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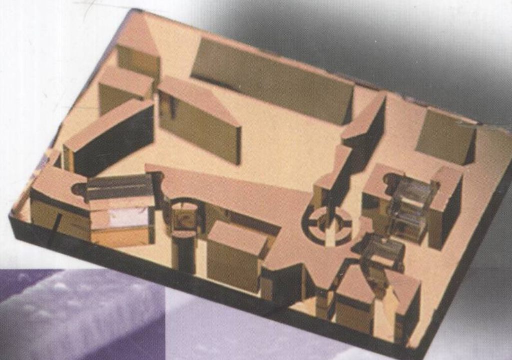

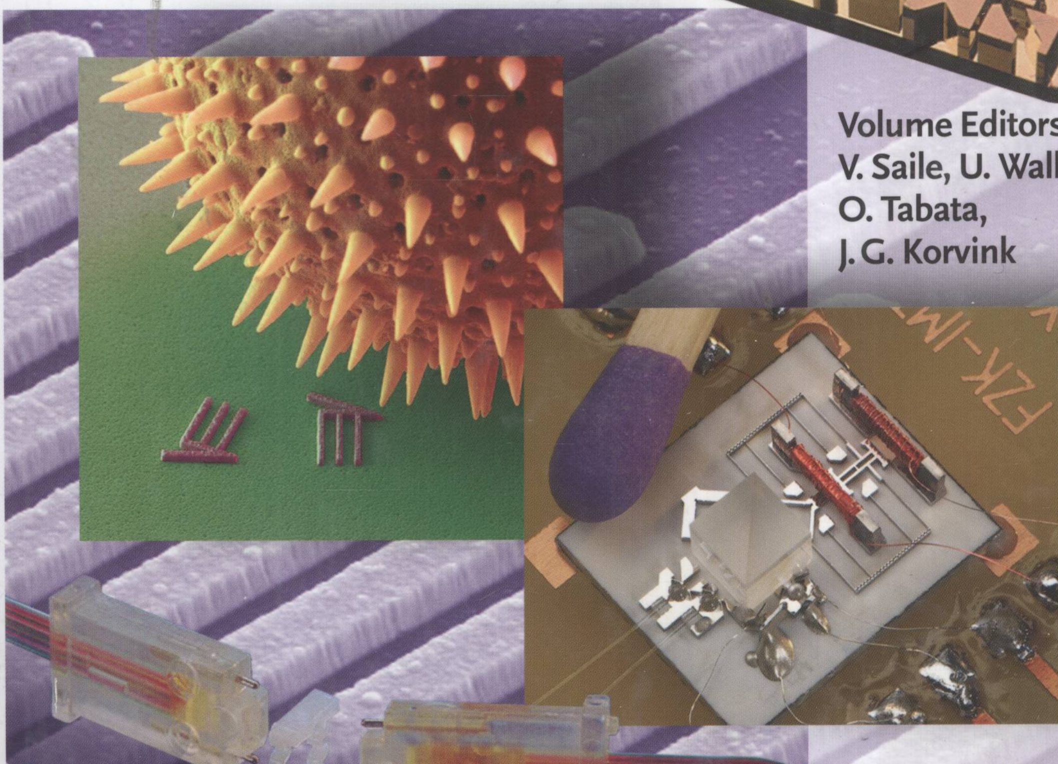

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Advanced Micro & Nanosystems
Volume 7

LIGA and its Applications

Edited by
Volker Saile, Ulrike Wallrabe, Osamu Tabata,
and Jan G. Korvink

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1
Introduction: LIGA and Its Applications

Volker Saile

1.1
LIGA Background

The first publication on LIGA technology–LIGA is a German acronym for lithography, electroplating and polymer replication–appeared in 1982, more than 25 years ago [1]. Since then, the LIGA technique has been successfully used in many research projects. Also components for industrial customers have been produced, but still on only a rather limited scale. A compilation of many relevant references for LIGA may be found in review papers, for example, Refs [2, 3]; the LIGA basics and technical limits are well documented and explained in textbooks, such as Ref. [4].

The core process in LIGA is deep X-ray lithography at a synchrotron radiation source. X-ray lithography (XRL) as such was proposed in the 1970s for semiconductor patterning and first demonstrated by IBM using synchrotron radiation at the German National Laboratory DESY in 1975 [5]. The results generated enormous interest among semiconductor manufacturers and also funding agencies. This enthusiasm was fueled by the hope of having found a technology for replacing optical lithography that was assumed to be at the end of its resolution capabilities in the 1970s or 1980s. Complete technology platforms for making chips with X-rays were developed in the United States, Japan and Europe [6] in the 1980s and large companies prepared for production in the early 1990s [7]. However, after spending a huge amount of money, far in excess of $1 billion, XRL was abandoned by the semiconductor industrial community in the mid-1990s. 'X-ray' became a synonym for wasting gigantic resources and extreme ultraviolet (EUV) lithography emerged as the new candidate for next generation lithography (NGL). Today, the

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future of EUV lithography is also open. The bottom line of the history of XRL is that an established technology, namely optical lithography, stayed ahead for over 20 years by continuous improvements to performance levels that nobody could imagine in the 1970s. However, it was not so much the performance that kept optical lithography ahead of XRL but more the confidence and trust of the production people in well-established technology rather than using disruptive processes. The rapid rise of XRL in the 1980s and 1990s originally also boosted LIGA, but later with the fall of XRL the viability of LIGA was also questioned.

The origins of LIGA are in nuclear technologies: the Nuclear Research Center KfK in Karlsruhe, Germany, had been developing new methods for separating uranium isotopes since the 1970s. Their specific approach was based on nozzles that exploit the mass-dependent centrifugal forces for a spatial separation of the two relevant isotopes. For an efficient separation process, nozzles with critical dimensions of the order of a few micrometers and a very high aspect ratio were required. After evaluating various manufacturing options for mass producing such devices, but, with limited success, the Karlsruhe team, headed by Becker and Ehrfeld, contacted the promoters of XRL in Germany, headed by Heuberger and Betz. One of the key capabilities of XRL that was actually not used in semiconductor applications is the large depth of penetration of such radiation. This property can be exploited for exposing very thick resist up to several millimeters and the actual penetration depth can be tailored to specific resist heights by varying the photon energy of the X-rays. The joint team, with a background in electrical engineering and lithography on one side and nuclear and mechanical engineering on the other, understood the enormous potential of using XRL at short wavelengths for fabricating devices with extreme resolution and very high aspect ratio. In the first publication in 1982 [1], all relevant features and properties of LIGA were described already (Figures 1.1 and 1.2).

LIGA was originally a technology for a single product only, namely the uranium separation nozzles. After a dedicated synchrotron radiation source for mass production of such nozzles was proposed in 1985 by the Karlsruhe laboratory, the customer for the nozzles, a consortium for constructing a uranium separation facility in Brazil, terminated the project. In addition, nuclear R&D in Germany was dramatically downsized. Among the survivors of the golden days of nuclear engineering was the LIGA technology, now often being oversold as the greatest technology for fabricating high-resolution, high aspect ratio devices. Research in developing and in using novel structures, devices and entire systems made with LIGA flourished in the 1990s, several synchrotron radiation facilities all over the world added LIGA beamlines and laboratories and the Forschungszentrum Karlsruhe (FZK) finally received permission and funding in 1995 to build their own synchrotron ring for supporting the LIGA activities. In the United States, Henry Guckel of the University of Wisconsin, Madison, brought LIGA to the new world. His laboratory contributed many new ideas and novel concepts in the 1990s. The DARPA-funded, so-called 'High-MEMS Alliance' involving the Center for Advanced Microstructures, CAMD, in Baton Rouge, LA, the University of

"X-ray lithography using synchrotron radiation has been applied in a multi-step process for the production of plastic molds to be used in the fabrication of separation nozzles by electrodeposition. For characteristic dimensions of a few microns a total height of the nozzle structure of about 400 μm has been achieved. Structural details of about 0.1 μm are being reproduced across the total thickness of the polymer layer. The surface finish of the metallic separation nozzles produced by electrodeposition was equivalent to the high quality of the polymer surface. The separation-nozzle systems fabricated by the described method allow an increase by a factor three of the gas pressure in separation-nozzle plants as compared to the present standard. This results in considerably savings in the enrichment of ^{235}U for nuclear power production."

Figure 1.1 Abstract of the 1982 LIGA publication, Ref. [1].

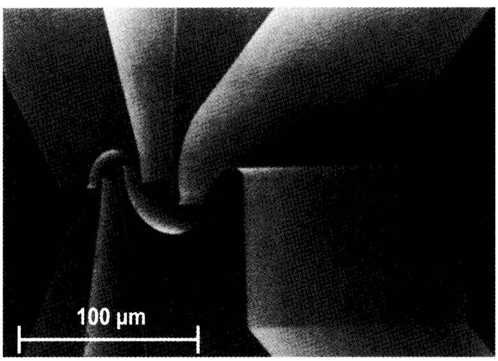


Figure 1.2 Uranium separation nozzle fabricated with LIGA; see Ref. [1].

Wisconsin, MCNC of North Carolina, IBM and others established a sound basis and a network for LIGA in the United States. Nevertheless, the expectations raised by the early promoters of the commercialization potential of LIGA were far too optimistic and they have not yet been realized. Therefore, after more than 25 years of LIGA, we should find answers to critical questions such as: will LIGA follow the path of XRL, that is, become obsolete for commercial implementation after more than 20 years of R&D? And if not, why not?

This long history of LIGA and the valid questions on the future of the technology led the Editors of this book to invite distinguished experts in LIGA to present reviews on the current status of the technology, on applications, on equipment and also on new ideas.

1.2
The Current Status of LIGA

Over the years, the science and technology community followed numerous attempts to establish LIGA activities all over the world. Fascinating LIGA pictures and results were frequently used in glossy brochures to convince agencies, politicians and the public to fund proposals on new synchrotron facilities. The postulate that high-tech research facilities lead directly to economic development is in fact intriguing but often too simple minded in reality. Professional LIGA work requires a significant infrastructure with cleanrooms and equipment, supporting laboratories, mask-making capabilities and, probably most important, highly qualified staff for operation of these facilities. Furthermore, reproducibility, manufacturability and acceptable cost turned out to be major challenges – issues that fall more in the area of competence of production engineers rather than scientists. As a consequence of insufficient financial or human resources or of a lack of patience of industry or government customers, we could follow rise and fall of several LIGA activities, for example, at LURE in France, at LNLS in Brazil, at SRS in the United Kingdom and, most recently, at Sandia National Laboratories, Livermore, CA in the United States. Synchrotron facilities with currently active LIGA programs are listed in Figure 1.3, where some activities are rather small whereas others are significant. Also included in Figure 1.3 are companies and organizations that have direct access to synchrotron facilities for manufacturing commercial LIGA devices for their customers.

When we discuss LIGA, we must distinguish between three rather different approaches that are usually all summarized under the name LIGA (see Figure 1.4):

Canada:	CLS – SyLMAND
China:	NSRL
Germany:	ANKA, BESSY-II
Italy:	Elettra
Japan:	NewSUBARU, Rits SR
Korea:	PLS
Russia:	VEPP-III
Singapore:	SSLS
Taiwan:	SRRC
USA:	ALS, CAMD

Facilities with Activities in Deep X-ray Lithography

(a)

ANKA COS, Karlsruhe, Germany
Axsun Technologies Inc., Livermore, CA, USA
BESSY Anwendezentrum, Berlin, Germany
MEZZO Corp., Baton Rouge, LA, USA
ht micro, Albuquerque, NM, USA

LIGA Manufacturers and Service Providers

(b)

Figure 1.3 (a) Synchrotron radiation facilities with active deep X-ray lithography activities. (b) Companies and organizations offering LIGA manufacturing capabilities.

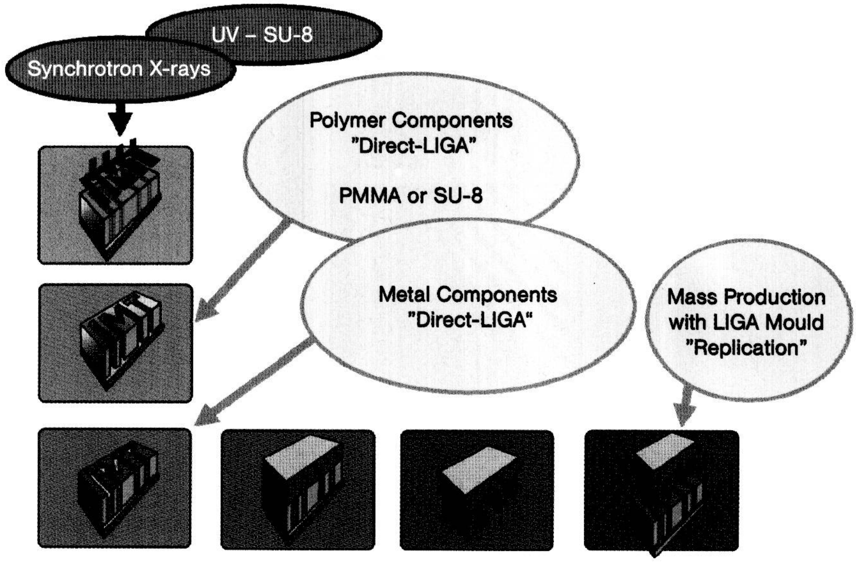
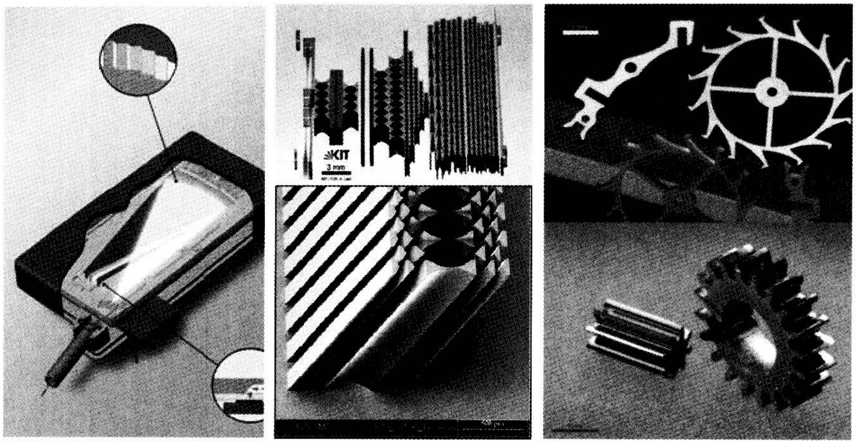


Figure 1.4 LIGA process sequence and variations including UV-LIGA and Direct-LIGA concepts. A thick resist layer (brown) is exposed with X-rays or UV radiation through a mask. After development polymer parts are available. Electroplating (blue) yields metal components. After over-plating, a mold can be separated from the substrate and employed in mass production schemes such as injection molding or hot embossing.

- The classical LIGA process sequence where deep X-ray lithography (DXRL) is used for fabricating a mold to be used in injection molding or hot embossing mass production schemes (see Figure 1.5a).
- Deep X-ray lithography where each individual component is produced lithographically just as devices in semiconductor manufacturing ('Direct-LIGA' [8]); typical resists are poly(methyl methacrylate) (PMMA) and also EPON SU-8. For an example, see Figure 1.5b and c.
- Replacing the X-ray source, a synchrotron, by UV radiation and exposing a specific resist system, EPON SU-8. The applicability of standard quartz masks is the major advantage of UV-LIGA over X-ray LIGA, but at the expense of a decrease in quality and the restriction to SU-8 resist.

Examples of the capabilities of DXRL for research applications, for the classical LIGA process sequence and for components fabricated by Direct-LIGA are displayed in Figure 1.5b, a and c, respectively.

Without any question, LIGA offers technical features–*precision, spatial resolution, aspect ratio and sidewall roughness–superior to any other microfabrication technology*. The results presented in the chapters of this book clearly demonstrate the outstanding capabilities and potential of LIGA. Nevertheless, it is still a niche technology with a rather limited spectrum of commercial applications.



(a) (b) (c)

Figure 1.5 (a) LIGA: commercially available microspectrometer manufactured by injection molding with a LIGA mold. For details, see Chapter 11. (b) Research with DXRL: X-ray lenses fabricated with LIGA. Such lenses are employed in novel X-ray microscopes. For details, see Chapter 9. (c) Direct-LIGA: gold gears for wrist watches and nickel gears for gear trains for micro- and mini-motors. For a discussion on the commercialization aspects for such devices, see Chapter 7.

Why is this so? There is a variety of reasons – some have a technical background, some are cost related and some are strategic or even psychological. Among the most prominent objections to LIGA are the following:

- *LIGA is too expensive:* The cost for LIGA is often overestimated; see also Chapter 7. X-rays at a synchrotron source are available at prices of the order of €200 per hour; such prices are based on the operational cost of a synchrotron facility without including depreciation as is usual for government investments. When compared with UV lithography, the main difference in cost is in the mask, which for a high-quality X-ray mask is in the range €10 000–20 000.
- *LIGA is too slow:* This statement is probably confirmed by the experience of many LIGA customers, but it is not so much technology related, but rather related the research-dominated environment of many LIGA laboratories.
- *LIGA is unreliable:* As with all high technologies, the transition from research to production is painful, requires time and demands significant resources for establishing high quality and high yield in production.
- *LIGA did not deliver; its promoters oversold its capabilities:* This is true and was due to the understandable enthusiasm of the early LIGA researchers.
- *LIGA lacks granularity – it is linked to a very few synchrotron sources:* LIGA shares this deficiency with XRL, where granularity had been declared as a highly important issue in the 1990s. Companies prefer wafer-steppers at their own