

Gray-Scale Lithography for MEMS Applications

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INTRODUCTION

Micro-electro-mechanical systems (MEMS) fabrication technologies originated directly from integrated circuit (IC) fabrication. IC devices require only two-dimensional or planar structures to be fabricated, because there are no mechanical operations taking place. Therefore structures fabricated for MEMS devices have been traditionally designed with nominally vertical sidewalls (anisotropic etching), undercut sidewalls (wet isotropic etching), or sidewalls that have limited angles due to the crystallographic orientation of the substrate (wet anisotropic etching).

The meaning of a three-dimensional (3-D) structure for our purpose pertains to arbitrarily sloped sidewalls in silicon. That is, a sidewall fabricated as vertical or sloped with a desired angle or profile. A 3-D technique could enhance the efficiency, reliability, and overall performance of various power MEMS devices. Such enhancements could be nozzle and diffuser elements in fluidic devices, trenches designed with specific sidewall profiles for ball bearing devices, and creating aerodynamic structures for rotary applications.

A technique called gray-scale lithography, typically in diffractive optics [1], is applied using a one level development process to create 3-D structures in photoresist. This technique utilizes planar processing and provides additional flexibility that is not supported in conventional IC fabrication technologies. The key components for the development of MEMS-based gray-scale lithography are presented.

APPROACH

The key components of gray-scale lithography include; the design of the optical mask and the use of a photolithography stepper system. A sub-resolution, two-dimensional binary optical mask and a photolithography stepper system together locally modulate the intensity of ultraviolet light. The modulated intensity of light will expose a photoresist to specified depths and a gradient height profile will remain once developed. The modulation of intensity comes from the use of different sized sub-resolution patterns (gray-levels) on the optical mask, shown in Figure 1. Once this optical mask is used in the photolithography stepper system, the light will be diffracted and the objective lens will act to filter out the higher spatial frequencies.

The resolution of the specific photolithography stepper system must be found in order to sustain all mask patterns as sub-resolution. The following equation can be used to get the resolution of a photolithography stepper system:

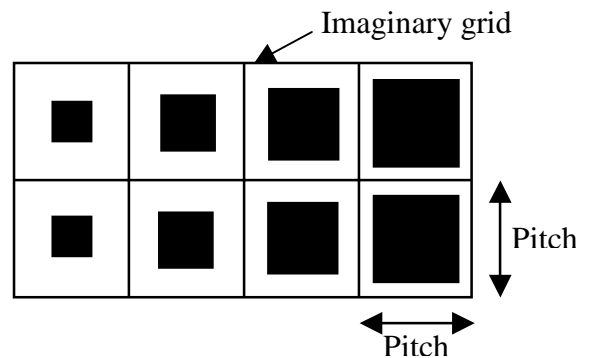


Figure 1: Example of a four gray-level mask pattern.

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$$R = \sigma \frac{\lambda}{NA}$$

where, R is the resolution of the photolithography stepper system, σ is the partial coherence of the light source λ is the wavelength of light used, and NA is the numerical aperture of the reduction lens system.

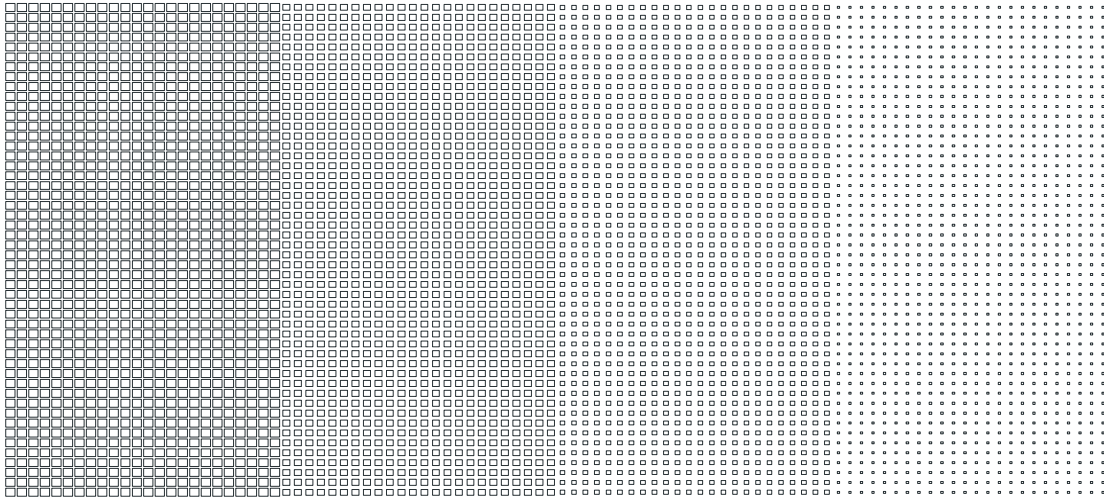


Figure 2: Layout of a gray-scale mask. The pitch is set to be 2.25 microns on the mask level and the squares (opaque) dimensions are .5, 1, 1.5, and 2 microns going from right to left.

An experiment has been developed using four gray-levels. Using the mask in Figure 2, a 5x GCA/ISI/Ultratech-XLS 7500 photolithography stepper system, and AZ 4620 photoresist, the profile in Figure 3 was achieved in the photoresist [2]. Three of four gray-levels were obtained in the photoresist. The fourth gray-level was not achieved, where high intensity of UV light is passing through the diagonal between mask patterns on the far right side of the mask shown in Figure 2.

CONCLUSION

The gray-scale lithography technique can produce 3-D structures in a photoresist layer, which can then transferred in silicon by use of dry etching. Overall, gray-scale lithography is an enabling technology for development of 3-D MEMS devices and systems.

REFERENCE

- [1] W. Henke, W. Hoppe, H. J. Quenzer, P. Staudt-Fischbach and B. Wagner, "Simulation and experimental study of gray-tone lithography for the fabrication of arbitrarily shaped surfaces," Proc. IEEE Micro Electro Mechanical Syst. MEMS 1994, Oiso, Japan, pp. 205-210
- [2] C. M. Waits, R. Ghodssi, M. H. Ervin, M. Dubey, "MEMS-based Gray-Scale Lithography," International Semiconductor Device Research Symposium (ISDRS), December 5-7, 2001, Washington D.C.

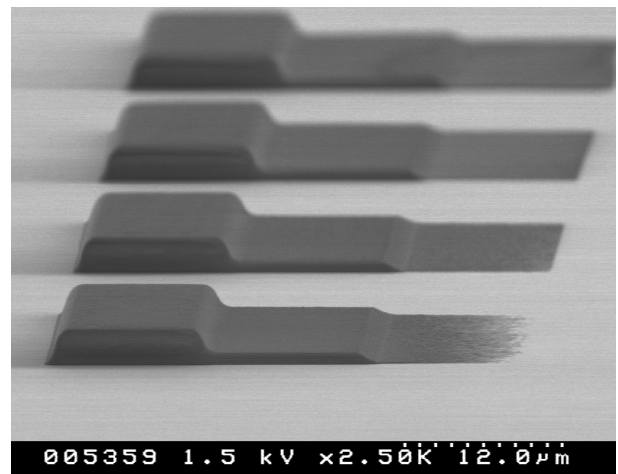


Figure 3: Three gray-levels produce three step heights in the photoresist shown.