

Position Paper: Developments of Ultra-Deep LIGA Processes

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Deep x-ray lithography developed in Germany around 1980's has been recognized to be an important micromachining technology. Using the combined technologies of electro-plating and molding, the micromachine parts can be manufactured with low costs. In addition, the choices of structure material for the final products are virtually unlimited, far beyond the conventional silicon-based processes.

Recently, researchers at the university of pittsburgh and the synchrotron radiation research center (srrc) in taiwan have focused on developing low-cost, ultra-deep LIGA (ud liga) processes. Developments of such processes are directed for specific applications for ten micron-deep and millimeter-deep microstructures. Since the typical single-exposure depth using srrc x-ray source without filters is limited to 200 μm , an alternative to increase the depth of microstructure is to use successive exposures combining the technology of conformal mask. To warrant a success of such an ud LIGA process, particularly for the millimeter deep microstructure, proper control of the wet developing process and the thermal stress is critically important. While increased exposure dosage combined with prevention of dosage absorption on the structural walls from the diffracted light alleviates the developing problem to a great extent, the thermal-stress induced crack remains to be a serious concern as the structure depth reaches three millimeters.

Better control of wet developing process requires shorter developing time. It is recognized that the developing time for large-aspect ratio microstructure is not exactly proportional to the photoresist thickness. Our collective experience leads to a conclusion that the two major factors determining the developing speed are: (1) attenuation of irradiation dosage and (2) mass transfer in developed trenches. To temper the dosage attenuation, hard x-ray irradiation based on synchrotron light source is certainly desirable; however, the side effect of high-energy photoelectrons becomes problematic. The successive exposure approach we developed is capable of boosting the dosage and increasing the speed of development by a factor of two to three. Hence a successful process can be warranted.

The issue of thermal stress is largely attributable to the enormous mismatch of thermal expansion coefficient between the photoresist and substrate. Cracks often occur in the photoresist as its thickness exceeds three millimeters. To ensure substrate flatness under different working temperature, a sandwiched substrate structure that has a balanced thermal stress from both sides has been developed. This design leads to a uniformly reduced level of thermal stress in the photoresist.

In an attempt to further improve the ud LIGA process as well as to gain fundamental insight of transport phenomena pertaining to thick-film lithography, significant research efforts have been devoted to analyze as well as to numerically simulate various aspects of the process. One of the primary goals here is to reveal explicit guidelines for process control, technology advancement, and user training. For instance, a general formula for irradiation dosage with synchrotron x-ray

exposure and various resist materials has been developed. In addition, developed wall profile can be predicted based on fresnel diffraction and exposure attenuation. This analysis is applicable to other lithographic processes including deep x-ray and uv irradiation. As for numerical simulation, detailed mass transfer process, in conjunction with chemical reaction, inside deep trenches has been modeled recently using finite-difference and finite-volume schemes. Further studies based on modern simulation tools to analyze the combined diffusive and convective transport phenomena in deep trenches are highly recommended.

While x-ray LIGA process today is widely used for making large-aspect-ratio microstructures, control of the post-x-ray-irradiation part of the process remains to be ineffective and difficult. It is necessary to develop design guidelines and simulation tools for modeling of the sub-processes, such as G-G development, electroplating and micromolding. In addition to x-ray LIGA, UV-LIGA processes, such as SU-8, for their potential in making ultra-deep structures deserve further investigation. These processes are much less costly and easier to be established than their x-ray counterparts. Research focuses for UV-LIGA should be directed to new approaches for improving product quality, particularly for highly accurate profiles and reduced surface roughness.