Mass Fabrication of Microstructured Parts with SR - Requirements to Throughput, Cost, and Quality

Markus Arendt¹, Pascal Meyer², Joachim Schulz²

¹ ANKA Angströmquelle Karlsruhe GmbH, P.O. Box 36 40, D-76021 Karlsruhe, Germany
² Forschungszentrum Karlsruhe, Institute for Microstructure Technology (IMT), P.O. Box 36 40, D-76021 Karlsruhe, Germany

Abstract

The deep X-ray LIGA technology is advancing from a pace maker technology ("haute couture") to a key technology for microsystems' fabrication ("prêt a porter"). However, LIGA is considered to be expensive, tedious, and non-reliable. The consistent and consequent activities on making the technology reliable within the last two decades now requires to focus on economic aspects: reduction of fabrication cost per piece, emerging a mass production line beyond the experimental and research setup for prototyping; further automation to reduce handling; establishing automatic quality control means. This paper deals with aspects regarding these issues, and sketches the concept of establishing a highly automated beamline designed for mass fabrication within a cleanroom environment.

Market situation of deep X-ray lithography

The LIGA technique, a German acronym consisting of the letters LI (Röntgen Lithographie meaning X-ray lithography), G (Galvanik meaning electroforming) and A (Abformung meaning molding) developed at the Research Center Karlsruhe, offers the possibility to manufacture microstructures with a number of unique features:

- Highest available aspect ratios (up to 50)
- Structural heights up to 3 mm
- Roughness of side walls < 30 nm
- Structural details < 1 µm (lateral resolution down to 200 nm)
- Variety of materials (metals, plastics, and ceramics)
- Directly fabricated structures or microstructured mold inserts, depending on the material, and on the geometry

With these properties, LIGA is on the leading edge of microfabrication. This is a well known issue to most participants in the micro sector. However, most actors consider LIGA to be very expensive, to employ much time from design up to realization, and to impose a number of quality problems. They therefore try to avoid LIGA, and only consider LIGA if the other fabrication methods fail to fulfill the requirements. These requirements, however, are often very challenging even for LIGA resulting in long development times, high failure rates, and of course high cost. This reinforces the above described perception resulting in a sort of vicious circle.

Together with the Institute for Microstructure Technology (IMT) at Forschungszentrum Karlsruhe we at the synchrotron ANKA address this situation by establishing a mass fabrication line for direct LIGA products at ANKA. We want to lower cost for directly fabricated LIGA parts significantly (by 60 %) and lower the fabrication time by 50 %. In addition, we enlarge the fabrication capacities by 80 % compared to the current situation.
For this purpose, we have identified the mass fabrication of high precision watch parts which shall help to make a real LIGA product known to the mass market.

**Optimization potentials within the fabrication process of deep X-ray lithography**

The fabrication process mainly consists of six steps (Fig. 1). The first step – CAD design and layout of the patterns and fabrication of the X-ray mask – is crucial because of the huge leverage effect for the subsequent mass production. As an X-ray mask may serve for several hundreds, often thousands of irradiations, attention must be drawn to the selection of the mask material as well as to the optimal distribution of the patterns on the mask which allows for maximum yield while maintaining quality issues. Some of these design rules include the application of auxiliary structures to minimize swelling and thermal expansion effects, or a layout as symmetric as possible [1]. At the moment there are no standardized design rules within the deep X-ray community. The usual procedure is still a build-and-test one as almost every new design leads to yet unknown effects whose impacts are not exactly known.

![Fabrication process of LIGA parts using direct lithography](image)

Once the mask has been manufactured mass fabrication may start with **resist deposition** onto a substrate by gluing of resist sheets thus allowing a complete adhesion and preventing bubbles, cracks or other defects. The aim is to use a robot that dispenses a precise volume of glue in a predefined pattern onto the substrate that lifts the sheet from a cassette by vacuum suction and that places it onto the substrate with negligible tolerance [2]. This process step is to be outsourced to qualified suppliers on the basis of interface specifications for minimum internal stress, low surface roughness, low thickness variation, minimum adherence of pillar structures, no remaining resist in the exposed region and no cracks and other defects in the sidewalls. The following standard should be reached: after exposure of a standard test mask and development, pillar structures with a volume of 30x30x400 µm³ have to adhere, no remaining resist in the exposed region and no cracks in the sidewalls are allowed.

The **X-ray irradiation** at a synchrotron is still a major process step as it can only be performed at a few sites around the world. Usually it accounts for about 15-30 % of the production cost (without mask fabrication cost) of a mould insert or a directly fabricated structure. This figure is highly dependent on several factors:

- the used resist material
- the structural height
- the physical properties of the beamline
- the irradiated surface
- the handling

On the other hand, any technological cost reduction potential immediately leads to higher risks and quality cost as many of the processes are not understood or not controllable. For example, using SU-8 as a resist decreases the irradiation time by two orders of magnitude, for this case handling cost such as charging and discharging become more important. A beamline that does not cut off the high energy of the flux allows for much shorter irradiation times, on the other hand the thermal effects on the substrate are much higher and less controllable.

A different issue is the irradiated surface. As the synchrotron beam is a slit line only an enlargement in width leads to cost reduction whereas an enlargement in height has absolutely no effect. For example if you consider to use a 85 mm round substrate surface instead of a 20x60 mm² surface, the irradiated surface is by a factor of 4.72 higher, the irradiation time, however, is 4.25 times longer. In addition, a number of quality issues occur: there is no reliable mask fabrication process with an acceptable quality for a 85 mm round mask, and the differences between those parts on the edges of the substrate compared to those in the centre are not negligible. The only major saving is a reduction of handling cost. We have therefore decided to implement a parallel irradiation of 5 masks with a common size of 20x60 mm² [3].

**Electroplating** is a key step for the fabrication of metallic micro components and tools like masks and molding tools. Established routine processes are often referred to by the kind of plating solution used and are highly dependent on the required hardness and on the geometry of the parts. The use of different materials, alloys, and additives which alter drastically the performance of the plating process makes standardization problematic. Typically, any new design requires a considerable number of test runs to optimize the electroplating procedure as parameters like stress levels, annealing behavior, and deposition behavior at walls and edges have to be adjusted. However, once this optimization has been done, the electroplating process is well controllable and the major cost contribution is the time a substrate has to stay in the electroplating bath requiring a number of costly baths.

After the electroplating step, the substrate has to be removed. The **stripping** process employed today for PMMA is a second X-ray irradiation, flowed by a stripping process. Even if the irradiation time is considerably lower than the time necessary for the first irradiation the use of ethylacetate is currently investigated as a substitute to maintain a low throughput time. For SU-8 this process step is still crucial as no standard method for stripping has yet been found. Recently, IMM published a wet-chemically method which is a modification of a removal method used for PMMA. The method is said to be suitable for copper, nickel, and nickel alloys, yet the widespread applicability has still to be proven.

**Measurement** is the last but still very important and expensive process step. Whereas in IC technology, measurement ask and accuracy requirements are well defined, no comparable situation pertains to MST; there is no tolerancing system, no standardized measurement approach, no system of calibration standards. Currently a semi-automated nearing technique with an optical microscope and an integrated CCD camera is applied. An approach to lower the cost is the development of a totally automated measurement of physical properties using the above described microscope-camera solution. Talking about
mass fabrication different measurement levels for samples are in discussion with the customer.

**Cost of the LIGA process**

For the fabrication of direct LIGA products major cost reduction can be achieved by the installation of a batch processing system (automatic handling of 25 wafers with minimized logistic cost and minimized waiting times), a parallel irradiation of 5 masks, an optimized testing strategy, and the employment of non-scientific personnel. This is to be realized at ANKA within the next 3 years requiring an investment of about 4 Mio. Euros. The main investment is used to build the scanner for parallel irradiation.

Our aim is to bring LIGA to a marketable stage by using cost reduction potential with the already known and experienced technology. New technological developments like the widespread availability of SU-8 or the use of second electroplating might contribute an even higher effect, but we consider them to be far from being experienced technologies.

![Cost structure of directly fabricated LIGA parts now and in the near future](image)

**Fig. 2:** Cost structure of directly fabricated LIGA parts now and in the near future

**Literature**


Fig. 3: Example of LIGA fabricated watch parts (gear wheel)