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Modelling and investigation of the silicon membrane actuator for nanopositioning

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1. Introduction

New technologies such as nanoimprinting, scanning microscopy, scanning instruments for surface research, nanolithography, automatic identification systems and micromachining, request for ultraprecision positioning instruments, which would ensure the nanometric accuracy of positioning.

Many micro/nanorobotic application require multidegree of freedom positioning at micro and nanoscales. Actuation technologies capable of providing motion at this scale include piezoactuators [1], microstepping motors, highly geared electromagnetic servomotors and Lorentz force-type actuators such as voice coil motors [2, 3]. The nanotechnology applications require more complex specifications, including the wide dynamic range of nanopositioning systems. It means the new, innovative solutions have to be found for the actuation methods, materials, and design. The silicon as mechanical material and laser micromachining open a new possibilities in actuators design.

So, real positioning, where the repetitiveness of positioning is in the nanometer level, may be ensured just in the systems without friction pairs. Nanopositioning systems have to feature a high directness of transmission characteristics, as well as mechanical, wide control circuit frequency zone, and the possibility to control the movement in nanometric range. Therefore the sub-nanometric resolution power is necessary. This may be ensured only by electromechanical systems without friction pairs [4].

When traditional methods and means used in micropositioning systems it cannot satisfy the requirements which are essential in nanopositioning systems, new achievements are used. The achievements include: solid activator, flexure mechanical systems, and low inertia collateral kinematics of many axes, active control of trajectory, and wide range and adaptable system control [5]. These allow solving positioning, metrological and other problems which appear in practical nanotechnology.

Microfabrication with lasers today is in the situation of competition between: machining quality and efficiency. Interest in picosecond lasers has increased recently. They have the potential to improve machining quality as compared to that achievable with longer pulses [6]. As femtosecond systems are complicated and the advantages of processing with ultra-short pulses are evident only at low laser fluences, picosecond lasers present a cost-effective alternative for machining of micro objects. Real industrial applications of ps-pulses require reliable laser sources and well-established technologies. In this work we present the theoretical modeling and experimental results of our research on microfabrication of silicon actuator by picosecond laser.

In this work we present the theoretical modeling and experimental results of our research on creation of silicon actuator by picosecond laser.

2. Electrostatic model of actuator

A model of electrostatic actuator operation is to consider a rigid plate attached by a spring and submitted to an electrostatic field (Fig. 1).

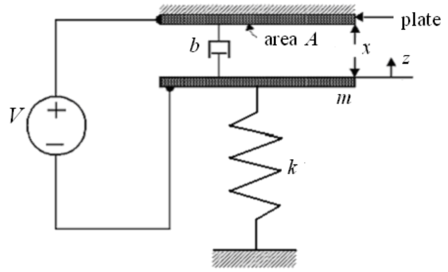


Fig. 1 Simple model of an electrostatic actuator

For the simulation of the system represented in Fig. 1, the calculation is based on the mechanical law governing the electrostatic actuator which can be expressed as follows:

$$m\ddot{z} + b\dot{z} + kz = \varepsilon_0 A/2(x-z)^2 V^2 \qquad (1)$$

where z is deflection, m is mass, b is damping factor, k is spring value. k depends on the geometry of the microstructure. The excitation is represented with the help of electrostatic pressure through a gap x applied on the plate surface A, with voltage V and permittivity ε_0. The mass can be expressed with the geometrical characteristics of the plate $m = = \rho h A$, where ρ is the volume density and h is the plate thickness.

Material properties of the membrane actuator are listed in Table.

Table

Material characteristics of membrane actuator

Material	E, GPa	ν	ρ, 10^3 kg/m^3	h, μm
Al	70.3	0.345	2.69	0.3
Si (substrate)	120	0.42	2.33	300

Note: E is Young module; ν is Poison ratio; ρ is density; h is thickness of the plate

As the membrane is symmetrical, for the acceleration of calculations a quarter of sample was modeled. Orbicular parameter is freely attached (fixed in a noncantilever way). While calculating, the free attachment was taken into consideration.

The modelling is performed using the finite element method, where the structure is meshed into the simple geometry finite elements and the type of them depends on the task solved. The ANSYS software package was selected for the analysis of membrane actuator. Shell 43 type finite elements were chosen to model this type of structures. These elements are usually used to model plane structures of various thickness and elastic material constructions (Figs. 2 and 3). Shell43 is a 4-nodes plastic large strain element [7].

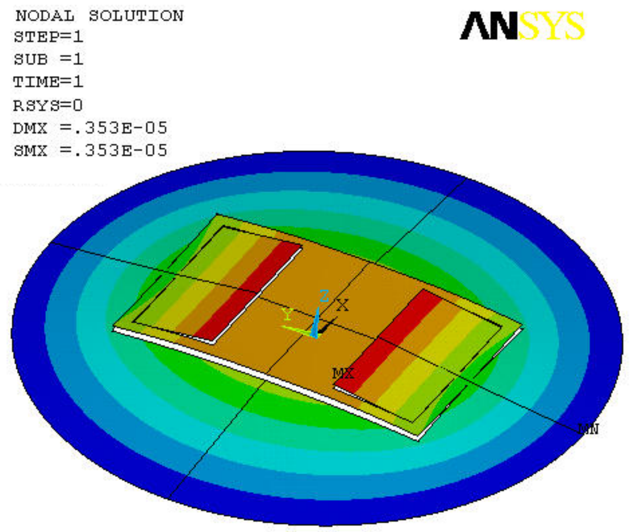


Fig. 2 Actuator displacement in static mode. Gap between the plate – 140 μm, control voltage – 250V

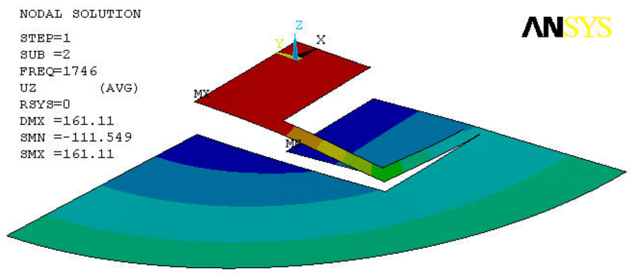
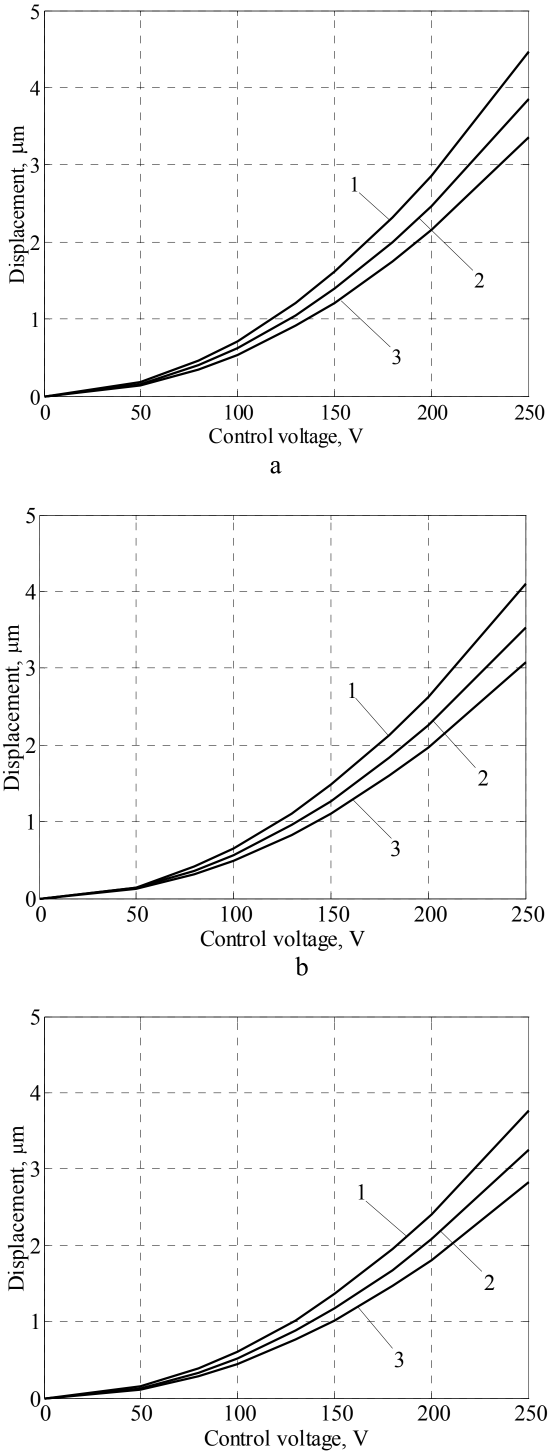


Fig. 3 Actuator displacement in dynamic mode *f*=1746 Hz

Fig. 4 shows the modeling results of a driving micro actuator at 0-250 V applied voltage.

3. Experimental set-up

Experiments were performed on silicon wafers with the thickness of 300 μm. Actuator displacements were investigated using AFM Quesant QScope-250 microscope (Fig. 5).



a

b

c

Fig. 4 Membrane actuator characteristics in static mode determined by FEM: leg width 0.5 mm (a), 1 mm (b), 1.5 mm (c). (*1* – a gap between the plates - 130 μm, *2* – 140 μm, *3* – 150 μm)

The design goals are as follows: stroke, output force, driving voltage. The stroke in the out-of-plane direction needs to be 5μm. The driving voltage needs to be less than 250 V. Actuator geometries obtained using laser micromachining are shown in Fig. 6.

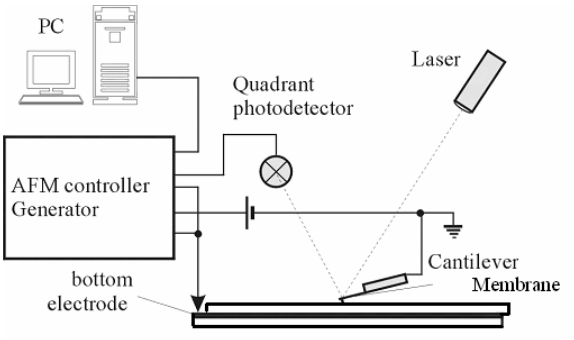


Fig. 5 Measurement scheme using AFM

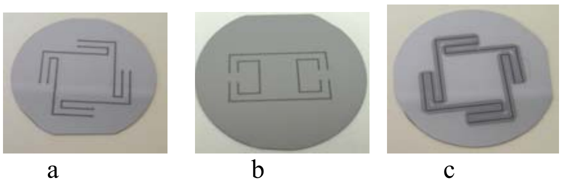
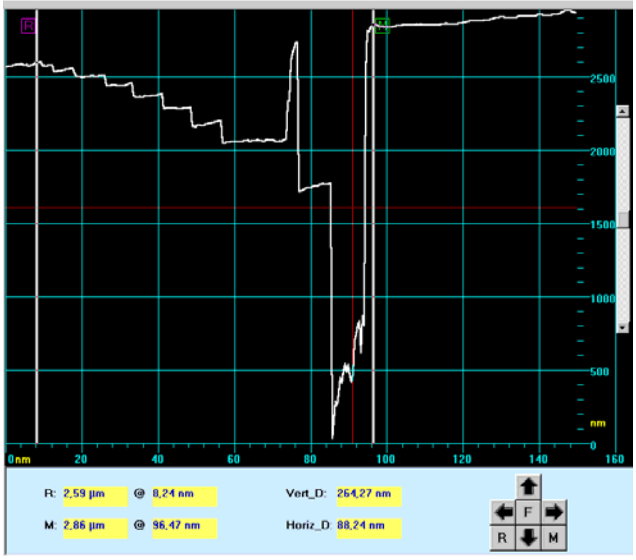


Fig. 6 Comparison of actuator geometries using laser micromachining: a) and b) plane flexures c) plane flexures 50 µm deepening

4. Results

Actuators displacement was investigated by atomic force microscope (AFM) Quesant QScope-250 in contact mode with cantilever force constant 0.1 N/m. The displacement was measured applying direct current voltage to the actuator and imaging the actuator surface during the scan (Fig. 7). The displacement was measured directly from the AFM image cross-section.



R: 2,59 µm @ 8,24 nm
M: 2,86 µm @ 96,47 nm
Vert_D: 264,27 nm
Horiz_D: 88,24 nm

Fig. 7 AFM image of the actuator surface displacement in static mode at different control voltage

Driving characteristics of the plane flexures were also examined. Fig. 8 shows the characteristics of the tip height versus the applied voltage. The driving voltage was used 0-250 V. The gap between the plates is 140 µm.

It was demonstrated that silicon micro machined electrostatic driven actuators can be used in different nanomanipulating systems.

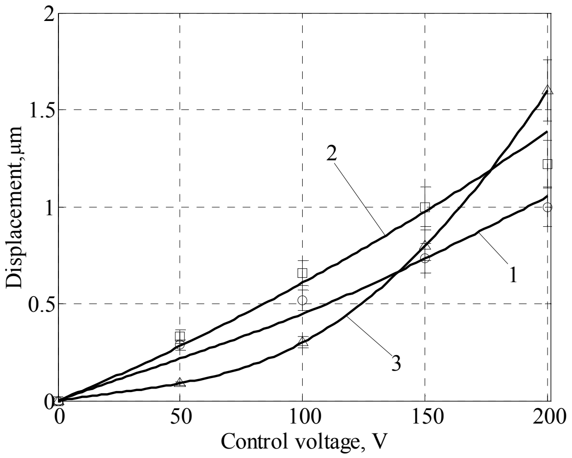


Fig. 8 Experiment results in static mode. Deflections from the plane: *1* – flat cantilever suspension with the depth of 50 µm; *2, 3* – cantilever suspensions of various constructions

The work quality of designed actuator was evaluated according the quality of received pictures which correspond to the picture quality using piezoelectric actuator. The picture of silicon surface is shown in Fig. 9.

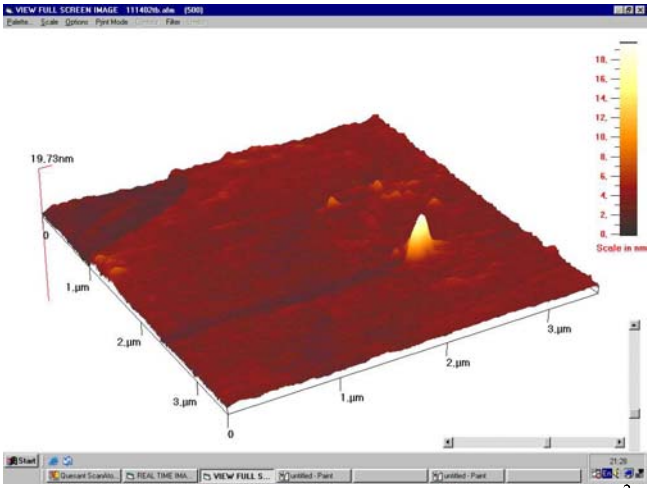


Fig. 9 Silicon surface view. Scaning area (3.5 x 3.5) µm^2. Z direction top value – 20 nm

Further research includes the realization of actuators for Scanning Probe Microscopy applications.

5. Conclusions

1. Computer model of membrane silicon actuator, operated by electrostatic field, is designed.

2. Static and dynamic characteristics were investigated. It was demonstrated that the developed actuator produce 5 µm displacement under the 250 V control voltage. The determined first mode resonance frequency of plane flexures was 1746 Hz.

3. Static characteristics of membrane actuator are evaluated using AFM system.

4. The investigations on operation possibility of membrane electrostatic actuator in the feedback network of the probe microscope Quesant Q250 showed that the actuator provided z-axis positioning range up to 5 µm. Sur-

face views of materials confirm the perspective of using such actuators for nanopositioning.

References

1. **Szita, N., Sutter, R., Dual, J. and Buser, R.A.** A micropipettor with integreted sensors.-Sensors and Acruators A, 2001. v.89, No.1-2, p.112-118.
2. **Molenaar, A., Zaaijer, E. H. and van Beek, H.F.** A novel long stroke planar magnetic bearing actuator. -The 4th Int. Conf. on Motion and Vibration Control, 1998, p.1071-1076.
3. **Bansevičius, R., Giniotis, V.** Increasing the accuracy of precision equipment: mechatronic approach. -Mechanika. -Kaunas: Technologija, 2004, Nr.1(45), p.33-38.
4. **Lendraitis, V., Mizarienė, V., Seniūnas, G.** Nanoposition - methods and means. -Mechanika. -Kaunas: Technologija, 2007, Nr.2(64), p.49-55.
5. **Bansevičius, R., Fallahi, B., Toločka, R. T., Varnavičius, V.** Smart underactuated manipulator: design and dynamics simulation. -Mechanika. -Kaunas: Technologija, 2002, Nr.6(38), p.63-66.
6. **Weikert, M., Foehl, Ch., Dausinger F.** Proc. 3d Int. Symp.on Laser Precision Microfrabrication, Proc. SPIE 4830, 2003, p.501-505.
7. ANSYS, Revision 10.0, Swanson Analysis Systems Inc., Houston, USA. 2005.-586p.

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SILICIO MEMBRANINIO AKTUATORIAUS SKIRTO NANOPOZICIONAVIMUI MODELIAVIMAS IR TYRIMAS

Reziumė

Straipsnyje nagrinėjama galimybė panaudoti Si membranas mikroobjektams nanopozicionuoti.

Baigtinių elementų metodu nustatytos membraninio mikroaktuatoriaus pagrindinės rezonansinės modos ir jų priklausomybė nuo skirtingos geometrijos Si plokštelių. Taikant mikrosistemų konstravimo technologijas sukurtas membraninio mikroaktuatoriaus prototipas. Naudojant atominės jėgos mikroskopo sistemą, nustatytos membraninių struktūrų statinės ir dinaminės charakteristikos.

Mikroaktuatoriumi gauti medžiagų paviršiaus vaizdai patvirtina tokio tipo mikroaktuatorių panaudojimo nanopozicionavimui perspektyvumą.

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MODELLING AND INVESTIGATION OF THE SILICON MEMBRANE ACTUATOR FOR NANOPOSITIONING

Summary

The article deals with the possibility to apply Si membranes for nanopositioning of micro objects.

Applying the finite element method the basic resonant modes and their dependence on the different geometry Si plates are identified. The prototype of membrane microactuator was designed applying micro system designing technologies. Using the atomic force microscopy system, the static and dynamic characteristics of membrane structures were defined.

Surface views of materials confirm the perspective of using such actuators for nanopositioning.

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МОДЕЛИРОВАНИЕ И ИССЛЕДОВАНИЕ КРЕМНИЧЕСКОГО МЕМБРАННОГО АКТЮАТОРА ДЛЯ НАНОПОЗИЦИОНИРОВАНИЯ

Резюме

В статье рассматривается возможность использования мембран из кремния (Si) для позиционирования микрообъектов с нанометрической точностью.

Методом конечных элементов определены основные резонансные моды мембраны и их зависимость от различной геометрии пластинок из кремния (Si). Используя технологии конструирования микросистем, создан прототип мембранного микроактюатора. При помощи системы микроскопа атомных сил определены статические и динамические характеристики созданных мембранных структур.

Полученные при помощи микроактюатора изображения поверхности материалов подтверждают перспективность исследования нанопозиционирующих микроактюаторов такого типа.

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