

Computational Modeling
of Electrodeposition in LIGA
Microfabrication of MEMS Devices

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LIGA (Lithographie, Galvanoformung, Abformung) is increasingly demonstrated to be a viable technology in microfabrication of MEMS (micro electro mechanical system) parts/devices. Electrodeposition is a key process in LIGA microfabrication, which consists of three essential steps: 1) exposing non-conducting PMMA (polymethylmethacrylate) molds by deep or high-energy x-ray lithography, 2) removing the exposed PMMA in a developer bath, and 3) filling the PMMA molds with a desired metal (e.g., nickel) or alloy (e.g., nickel iron). Electrodeposition involves complex multiphysics phenomena: diffusion, migration, and convection of charged species in a centimeter-scale electrolyte-bath region and in micron-scale feature-cavity regions; homogeneous and heterogeneous electrochemical reactions; and moving deposition surfaces. Forced convection takes place due to stirring or agitation in the electrolyte bath and buoyancy-driven natural convection arises within the features from density differences caused by deposition of heavy metal species.

Griffiths et al. (1998) developed one and two-dimensional numerical models describing electrodeposition of metal into high aspect-ratio molds to better understand and to help optimize the electrodeposition step of the LIGA process. Their one-dimensional model addressed dissociation, diffusion, electromigration, and deposition of multiple ionic species; their two-dimensional model for a representative species included transport induced by forced flow of electrolyte outside the mold and by buoyant flow associated with metal ion depletion within the mold.

The present effort is focused on developing a transient multi-dimensional multicomponent computer model for simulating electrodeposition in LIGA microfabrication. Specifically, a Poisson equation (essentially the law of charge conservation) that explicitly describes the electrical potential in the electrolyte solution is derived by utilizing the species mass conservation equations and the electroneutrality constraint. Multiple species mass conservation equations and the Navier-Stokes equations along with the mixture continuity equation are also solved. The nonuniform moving deposition surfaces are tracked using a pseudo-solid mesh motion algorithm (Schunk et al., 1998); remeshing is performed using CUBIT (a finite-element mesh generation toolkit being developed at Sandia). Butler-Volmer kinetics describes the electrochemical reactions on the deposition surfaces. For the work presented in this paper, we assume that the homogeneous electrochemical reactions are infinitely fast. The resultant set of nonlinear time-dependent governing equations are solved using the finite-element method and a fully-coupled implicit solution scheme via Newton's method (Schunk et al., 1998). Results are presented for

electrolyte potential, species concentrations, flow field, and position and shape of the deposition surfaces for nickel plating in 2-D trenches on a PMMA mold. The effects of forced flow and buoyancy induced convection on the rate and the uniformity of the electrodeposition are demonstrated.

References

S. K. Griffiths, R. H. Nilson, R. W. Bradshaw, A. Ting, W. D. Bonivert, J. T. Hachman and J. M. Hruby, Sandia National Laboratories Report, SAND98-8231 (1998); see also, *Microsystems Technologies*, Vol. 4, No. 2, 98-101 (1998).

P. R. Schunk, P. A. Sackinger, R. R. Rao, K. S. Chen, R. A. Cairncross, T. A. Baer and D. A. Labreche, Sandia National Laboratories Report, SAND97-2402 (Reprinted September 1998).