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FABRICATION OF MICRO GEAR WITH HELP OF UV-LIGA PROCESS

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Abstract: - A major breakthrough in UV-LIGA (Lithographie, Galvanoformung and Abformung) started with the use of epoxy-based EPON® SU-8 photoresist in the mid-1990s. Using this photoresist has enabled the fabrication of tall and high aspect ratio structures without the use of a very expensive synchrotron source needed to expose the photoresist layer in X-ray LIGA. SU-8 photoresist appeared to be well-suited for LIGA templates, but also as a permanent material. , the UV-LIGA production procedure and the processing parameters on fabrication of micro gear were determined through manufacturing experiments. The involute profile micro gear samples and the cases were fabricated based on UV-LIGA technology. The micro gears with parameters of modular m=0.04mm, tooth number z =18 was made of Nickel. The size, elastic modulus and the indentation hardness of the micro gear were measured. The results indicate that the structure of the micro gear is clear, the surface and the curve of tooth profile are smooth, and the sidewall is vertical. Micro gear transmission device was assembled by micro gear and micro case, and it can transmit continuously. The work provided some reference for the fabrication of micro gear transmission device.

Keywords: - Micro gear, UV-LIGA technology, Fabrication, Involute profile, SU-8, thick photoresist, micro-components, high aspect ratio.

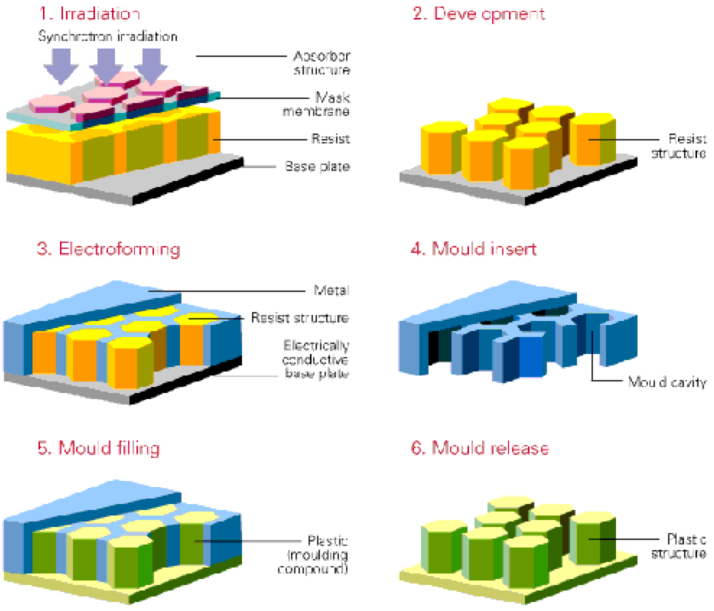
INTRODUCTION

With rapid development of Micro Electro Mechanical Systems (MEMS) technology, the demand for micro structure increasing continuously. The traditional micro fabrication method of micro structure can’t meet the need of application. The UV-LIGA technology takes general ultraviolet light as light source and has advantages of high efficiency and stable quality etc. So, UV-LIGA technology is regarded as an important developmental direction of micro fabrication technology. MEMS is an outcome of the crossing and fusion of micro-electronics with mechanics, optics and electronics. Because of the limit of the working principle and volume, the rotational speed of the current micro motor is generally high. Therefore, a micro gear reducer is needed to transmit motion and torque to the executing mechanism. The present studies on micro reducer focus on the fabrication of single transmission part, only a few researchers work on the assembly and experiment of micro gear transmission system. In the paper, a single stage micro gear transmission device was designed. The micro involute profile gear samples with shaft and the micro cases were fabricated by UV-LIGA technology. The size, elastic modulus and the indentation hardness of the micro gear were measured. The works provide a reference for the production of micro gear transmission system through UV-LIGA technology.

LIGA process: - LIGA is the need of high-energy X-rays that can only be achieved with a synchrotron and the expensive X-ray masks needed for exposure make the cost for the process high. To reduce the cost of LIGA, especially the investment costs for the synchrotron, the usage of traditional lithography light sources in the UV range is being investigated in combination with other photoresist materials like SU-8 (rather polyamides or standard photoresists than the polymers used in X-ray lithography). Using these processes, structures of up to 80 microns in height can be produced with this technique.

Working Principle: - The principle of the UV-LIGA process consists of depositing a relatively thick layer of a polymer sensitive to UV-rays on top of a conductive substrate or one covered with a conductive seed layer. This can be done by applying multiple coats of photoresist during spinning the substrate wafer for thicknesses of up to a few hundred microns. For thicker polymer layers (millimeters) it is common to buy prefabricated plates of SU-8 or PMMA (polymethylmethacrylate, a polymer often used as photoresist), attach them to the substrate plate and mill them back to the desired thickness.

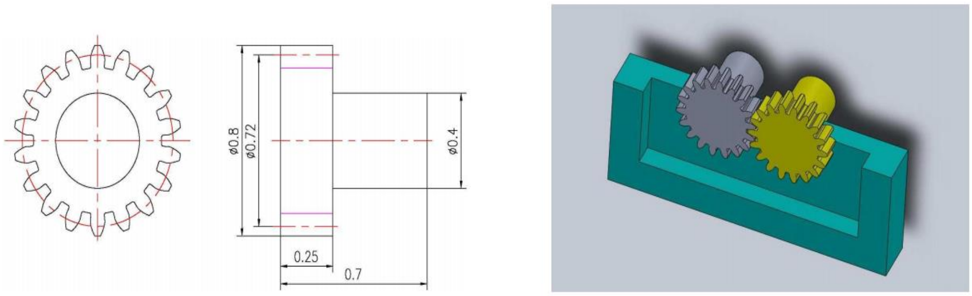
After exposure through an appropriate UV-ray-mask, a developer removes either the exposed (positive photoresist) or the unexposed (negative) areas of polymer, and metal layers are grown by electroplating in the spaces now free from cover. Often the metal is grown higher than needed and then milled back to the desired thickness together with the photoresist. Having removed the unwanted areas of the polymer, the resulting metallic structure can be used. Free mechanical structures can be manufactured by using a sacrificial layer between the wafer substrate and the grown metal film and dissolving this layer, thus yielding the structure in the end of the process; this technique is called sacrificial LIGA (SLIGA).



SU-8 Microstructures: - Due to its good mechanical, thermal and chemical stability, SU-8 turned out to be a very promising material for polymeric microstructures, also known as photoplastic parts. Low-cost micromechanical structures with micrometer and sub-micrometer features could be fabricated using this resist and standard photolithography steps. Near 3D microstructures could be batch fabricated on a wafer-scale, like micropumps, gearwheels or microengines. The low Young’s modulus of this material made it especially suitable for mechanical structures where low-stiffness parts were needed. Scanning probes for AFM (atomic force microscopy) or SNOM (scanning near-field optical microscopy) are good examples of possible applications brought by this photoplastic material. Figure shows an example Micromachines 2014, 5 488 where a complete cassette consisting of five different probes with pre-defined cut-off zones is entirely fabricated in SU-8. SU-8-based technology has established itself as an intermediate solution between the low-cost, high-volume fabrication provided by injection moulding and the fine, controlled feature characteristics given by silicon technologies. (a) SU-8 cantilever cassette probe (shown tip-side up). The first lever is protected for ease of handling; (b) After breaking off the protective blocks, a cantilever is made ready for scanning. Trenches to facilitate the breaking off are clearly visible. Adapted from. Direct use of SU-8 as a material has also been reported in numerous applications, like spacers for liquid crystal displays, waveguide and optical devices, micro-well arrays in microfluidic, dielectric material or as a barrier layer in inkjet printing system, just to mention a few. The range of applications of SU-8 has reached such a great number that an exhaustive list is now far beyond the scope of this article.

Design Structure and Parameters: - As shown in Fig. 1 a), the parameters of the micro gear are as follows: modular m=0.04mm, tooth number z=18, tooth width B=250µm, shaft diameter d=400µm, shaft length l=450µm. The accurate involute profile of the micro gear is generated by a program. The structure of the micro gearbox is shown in Fig. 1 b).

Two reticles including micro gear reticles and shaft reticule are adopted in the procedure of fabrication, and the structure of case is also designed in the two reticles.



a) b)

Fig. 1 Structure of the micro gear and the micro gearbox

The Procedure and Process Parameters: - Micro Gear Fabrication According to the structure character of the micro gear, the main process stages include making photoresist mold, micro plating (metal deposition) and separating metal structure from photoresist to get the three-dimension metal structure. The detailed procedures are as following:

1) Substrate cleaning. The substrate is made of glass ceramics with the thickness of 0.5mm, and the cleaning method is ultrasonic cleaning with alcohol.

2) Sputtering seed layer. Firstly, sputtering a layer of TiW with thickness of 0.05μm as adhesive layer. Then Au with thickness of 0.15μm is sputtered above TiW as the seed of electroplating layer (conductance layer).

3) Preparation of plating mold for micro gear. Coating SU-8 (100 type) photoresist. The mold with thickness of 250μm was formed through pre-bake, exposure, post-bake and development. Micro gear and micro case were designed in the same mask plate.

4) Removing bottom photoresist by plasma etching. Put the substrate in the oxygen plasma environment for 10 minutes to clean the substrate surface thoroughly and exposed the metal surface of the seeds layer.

5) Electroplating nickel gear. The amino-sulfonic nickel-plating system is adopted with current density of 3mA/cm2 and plating speed of 0.3μm/min. The final coating thickness of metal is controlled to be uniform with the depth of plating mold.

6) Preparation plating mold for micro gear shaft. The designed thickness of the shaft is 450μm, so the forming of the shaft mold with 450μm length needs 2 times of SU-8 photoresist coating. Through processes including coating SU-8 (100 type) photoresist 2 times, pre-bake, exposure, post-bake and developing, the plating mold with thickness of 450μm was formed.

7) Remove bottom photoresist with plasma etching method. Put the substrate in the oxygen plasma environment for 10 minutes to thoroughly clean the substrate surface and expose the metal surface of the seeds layer.

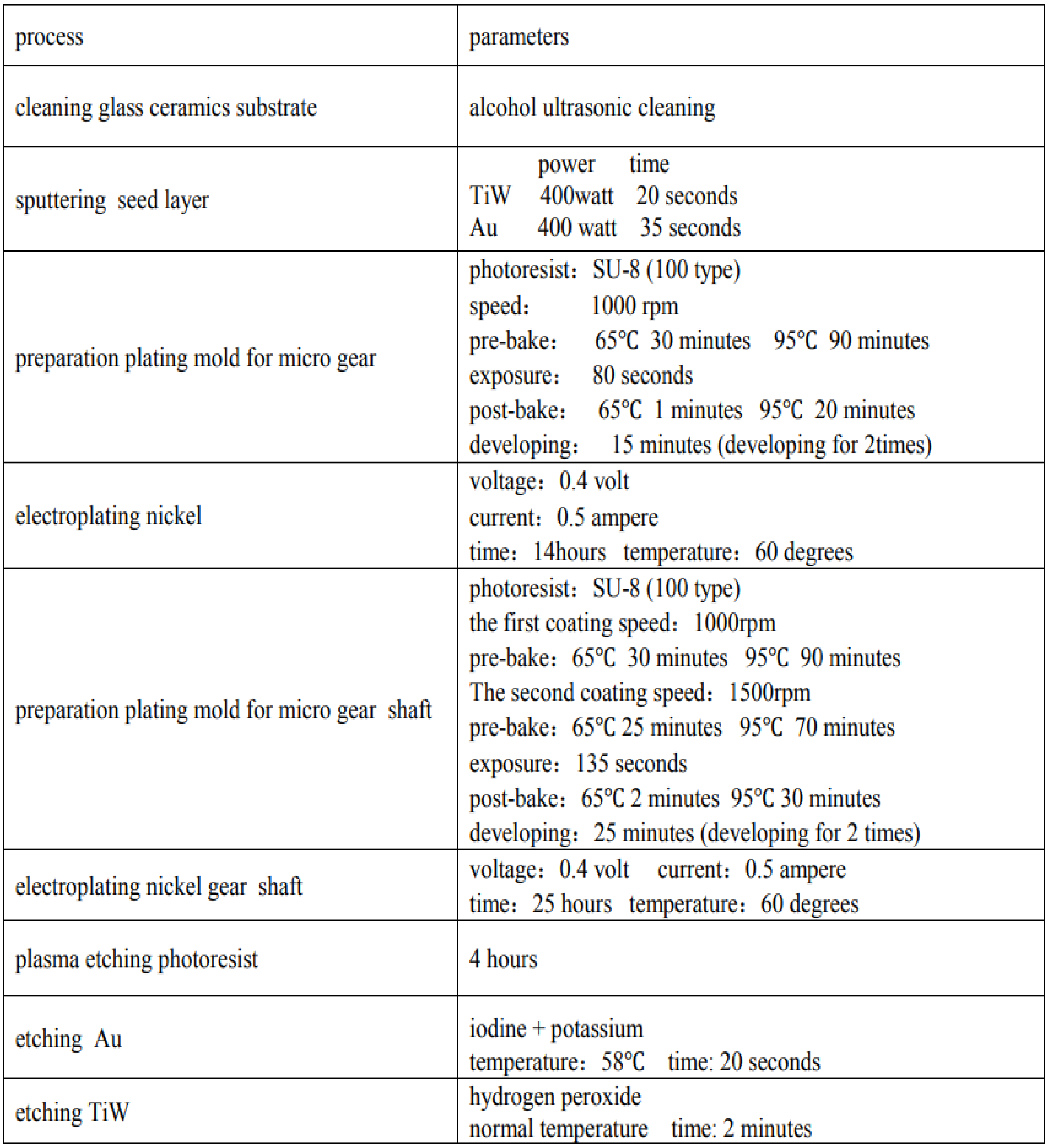
8) Electroplating nickel gear shaft. The amino-sulfonic nickel plating system is used, and the current density that adopted is 3mA/cm2 , plating speed is 0.3μm/min. The thickness of coating metal should be controlled to be uniformed with the depth of plating mold.

9) Removing plating mold. To clean the substrate surface with plasma etching method thoroughly.

10) Removing residual seed layer. The wet etching process is adopted to remove the residual seed layer on the surface of the nickel gear.

11) Separation of the micro gear. Scrap the glass ceramics and etch the residual glass ceramics by hydrofluoric acid, so the micro gears and cases will be separated from the glass substrate. After the processing experiments, the optimal parameters of UV-LIGA technology on micro gear.

Table 1 Process parameters of the micro gear fabrication



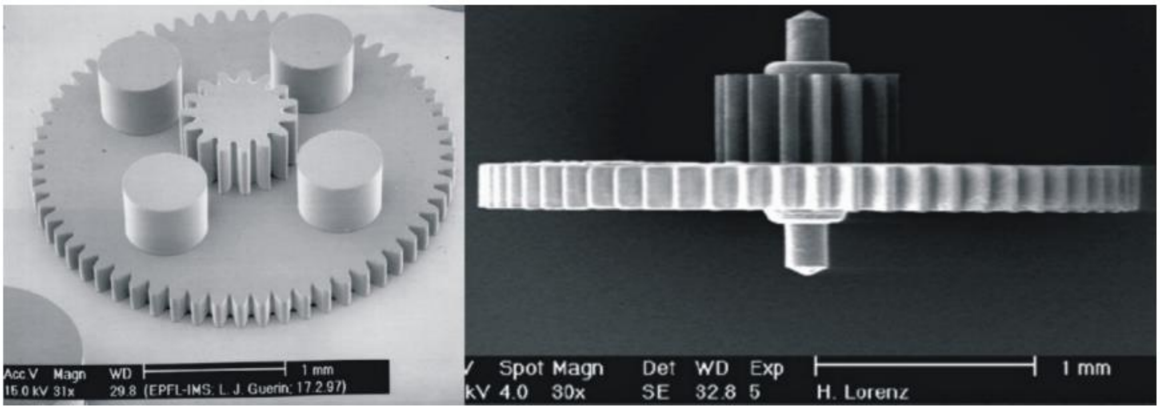
process	parameters
cleaning glass ceramics substrate	alcohol ultrasonic cleaning
sputtering seed layer	power time TiW 400watt 20 seconds Au 400 watt 35 seconds
preparation plating mold for micro gear	photoresist：SU-8 (100 type) speed： 1000 rpm pre-bake： 65℃ 30 minutes 95℃ 90 minutes exposure： 80 seconds post-bake： 65℃ 1 minutes 95℃ 20 minutes developing： 15 minutes (developing for 2times)
electroplating nickel	voltage：0.4 volt current：0.5 ampere time：14hours temperature：60 degrees
preparation plating mold for micro gear shaft	photoresist：SU-8 (100 type) the first coating speed：1000rpm pre-bake：65℃ 30 minutes 95℃ 90 minutes The second coating speed：1500rpm pre-bake：65℃ 25 minutes 95℃ 70 minutes exposure：135 seconds post-bake：65℃ 2 minutes 95℃ 30 minutes developing：25 minutes (developing for 2 times)
electroplating nickel gear shaft	voltage：0.4 volt current：0.5 ampere time：25 hours temperature：60 degrees
plasma etching photoresist	4 hours
etching Au	iodine + potassium temperature：58℃ time: 20 seconds
etching TiW	hydrogen peroxide normal temperature time: 2 minutes

COMMERCIAL APPLICATIONS

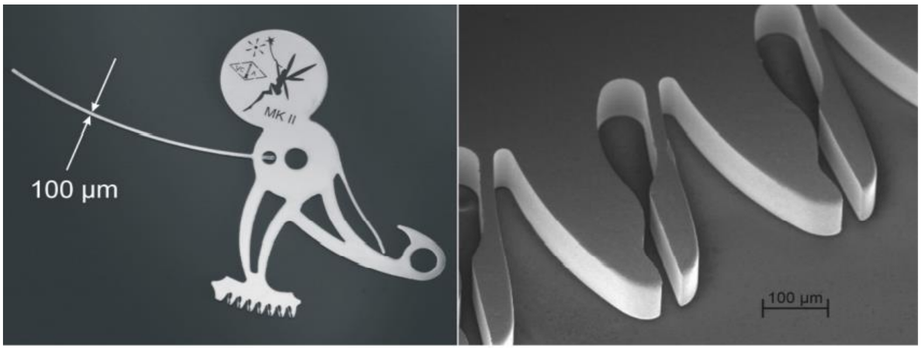
Micro moulds: - The first real industrial applications using UV-LIGA technologies were developed in 1998 with the fabrication of micro mould cavity inserts for injection moulding. The advantages compared to traditional fabrication techniques, like wire electro discharge machining (WEDM), are very smooth sidewalls and the possibility to produce multi-layered auto-oriented cavities with sharp angles combining basic photolithographic steps and electroplating. Layer by layer, the epoxy photoresist is spin-coated onto a substrate, cured, exposed through a photomask and developed, resulting in a master built of SU-8. This master is then electroplated with nickel and destroyed. Afterwards, the resulting mold cavity is lapped down to a desired thickness and is ready to be used for micro moulding plastic components.

Micromachines (a) Two-level photoplastic SU-8 structure as a basis for micro mould fabrication. (b) A micro moulded multi-auto-oriented-level plastic polyoxymethylene (POM) component fabricated from an SU-8-based micro mould.

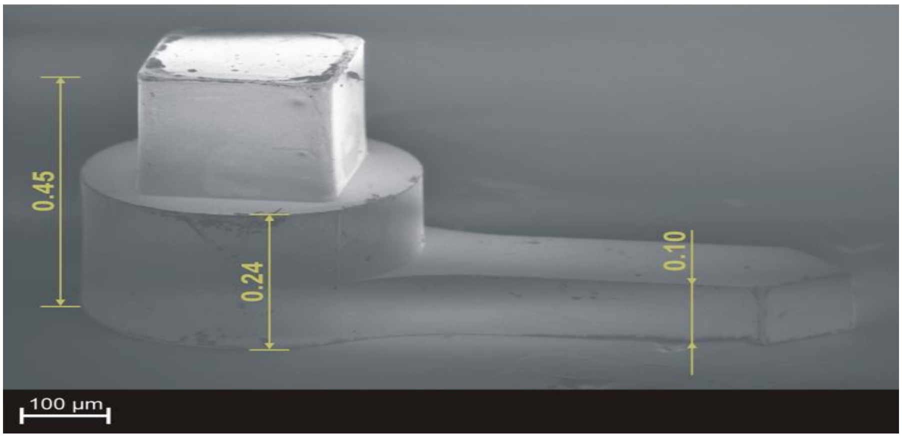
Microparts: - Fabrication of metallic stand-alone parts without the idea of replication by injection moulding was developed by a derivative process of LIGA. The structuration of the negative of the desired component into the photoresist and subsequent electroplating into this template resulted in the direct lateral definition of the parts. The micro connector, medical, pharmaceutical and biotechnology industries have a great need for components like mold inserts and microparts, but the watch industry has been shown to be the most receptive market for UV-LIGA.



Play-Free Engagement Gearing: - In addition to a small sidewall roughness, the advantages given by the design freedom in the x-y plane enabled the fabrication of mechanical parts with integrated new functionalities. One of the most impressive examples of this characteristic has been shown with the manufacturing of gears with slotted teeth. Developed by a Swiss watchmaker inspired by the UV-LIGA technique, this invention resulted in revolutionary improvements in mechanical watch movements. Thanks to unique design freedom brought by SU-8 photolithography, every tooth can be carved with an engineered shape in order to integrate a spring compensating any play in the gearing. First used in 2002, this play-free engagement system is now widely used in watches and delivers optimal transmission of force, a smooth display and more stability to the watch hands. Figure shows a sector with different functions, like an identification number, an integrated logo, two spring blades and slotted teeth for play-free engagement. Figure shows a close-up of the teeth. The part thickness is 120 µm, while the spring blade is 20 µm at its narrowest width.



Multi-Level Parts: - The multiple photolithographic steps of SU-8 permitted the fabrication of multi-level parts. A single electroplating step on a multi-level mold obtains multi-level components. This solution reduces difficulties, uncertainties and failure risks brought by the subsequent assembly of sub-systems. Figure 5 shows a multi-level component fabricated in one electroplating in a multi-level resist template. A dart with a square foot and three auto-orientated levels have been electroplated in a three-level template. Figure 5. SEM of a three-level dart. This part is shown upside-down, relating to its orientation during fabrication. Micromachines One advantage of using LIGA for fabricating mechanical elements is the excellent alignment between the different levels. This accuracy is a result of the alignment capabilities of mask alignment tools used during the photolithographic steps. Thanks to design freedom in the x-y plane, it is also possible to have levels with geometries difficult to obtain with standard machining techniques.



CONCLUSION

The thickness of the micro gear reaches 250µm, and the length of the shaft is 450µm. While this size can't be achieved by common UV-LIGA technology. So, the SU-8(100 type) photoresist technology was experimented. The results indicated that the mold produced by SU-8(100 type) photoresist have clear structure, vertical sidewall, and the depth can meet the design requirement completely. The process problems on fabrication of micro gear transmission device were resolved through the study of the thick photoresist techniques and micro plating technology. Micro gear and micro gearbox samples were fabricated with the method of UV-LIGA technology. The size, elastic modulus and indentation hardness of the substrate material were measured. This provided a reference for the production of micro gear transmission system.

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