10th World Congress on Structural and Multidisciplinary Optimization
May 19 -24, 2013, Orlando, Florida, USA

Photomask optimization of micromachined 3D structure using multistep projection targeting minimization of residual displacement

Tsuyoshi Nomura[1], Takashi Ozaki[2], Norio Fujitsuka[2] and Keiichi Shimaoka[2]

[1] Toyota Research Institute of North America, Ann Arbor, Michigan, USA, tsuyoshi.nomura@tema.toyota.com,
[2] Toyota Central R&D Laboratories, Inc., Nagakute, Aichi, Japan

1. Abstract

Study of topology optimization methods for micro electro mechanical systems, MEMS, have been reported, but most of them were limited to 2D structure [1,2]. One reason is that micromachining processes itself is suitable for 2D structure, thus it is sometimes not capable to fabricate complex 3D structure which tend to be generated with 3D topology optimization. In reality, however, many of the MEMS structures have 3D geometrical shapes or material property distributions such as structures with concavo–convex patterns, out-of-plane deformation/actuation, an internal stress gradient and so on. In order to consider such situations, we propose a new 3D FEA based topology optimization method which is compatible with micromachining processes. In this method, level set based topology optimization is performed on a 2D photomask, and multistep projection, which models a micromachining fabrication process, produces 3D MEMS structure from the 2D photomask data.

The proposed method is applied to design of reinforcement ribs of electrostatic micromirror to minimize deformation induced by internal residual stress distribution. The ribs are formed on top electrode structure of parallel plate electrostatic actuator made of SiO2/poly-Si/SiO2 layers.

The photomask is modeled with 2D level set function which maintains signed distance function characteristics by geometry based reinitialization. The projection provides two phase density distribution for SiO2 and Poly-Si and internal stress distribution in 3D space. These distributions represent 3D shape of top electrode for FEA to analyze initial stress induced elastic deformation. After that, level set function is updated based on Hamilton-Jacobi equation driven by adjoint sensitivity from 3D FEA[3].

The proposed method have been implemented and applied for real prototype design. The optimized top electrodes were fabricated. Additionally intermediate designed produced during the iteration steps were also fabricated. Deformations were measured by confocal laser microscopy. From measurement, we observed 87% deformation reduction was achieved. This method is applicable to various MEMS devices by modifying the mapping steps to make them suitable for the respective fabrication processes.

2. Keywords: MEMS, Photomask optimization, topology optimization, level-set method

3. References

[1] T. Chen, Z. Liu, J. G. Korvink, S. Krausse and U. Wallrabe, *Proc. MEMS 2009*, 1019–1022, 2009
[2] K. Maute and D. M. Frangopol, *Computers and Structures*, 81, 813–824, 2003
[3] S. Yamasaki, S. Nishiwaki, T. Yamada, K. Izui and M. Yoshimura, *Int. J. Numer. Meth. Engng*., 83, 1580–1624, 2010