熱動式撓性微型機構的設計與製作（II）

Design and Fabrication of Thermally Driven Compliant Micromechanisms （II）

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一. 中文摘要

本計劃提出一種可利用不同加熱電壓方式，產生內外水平兩個方向作動的微夾機構。此一微夾機構主要是由兩組微熱致動器構成，每組微熱致動器是利用一對長短不同的旋臂樑受熱膨脹量不同而產生單方向水平偏移。兩組微熱致動器經過適當組合，利用不同加熱方式，就可產生雙向水平偏移，在此我們分別以單晶矽及多晶矽為材料致作出多種尺寸之雙向微夾機構，並用解析及有限單元法作模擬，並與實驗量測位移結果作比較，例如一個 750μm x 3.2μm x 2μm的多晶矽微夾機構,最大誤差為7%。

英文摘要

Here we present laterally driven electro-thermal microgrippers which can deflect in two-way(opposite) directions by only varying driving voltage modes. The main unit of these microgrippers is composed of a pair of adjacent cantilever beams with different lengths to exhibit the elastic deflection under uneven thermal expansion. To demonstrate the design principle, the microgrippers made of two different materials including single crystal silicon (SCS) and polysilicon are fabricated by IC compatible and simple processes with only one mask. The analytical model of the microgrippers is derived and verified by finite element model and experiment. Some key design parameters are also discussed. A 750μm long, 3.2μm wide, and 2μm thick polysilicon-made microgripper, for example, can have gripping force about 0.41 μN and gripping range(including inward and outward displacements) around 10 μm with a current of 1.4mA at 15 V. The maximum error between simulation and calibrated is 7 %.

二、計劃目的**(Introduction)**

Microgrippers utilizing a grip method by two or more fingers have the potential applications in microrobotics, microoptics, and biomedicine to accomplish micro-macro size interfacing for real world. Various couple field effects such as piezoelectric, shape memory, electrostatic, or thermal-mechanic effects have been applied to the actuation mechanism of micro-grippers. Although different types of microgrippers have been presented, they perform deflection only in one direction(inward or outward). Thermally actuating microgrippers are capable of large deflection and high forces in a current/voltage regime that is compatible with standard IC fabrication process. In this project, we accomplish electro-thermally and laterally driven microgrippers which can deflect in opposite (two-way) directions by only varying voltages modes. They are based on the effect of Pan and Hsu's operating principle.

三、研究方法(Current Approach)

Concept Design and Operating Principle

Figure 1 shows the schematic diagram of the basic electro-thermally driven microactuator. Due to the unequal thermal expansions of the two connected beams as they are heated by applying voltage(current), the microactuator produces deflection toward the short or cold beam.

By combining two basic microactuators with extended jaws symmetrically, then a two-way deflection microgripper can be formed. Figure 2 displays two operating conditions of the microgripper with its equivalent circuit. In Figure 2(a), the central two beams are heated along full beams, and in Figure 2(b), only partial length of the central two beams are heated.

Analytical Modeling

From analytical derivation, the values of axial force P, transverse force F, bending moment M, and the displacement of the tip can be calculated. It is found that Young's modulus of the structure and the thickness of the beams don't affect the displacement of the tip at all.

Since two cantilever beams are much longer than the length of the tip beam, one dimensional model is used to find the electro-thermal relationship between applied voltage(V) and temperature distribution along two cantilever beams. From heat flow equation under steady-state condition, the following second-order differential equation is obtained,

$$K \cdot \frac{d^2T(x)}{dx} = -J^2 \cdot \rho(T(x)) \qquad (1)$$

where K is the thermal conductivity, T(x) is the temperature distribution along the beams, J is the current density, and ρ(T(x)) is the temperature dependent electrical resistance. Then the average temperature changes along the long and short beams can be found analytically, so is the displacement of the tip.

Exerting force

The gripping force of the proposed microgripper, in fact, is distributed along the actuating beams. However, a concentrate force F_c exerting at tip point O is considered. The detailed derivation is performed.

Finite Element Modeling

The commercial finite element code ANSYS 5.0A has been used to perform coupled field analysis of the electro-thermo-mechanical behavior to verify the analytical results of outward deflection. It also perform the inward deflection behavior. Material properties such as the thermal expansion coefficient, thermal conductivity and the Young's modulus are treated as constant values. Only resistance is regarded as a linear function of temperature.

四、結果與討論(Results and Discussions)

Figure 3 displays the relation between the calculated displacement and the gap distance (S) of a polysilicon-made microgripper. It indicates that increasing gap distance will reduce the displacement.

Figure 4 displays the calculated gripping forces at the extended jaw tip of a polysilicon microgripper as function of various applied voltage for two-way deflection.

The surface micromachining processes are used to fabricate polysilicon-made microgrippers. As for SCS-made microgrippers, a wet etching bulk micromachining technique is used.

The comparison between simulation results and experimental results is shown in Figure 5. The dimensions of the testing microgrippers are not optimal design here. They just demonstrate the two-way deflection effect and verify the simulation results.

The average error of outward deflection is about 5% between experimental results and analytical results for polysilicon-made microgripper, and is around 3% between experimental results and FEM results. The average error of inward deflection is about 7 % between experimental results and FEM results, which seems larger than that of outward deflection. This may be resulted from the complex influence of the heat transformation through the "r" beam structure and the corresponding thermal expansion.

Figure 6 displays the SEM micrographs of the two-way-deflection microgrippers made of SCS and polysilicon, respectively. It is found that only low applied voltage(0 ~ 20V) and power consumption(0 ~ 48mW) are required.

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六、圖表

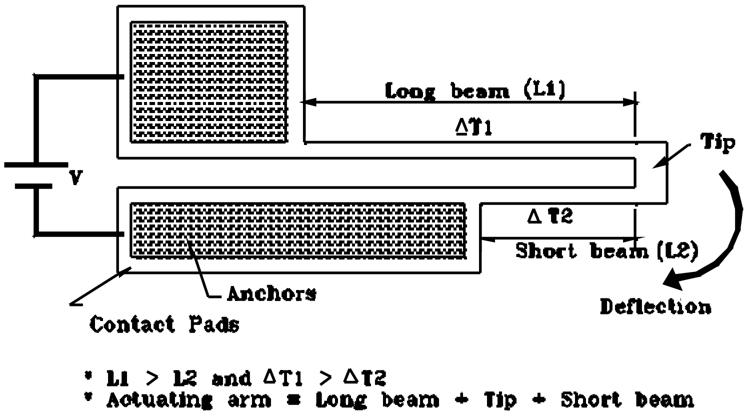
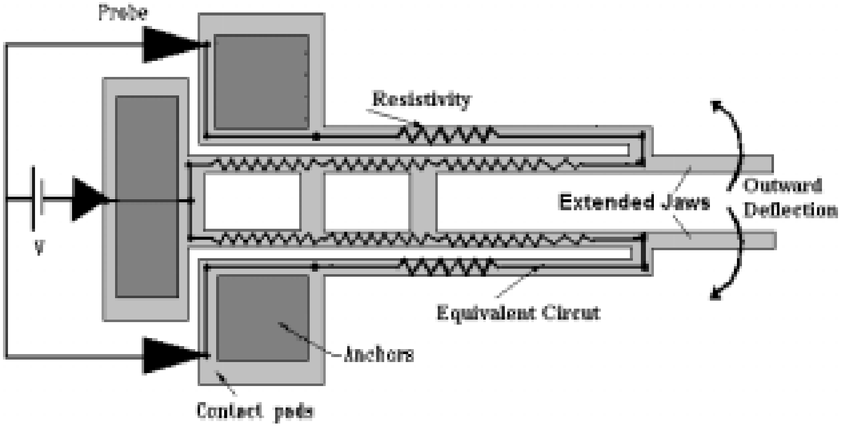
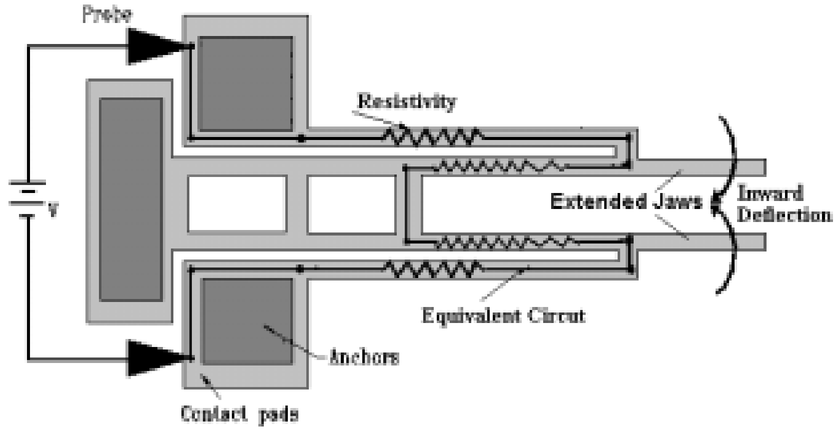


Figure 1. The schematic diagram of the basic electro-thermally driven microactuator proposed by Pan and Hsu[15].



(a) outward deflection



(b) inward deflection

Figure 2(a)-(b) Two operating conditions of a two-way-deflection microgripper by applying the voltage in different ways.

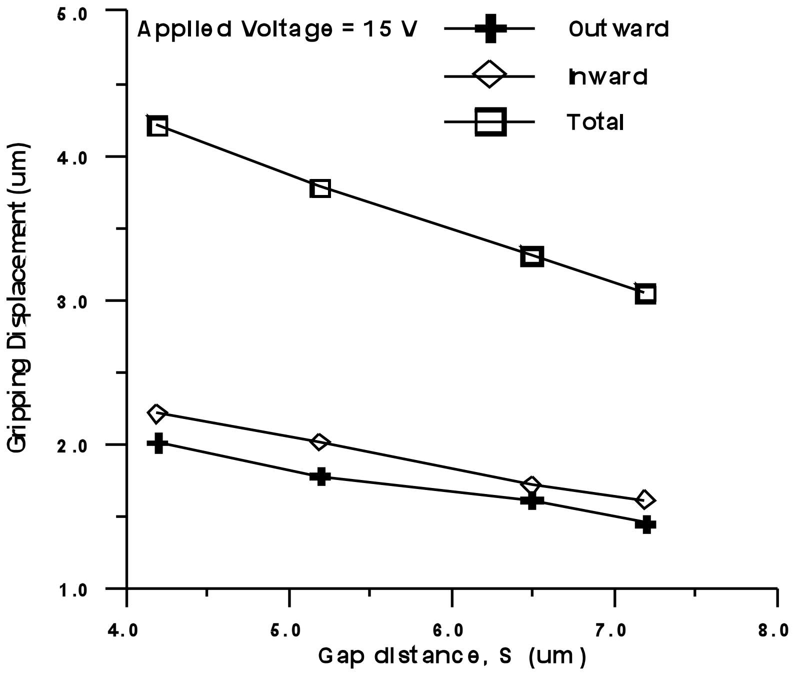


Figure 3 The calculated displacement versus the variation of the gap distance of a polysilicon-made microgripper at different applied voltages for two-way deflections.

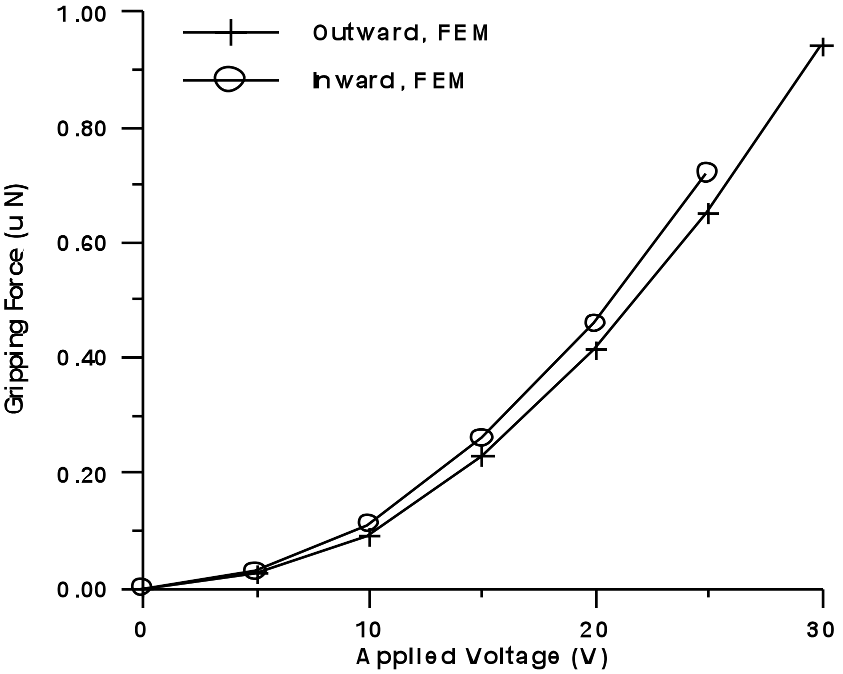


Figure 4 The gripping forces at the tip point O of a polysilicon-made microgripper under various applied voltages for two-way deflections.

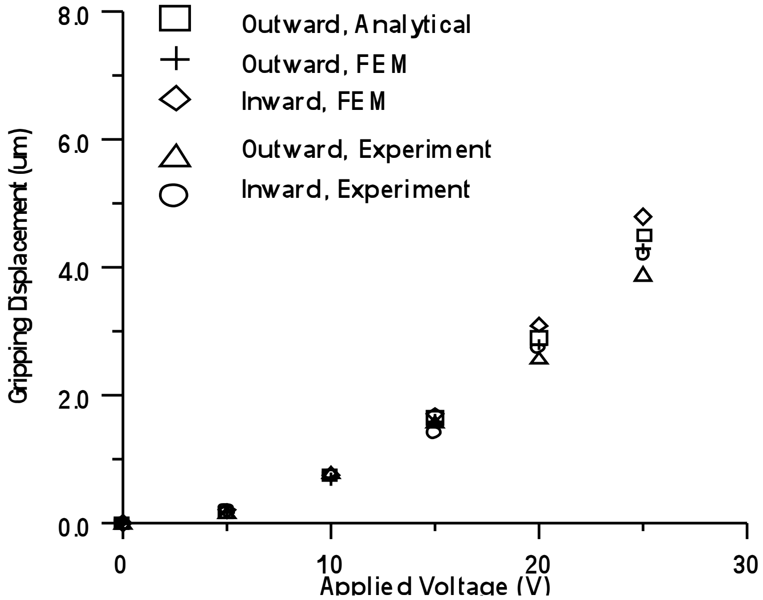
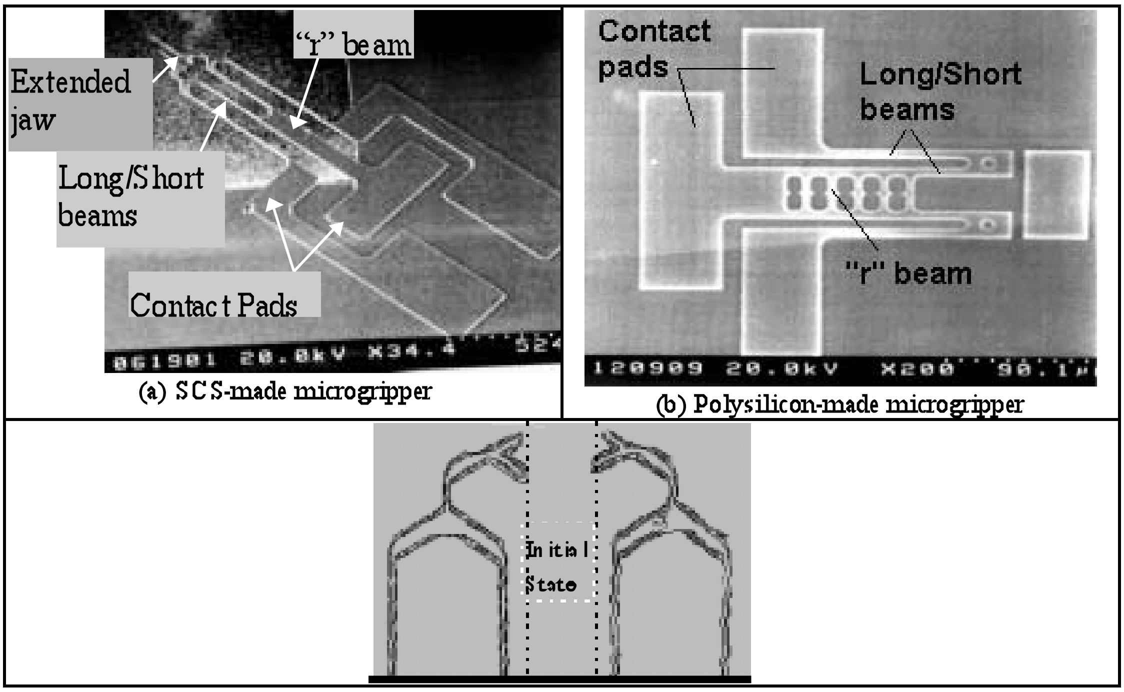
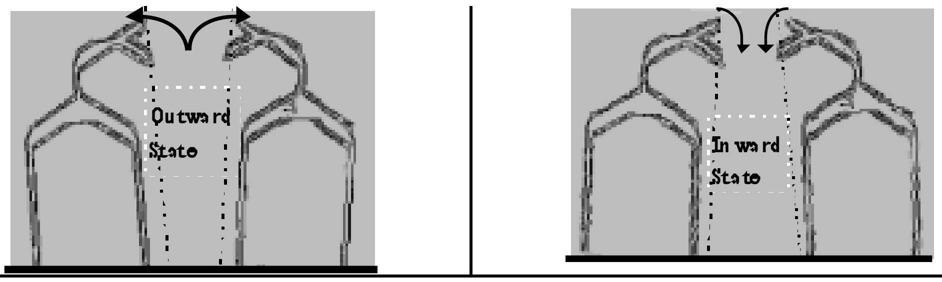


Figure 5 The simulating and experimental displacements of the extended jaw tip under different applied voltages for two-way deflection.



(a) SCS-made microgripper

(b) Polysilicon-made microgripper



Two-way deflection of SCS-made microgripper by image capture pictures

Figure 6 SEM micrographs of two-way deflection microgrippers made of SCS and polysilicon. The operating status of two-way deflection by image capture pictures are also presented.