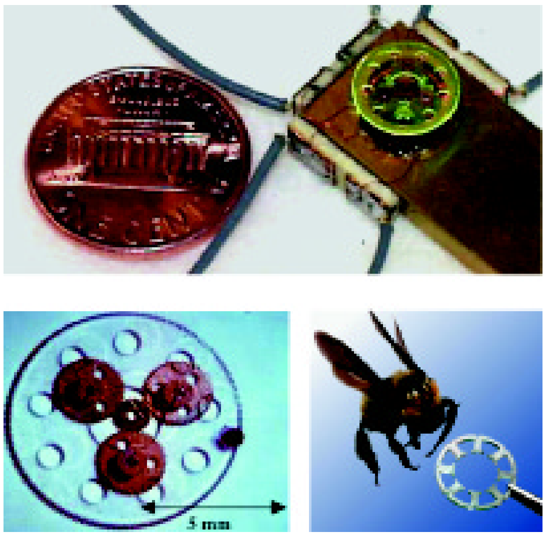
LIGA Process Modeling: Science-Based Microfabrication



LIGA is used to produce metal or plastic micro-devices having feature sizes down to a few microns. Shown above: 8 mm motor (top); planetary gear set (left); and stepping motor stator (with bee).

LIGA is a fabrication process used to produce microdevices having overall dimensions up to several centimeters and feature sizes down to a few microns. The acronym is derived from the German words for lithography, electroforming, and molding.

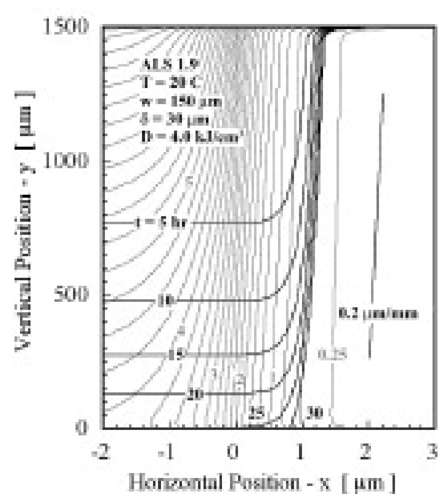
In the LIGA process, high-energy x-rays produced by a synchrotron are used to expose a thick photoresist through a patterned absorber mask. The photoresist, typically polymethylmethacrylate (PMMA), is then developed by chemical dissolution of the exposed areas. This development yields a non-conducting mold that is subsequently filled by electrodeposition. The resulting metal parts may serve as the final product or may be used as molds for mass production of plastic parts via embossing or injection molding.

Defense Programs applications for LIGA now under preliminary development include motors, accelerometers, and a variety of miniature piece parts. Many additional applications will arise as existing weapon subsystems are upgraded and miniaturized to enhance surety and improve performance.

Although the basic LIGA process is straightforward in concept, process improvement and optimization require a detailed understanding of the complex physics underlying each process step. To this end we are developing models of x-ray exposure, mold development, and electrodeposition.

Modeling x-ray exposure of the PMMA resist consists of computing the spectrum of x-rays produced by the synchrotron, the transmission and absorption of these x-rays through beam filters, and transmission and absorption in the PMMA. In addition to this primary radiation, secondary radiation in the form of photoelectrons and x-ray fluorescence must also be modeled. Some of this secondary radiation is absorbed in masked regions of the PMMA and so is important in determining the dimensional tolerances of the developed mold and in ensuring that free-standing features remain firmly attached to the conductive substrate required for electrodeposition.

Development rates of the PMMA resist depend strongly on the absorbed x-ray dose. X-rays absorbed in the PMMA result in scission reactions, producing PMMA fragments of low molecular weight more soluble in the developer.



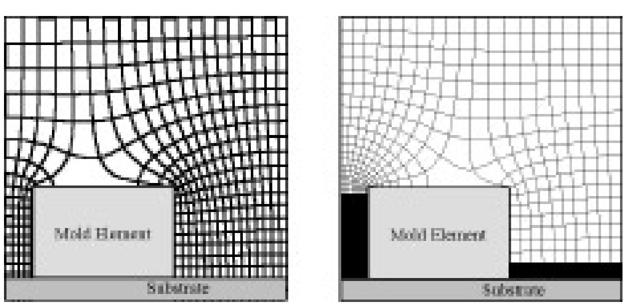
Computed development history for a thick PMMA resist. Dark curves are profiles of the development front at five-hour increments; lighter curves show the total dose due to primary and secondary radiation.

Higher doses lead to smaller fragments and higher development rates. Thus modeling the development history must take into account these dissolution kinetics and the dose distribution (primary and secondary) within the entire resist, as well as the transport of PMMA fragments out of the evolving mold cavity.

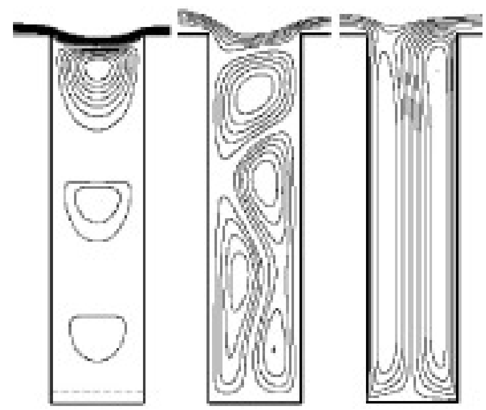
The recessed features of the developed PMMA are filled by electrodeposition to produce metal structures. The deposition rate, spatial uniformity and alloy composition of the deposit are modeled using a mathematical description of the electric field and the diffusive and convective transport of ions within the electrolyte bath and mold cavities.

Both the development process and electrodeposition depend on fluid flow and transport within mold cavities. Deep narrow features generally have weaker transport and so tend to develop or fill more slowly than wider features that are more effectively stirred by flow over the mold top; when the feature aspect ratio is large, such convection stirs only the upper portion of the mold cavity. For electrodeposition, this disparity in transport rates is reduced by buoyancy-driven flow supported by variations in ion concentration. A similar improvement in development uniformity can be obtained through acoustic agitation of the development bath using high-frequency sound. Such agitation produces a steady streaming flow along the full height of a feature, even when the aspect ratio is very large.

These models of the exposure and development processes are combined in an interactive computer program known as LEX-D. The LEX-D code is now used routinely to compute the required mask absorber thickness, exposure times, the resulting dose profiles, required period of development and expected part tolerances. It is also used to improve the process through analysis of mask membrane and PMMA substrate materials yielding reduced secondary radiation. The models of transport during electrodeposition are used to help identify optimum conditions for uniform deposition over varying feature sizes and for obtaining compositional uniformity during co-deposition of binary alloys in deep molds having high aspect ratios.



Field lines for electrodeposition into two adjacent cavities of differing size. Small features bounded by large mold elements tend to fill more rapidly due to strong conver-gence of electric flux lines.



Flow within a feature determines transport rates for development and electrodeposition processes. Calculated streamlines for forced convection (left), buoyancy-driven motion (center) and acoustic agitation (right) indicate widely differing transport rates.

The Sandia/Livermore LIGA process modeling team. Back row left-to-right: Greg Evans, Stewart Griffiths, and Rich Larson; front row Aili Ting, and Bob Nilson all of organization 8728.