LOW COST LIGA PROCESSES

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Recently there has been growing interest in LIGA processes where the x-ray lithography step is replaced by a cheaper, lower resolution alternative. Such processes provide an economical route for realising three-dimensional microstructures in applications where the extreme precision of x-ray LIGA is not required, and also allow prototyping of devices eventually destined for fabrication by the x-ray process. In the former case, the use of cheap, accessible lithography tools may also allow direct fabrication of final products, eliminating the requirement for mass replication by injection moulding or embossing.

Several mould fabrication methods have been investigated for low-cost LIGA, including conventional UV photolithography\(^1\) and deep reactive ion etching\(^3\). UV lithography using positive photoresists can produce moulds with depths of up to around 100 \(\mu\)m (limited by optical absorption) and aspect ratios of around 5:1. Accurate control over linewidths and sidewall profiles is difficult, but on the other hand the process is cheap and widely available. Reactive ion etching offers better performance in terms of linewidth control and aspect ratio, but the process is more involved, and the maximum practical depth is limited, at least for conventional etching technology, by the low material removal rate.

A third method suitable for producing deep resist moulds is to use excimer laser ablation\(^5,6\). Here the resist is etched directly by pulses of UV radiation, usually at 248 nm or 193 nm wavelength, and three-dimensional relief is produced either by scanning a shaped beam over the resist surface, or by projecting a mask pattern. This approach has a number of attractive features. Firstly, unlike UV lithography it is not limited in processing depth, because the material exposed by each laser pulse is ejected and dispersed before the next pulse arrives. Secondly, complex three-dimensional relief can be produced in the resist, either by varying the scanning speed and beam shape in a serial system, or by means of variable transmission masking in a projection system. Thirdly, a wide range of polymer materials can be ablated, increasing the potential for multilevel processing and integration with other microengineering processes.

In this paper we describe a generic low-cost LIGA process, in which structures are built up by repeated application of a simple process cycle consisting of seed layer deposition, resist deposition, lithography and electroforming (see Figure 1). By using this approach, and combining contact lithography with excimer laser machining, we have made multilevel nickel microturbo parts with structural heights in the range 10 to 100 \(\mu\)m per level.

Our contact printing work is based on Hoechst AZ4562 photoresist, which can be spin-coated to a thickness of up to 20 \(\mu\)m without using special techniques. At these thicknesses, some care has to be taken to avoid degradation of the underlying resist layers when fabricating multilevel devices. In particular, the mismatch between the expansion coefficients of the resist and electroformed metal can lead to cracks in the resist which propagate from the outside corners of metal structures. We have largely eliminated this problem by radiusing all outside corners at the mask design stage, and by controlling the temperature profile of each resist bake cycle. After soft-baking, the resist is exposed using a Quintel Q-2001CT aligner, and developed by immersion in AZ400K developer.

For structures with heights in excess of 20 \(\mu\)m we use a laminated dry film resist (Laminar 5000 series), patterned by laser micromachining. Dry film resists, which are well-established in the printed circuit industry, offer ease of application, good thickness uniformity, and film thicknesses up to several hundred \(\mu\)m. They are also well-suited to laser machining as they do not produce excessive amounts of ablation debris, and deep structures can be machined without significant thermal damage to surrounding material.

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Using the laser technique we have previously demonstrated 100 µm-high structures with vertical sidewalls and aspect ratios in excess of 5:1. For comparison, conventional processing of dry film leads to undercut sidewalls and is typically limited to aspect ratios of around 3:1. On the other hand, the throughput is much lower for the laser process, so it is better suited to the fabrication of critical structures than to routine mould production.

In general it is necessary to deposit a conducting seed layer prior to each lithography step. This protects the underlying resist during exposure and development, and also allows initiation of electroforming in areas where there is no underlying metal. Unless an extra process step is introduced to pattern the seed layer, it becomes sandwiched between successive metal levels, and forms an integral part of the final structure. It therefore needs to adhere well to the structural metal, and be compatible with the intended application. It must also be amenable to selective etching in the presence of the structural metal, so that excess seed material can be removed at the end of the fabrication process. A further consideration in the case of laser machining is that the seed layer must be able to withstand laser exposure without serious degradation.

Seed layer deposition is complicated by several factors. Firstly, there is a tendency for the underlying resist to out-gas in any vacuum deposition process. Secondly, even if a seed layer is successfully deposited it can be damaged during the subsequent lithography process as a result of instability in the underlying material. For sputtered copper seed layers, we have found that these problems can be alleviated to a large extent by hard-baking the resist prior to seed layer deposition, and by employing a very low deposition rate to minimise substrate heating. Hard-baking inevitably leads to some reflow of the resist, and the effect of this on the surface topography must be taken into account when designing critical structures.

To date we have worked mainly with nickel as the structural metal, and sputtered copper as the seed material. Nickel electroforming is performed using a commercial sulphamate bath (Schloetter type MS), excluding any brighteners or levelling agents. Low stress deposits are obtained at a temperature of 50 °C and a deposition rate of around 10 µm/hr. Continuous recirculation with particle filtering to 1 µm is employed. Following the final electroforming step, the resist and excess seed material are removed using a combination of commercial dry film resist stripper (Dynachem Alkastrip SQI), Isoform Aluminium Etch (a good selective etch for copper in the presence of nickel) and acetone. Ultrasonic agitation is also used where necessary.

Figure 2 shows a partially completed Francis microturbine, fabricated in nickel using the above process. At this stage of fabrication, the device has four levels (out of a total of six), three of which are defined by UV lithography, with the fourth - the turbine blades - being laser machined. The rotor is fabricated in situ, and is separated from the turbine housing by a sacrificial resist layer (level 2 lithography). The view from above (Figs 2a and 2b) shows the rotor disc (level 3) and blades (level 4), while the view from below (Figs 2c and 2d) shows the rear bearing (level 1) and the reverse side of the rotor disc. Each of the contact printed layers is 15 µm high, while the blade height is 80 µm, giving a total device height of 125 µm.

In conclusion, we have demonstrated a low-cost LIGA process which combines contact lithography with excimer laser micromachining, and can produce multilevel nickel structures with heights in the range 10 to 100 µm per level. Processes of this type provide an economical route for the realisation of truly three-dimensional metallic microstructures.

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References


Figure 1. Generic low-cost LIGA process for 3D microfabrication.
Figure 2. Partially fabricated nickel microturbine: (a) rotor disc (level 3) and blades (level 4); (b) detail from (a); (c) rear bearing (level 1) and reverse side of rotor disc (level 3); (d) detail from (c).