研 究 速 報

Design and Chartacterization of High-Torque Silicon Based Electrostatic Micromotors

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1. Introduction

Polysilicon electrostatic micromotors using stator/rotor contact interactions are particularly studied. New mechanical architectures involving flexible components (e.g. the stator and/or the rotor) are proposed. The components are designed in order to allow the cooperation and the driving force superposition of arrayed direct drive actuators . Scratch drive actuators combining active frictional contact mechanisms and electrostatic actuation are analyzed, according to their ability to develop high torque/low speed characteristics. Millimeter size tubular electrostatic micrometers are investigated using an hybrid fabrication process.

2. Silicon based annular electrostatic micromoters

Scratch drive actuators (SDA) have been already successfully applied, as an example for self assembling microstructures and micro optical bench actuation1-2). Such interesting results which have been performed by using an individual or a few number of SDA led us to make further investigations in order to optimize this new promising actuator technology. Consequently, we mainly focused on new mechanisms which integrate combinations of numerous direct drive electrostatic actuators, in order to allow powerful micromoters to be designed, machined, and then characterized. Annular micromoters have been fabricated using the silicon surface micromachining technology. A large number of architectures were designed in order to analyze the role of the main mechanical parameters, through a further experimental study. Each motor integrates however a self-adjusted driving force sensor in order to allow the torque/speed characteristics to be measured in situ. Figure 1 gives the design of a typical annular electrostatic micromotor while Figure 2 shows a photograph of a 500μm diameter micromotor.

The rotor integrates 36 torsion beam actuators and 3 buckling

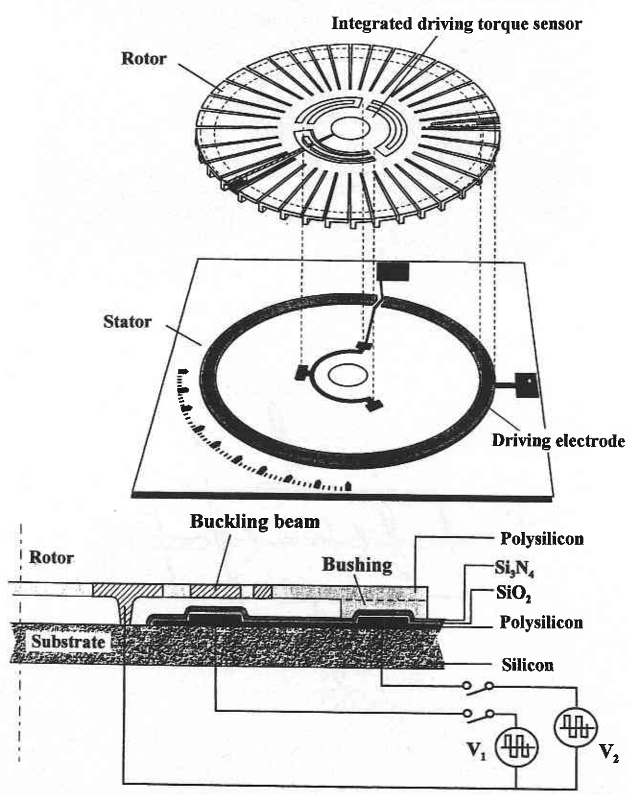

Fig.1 Design and operating principles of annular direct drive electrostatic micromotors.

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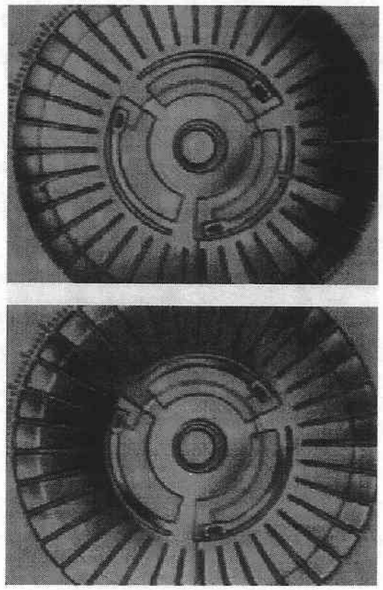

Fig.2 Annular electrostic micromotor, ϕ= 500μm, 36 torsions beams and 3 buckling beams.

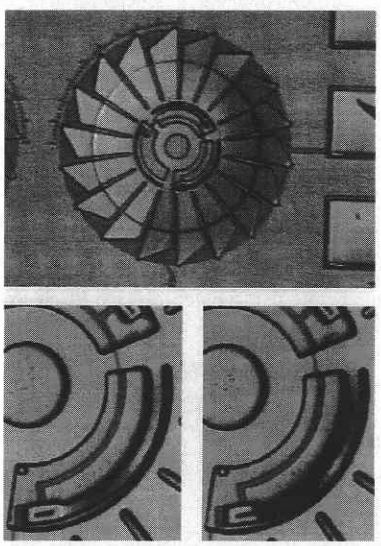

Fig.3 Video acquisition of torque measurement before actuation, buckling initialization and after buckling.

Table1 Torgue/speed characteristic of flexible polysilicon electrostatic micromotors.

motor diameter (μm)	100	150	200	250	300	350	400	450	500
Maximum driving torque (10^{-9} Nm)	25	56	100	156	225	306	400	506	625
Maximum Continuous rotation speed	1500	1000	750	600	500	430	370	330	300
Maximum instantaneous rotor speed	3750	2500	1900	1500	1250	1100	900	800	750

beams that are dedicated to direct torque measurements. The buckling beams are free to rotate at the beginning of the motor test and, as a consequence, there is no external torque applied onto the rotor shaft. The ends of the three beams can be clamped onto the substrate, through electrostatic attraction, when a voltage is supplied onto the torque sensor electrode. Depending on the previous rotation of the rotor with respect to the underground torque sensor electrode, the length of the beams and the corresponding torque sensor mechanical stiffness are then adjusted, as a function of the driving characteristics to be measured. The theoretical driving torque may be however easily evaluated, through a unite element calculation, as a function of the beam mechanical parameters. The acquisition of the driving torque can be consequently performed «in situ», through buckling beam measurements. As an example, Figure 3 points out a direct torque measurement performed on a polysilicon annular motor. Numerous tests have been performed in order to analyze the driving force superposition expected from arrayed electrostatic actuators. Speed characteristics as well as lifetime characteristics was also studied. Corresponding results are summarized on Table 1.

3. Hybrid Fabrication of Tubular Electrostatic Micromotors

In spite of performances summarized above, elementary actuators that can be distributed around annular rotors are quite restricted for a given diameter. Tubular motors which allow the actuator's number to be considerably increased have been consequently studied. Figure 4 gives a short description of the main principles that are under progress in order to develop a new generation of self-assembled tubular electrostatic micromoters. In order to realize high torque micromoters whose diameter and length are respectively 1 and 2 mm, large size polysilicon sheets including up to several thousands SDA have been processed from silicon surface-micromachining technology. Visual acquisitions give the prove that internal forces as high as $10^5 \mu$N are available from 2 x 3 polysilicon sheets including 1430 arrayed SDA. The self-assembling method that will be involved in the hybrid fabrication of the motors is however shown by both Figure 5 and Figure 6. In a first step (Figure 5), the sheets are released from the silicon wafer by applying a voltage on a «releasing electrode» which is localized under the firsts ranks of SDA. The SDA under voltage allow the displacement of the polysilicon sheet with respect to the wafer. The corresponding motion is responsible of out-of-plane bending effects which occur on the linkages localized on both edges of the sheet. These bending effects allow the sheet

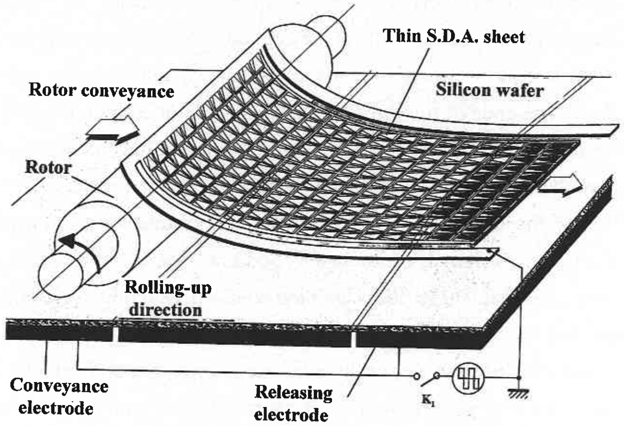

Fig.4 Hybird fabrication principles of a macroscopic tubular motor.

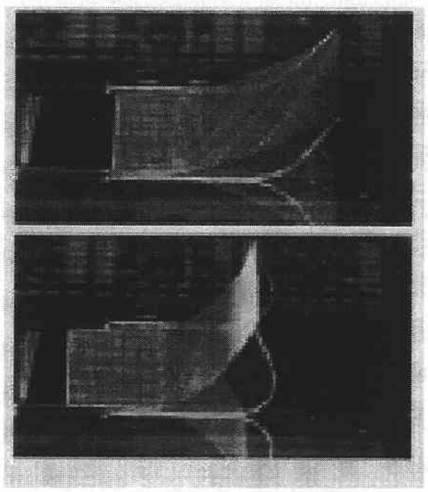

Fig.5 video recording showing the self-releasing of an active polysilicon sheet.

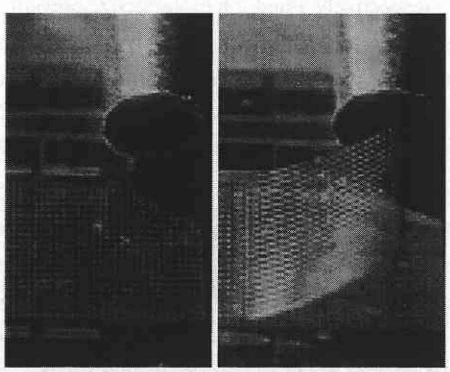

Fig.6 Video photographs of the motor assembling.

to be released from the substrate because its back side isn't pulled down by electrostatic attraction. The typical thickness of a polysilicon sheet is 1.7μm. The sheet thickness is consequently verysmall compared with its lateral dimensions (2 by 3millimeter s) ; the corresponding flexibility allows the polysilicon sheets to be easily formed, according to the tubular shape which is required by the motor geometry. Figure 6 gives however some photographs which was obtained during the rotor/polysilicon sheet self-assembling. The sheet is rolled around an insulated metallic shah (aluminum shaft with thin natural oxide layer), through electrostatic attraction and then inserted into the gap between the shaft and the motor frame (outer pipe).

4. conclusion

The obtained results point out considerable torque/speed characteristics, therefore showing the relevance of the proposed design rules. Unusual torque characteristics 1000 to 1400 times higher than those obtained on current electrostatic wobble motors was measured. However, a considerable speed control was also performed according to the driving voltage frequency which ranged from 0Hz up to 500kHz, therefore leading to a rotor rotation speed ranging from 10^{-3} up to 750 rpm. Annular electrostatic motors produce mechanical power 1,000,000 times higher than the famous ϕ120μm electrostatic motor developed by R.S. Muller ten years ago (the mechanical power ratio is still 200,000 considering same diameters). For the first time, visible effects up to the human scale are conceivable using batch processed electrostatic micro-motors.

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Reference

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