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HIGH EFFICIENCY MICROMACHINING SYSTEM APPLIED IN NANOLITHOGRAPHY

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Scanning probe lithography such as direct–writing lithographic processes and nanoscratching techniques based on scanning probe microscopy have presented new micromachining methods for microelectromechanical system (MEMS). In this paper, a micromachining system for thermal scanning probe lithography is introduced, which consists of the cantilever arrays and a big stroke micro XY–stage. A large machining area and high machining speed can be realized by combining arrays of cantilevers possessing sharp tips at their top with the novel micro XY–stage which can obtain big displacements under relatively low driving voltage and in a small size. According to the above configuration, this micromachining system is provided with high throughputs and suitable for industrialization due to its MEMS–based simple fabrication process. The novel micro XY–stage applied in this system is presented in detail including the unique structure and principles, which shows an obvious improvement and distinct advantages in comparison with traditional structures. It is analyzed by mathematical model and then simulated using finite element method (FEM), it is proved to be able to serve the micromachining system with high capability.

Keywords: Thermal lithography, Micro XY–stage, Heater integrated cantilevers

1. Introduction

Photolithography (optical lithography) is one of the most common and popular lithography methods, it uses the light to transfer a designed pattern from a photomask to a light sensitive chemical on the silicon substrate. Although the photolithography technique has advantages for mass production of micro/nano mechanical devices, it is limited by its intrinsic bottlenecks. Its resolution is confined by the wavelength and diffraction of the light source, it often requires a mount of time and high expense to produce the requisite photomask, in addition, the patterns on the photomask are unchangeable once they were fabricated, which is analogous with block printing [1] in ancient time.

Scanning probe lithography (SPL) has brought a major impact on lithography techniques, which can achieve high resolution and arbitrary patterns using scanning probes based on scanning probe microscopy (SPM). Employing the SPL, a sharp tip in proximity to a sample substrate can pattern nanometer scale features. SPL consists of several categories, such as chemical and molecular pattern (dip pen nanolithography[2]) and mechanical pattern (nanoscratching[3]). However, those lithography techniques are limited by the factors like tip wear, short lifetime, slow speed and ink instability.

In this paper, we propose a new concept of the lithography, a SPL based micromachining system utilizes the thermal lithography mechanism to realize nanolithography.

2. Principle of the System

In this micromachining process, the tip with high temperature works as a heater to hard bake the photoresist on the substrate by hardening the photoresist it scanned through, as illustrated in Fig.1.

To overcome the usual drawbacks in the conventional nanolithography, i.e. low processing speed, small processing strokes and low throughput, the combination of the

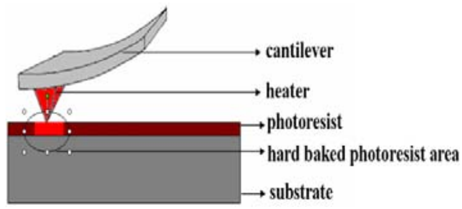


Fig.1. The working mechanism of the thermal lithography

cantilever arrays[4] with novel micro XY–stage is introduced to enhance the capability of the system. Fig.2 shows a simple configuration of the whole micromachining system.

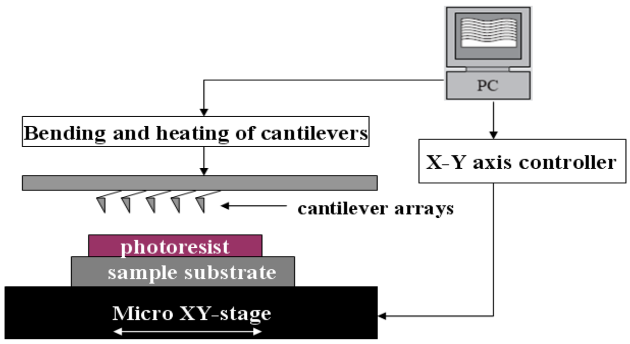


Fig.2.The layout of the whole micromachining system

In this system, micro XY–stage is responsible for loading the sample and giving a precise two dimensional positioning of a platform in X, Y directions. An array of cantilevers with various micro- and nano- size heaters illustrated in Fig.3 can be switched independently to bend and approach to sample surface by electrostatic force instead of Joule heat, because the electrostatic force needs less power consumption. Tips have different sizes from 10 nm to 5 μ m, this sizes variety enables a wide range of pattern sizes and makes our nanolithography system more versatile for practical application. For getting a desired pattern, firstly, the needed cantilevers bend under exact control and touch the sample surface covered with photoresist, the tips are heated due to current flowing through them and contact the photoresist to bake it with high temperature. Then,

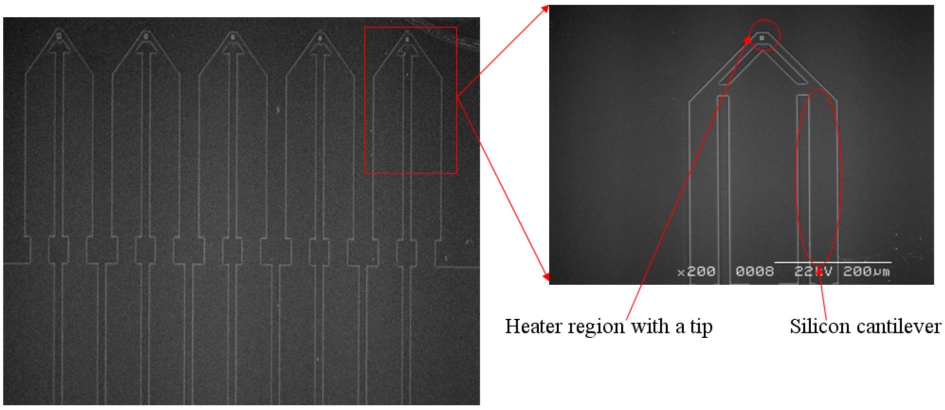


Fig.3.The scanning electron microscope image of cantilever arrays and a cantilever with its tip at the top

the micro XY–stage will move along with the sample under the appointed route which was calculated for getting the patterns shape. The heated tip will heat and hard bake the expected photoresist area accompanying with the movement of the sample driven by the micro XY–stage. Various permutation and combination of the cantilevers bend make the large pattern area and diverse-sizes pattern available. The hard baked photoresist remains after the photoresist development because their hard bake induced cross-linking reaction offers strong resistance to photoresist developer, accordingly the desired photoresist pattern is left[5].

By applying the cantilever arrays, they can compensate for the low speed caused by single probe pattern process. To increase the processing strokes for the purpose of the big area sample nanolithography, a novel micro XY–stage is presented in detail at the next section.

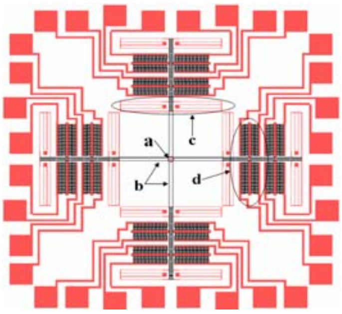
3. Micro XY–stage

As a major driving component, micro XY–stage with electrostatic force actuators is responsible for the precise movement of the sample, through which the system realizes the nanometer scale pattern. Comb-drive actuators, a type of electrostatic force actuator, are used here instead of piezoelectric actuator[6] due to its high speed and good compatibility with microfabrication. Big strokes, simple fabrication, low driving voltage and small size are key factors for the micro XY–stage. To realize the above requirements, a micro XY- stage with new configurations is reported here.

3.1. *Micro XY– stage mechanism*

As shown in Fig.4, this micro XY– stage consists of a central movable platform, eight comb-drive actuators[7], eight supporting beams, eight spring-like folded flexures and a substrate. The central movable platform is suspended by eight orthogonal supporting beams, both the supporting beams and the movable comb drives are suspended above the substrate by the folded flexures through the anchors which connect the folded flexures with the substrate. A large stage can be mechanically connected to the top of the platform, therefore, a large area working stage will be achieved.

This micro XY–stage is driven by comb-drive actuators which can generate the electrostatic force when the voltage difference is formed between the movable comb drives and the fixed comb drives. The force balance between the spring restoring force and the electrostatic force determines the position of movable comb drives, hence the desired displacement of the micro XY–stage can be achieved.



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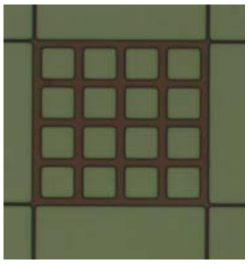

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Fig.4. The layout of the micro XY– stage. (a) Platform (b) Supporting beams (c) Folded flexure (d) Comb-drive actuators (Ⅰ) and the microscope image of the platform（Ⅱ）.

3.2. *Mechanical spring beams configuration*

Folded flexure structure shown in Fig.4 is one of the mechanical spring beams, which is suitable for large stroke actuation. It is desirable to be compliant in the moving direction and stiff in the orthogonal direction. Proper design of the each geometry parameters for the folded flexure allows a high stiffness ratio between moving direction and orthogonal direction, hence it can enable a large displacement for the whole system.

3.3. *Novel comb–drive actuators structure*

The new arrangement of the comb–drive actuators are composed of one set of movable comb drives and two sets of fixed ones which are located at each side of the movable comb drives instead of one set of movable comb drives and one set of fixed comb drives next to the moving parts in the conventional structure. Both of the fixed comb drives can give the movable comb drives electrostatic force from either left or right direction, so this novel arrangement allows single comb-drive actuator to possess two-sided actuation mechanism. In this micro XY–stage, by using this arrangement, in addition to the original pulling forces, the comb-drive actuators can provide pushing forces to the platform, therefore additional displacements can be achieved which are as big as the displacements generated by the original pulling forces. It makes the driving forces more symmetric for the platform. In terms of actuation capability, one comb–drive actuator here is equivalent to two conventional comb–drive actuators, hence this arrangement saves the area yet generates the same driving forces when compared with the conventional structure, making the device more compact. Fig.5 demonstrates the image of the novel arrangement.

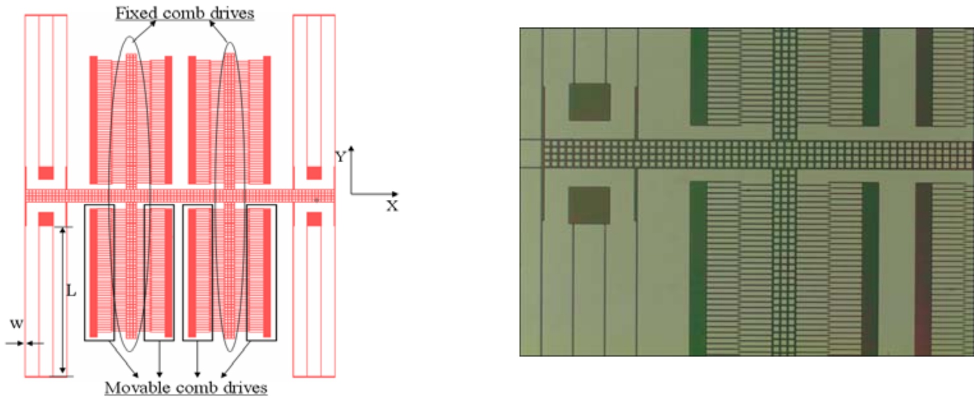

Fig.5. The L-edit image of the new comb–drive actuators and the microscope image of corresponding results.

3.4. *Mathematical modeling and simulation*

According to the research on comb-drive actuator[8] and the folded flexure[9], the electrostatic force and the spring constants of the folded flexure are give respectively by

$$F_x = \frac{N\varepsilon t}{g} V^2 \tag{1}$$

$$K_{system} = 4K_{folded-flexure} + 4K_{suspension} \tag{2}$$

where N is the number of comb drive fingers, ε is the permittivity constant of air, t is the comb drive fingers thickness and g is the fingers gap spacing. Under Hooke's law, the displacement can be known by calculating the driving forces and spring constants relation with Eq.(1) and Eq.(2) . Then the displacement in x-direction is equal to

$$L_d = \frac{4F_x}{4K_{folded-flexure} + 4K_{\sup}} = \frac{\frac{N\varepsilon}{g}V^2}{\frac{2Ew^3}{L^3} + \frac{Ew^3}{L_{\sup}{}^3}} \tag{3}$$

With the parameters of this system[10], we can get both mathematical model and the simulation results by finite element method (FEM), comparing mathematical calculation results with FEM results demonstrated in Fig.6, it shows a good agreement. The fabrication results also coincide with the theoretical analysis.

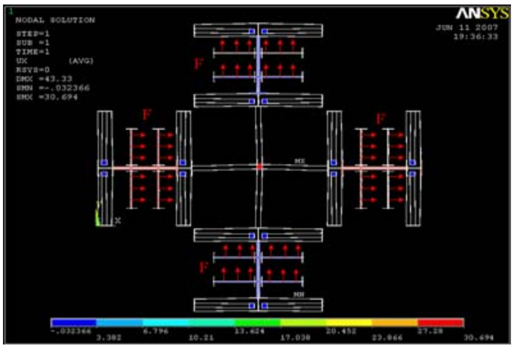

Fig.6. The FEM model. 30.694μm stroke in x-direction under voltage squared 1412

4. Conclusions

An excellent nanolithography system is presented in this paper with the combination of cantilever arrays and novel micro XY–stage with unique structure. This micro XY–stage saves area yet generates the same force with conventional structure, therefore, larger processing strokes are achieved in this system. The feasibility of the system is verified numerically using FEM and values derived from the mathematical model.

Acknowledgments

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