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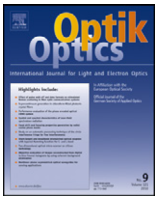

Design of a MEMS micromirror actuated by electrostatic repulsive force

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ABSTRACT

A microelectromechanical system (MEMS) micromirror actuated by electrostatic repulsive force is demonstrated. The design is based on the principle that an asymmetric electric field produced by special layout of the electrodes can generate a repulsive force, which moves the mirror surface upwards. The factors affecting the magnitude of the driving force of the micromirror actuator are analyzed by FEA. The prototype is fabricated using a commercial available surface micromachining process and successfully tested using a Zygo NewView7300 interferometer. The displacement of the micromirror reaches 1.2 μm at 60 V.

1. Introduction

Electrostatic actuated microelectromechanical systems (MEMS) micromirror has the advantages of small volume, low power consumption and fast response. Therefore, it has many applications, such as laser beam-shaping [1], micro-scanner [2], optical coherence tomographaphy [3] and many adaptive optics systems [4–6]. In most cases, the micromirrors are driven by electrostatic attractive actuators. The major disadvantage of them is that their strokes and reliabilities are confined by the electrostatic “pull-in” effect. However, large stroke is required in many applications, such as in giant astronomical telescopes [7] and in human retinal imaging systems [8]. Many efforts have been dedicated to increasing the stroke of conventional electrostatic attractive actuators, such as applying “leveraged bending” and “strain-stiffening” methods [9], using a dynamic voltage drive [10], inserting an insulation layer between the upper plate and the substrate [11], introducing an initial-residual-stress to the actuator [12], using a charge injection method [13] and series connecting capacitors [14]. Although relatively large strokes have been achieved, these attempts are difficult to implement in a batch conventional micromachining process due to the complexities of fabrication or the requirement of precise controlling of the charges, the voltages or the residual stresses. In order to eliminate the limitation of “pull in” instability, an electrostatic repulsive force actuation scheme has been introduced in [15], but the actuator has only an in-plane movement. A vertically translated two-layer electrostatic-repulsive-force micro actuator has also been presented in Refs. [16,17]. However, the device is not compact and it is not able to achieve a high-actuator density for their effective reflecting area is less than 20% of the whole area of the device. In addition, the micromirror has five separated bottom electrodes and is inconvenient to be electrically connected.

In this paper, a micromirror actuated by electrostatic repulsive force is presented. The remarkable characteristics of the micromirror are: (1) it has a large driving force to achieve a large displacement at low voltage owning to the implementation of central bottom electrode and wandering springs; (2) it is compact and has potential to form an array with a large number of micromirrors; (3) it is easy to be electrically connected due to its special lay out of bottom electrodes.

Design principle, i.e. working mechanism is described in Section 2, FEA simulation of the driving force are implemented in Section 3, the fabrication process flow is presented in Section 4, and the experiment and discussion are given in Section 5. Lastly, the conclusions are drawn in Section 6.

2. Design principles

The micromirror structure is depicted in Fig. 1, it consists of three layers which are parallel to each other. The top layer is a mirror surface with a size of 190 μm by 190 μm, which is supported by a post (Fig. 1b) on the surface of the middle layer. The middle layer (Fig. 1c), which contains many movable fingers, four springs and a central plate, is the upper electrode. The central plate is suspended by four springs which connect to four side anchors. The bottom layer (Fig. 1d), which is divided into two separated parts, i.e. the positive electrodes and the ground, is fixed to the substrate and used as the bottom electrodes.

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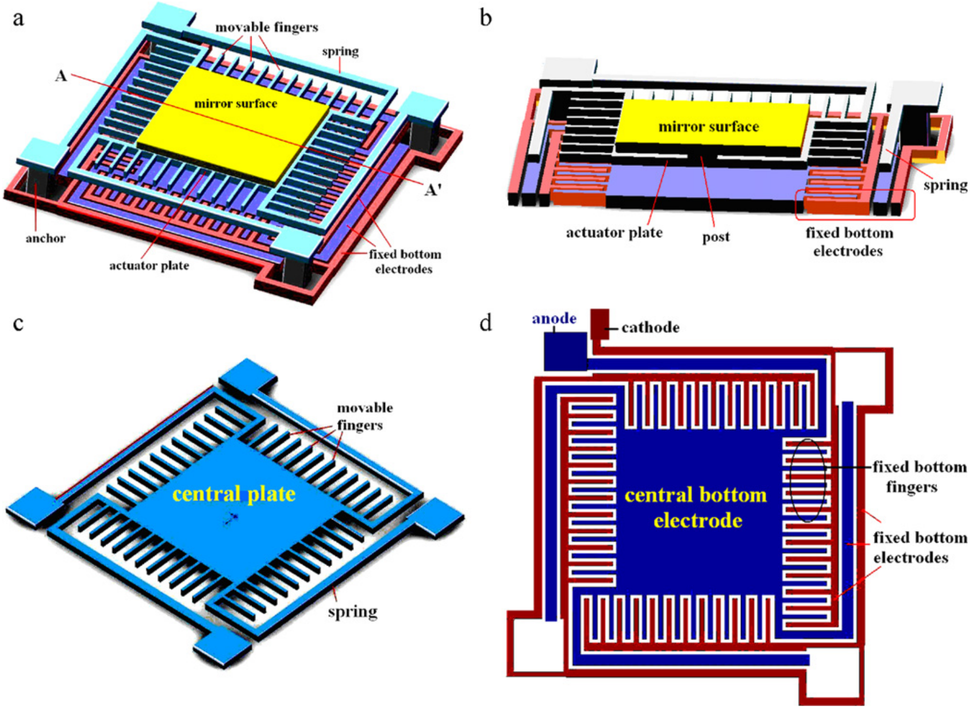

Fig. 1. Schematic of micromirror structure (a) 3D view of the mircomirror (b) cross-section view along line *AA*' (c) middle layer (d) bottom layer.

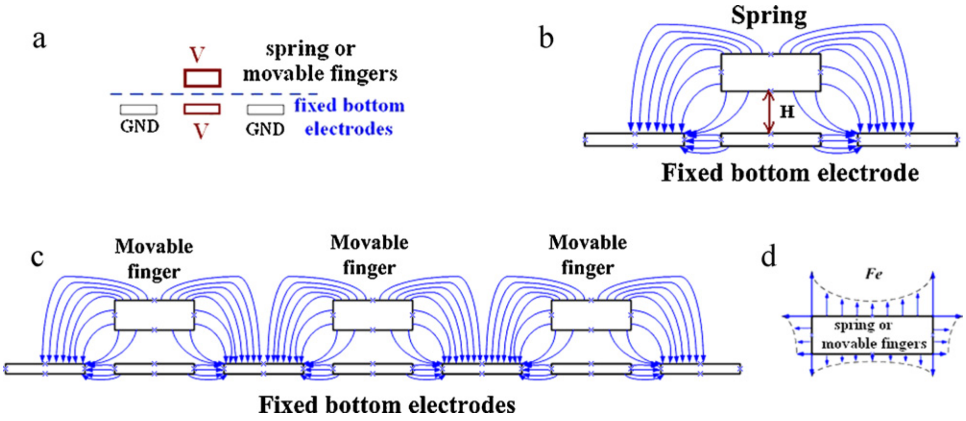

Fig. 2. Working mechanism of the micromirror (a) cross-section view of the distribution of the spring, movable fingers and bottom electrodes (b) electrostatic field around spring (c) electrostatic field around movable fingers (d) electrostatic force exerted on the spring or movable fingers.

The cross-section view of the distribution of the spring, movable fingers and bottom electrodes are illustrated in Fig. 2a. When the spring (or fingers) and the fixed bottom electrodes right below them are applied the same voltage *V* (e.g. *V* = 40 V) and the other bottom electrodes are grounded (GND), the electrostatic field distribution around the springs and the movable fingers can be calculated using an electro-magnetic finite element analysis (FEA) software Maxwell. As illustrated in Fig. 2b and c, these two electrostatic fields are asymmetric and the intensity of the electric fields on the top surface of the spring and the fingers are greater than the intensities of the corresponding points on the bottom surface of the spring and the fingers. Thus, the forces produced on the top surface of the spring and the fingers are stronger than those of the corresponding points on the bottom surface, as shown in Fig. 2d. The electrostatic forces on both sides of the spring and the fingers are equal in magnitude but opposite direction. As a result, the direction of the net electrostatic force is upward, i.e. it is an electrostatic repulsive force, and it pushes the spring and the fingers move up when a voltage is applied. Thus the actuator plate and the micromirror are pushed upward, and the deflected micromirror under applied voltage is shown in Fig. 3.

3. Driving force

The driving force is an important concern when designing a micromirror actuator. To know the law of the repulsive force chang-

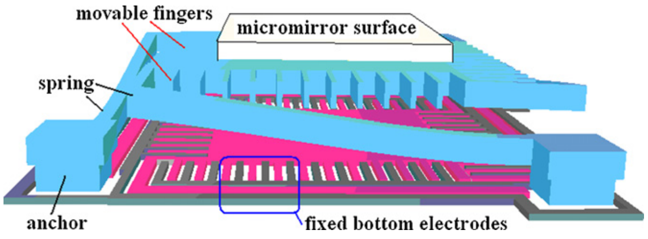

Fig. 3. Deflected micromirror under applied voltage.