行政院國家科學委員會補助專題研究計畫成果報告

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微機電磁浮式可定址控制靜電垂直致動之垂直鏡面光通訊開關(II)

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計畫類別：□**個別型計畫**　　□**整合型計畫**
計畫編號：NSC89－2218－E－002－064
執行期間：89 **年** 7 **月** 31 **日至** 90 **年**　7 **月** 31 **日**

計畫主持人：黃榮山

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執行單位：國立台灣大學應用力學研究所

中　華　民　國 90 年 10 月 31 日

A Novel Dual Torsion Actuator for Large Displacement and Low Driving Voltage

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Abstract

An innovative, dual torsion actuator for large displacement and low driving voltage is presented. In the structural segment with a dual torsion design, the magnetically twisted micro actuator in the up position demonstrates a higher levitation compared to one torsion design. In addition, the actuator is electrostatically driven, clamping continuously down with a lower voltage. Fabrication and characterization of the micro actuator has been first demonstrated. The calculation of the twisted angle with respect to external magnetic fields is also conducted in a good agreement with the experiment. The present study of a large displacement of 570 μm and a low clamping voltage of 13 volt has been simultaneously achieved.

1. Introduction

Electrostatic actuation is the most popular mechanism in micromachining technique due mainly to the ease of available processing materials and manufacturing merits. In principle, the stored energy density of electrostatic actuation shows a great superiority over other means in a very short distance of within several microns. However, a large moving distance or a gap-closing actuation from an initial large separation can be seen in many applications as extremely adverse to an electrostatic means. The trade-off between a low voltage and a large displacement or a large gap separation still remains unsolved.

A magnetically twisted, electrostatically addressable torsion-beam plate shows highly potential applicability for optical scanners, switches and display [1,2]. As the plate-rotated angle approaches nearly a vertical position, the electrostatic clamping mechanism exhibits serious challenges to drive the plate down. In this paper, a novel design of dual torsion approach for an actuator may take both mechanism advantages of magnetic levitation and electrostatic clamping to achieve a low voltage and a large moving displacement.

2. Design Concept

This paper proposes a novel design for a segmental, dual torsion microstructure of an actuator to achieve large displacement and low driving voltage. The microstructure consists of two segments, both of which are a torsional plate as shown in Fig. 1. One is a base torsion whose bars are attached to the fixed substrate; the other is a major torsion plate designed to construct on its rotatably base torsion plate and twisted in a large angle. With the structure design under an externally upward force, both torsion structures are twisted individually. Therefore, the total rotation of the major torsion plate by adding the base torsion angle creates a large angle, resulting in an even great displacement.

As illustrated in Fig. 1, the actuator employs an off-chip magnetic field to torsionally levitate the microstructure, and is able to clamp down by the application of an on-chip electrostatic force.

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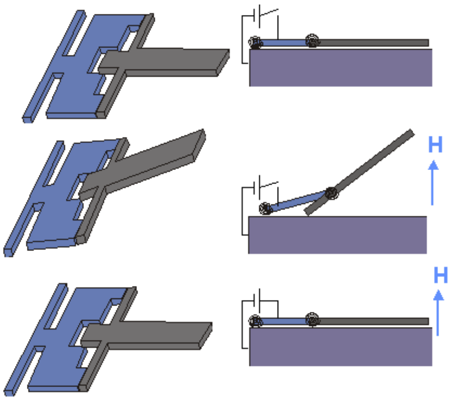


Fig. 1 Operation illustration of a segmental, dual torsion actuator

3. Theory

As described previously, the actuator is composed of material that includes magnetized electroplated Ni plate mainly driven in a magnetic field, and evaporated copper as an electrode. In the microstructure segments, the Ni plate is deposited on the major torsion plate that encloses a volume of 3000 x 690 x 25 μm^3. The other segment of the base torsion plate possesses 1000 x 4700 x 12 μm^3.

a. Mechanical Analysis

Proper design of torsion stiffness is required to achieve desired rotation of the two plates. In Hooke's law, the torsion stiffness k_{ϕ} can be expressed as

$$k_{¤} = 2\frac{K_{beam}G}{l_{beam}}$$

Where l_{beam} is length of a torsion beam, K_{beam} stands for a cross-section factor, and G is shear modulus. For a torsion beam, has a rectangular cross section of width w_{bar} and thickness t_{bar}, the cross-section factor can be expressed as

$$K_{beam} = \frac{(2a)^3(2b)}{3}\left[1-\frac{192}{®^5}\left(\frac{a}{b}\right)\times\sum_{n=1,3,5}^{\infty}\frac{1}{n^5}\tanh\left(\frac{n®b}{2a}\right)\right]$$

Where w_{bar} is width of a beam rectangular cross section; t_{beam} stands for thickness; 2a＝min（w_{beam}, t_{beam}）, and 2b＝max（w_{beam}, t_{beam}）. Meanwhile, the shear modulus G of single crystal silicon is 73 GPa.

After calculation, the major torsion stiffness k_{major}= 4.6 x 10^{-6} Nm/rad in a beam dimension of 1800 x 100 x 12 μm^3; and the base torsion stiffness k_{base} = 1.6 x 10^{-5} Nm/rad in a beam dimension of 500 x 100 x 12 μm^3. The induced mechanical moment in a magnetic field can expressed as

$$M_{mech} = k_{\phi}\boldsymbol{\phi}$$

b. Magnetic Analysis

When the microstructure with magnetized material is generated in magnetization *ì* subject to a magnetic field ***H***, a moment M_{mag} can be expressed as

M_{mag} = *ì* **ν** H sin(ã-è-Ö)

with magnetic volume **ν** ＝*lwt*＝3000 × 690 ×25 μm^3, the angle between ***H*** and horizontal is **γ**, the angle between *ì* and magnetic plate is **θ**. For a nickel material, the saturated magnetization is *ì* ＝0.7 T with a vertically applied magnetic field (ã＝90^o) [3].

4. Fabrication and Assembly

The fabrication process begins with a double-side polished silicon wafer deposited with 1000 Å silicon dioxide and 1500 Å silicon nitride. The wafer was backside etched and left a 30 µm thin film.

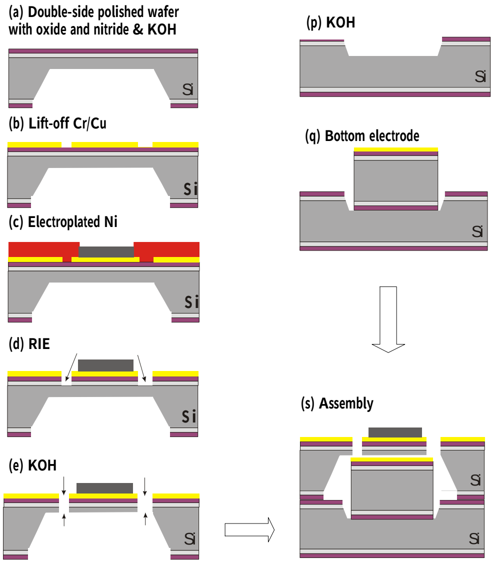


Fig. 2 Fabrication process of an actuator

The wafer frontside was structure-pattern defined, and copper/chromium were evaporation deposited and also served as an electroplating seed layer. The 25 µm Ni film was electroplated and servesd as a magnetic material. After the wafer is dry etched to remove pattern nitride and oxide layers and then wet etched in a KOH solution, the complete silicon structures were finally formed.

The lower electrode substrate was simply fabricated and then assembled for electrostatic actuation. First, a 20 µm deep fillister was formed by slightly etching in a KOH solution for precise control of the electrode gap. Then, a silicon block was assembled on the fillister. An accurate gap between upper and lower electrodes was then controlled with the depth of the fillister. At last, the entire device was accomplished by assembling two chips of the upper dual-torsion microstructure and the lower gap-controlled electrode.

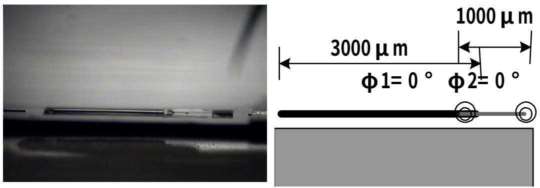
5. Results and Discussion

The characterization of the novel structure was first investigated with respect to magnetic fields as well as the calculation. The magnetically rotated actuator in the up position was also examined with an applied voltage.

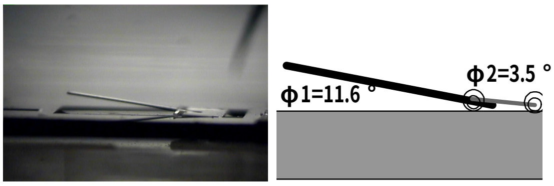
First, the segmental, dual torsion angles can be measured with the variation of the controlled magnetic fields through a CCD image capture. Fig. 3 has proven the concept of segmental, dual torsion angles increase in an increase of external magnetic fields. In the present result, the dual torsion microstructure was measured to be 3^o for base torsion plate and 10^o for the major one in a magnetic strength of 100 Gauss. In the up position of the actuator, the voltage of 13 volt was applied to clamp the microstructure down, which was relatively in a low driving voltage.

Fig. 4 demonstrated the experiment and calculation results of angles to corresponding magnetic fields in the dual torsion microstructure. Both of the base and major torsion plates were matched experimentally and theoretically.

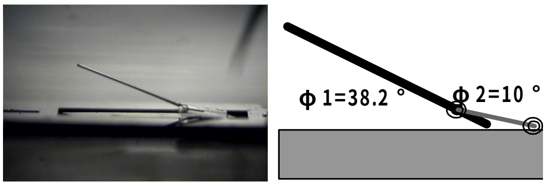
As the magnetic field continued to increase, a seriously mechanical deformation occurred at the connection of the major torsion bars to the base torsion plate in an excess of magnetic strength, as illustrated in Fig. 5. This also explain the outrageous data of the major torsion angle in a 380 Gauss magnetic field far away from the calculation result. An improved design is required to avoid the undesired outcome.



(a) 0 Guass



(b) 120 Guass



(c) 380 Guass

Fig. 3 Twisted angles of a segmental, dual torsion structure under externally magnetic fields.

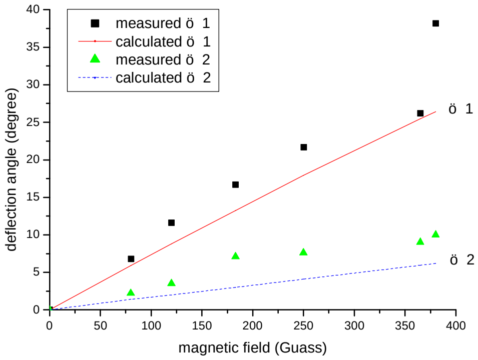


Fig. 4 The calculated and experimental results of torsional rotated angles with respect to magnetic fields

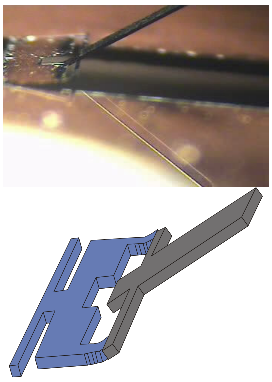


Fig. 5 The mechanical deformation occurs in an excessive magnetic field and its measured angle of 50^{o}.

6. Conclusion

We have demonstrated the segmental, dual torsion actuator for a large displacement and low driving voltage. Fabrication and characterization of the actuator has been investigated. The base and major dual torsion plates were experimentally and theoretically verified in magnetic fields. In the up position of the magnetically twisted dual torsion microstructure, the actuator was applied in a low voltage of 13 volt to clamp down. The actuator with magnetic levitation and electrostatic actuation was able to be addressable, individually controlled in an array configuration. Therefore, the novel design of the present study is expected to have wide applications of large displacement and low driving voltage as well as the potential of an array configuration.

Acknowledgements

The authors would like to thank the staff of the National Science Council Northern MEMS Research Centre for supports and services. The project is supported by National Science Council (NSC89-2218-E-002-064) and Walsin Lihua company.

References

1. J. W. Judy, R. S. Muller, “Magnetically Actuated, Addressable Microstructures,” *IEEE, Journal of Microelectromechanical Systems,* vol. 6, no. 3, Sept. 1997, pp. 249-256.
2. M. H. Kiang, D. A. Francis, C.J. Chang-Hasnain, O. Solgaard, K. Y. Lau, R. S. Muller, “Actuated Polysilicon Micromirrors for Raster-Scanning Display,” International Conference on Solid-State Sensors and Actuators, Chicago, June 16-19, 1997, pp. 323-326.
3. B. D. Cullity, *Introduction To Magnetic Materials*, Addison-Wesley Pub. Co., 1972.