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Research on micro-electric resistance slip welding of copper electrode during the fabrication of 3D metal micro-mold

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ABSTRACT

3D micro-mold fabricated by the micro double-staged laminated object manufacturing process (micro-DLOM) is formed via stacking and fitting of multi-layer 2D micro-structures. The connection of 2D micro-structures is related to forming accuracy and mechanical properties of 3D micro-mold. In this research, micro-electric resistance slip welding of copper electrodes was proposed to connect multi-layer 2D micro-structures. Firstly, the proper process parameters of slip welding were obtained through the welding experiment, and the temperature field of micro-electric resistance slip welding under such process parameters was simulated. Secondly, deposition effect of the copper bar electrode produced during slip welding was studied and the study results show that the copper element deposited in the slip welding area decreases as the surface roughness of copper electrode decreases. Finally, based on the above research, a square micro-cavity mold with micro-channel, a circular micro-cavity mold with cross keyway and micro gear cavity mold with two-stage steps were welded by the micro-electric resistance slip welding.

1. Introduction

With the development and application of MEMS, micro parts have been successfully applied in micro-electronics, micro-machinery, precise instruments, biomedicine and so on. However, it is difficult to use common processing methods to fabricate micro parts due to their tiny structure size and extremely light weight. With the intensive study in this area, a series of technologies for fabricating micro parts have emerged. Through UV-LIGA technology, Yan et al. (2012) fabricated hollow micro-needle structures by using SU8 and they also replicated the metal micro-needle structure via the electroplating technology. Based on the UV-LIGA technology, Yoon et al. (2006) used multidirectional ultraviolet (UV) lithography to fabricate the 3D micro-structure with specific inclined wall structure. Using LIGA technology, Shibata et al. (2008) also fabricated a micro-structure with a sidewall angle of 65–84° by varying the distance between the photomask and the photoresist surface.

On the basis of the laminated manufacturing principle, Pfeiffera et al. (2011) used femtosecond laser micromachining to fabricate 3D micro-structures with depth of 100 μm in cemented carbide and stainless steel plate. Using a combined process based on micro-EDM and electrochemical polishing, Richter et al. (2012) processed the micro-channel structure with surface roughness of 80 nm and the spherical probe structures with diameters of 40–200 μm. Habib et al. (2009) applied localized electrochemical deposition to fabricate the electrodes with complex cross-section and the deposited electrode could be used directly for micro-EDM. In order to improve the processing precision of micro-EDM, Schulze et al. (2012) adopted on-machine system to measure the surface of the machined cavity by utilizing confocal white-light sensor and thus reduced its machining error within 2 μm. To obtain micro-structure of ceramic material, Li et al. (2012) processed micro-cavity structures on ceramic bodies at the pre-sintering temperature of 850 °C by using the ceramic green machining method. Based on the laminated manufacturing principle, Liu et al. (2012) fabricated 3D micro-structures (45 μm deep) on stainless steel material by utilizing micro electrochemical milling (EMM) technology.

Through the laser cutting and welding method (LCWM), Shiu et al. (2012) fabricated the metal mold with micro-channel and they replicated the micro-channel by using PDMS material. Huang et al. (2012) mass-produce 200 μm-wide and 185 μm-deep glass-based biochips via laser micro-machining (LMM) and precision glass molding (PGM) techniques. By using electrical-assisted

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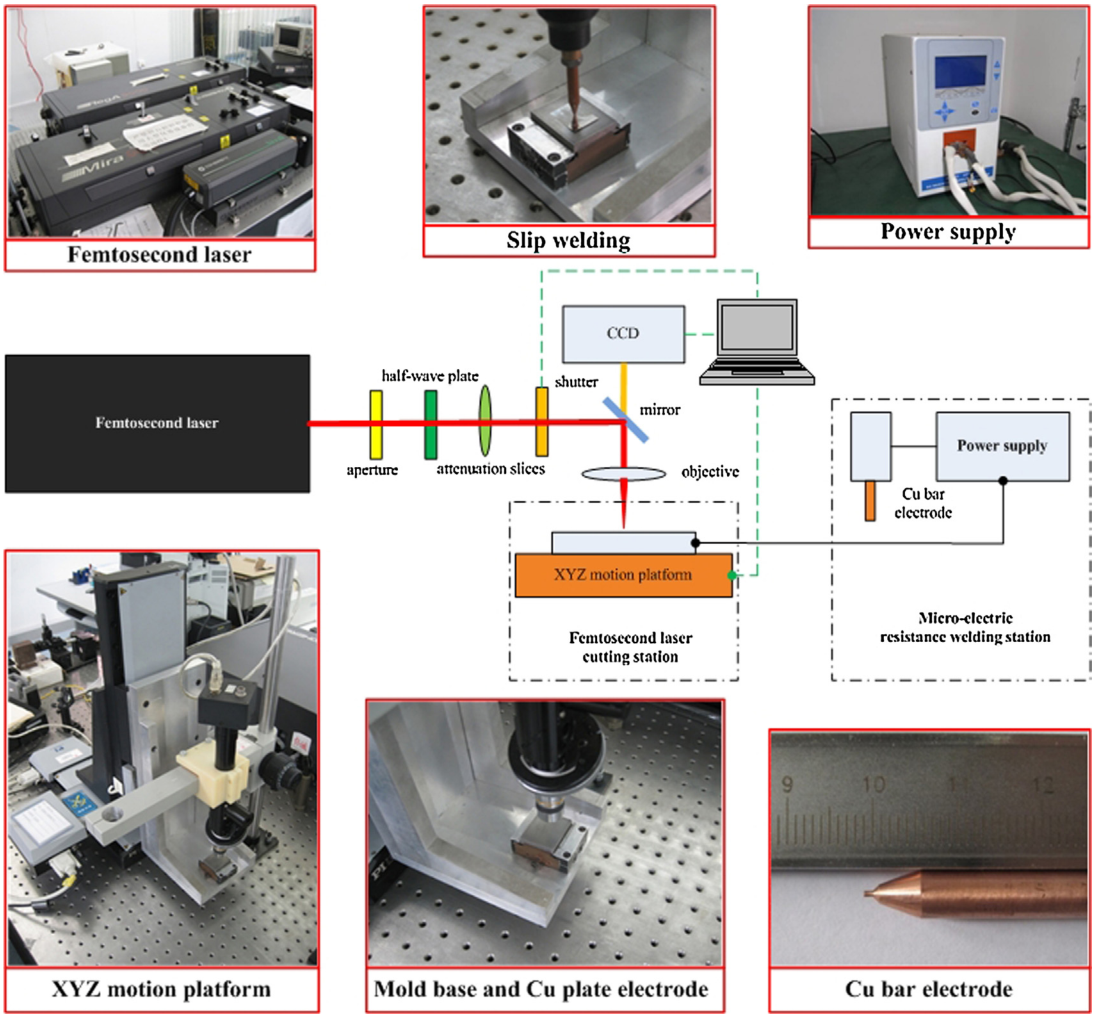

Fig. 1. Schematic diagram of micro-DLOM.

embossing process, Mai et al. (2013) fabricated micro-channels on 316L stainless steel plate. Recently, Liu et al. (2010) proposed a facile process based on mechanical cutting combined with photolithography processes to fabricate micro-scale thermoelectric modules whose thermoelectric legs have 200 μm × 400 μm in cross-section with a height up to 600 μm. Base on this, they also fabricated thermoelectric micro-modules with high-aspect-ratio thermoelectric pillars by a glass molding and electrodeposition method (Liu and Li, 2011).

The studies mentioned above have carried out many explorations and experiments for the fabrication of 3D micro-mold and it could be good references for the fabrication of 3D micro-structure. Based on these good studies, Xu et al. (2012a,b) proposed that 3D micro-mold can be fabricated by combining femtosecond laser cutting with micro-electric resistance slip welding (micro-DLOM). Micro-DLOM is based on the laminated object manufacturing (LOM) technology and it is composed of femtosecond laser cutting station and micro-electric resistance slip welding station. In femtosecond laser cutting station, 2D metal micro-structure was obtained through the femtosecond laser cutting of 10 μm-thick 0Cr18Ni9 stainless steel foil. Then, multi-layer 2D metal micro-structures were connected in micro-electric resistance slip welding station to approximately fit the 3D micro-mold. Compared with LIGA/UV-LIGA, micro-DLOM can fabricate 3D micro-structure with a complex structure. Compared with micro-EDM, micro-DLOM does not have electrode loss and thus it can fabricate 3D micro-structure with high depth-to-width ratio. Based on the large area ablation of material, laser micro-machining can fabricate 3D micro-structure but this processing method will cause the low machining efficiency. By comparison, micro-DLOM just cut the profile of 2D metal micro-structure, thus micro-DLOM will have high machining efficiency.

In micro-DLOM technology, the multi-layer 2D micro-structures in 3D micro-mold were connected merely by several welding points. These welding points were used to avoid the horizontal movement of steel foil for guaranteeing the femtosecond laser cutting precision (<2 μm). However, these welding points were impossible to achieve full connection of 2D micro-structures within the slip welding area and gaps inevitably existed between every layer of 2D micro-structures. Therefore, in order to eliminate the gaps for guaranteeing the forming precision and mechanical properties of 3D micro-mold, micro-electric resistance slip welding of micro-bar electrode was adopted to complete full connection between multi-layer 2D micro-structures. However, when tungsten bar electrode was utilized in slip welding of micro-molds, the plastic deformation of micro-mold easily happened due to good plasticity of stainless steel foil and high hardness of tungsten electrodes, which will influence the dimensional precision of micro-mold in height direction (Xu et al., 2012a,b). In order to solve this problem, in this research, the copper electrode which has relatively soft mechanical property was used to weld 3D micro-mold. Moreover, the deposition effect of copper electrode during slip welding was also studied.