Modeling and Simulation of Silicon Optical MEMS Switches Controlled by Electrostatic Field

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Abstract: The use of optical sensors in the industry is still growing. A transmission of signal from the sensors is mostly done by optical fibers. Switching the signals from optical paths may be done by using micromechanical silicon switches [1,2]. The main advantage is an ability to transmit data from many sensors using different wavelengths, simultaneously minimizing optical power losses [3].

The study shows an analysis of the electrostatic transducer controlling the silicon beam's displacement. The Comsol Multiphysics 4.3b was used for the modeling. In the models, coupled mechanical and electrostatic fields were used (MEMS, AC/DC, Electromechanics modules). The 3D distribution of electric field generated by plain electrodes of the transducers was analyzed.

The study shows results of modeling of the electrostatic transducer with the movable beam.

Results of a practical research for an optical system show in figure 1. are presented in the paper. Optical power in receiving fibers for different deflection angles of the cantilever was measured. The practical results were compared with simulation results.

Keywords: silicon microactuators, MEMS, controlled by electrostatic field, modeling, optoelectronic system

1. Introduction

The construction of the optical switch is shown in fig. 1. A silicon beam with an Al layer is an actuating element. It is a mirror and an electrode of an electrostatic actuator at the same time. The second electrode is placed under the beam. A change in the electrostatic field causes a deflection of the beam.

The optical transducer consists of two fibers: the transmitting fiber T and the two receiving fibers R_1 and R_2. A light source lightens the moving mirror surface (the beam's surface) by the transmitting fiber. Reflected light is collected by the receiving fibers. Light intensity in the photodetectors (for the receiving fibers R1 and R_2) depends on the deflection of the beam. By controlling a voltage supplying the electrostatic transducer, the light intensity collected by the receiving fibers R_1 and R_2 can be changed [3].

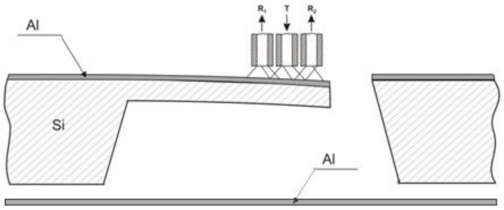

Figure 1. Construction of an optical fiber transducer

2. Modeling and Simulation of an Electrostatic Optical Switch

Electrostatic force acting on the cantilever with mirror can be described by a derivative of electric field energy [3]. For small deflection angles, capacity of two electrodes configuration can be described by the equation :

$$C = \frac{\varepsilon_0 A}{(\frac{d}{\varepsilon_r} + t)} \qquad (1)$$

Where: ε_0, ε_r- permittivity of free space and permittivity of dielectric layer , A- plate area, d- dielectric layer, t- air-gap thickness

For the controlling V voltage supplying eletrodes, the force acting on the cantilever (with mirror on it) is:

$$F = \frac{1}{2}\left(\frac{dC}{dz}\right)V^2 = \frac{\varepsilon_0 A V^2}{2(\frac{d}{\varepsilon_r} + t)^2} \qquad (2)$$

Electrostatic clamping acting on the cantilever causes its deflection. For the case, when the cantilever is attached by two thick beams, rotation of the cantilever is observed (mechanical stiffness of the cantilever is much bigger than for the two thick beams). When the electrostatic clamping is balanced with the elasticity moment, angle is steady.

For the modeling and the simulation, Comsol Multiphysics 4.3b was used. Figure 2. shows a mechanical construction of the tested structure. The upper part is movable, the electrode is simultaneously a mirror (reflecting the beam coming out of the transmitting fiber) and a controlling electrode. Electric field is generated in a movable upper electrode / fixed lower electrode setup. The Electromechanics (emi) module and material parameters for polysilicon, dioxide silicon and aluminum were chosen for the simulation. Different constructions of simple cantilevers were tested. For the assumed dimensions of the cantilevers (length/width), thickness of the cantilever, gap between the electrodes and the attachment of the movable part were being changed. In the most unsophisticated case, the movable part was a full cantilever. During the further research the cantilever was attached by two thick elements (figure 2.). Characteristics show effects of the simulations – an influence of the construction's parameters and controlling voltage on a deflection of the upper electrode. The loss of stiffness of the construction resulted in much bigger deflections.

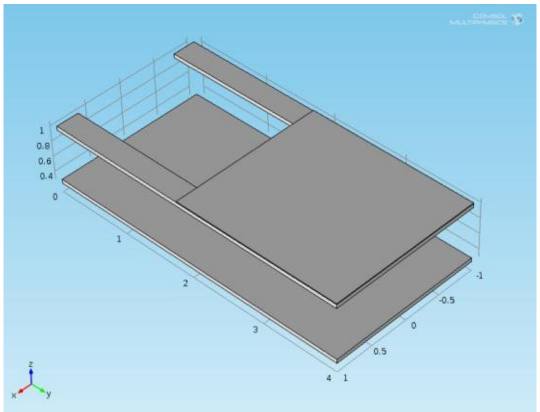

Figure 2. Mechanical construction of the tested structure

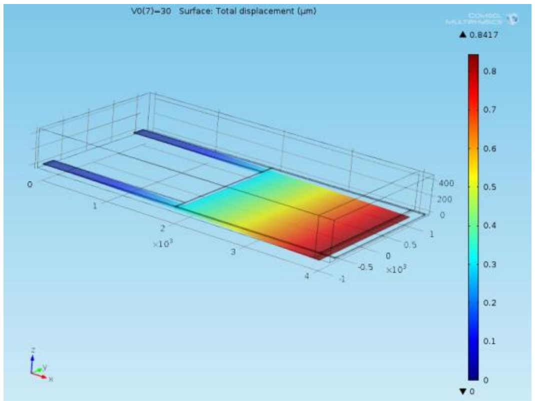

Figure 3. Maximum simulated deflection of the cut-out cantilever mounted on two 2x0,2mm beams, for 20μm air-gap between electrodes

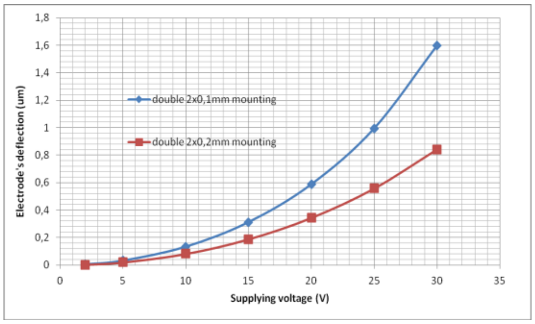

Figure 4. The deflection of the cut-out cantilever constructions for basic dimensions of the attaching beams (thickness 10μm, polysilicon), for 20μm air-gap, in function of supplying voltage

3. Use of COMSOL Multiphysics

The cantilever was attached from the one side by the „fixed constraint" option. Electromechanical interference analysis was used. Upper electrode was designed as a terminal (voltage type). The lower boundary (lower electrode) was marked as a "ground". Prescribed mesh displacement was used in some points, according to the Comsol tutorials, in order to reduce the time of the model computation. Tests were carried out for different types of meshes: user controlled, physics controlled, mapped. The final result was about 800 000 degrees of freedom and time of the computation about 3 hours for the most sophisticated models and 7 voltage parameters (2,5,10,15,20,25,30[V]).

Material properties for the polysilicon were: $E=160e^9$ Pa, $\nu=0.22$, density 2320 kg/m^3, $\varepsilon_r=4.5$;

aluminum: E=70e^9 Pa, density 2700 kg/m^3, ε_r=1; silicon dioxide: density 2648 kg/m^3.

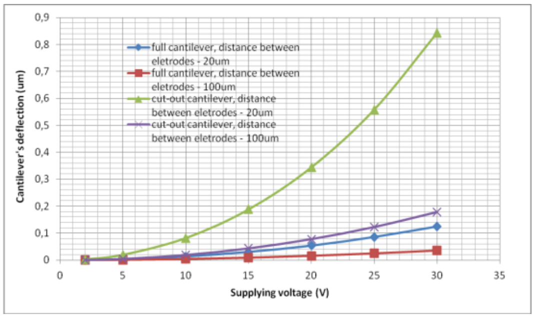

Figure 5. The deflection of the cantilever for the different constructions and varying supplying voltage. Cut-out electrodes mounted on two 2x0,2mm polysilicon beams

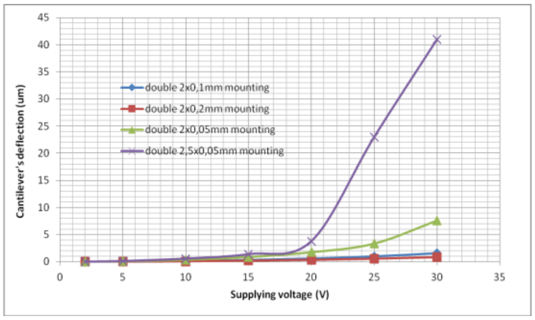

Figure 6. The deflections of the cut-out cantilever constructions in function of supplying voltage for different dimensions of mounting beams (thickness 10µm, polysilicon)

4. Practical Tests of the Designed Optical System

Characteristics for a layout consisting two receiving fibers (figure 8) were assigned using a test-stand shown in figure 6. The test-stand consists of: adjustable rotating stand (1) with an attached mirror and an optical system with a measuring head, a light source (2), measuring probes (3) and optical power meters (4). Silica glass step-index multi-mode fibers were used (core diameter 2a=50µm, n_{core}=1.4776, n_{cladding}=1.46, NA=0.2274). Characteristics for constant wavelength λ=1310nm were measured. Sun-Telecom adjustable light source was used (output optical power ~0.3mW). As for measuring probes, Thorlabs photodiodes type S120C were used (screen diameter 9.5mm, range 50nW – 50mW, nonlinearity ±0.5%, resolution 1nW).

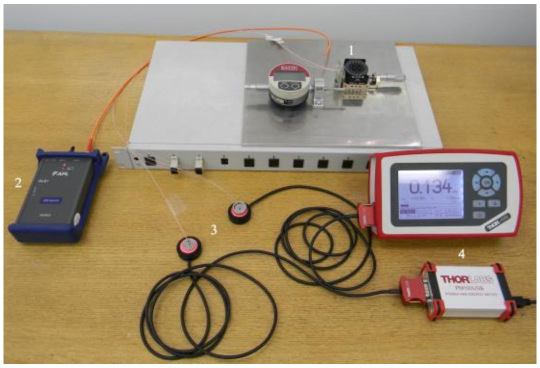

Figure 7. Optical test-stand

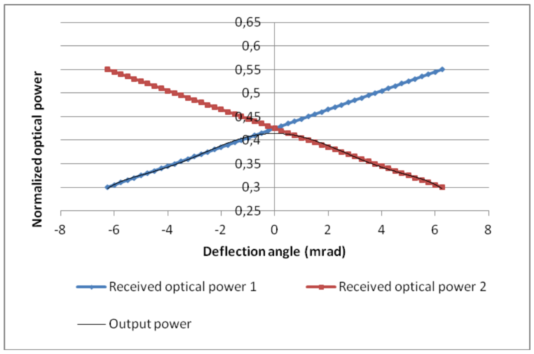

Figure 8. Practical results of the optical test-stand measurements, refering to results shown in figure 6. Deflections from -25µm to 25µm (-6mrad to 6mrad).

5. Conclusions

The study shows the analysis of the electrostatic transducer controlling the silicon cantilevers' displacement. The Comsol Multiphysics 4.3b was used for the modeling. In the models, coupled mechanical and electrostatic fields were used (MEMS, Electromechanics modules). The 3D distribution of electric field generated by plain electrodes of the transducers was analyzed.
The study shows results of modeling of the electrostatic transducer with the movable cantilever. The characteristics of the light intensity in the optical transducer in function of the controlling voltage were analyzed for

different parameters of the electrostatic transducer.

The results of the numerical modeling in Comsol Multiphysics – computed deflection of the cantilever controlled by electric field can be used for adjustment of optical power received by the fibers.

In the models, attachment of the cantilever and parameters of controlling electric field were being changed. The results are show in characteristics (figures 3-7). Practical tests resulted in 20-30% optical power changes in the fibers for the -6mrad to 6mrad cantilever's deflections. Further change in the received optical power can be achieved for bigger cantilever's deflections. Bigger deflections can be achieved for lower air gaps between electrodes and higher supplying voltage. Attaching the cantilever/upper electrode on two thick beams effects in the noticeable loss of stiffness of the whole construction.

6. References

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