduction

In recent years, the demand for thick photo resist microstructures in the field of MEMS has increased. These thick micro components often consist of high aspect ratio features. UV-LIGA in SU-8 has been a preferred technique for realizing high aspect ratio electroforming moulds for its low fabrication costs. SU-8 is well known for its relatively good mechanical properties. The material is also known to be a permanent resist, which makes it difficult to remove cross linked SU-8 epoxy moulds without harming the integrity of micrometallic components. It is particularly difficult to remove SU-8 surrounded by metallic components. The microfabrication of thick electroforming micro moulds using a KMPR negative tone photoresist has recently been proposed [1]. Although it was reported that the KMPR moulds can be easily stripped without damaging the metal components [1] we found this to be challenging especially at the sub-10 µm level.

In this paper experiment studies have been conducted with the aim to fabricate Ni moulds for injection moulding of components featuring sub-10 µm details with a final height of tens of micro metres. PMMA, a commonly used positive tone resist, is used in the study which can be easily removed without compromising the Ni moulds. Earlier research work [2, 3] has shown that the combination of PBW and electroplating of PMMA resist can give smooth Ni moulds with sub-10 nm RMS side wall roughness and 20 nm details. This makes it a powerful tool for Ni mould fabrication. The energy loss of the MeV protons impinging on and penetrating into a photoresist, is governed by the Coulomb interaction of the incident particle with the electrons and nuclei of the target. The main form of energy loss is via substrate electrons [4]. Due to the mass mismatch between proton and electron, the delta rays (induced secondary electrons) have low energy; the range of the delta rays is therefore limited [5, 6, 7]. The limitation of using PMMA resist for our Ni mould fabrication lies in the fact that the maximum depth at which PMMA can be structured is limited to about 10 µm if a 248 nm deep UV lithography is used.

Here we present a two step process in which the fabrication of a resist master mould is carried out using maP1275 hv by PBW for the fine structures, while UV lithography is used for the large structures. The positive tone resist maP1275 hv is employed as it can achieve layers of tens of micro metres easily.

Experimental Procedures

PBW has been developed at the Center for Ion Beam Applications (CIBA) in the Department of Physics of the National University of Singapore. The PBW system employs a MeV focused proton beam, scanned in a predetermined pattern on a photoresist (e.g. SU-8, PMMA and maP1275 hv), which is subsequently chemically developed. The UV source employed for exposure of maP1275 hv is a 365 nm UV light illuminator. The UV lamp is assisted with a yellow light camera and a precisely movable sample stage for aligned exposure.

In the first step, PBW is used to generate the fine features with smooth sidewall profiles, as PBW has a very low proximity effect [8, 9]. In a second step, UV lithography is used to finalize the chip design and generate the large areas of the lab on chip device. In this way we combine the short patterning time of UV lithography and the high smoothness of PBW for fine features. The detailed process is shown in Fig 1.

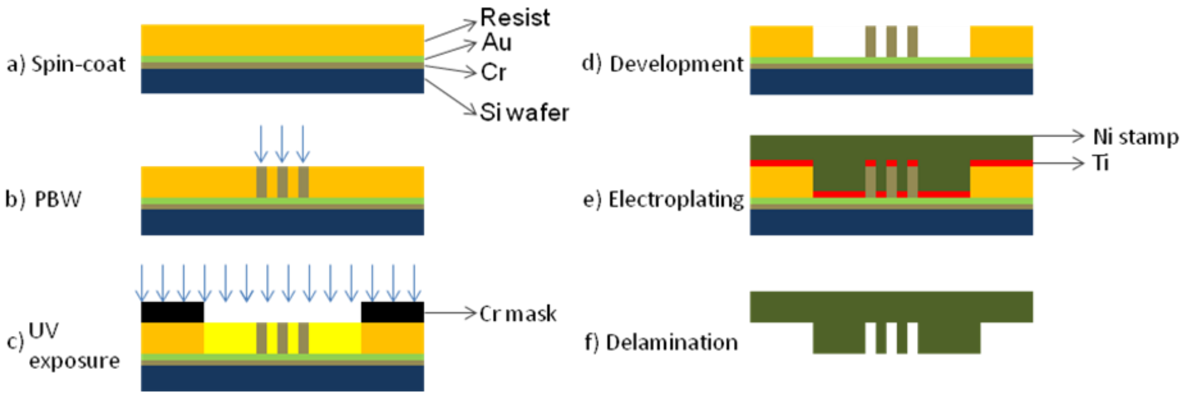

Figure 1 Ni injection mould fabrication schematic process using PBW and UV lithography

PBW and UV lithography on maP1275 hv. In this study of maP1275 hv resist, a thin layer of Cr and Au is pre-coated on a Si wafer to provide good adhesion between the metal layer and Si wafer and improve the conductivity for electroplating in the later process. A 10 µm thick layer of resist is then spin-coated on the Si wafer, followed by 300 s bake at 80 °C for edge bead removal followed by 120 s at 120°C. After PBW and UV processes the samples are developed in a 2.38% tetramethylammonium hydroxide (TMAH) solution for 120 s, followed by a DI water rinse.

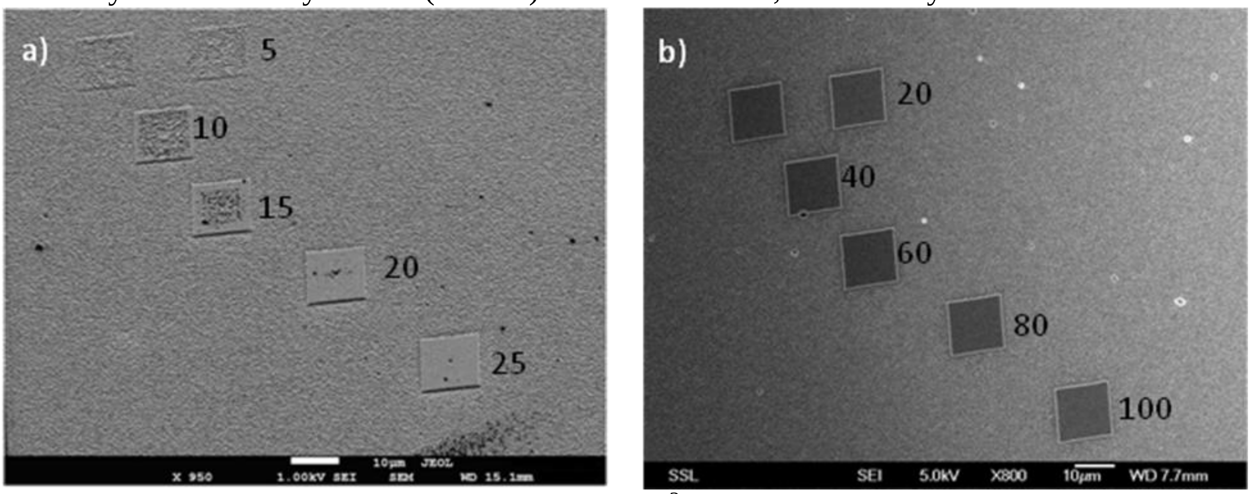

Figure 2 SEM images of 1 MeV PBW of 10x10µm^2 pillars on maP1275 hv after development, a) dose of 5-25 nC/mm^2 , and b) dose of 20-100 nC/mm^2, showing cross linking of the resist.

MaP1275 hv (MRT resist Germany) is a positive tone resist under 365 nm UV exposure. The UV light absorbed by maP1275 hv preferentially breaks the molecular bonds. Hence the exposed resist can be removed later via chemical development. During the study of PBW on maP1275 hv, different doses (1-500 nC/mm^2) were administered to write arrays of 10x10 µm^2 squares using 1 MeV proton beams, as shown in Fig. 2. The proton beam exposed pattern shown in the figure cannot be removed after development. This indicates the maP1275 hv resist mainly shows cross-linking and can therefore only be used as a negatively under PBW. One important observation form this experiment is the relationship between resist cross-linking and PBW dose. As shown in Fig. 2a, the square pillars written with a dose of less than 20 nC/mm^2 are not fully cross-linked and defects are observed. While the, the square pillars written at 20 nC/mm^2 and above as shown in Fig. 2b are almost free of defects after development, indicating full cross-linking at or above this dose level.

The designed pattern on the resist for the injection mould consists of 3 circular pillars of 60 µm diameter located in a 300 µm wide channel. PBW is employed to write the pillar features, enabling smooth demoulding. UV lithography is employed to fabricate the long microfluidic channels. Arrays of circular pillars with a diameter of 60 µm are written by PBW at doses of 10, 20, 50 and 100 nC/mm^2, followed by development. Next the samples are exposed to UV irradiation to obtain 300 µm wide channels containing the PBW written pillars. Since cross-linking during PBW is incomplete at or below 20 nC/mm^2, the chain-scissioning induced by UV exposure is sufficient to render the resist developable, resulting in positive resist behavior. Since the proton beam-induced cross-linking dominates, the pillars written at 50 and 100 nC/mm^2 are still observed after UV exposure and development.

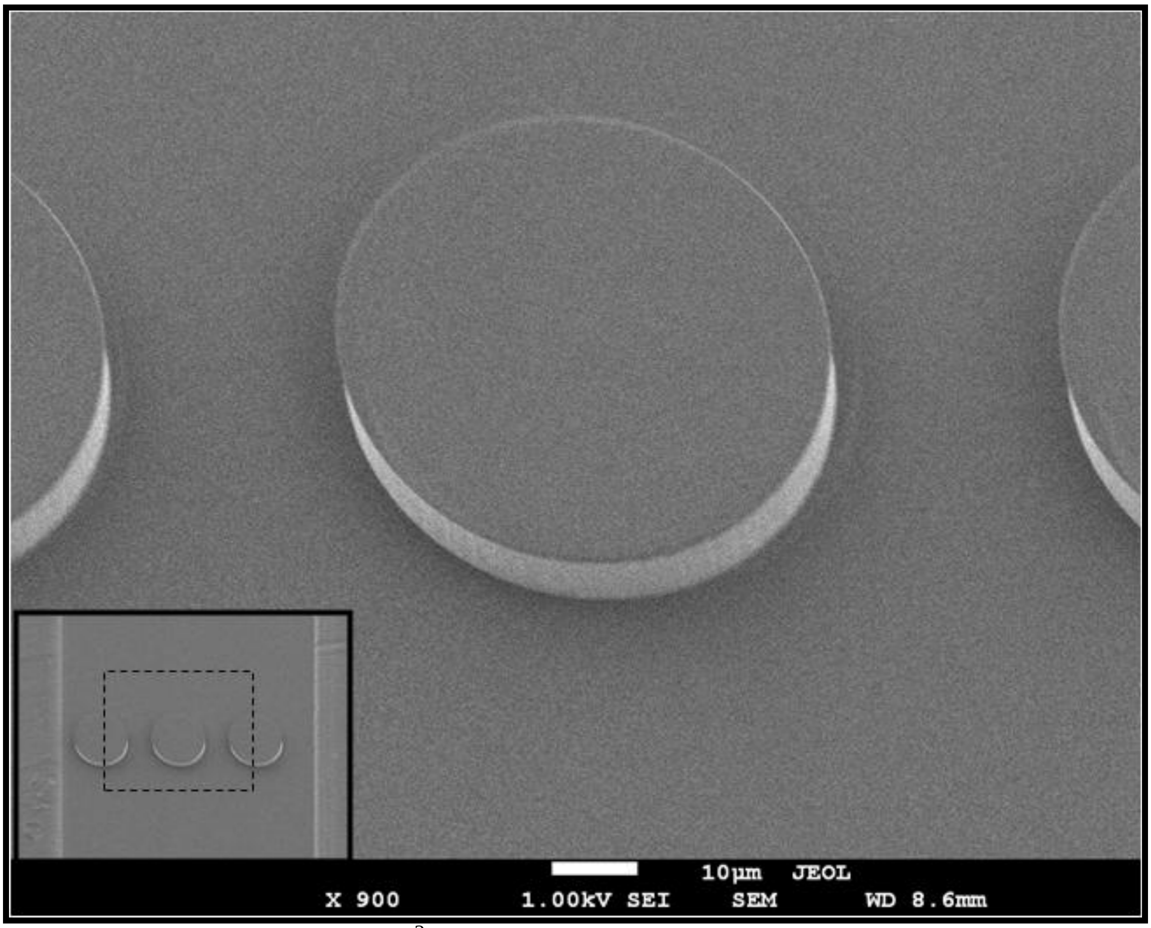

Figure 3 SEM images of 50 nC/mm^2 PBW written maP1275 hv pillars in a UV exposed channel (inset).

Fig. 3 shows a SEM photograph (30 degree tilt), featuring smooth and straight maP1275 hv pillars (56 µm diameter and 9.2 µm high) exposed using a proton dose of 50 nC/mm^2. Further research is planned to compare the sidewall smoothness of the maP1275 hv pillars with the earlier reported

PBW resist structures in SU-8 and PMMA resist, featuring a sidewall roughness of better than 3nm RMS and a side wall angle better than 89.5º [2, 10, 11, 12].

Ni mould fabrication by electroplating. The Ni electroplating system available in CIBA employs a commercial plating system RD.50 from Technotrans AG, with a nickelsulfamate bath solution without organic additives at pH 3.5 and a temperature of 50°C [13].

The resist moulds were first coated with a thin Ti layer serving as a seedlayer for electroplating. A 500 µm thick Ni stamp was plated (Fig. 1e). The Ni mould was delaminated from the Si wafer (Fig. 1f) after 10 minutes in acetone under ultrasonic agitaion.

The maP1275 hv resist was observed in the Ni mould fabricated using a 100 nC/mm^2 proton dose. Even after further treatment in acetone resist was still presented on the Ni mould. This indicates that the PBW dose has to be kept below 100 nC/mm^2. On the other hand, the Ni mould fabricated at a 50 nC/mm^2 proton dose doesn't contain resist as shown in Fig. 4. This indicates that the optimal PBW dose of maP1275 hv in combination with UV lithography is about 50 nC/mm^2. From the SEM image, the depth and diameter of the circular hole in the Ni mould were measured as 9.2 µm and 56 µm respectively, nicely matching with the sizes, straightness and smoothness of the resist pillars.

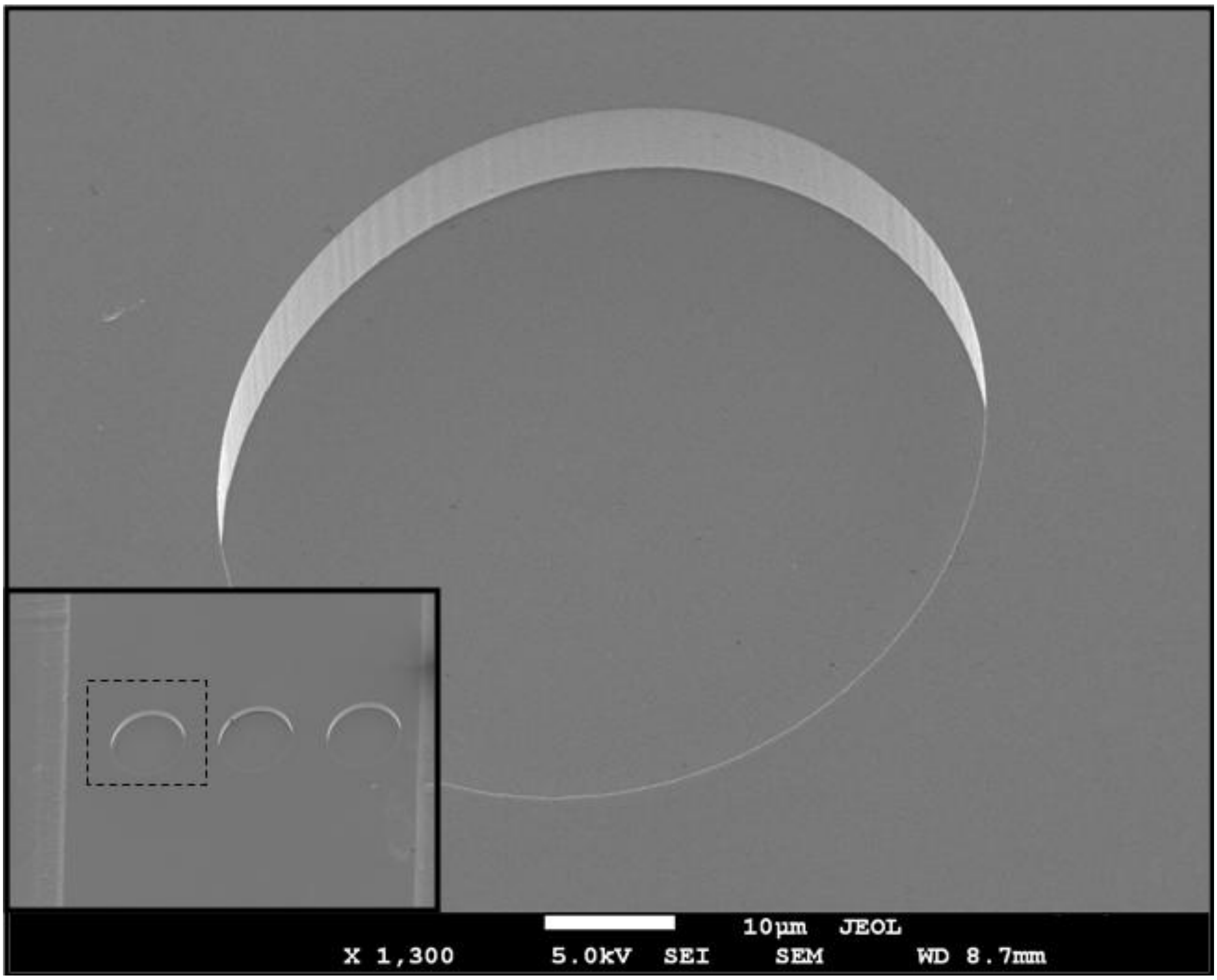

Figure 4 SEM images of Ni mould fabricated from the sample which was exposed to a 50 nC/mm^2 proton dose used to write the resist pillars, positioned in a UV exposed ridge (inset).

Summary

Proton beam writing (PBW) has shown great advantages in writing very fine features with smooth and straight sidewalls. For the fabrication of large area injection moulds, UV lithography provides high productivity and short production period. The new resist maP1275 hv has been successfully patterned by PBW and UV lithography, achieving features with smooth and straight sidewalls. The resist behaves as a negative resist under PBW, in contrast to UV lithography where a positive resist behavior is found. The optimum dose for PBW experiments in combination with UV lithography on this maP1275 hv resist is around 50 nC/mm2. The exact dose window will be determined in the future. Ni moulds formed on these resist moulds are completely free of resist and are identical in smoothness and size compared to the original polymer structures. The moulds shown here will be used in injection moulding experiments.

The characterization and results of PBW fabricated Ni stamps in combination with PMMA resist have been discussed previously and a sidewall smoothness of 3 nm has been achieved [13]. The smoothness of the sidewalls of the resist and Ni structures in combination with maP1275 hv will be measured using atomic force microscope (AFM) in future experiments.

Acknowledgements

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