Paper: Deep X-ray Lithogrphy for Micromechanics
T.R. Christstenson, H. Guckel
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Introduction

As the size and tolerance requirements for machined parts continues to decrease, a new technology is need to construct micro-scale parts for opto-mechanical applications. To fill this need, increasing research has been done into the use of deep x-ray lithography for define these tiny parts. This process, called LIGA, is based on the German words for Lithography, Electroforming, and Molding, and has become a rapid growing, cost effective method for producing precision micromechanics.

The most accurate methods for micromachining is single point diamond turning, which has a dimensional tolerances of about 1 to 10 parts per million. However, using LIGA, dimensional tolerances of 0.1 μm per 100 μm can be achieved. Another advantage of LIGA is the potential for lower production costs. For parts constructed using diamond turning or other material removal methods, each piece must be constructed separately. With LIGA, the same mask, exposure, and development can be used to produce a set of pieces. Additionally, using the same and method to produce a number of sets of parts increases the repeatability of the machining process.

There are four steps in the LIGA process. First, layer of photoresist is applied to a base substrate. A mask is placed over the substrate and it is exposed to x-ray light, changing the polymerization of the photoresist. Then the substrate is immersed in a chemical bath that etches away the polymerized photoresist. Last, the remaining resist is electroplated. At this point, the electroplated photoresist can be used in a number of applications. It can be used as a mechanical part or it can be used as a mold for injection molded plastics or ceramics. [2]

Deep X-ray Lithography Based Micro-Fabrication

Photoresist Application

The first of four steps in the LIGA process is the application of photoresist, usually polymethylmethacrylate (PMMA). In traditional lithography a layer of photosensitive material, called photoresist, is spread onto a substrate by applying the material to the substrate and spinning the substrate very quickly, allowing the centripetal force to act on the material and leaving a very thin layer of photoresist. This method works well when the thickness of the photoresist is in the order of a few hundred microns. However, for LIGA a thicker layer is needed, usually above 1 mm, and it is difficult to spin coat photoresist with that thickness because repeat application and curing of the photoresist causes strain in the resist. In the LIGA process described in this paper, a thin layer of photoresist is spun onto a substrate and baked, and a sheet of commercial, pre-cast photoresist is bonded onto the thinner layer. This greatly reduces the internal strain in the PMMA and allows it to be used as a structural material.

X-ray Exposure

The first part of the exposure step is creating a mask, which is used to select which parts of the photoresist are exposed to light. The light source determines the type of material used. This paper gives two examples of light sources, a 1 GeV Aladdin storage ring and a 2.5 GeV storage ring in two different laborotories. For the less powerful source, a thinner, membrane mask has to be used to insure the right contrast as the light is attenuate as it passes through the mask. For the more powerful source a thicker silicon wafer can be used as a mask.

Ideally, the photoresist would be exposed equally at all depths. However, this is difficult to due for a number of reasons. For example, the lower order spectral regions only contribute to the polymerization of the surface, so it is important to filter the light to remove those regions. The paper provides a plot of Absorption length v. Photon Energy. This plot essentially shows that for a given input energy, how deep into the resist the light will be absorbed, where the higher energy photons penetrate more deeply. One notably example was when using a 35 GeV source, 11 cm of resist was exposed.

Development

The development of the exposed photoresist removes the exposed photoresist by immersing it in a chemical bath. It is important to select the right developer that will only remove the exposed resist. If the unexposed resist starts being etched away, the features and edges will become more rounded. The paper cites a German developer solution as a good choice.

Electroplating

In order for the PMMA to have the stiffness needed to be used as a mechanical part or as a mold, it must be electroplated. Electroplating is the process of coating an object with a thin layer of metal using electrical current. For example, a rod of the metal to be used to coat is connected to the positive end of a power source and placed in a salt solution. Then, the object to be coated is connected to the negative end and placed in the solution. As the metal oxidizes, the metal ions are attracted to the negatively charge object and bond to the object, creating the thin metal layer. [3] This paper notes that a wide range of materials can be electroplated, including magnetic materials that are important in the construction of microactuators.

Results

The paper lists a number of ways LIGA has been used, such as precession dies, microsurgical tools, inkjet nozzles, and gratings. The paper also gives two specific examples of microactuators that the authors have made, specifically linear and rotary actuators.

Microactuators

+Linear Actuator

The linear actuator built in this paper has three main parts. [See Fig. 1] The parts are a wound coil to produce a variable electrical field, a magnetic circuit that allows the magnetic flux to travel to a spring constrained plunger that is connected to part to be moved and that moves as a result of an applied magnetic field through the circuit. The measured sensitivity of the actuator is about 1 μH per micron of movement, and the actuator can move a total of 250 μm.

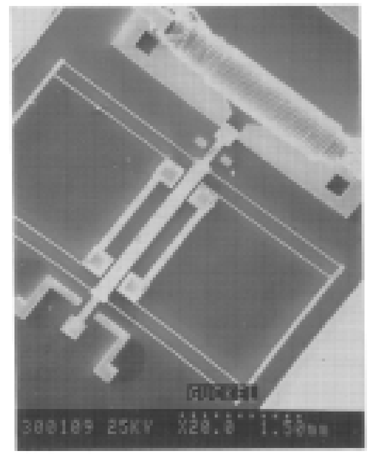

Figure 1. Linear microactuator.

+Rotary Magnetic Actuator

In the paper there is not much detailed information about the parts of the rotational actuator. It has a 150 μm diameter and integrated coils. Also, rotate at up to 150 krpm.

Conclusions

This paper provides a good overview of the general process of LIGA manufacturing. While there are more recent developments in LIGA technology, this paper is good for those who have not been exposed to LIGA or who have little experience with the lithography process.

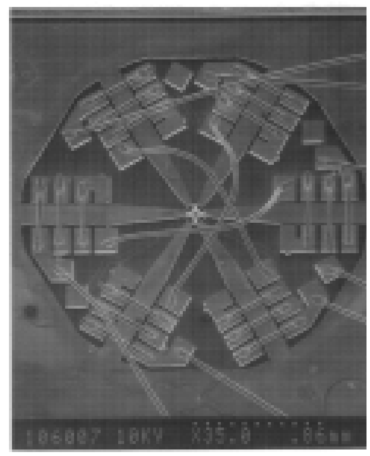

Figure 2. Rotary microactuator.

I chose this paper because my research group has used LIGA manufacturing in a number of our micro-optical designs and have been collaborating with T. R. Christenson on these projects. Within my group, there are two examples of different applications of LIGA technology. First, it was used to construct cylindrical, stackable pieces to hold the lenses. These pieces have precision springs to insure that the lens are mount along the same axis, and then the pieces are assembled with precision screws. [4] The other example is the use of a micro-optical table where the lenses are held upright by a bi-stable spring with tight distance tolerances. Additionally, a comb drive can move a grating to allow different imaging techniques. [5]

References

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