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Computational MEMS Process Design and Development

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1. Introduction

During the last two decades, micro electromechanical systems (MEMS) /microsystem technologies (MST) have been growing and expected to become a platform technology in the 21st century. This expansion trend in MEMS/MST is reflected in the number of total submitted papers to the international conference on MEMS. Although many MEMS/MST products are now on the market, a view point of optimum method for MEMS/MST manufacturing is lacking now and it is beyond doubt that it will become crucial for further progress. The manufacturing includes design, fabrication, package/assembly and testing. The required specification for a MEMS/MST including cost performance should be satisfied by a proper combination of these steps. Since these steps are closely related each other in MEMS/MST compared to other electronics related products such as LSIs, the necessity of total manufacturing design is essential. Computer simulation softwares for MEMS/MST which can handle multi physics and multi scale domain which is the key feature of MEMS/MST have been widely accepted as a useful tool for the MEMS/MST design and prediction of their performances. However, a computational approach toward total manufacturing design is still in the early stage.

Three dimensional (3-D) micro fabrication technologies such as anisotropic etching of single crystal silicon, Deep reactive ion etching (RIE) of silicon, LIGA (Lithographie Galvanoformung Abformung) are the key-technologies for MEMS/MST. With increasing demand for the controllability of a 3-D shape for MEMS/MST, process parameters determination at process development stage to realize the required 3-D shape has become more and more difficult. In this paper, using the 3-D microfabrication process with deep X-ray lithography as an example, the usefulness and future trend of a computational process design and development is demonstrated and discussed.

2. Deep X-ray Lithography for 3-D Microfabrication

A double deep X-ray lithography (D^2XL) and moving mask deep X-ray lithography (M^2DXL) developed by author's group are very unique and powerful deep X-ray lithography techniques to realize 3-D microstructures. Since the resist dissolution rate is defined by an absorbed X-ray energy, a 3-D microstructure shape is controlled by controlling an absorbed X-ray energy distribution in the resist. At first, the principles of these two microfabrication technologies will be briefly explained.

2-1. D^2XL [1-3]

D^2XL can be applicable to any deep X-ray lithography system since special apparatus is not necessary to perform. Figure 1 schematically shows the procedure of 3-D microstructure fabrication by the D^2XL. Irradiation of a whole resist surface without an X-ray mask is carried out after the first exposure with an X-ray mask. Since the resist area dissolves with different dissolution rate between exposed and non-exposed area by the first exposure, ramps of the resist microstructure is formed. On the other hand, since the whole resist surface area is irradiated by the second X-ray exposure, the surface also dissolves laterally. Thus, the resist dissolution propagation advances to various directions and eventually 3-D microstructure is formed. For example, a micro needle array with very sharp tip can be realized as shown in Fig.1 bottom.

2-2. M^2DXL [4-6]

The concept of M^2DXL technique is shown in Fig.2. An X-ray mask is moved during exposure to yield a controlled energy distribution in the resist to define 3-D microstructures. Compared to D^2XL, this has more potential to realize microstructures with controllable inclined or curved wall by combining various mask patterns and mask movement trajectory. The validity of this technique has been demonstrated by fabricating various microstructures including micro optics components and μ-TAS chips.

3. X-ray Lithography Simulation System for 3-D Fabrication (X3D)

Although M^2DXL and D^2XL are very powerful and useful techniques to fabricate 3-D microstructures, it is not easy to define complicate process parameters empirical try and error approach. To address this problem, an deep X-ray lithography simulation program for 3-D fabrication named (X3D), shown in Fig.3, was tailored to simulate the fabrication process of 3-D microstructures using M^2DXL and D^2XL [7-9]. The X3D consists of three modules: mask generation, exposure and development. The exposure module calculates a dose distribution in a resist using an X-ray mask pattern and its movement pattern. The development module adopted the "Fast Marching Method" technique. This technique can take into account the dose distribution in a resist and resultant dissolution direction of the resist during development process. Therefore, the X3D made it possible to simulate the 3-D dissolution process for M^2DXL and D^2XL and can predict the resultant 3-D microstructures accurately. In this respect, X3D differs from previous X-ray lithography simulation which can not handle a resist dissolution process and the resultant 3-D microstructures.

The X3D makes it possible to perform the iterative computer prototyping to find complicate process parameters without empirical try and error approach experimentally. The author calls this approach as a "Forward approach". However, the final goal of a computational process design and development is a deterministic procedure to define process parameters without any iterative simulation. The author calls this approach as an "Inverse approach". The approach using inverse Fourier transformation proposed by authors are one of the examples for this direction [10]. The feature of the "Inverse approach" is that it can provide even the negative answer, namely an operator can know that the feasibility to fabricate the required microstructure with present process technology. This is a great step toward the optimal computational manufacturing for MEMS/MST.

4. Conclusions

The computational process design and development approach for MEMS/MST was shown using a deep X-ray lithography for 3-D microfabrication as a complicated process example. Furthermore, the concept of an "Inverse approach" was also shown as a direction for the future.

Acknowledgments

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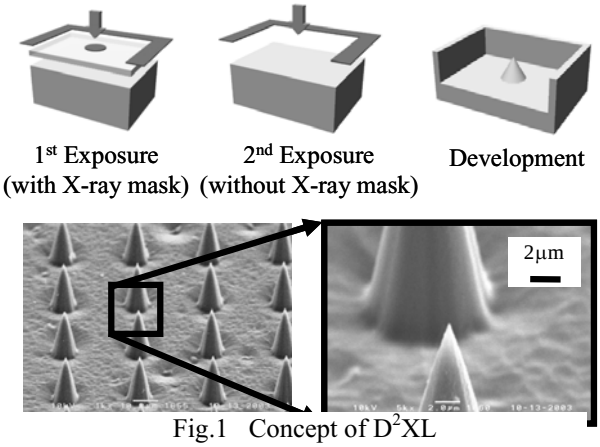

Fig.1 Concept of D^2XL

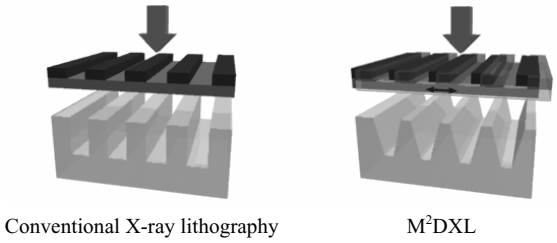

Fig.2 Concept of M^2DXL.

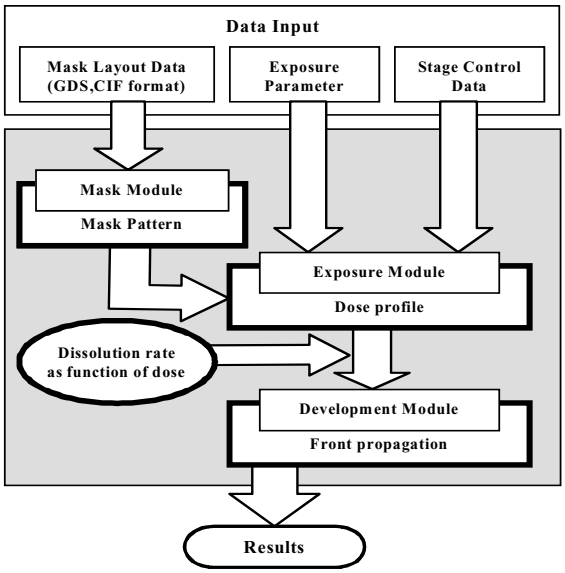

Fig.3 Configuration of X3D.