Optically Assisted Electrostatic Actuation Mechanism

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Abstract

We propose a new non-contact actuation principle for MEMS actuators using light beams. A silicon PN-junction photodiode is combined in parallel with a polysilicon capacitive actuator, where driving voltage is controlled by the photocurrent under light illumination. For a proof-of-concept demonstration, we used a photo-coupler with surface micromachined electrostatic cantilever, and observed the mechanical motion to be controlled by incoming optical signals. This principle has potential for controlling arrays of micro/nano mechanisms such as optical computing, optically-tunable opto-electromechanical components, and optically addressed data storages.

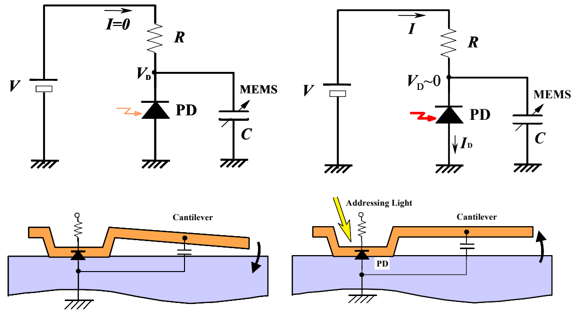
Keywords: optically assisted electrostatic actuation, electrostatic actuator, non-contact actuation

1. Introduction

Most MEMS actuators today are electrostatically controlled by using electrical interconnections. One-to-one connection between electrodes and actuators is possible when device size is large enough to accommodate interconnection patterns. In a high-density layout of MEM devices, electrical interconnection needs aid of integrated circuits. With the further progress of MEMS miniaturization to nanometric scale, intra-chip electrical interconnection would become practically impossible.

Optical addressing of micro/nano objects would be a solution to this problem thanks to the parallelism of traveling beams and immunity to electromagnetic fields. Several methods of optical actuation have been proposed such as laser micromanipulation [1] and photo-thermo mechanism [2]. However, sole use of optical energy is not powerful enough to drive tethered electrostatic actuators; a 1-mW light has merely pN force output.

In this paper, we propose a new method of microactuation called "Optically Assisted Electrostatic Actuation." In this system, a silicon PN-junction photodiode is integrated in parallel with a MEMS capacitive actuator, where driving voltage for electrostatic actuation is controlled by the photocurrent under light illumination. Hence, driving force is expected to be as large as that of the conventional electrostatic force, while electrical interconnetion is simplified after replacement with free-space optical addressing.



(a) (b)

Fig.1 Equivalent circuit and schematic structure of the device (a) before light irradiation and (b) after

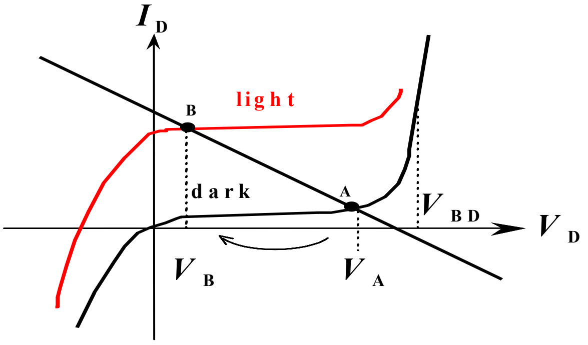


Fig.2 Operation point of optically assisted electrostatic actuation on the photocurrent-voltage curve

2. Principle of Optically Assisted Electrostatic Actuator

Fig.1 (a) shows a schematic structure of the proposed device and its equivalent circuit. The microactuator is a polyslicon cantilever with its anchoring pad being a silicon photodiode. When reverse voltage V is applied to the photodiode PD, the electrostatic actuator connected in parallel receive a drive voltage V_D at the same level as the power source. Hence, the actuator is attracted downward to the substrate. When a light is introduced to the photodiode as shown in Fig. 1(b), the photocurrent causes voltage drop at the resister R, and the MEMS actuator accordingly receives less voltage, resulting in smaller deflection. Actuators deflection/displacement can be controlled by tuning the intensity of light beam.

Detail description of the driving voltage V_D and photocurrent is shown in the I-V curve in Fig. 2. Actuator's drive voltage in the dark condition is represented by the intersection point of photocurrent curve and the IV-curve of the resister, V_A. Drive voltage would drop to V_B with incoming light. Therefore, the dynamic range of actuator is determined by V_A - V_B, and maximum displacement is limited by the breakdown voltage V_{BD} of photodiode.

Fig. 3 shows the fabrication steps of the optically assisted electrostatic actuator using a p-type silicon substrate. In step-1, an anchoring window (10 **x** 10 ~ 200 **x** 200 um^2) is opened in a silicon oxide layer. LPCVD polysilicon is deposited and doped with phosphorus (n-type) by using a

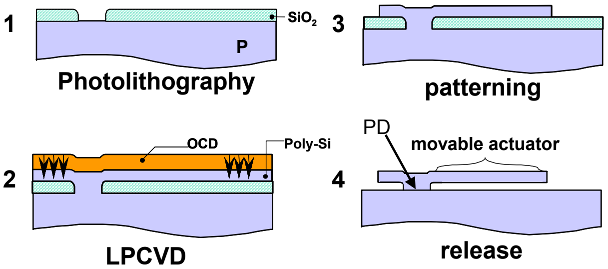


Fig.3 Process chart

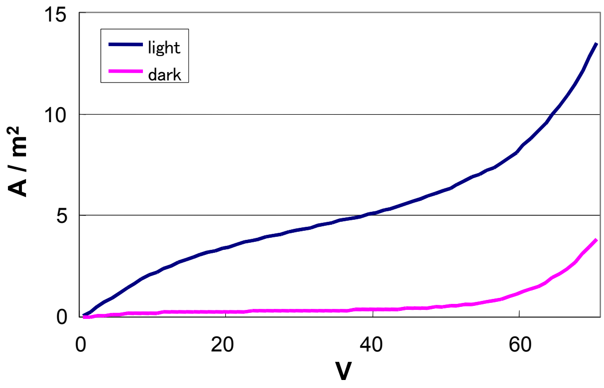


Fig.4 Photocurrent-voltage curves of fabricated PD

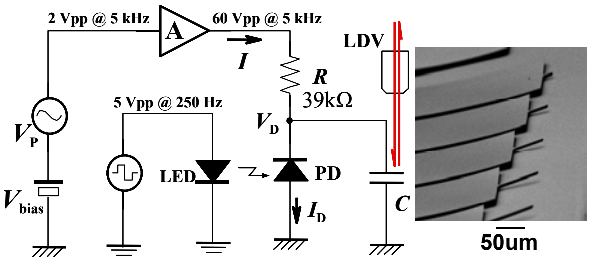


Fig.5 Equivalent circuit of experimental setup

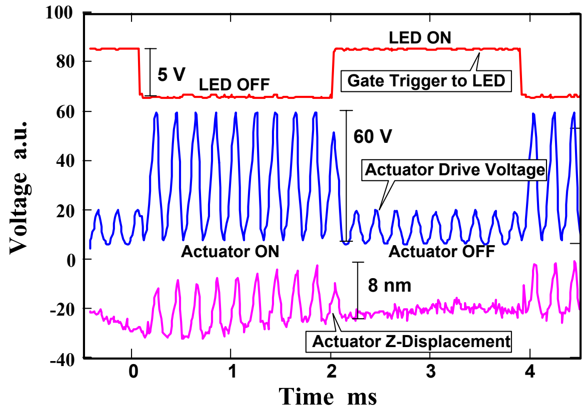


Fig.6 Experimental results

spin-on-glass source OCD (Tokyo Ohka Kogyo Co. Ltd); the anchoring pad serves as a self-aligned photodiode. In step-3, the polysilcon layer is patterned into actuator (20~100 um long and 5~30 um wide) by reactive ion etching, and then sacrificially released in vapor HF.

Fig. 4 shows IV-curves of a fabricated photodiode in the dark condition and under 1 mW laser illumination (λ = 632 nm). Because of the low quantum efficiency of polysilicon PD cathode, photocurrent was measured to be very small (0.1 micro ampere); which is under development.

For proof-of-concept experiment of optically assisted electrostatic actuator, we set the cantilever device with an external discrete photodiode (λc = 960 nm) and a resister as shown in Fig. 5, and observed the actuator's motion with the laser Doppler vibrometer (LDV). A sinusoidal voltage is used to make the actuator's motion be detectable with the LDV, and the voltage is modulated by the photocurrent induced by an external LED (λc = 950 nm). Fig. 6 shows the experimental results of actuation. The curve on the top is a trigger voltage to the LED, and the middle one is the drive voltage to the actuator measured at V_D. When the PD received light from the LED, the actuation voltage decreased to 1/4 of the initial value, where the actuator ceased to oscillate.

3. Application

Optical computing device is a potential application target for the proposed principle. Fig. 7 shows a schematic illustration of micro mirror with two photodiodes that is expected to work as a NOR block by interpreting the incoming light beams as binary inputs, and the mirror's reflection angle as an output.

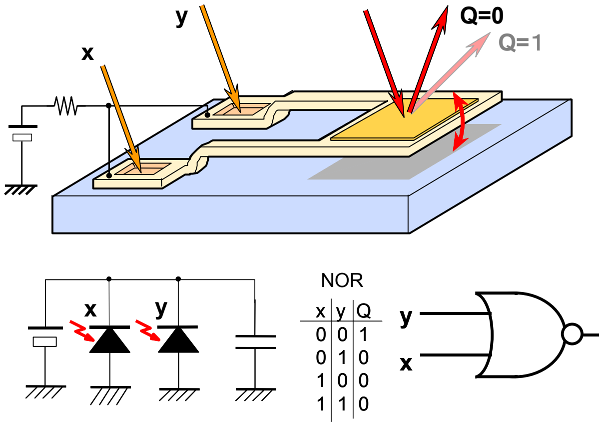


Fig.7 Application – optical computing device

4. Acknowlidgment

We used VLSI Design and Education Center (VDEC) of University of Tokyo for manufacture of masks.

[1] E. Higurashi et al., J. Micromech. Microeng. 11 (2), pp.140-145, 2001.

[2] S. Baglio et al., Sensors and Actuatos A 101 (1-2), pp.185-193, 2002.