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Article

Fabrication of a Metal Micro Mold by Using Pulse Micro Electroforming

Xiaolei Chen [1,2], Li Liu [1], Junfeng He [1,*], Fei Zuo [1] and Zhongning Guo [1,2]

[1] School of Electro-mechanical Engineering, Guangdong University of Technology, Guangzhou 510016, China; xlchen@gdut.edu.cn (X.C.); llgdut@163.com (L.L.); feizuo108@outlook.com (F.Z.); znguo@gdut.edu.cn (Z.G.)
[2] Guangzhou Key Laboratory of Nontraditional Machining and Equipment, Guangzhou 510006, China
* Correspondence: hejunfeng89@126.com; Tel.: +86-20-39322412

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Abstract: Microfluidic devices have been widely used for biomedical and biochemical applications. Due to its unique characteristics, polymethyl methacrylate (PMMA) show great potential in fabricating microfluidic devices. Hot embossing technology has established itself as a popular method of preparing polymer microfluidic devices in both academia and industry. However, the fabrication of the mold used in hot embossing is time-consuming in general and often impractical for economically efficient prototyping. This paper proposes a modified technology for preparing metal micro molds by using pulse micro electroforming directly on metallic substrate, which could save time and reduce costs. In this method, an additive was used to avoid surface defect on deposited nickel. A chemical etching process was performed on the metallic substrate before the electroforming process in order to improve the bonding strength between the deposited structure and substrate. Finally, with the aim of obtaining a metal micro mold with high surface quality (low surface roughness), an orthogonal experiment was designed and conducted to optimize the electroforming parameters. Additionally, metal micro molds with different structures were well prepared by using the optimized parameters.

Keywords: microfluidic devices; micro mold; electroforming; surface quality; surface roughness

1. Introduction

Microfluidics has been developing for three decades [1], and there is significant development in microfluidic devices for biomedical and biochemical applications, which are used to perform mixing, chemical reactions, particle detection and separation, and so on [2–4]. In the early years of microfluidics, devices were predominantly made of materials like glass, quartz or silicon [5]. Recently, compared with silicon and glass, polymethyl methacrylate (PMMA) has attracted more attention for its application in chemical and biological microfluidic applications, due to the advantages of low cost, favorable optical properties, resistance to chemicals, and reduced contamination effects Also, thermoplastics possess inherent robustness to mechanical deformation [6,7].

A number of approaches are available for preparing polymer microfluidic devices, such as micro milling [8], laser ablation [2], etching [9] and lithographie, galvanoformung, abformung (LIGA) [10]. Compared with other methods, hot embossing technology has established itself as a popular method for high-volume fabrication of microfluidic device in both academia and industry [11,12]. This technology involves a comparatively simple process that simplifies the selection of processing parameters, has relatively low requirements for mold structures, has a large range of suitable materials and good availability of commercial products [13].

The functionality and reliability of microfluidic devices are mainly determined by the geometrical tolerances in the channel geometry and surface roughness. It has been reported that devices fabricated by direct writing methods such as micro milling or laser ablation always have poor surface quality [14,15]. In hot embossing processes, all the properties of the replica are directly impacted by the geometric tolerances and the surface quality of the reverse mold structures. Hence, it is important to improve the quality of mold structure.

Generally, the mold structure is fabricated from photolithographic procedures such as silicon bulk micromachining or surface micromachining employing high-aspect-ratio resists such as SU-8 [16]. In the typical conventional procedure for preparing the mold, a silicon or SU-8 photoresist structured primary mold is treated with a conductive layer on the surface, and then electroforming is performed in a galvanic bath to form the secondary mold. As the whole mold, including the structure and substrate needs to be prepared by an electroforming process, the manufacturing of micro structured metal masters is a complex and rather lengthy process, often making it impractical for economically efficient prototyping [17]. Although enhanced current densities could increase the growth speed [18], it also tends to increase the internal stress, which can lead to warped metal mold exhibiting insufficient surface quality. Hence, the electroplated mold needs to be post-processed by mechanical machining. To reduce the time for the testing of novel microfluidic designs and limit the risk of the electroplating process, an alternative technique for generating a high-quality metal mold with a sufficient lifetime for a small-lot replication is required.

This paper proposed a modified method for preparing metal micro molds by using pulse micro electroforming directly on metallic substrate, which could save time and reduce the cost. In this process, an additive was used to avoid surface defects on deposited nickel. A chemical etching process was performed on the metallic substrate before the electroforming process in order to enhance the bonding strength between the deposited structure and substrate. Finally, to obtain a metal micro mold with high surface quality (low surface roughness), an orthogonal experiment was designed and conducted to optimize the electroforming parameters. Also, metal micro molds with different structures were prepared by using the optimized parameters.

2. Materials and Methods

2.1. Materials and Equipment

In this paper, SU-8 2050 negative photoresist and propylene glycol methyl ether acetate (PGMEA, 1-methoxy-2-propanol acetate) developer (MicroChem Corp., Westborough, MA, USA) were used to prepare the micro electroforming mold. Polished 1 mm thick stainless steel (1Cr18Ni9Ti) sheet was employed as the substrate. An n-methyl pyrrolidinone solution was used to remove the cross-linked SU-8 structure after micro electroforming. The structures and roughness were examined using a confocal laser scanning microscope (CSLM, Olympus LEXT OLS4000, Olympus Corporation, Tokyo, Japan).

2.2. Methods

2.2.1. Preparation of the SU-8 Mold

Figure 1 shows the schematic diagram of the process for preparing the SU-8 mold.

(1) Pretreatment of the Substrate

In order to obtain the well adhesion between the substrate and photoresist, the substrate should be pre-treated before the photoresist is coated.

First, the stainless-steel substrate was put into the acetone solution in an ultrasonic cleaner to remove the oil film from the substrate. Second, acid washing was employed to remove the oxide film from the substrate surface. Third, the substrate was put into the acetone solution again to remove any remaining acid. Finally, the substrate was rinsed with deionized water and placed into a drying oven with a temperature of 150 °C for 10 min to remove the residual water (Figure 1a).