An Electron Beam Lithography Method for Curvilinear Microstructure

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Abstract

In order to meet the processing demand of complex three-dimensional microstructures of MEMS, we devised a pattern generator of e-beam lithography system based on DSP chips which is able to generate the processing data and relevant control strategy at high speed. The generator can scan with flexible method according to processing requirement. We can get different patterns by exposing their position with different doses. After the development, three-dimensional structures with diverse curvature can be achieved. Then 3D-Microdevices are fabricated through micro-galvanoforming.

Keywords: DSP; pattern generator; LIGA; three-dimensional Curvilinear Microstructure.

1. Introduction

The silicon-based microelectronic technique which is delegated by integrate circuit (IC) has come into deep sub-micro processing. As the development of the technique, the appearance of MEMS (micro electron mechanical system) is considered as a new breakthrough of the microelectronics [1]. MEMS can integrate micro-sensor, micro-processor and micro-driver into one chip. In order to integrate them into IC, the producing of microstructure is indispensable. Because it includes sensor and movable elements, the shape of device is more complex than IC's. Moreover, the structure of micro optical lens, micro probe and biologic sensor is associated with stereo microfabrication, such as structure with curvature and micro tip array, etc. Presently, the hot field in the fabrication of MEMS is on the changing from planar technique to stereo processing technique, especially the processing method of high aspect ratio structure, such as LIGA (Lithographie Galvanoformung Abformung)[2] and LIGA-Like technique which is based on LIGA (UV-LIGA[3], Laser-LIGA [4][5], DEM[6],etc). In addition, laser direct-writing technique has made rapid progress. The above-mentioned methods can process many vertical, deep elements, but they are quite inconvenient to manufacture curvilinear and inclined microstructure.

Theoretically, the e-beam can be focused to around 10 $\mathring{A}$ (beam spot) and easily be controlled [7], furthermore, it can expose various photoresist. These features make it still important in mask-making of super IC, and can't be replaced by other methods until now. During the lithography, the photoresist (PMMA) is spun-coating to be proper thickness. Under the different requirements of the element, we change the scanning strategy so that different location is exposed at different scanning speed. Due to the different exposure doses, microstructure can be obtained after development.

The technique is able to produce three-dimensional structure directly in base plate, such as vertical, curvilinear microstructure and micro tip. It is applied to make specific mask. Then micro electron mechanical devices can be produced in bulk through micro-galvanoforming or hot-press technique. Compared with LIGA, this method not only can substitute the two expensive steps that is synchronous X-ray lithography and mask-making in lithography, but also it is far simpler than LIGA at producing vertical, curvilinear microstructure and micro tip array. Consequently, it is more suitable to a large quantity of production in micro mechanical system. But the previous pattern generation was devised to produce the masks of IC without considering the function of producing three-dimensional microstructures.

2. Pattern Generator Based on DSP

Pattern generator is a critical element in e-beam lithography system. It is located between computer and accurate deflexed amplifier. Its main function is to deal with data of unit pattern from computer, then orderly calculate the exposure spot 's coordinates of x and y(16 bits) through the hardware system. After that the coordinates are converted into correspond analog through the high-speed and accurate D/A (digital/analog) convertor to drive the deflexed amplifier control the deflexion of e-beam. According to the coordinates, the high-speed D/A (12 bits) is controlled to scan and expose the mask or silicon substrate. The pattern generator is additionally used to turn the e-beam on and off as it scans. At the same time, it receives the various correction values (field size, field rotation, field distortion, adjustment of the exposure dose, etc) from computer. After correspond conversion and sum, these values can control the deflexion of e-beam, so as to correct the above errors.

For the e-beam lithography machine using circular beam vector scanning, in order to fabricate three-dimensional curvilinear structure, the generator has to calculate the time that the e-beam stayed (or the scanning speed). The calculation should take into account effect of many factors. One is the relation between the energy deposition and the scanning speed. When the incident electron incidents in thick-layer resist, the incident electron, reflectance electron and secondary electron deposit the energy [8] in it. The other is the proximity caused by the transversal and the longitudinal structure. Also, there are many other factors should be considered. Although these algorithms can be finished off-line before the scanning, and be transmitted to the corresponding D/A, the quantity of data transmission is great. The generator we devised (shown in Figure 1) to use the TMS320VC33 [9] DSP (Digital Signal Processor) of TI company as main controller to complete on-line calculation. Data processing computer can process off-line kinds of complex correction calculations of pattern in specific thick resist and exposed by given e-beam spot parameter, such as dimension correction caused by the reciprocal effect of near pattern and field distortion correction of scanning. At last it gets the simple symbols and parameters of the pattern. The manipulative computer transmits these symbols and parameters to DSP during the scanning. The symbols are just the coordinates of pattern, symbols of pattern (rectangle, circle, ring，etc), curvature symbols and parameters of transversal and longitudinal. DSP calculates the scan speed of every spot according to the symbols and parameters which enormously reduces the quantity of data transmission from host-computer to pattern generator.

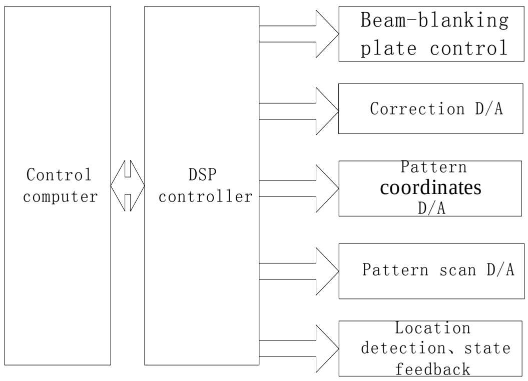

Figure1: Controller of Pattern Generator

3. Basic Patterns of new Pattern Generator

3.1 **Two-dimensional Patterns** (Scanning at Constant Speed).

1. Rectangle 1: X (width) ≥ Y (length). (x, y): coordinate of upper-left corner. ΔX: length in x-axis, ΔY: length in y-axis.
2. Rectangle 2: X (width) <Y (length). (x, y): coordinate of upper-left corner. ΔX: length in x-axis,

ΔY: length in y-axis.

3. Trapezoid 1: parallel to the x-axis. (x1,y1): coordinate of upper-left corner. (x2,y1), (x3,y4), (x4,y4): coordinates of points along clockwise.

4. Trapezoid2: parallel to the y-axis. (x1,y1): coordinate of upper-left corner. (x4,y1), (x4,y2) , (x1,y2): coordinates of points along clockwise.

5. Circle: (x, y): coordinate of circle's center. r: radius of circle.

6. Ring: (x, y): coordinate of circle's center. r1: radius of larger circle, r2: radius of smaller circle.

3.2 Three-dimensional Patterns (Scanning at Changing Speed, Shown in Figure 2).

1. Positive rectangle: upper rectangle is equal to the lower rectangle.

Parameters of the upper and lower rectangles: (x, y): coordinate of upper-left corner. ΔX: length in x-axis, ΔY: length in y-axis, ΔZ: depth of z-axis.

2. The conic of positive trapezoid: size of upper rectangle is larger than the lower's, and the lower rectangle can reduce to one point.

Parameter of the upper rectangle: (x, y): coordinate of upper-left corner. ΔX: length in x-axis, ΔY: length in y-axis.

Parameter of the lower rectangle (x1, y1): coordinate of upper-left corner. ΔX1: length in x-axis, ΔY1: length in y-axis.

ΔZ: depth in z-axis.

3. The conic: size of upper circle is larger than the lower's. The central coordinates of the two circles are the same in x-y space, and the lower circle can reduce to one point.

Parameter of the upper and lower circle: (x, y): coordinate of circle's center, r1: radius of upper circle, r2: radius of lower circle. If r2 is equal to zero, the lower circle reduces to one point.

ΔZ: depth of z-axis.

4. Circular surface: (x, y): coordinate of circle's center, r: radius of upper circle, R: radius of circular surface.

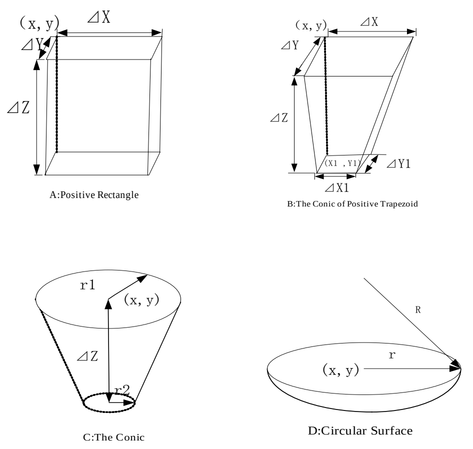

Figure2: 3D Patterns

3.3 Unit of Pattern

1. Pattern Group: It is unit of pattern (basic pattern or pattern group) arranged regularly, as is shown in Figure 3.The basic figure can be planar or three-dimensional.

Parameter: X (space in x-axis), Y (space in y-axis), nX (numbers in x-axis), nY (numbers in y-axis).

2. Pattern Database: The pattern Database saves patterns which are made up of planar patterns, three-dimensional patterns and pattern group, etc. One database can be included in another.

Pattern database includes beginning symbol (name of the database), unit of pattern (kinds of basic 2-D patterns, three-dimensional patterns, and pattern group), pattern database, end symbol.

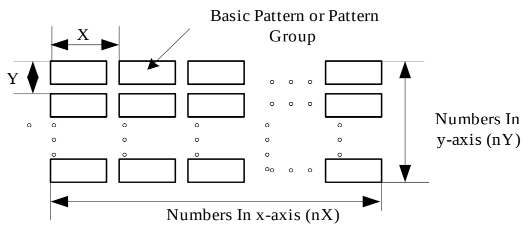

Figure 3:Pattern Group

4. Conclusion

The new pattern generator can generate the processing data and relevant control strategy at high-speed according to the demand of micro-devices. It controls the exposure doses to obtain the demanded curvilinear microstructure according to the different surface. After development, the resist can obtain the required curvilinear microstructure. Then the needed three-dimensional microstructure is got through micro-galvanoforming.

1. For mask-making of IC, we only use 2D patterns now.

2. If the lithography includes planar and three-dimensional patterns, and the masks fabricated are applied to micro-galvanoforming, the planar patterns are considered as a special case of three-dimensional patterns. Because of the thick-layer of photoresist, the exposure speed is slowest.

3. If the lithography includes planar and three-dimensional patterns, and the masks fabricated are applied to further lithography, because different position of mask has different grey, which would lead to different transparency in three-dimensional microstructure. So the structure is comparatively complicated, and the benefit needs to be further studied.

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