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MEMS On/off and 1x2 Optical Switch with Integrated Fiber Alignment Capability

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Abstract **An on/off free space optical switch is described in this paper. The device consists of intersecting cantilevers and is electrostatically actuated. A fiber is put onto the cantilevers and by controlling the position of the fiber through actuation, switching operation can be achieved. The device is also suitable for in-package fiber alignment application, where the cantilevers can be used as passive or active fiber alignment microstructure.**

I. INTRODUCTION

Optical switches are a next generation network element to enable all optical switching. All optical switching has a lot of advantages over conventional switching utilizing optical-electronic-optical (OEO) switches and are discussed in details in [1]. Optical switches are needed due to the increasing importance of their capabilities of setting alternate routes and effective operation of a network. Optical switches work at a much wider window of data transmissions rate than OEO switches and can handle optical signals directly.

In this paper, a new microelectromechanical system (MEMS) based free space optical switch is reported. The switch is fabricated using the Multi User MEMS Processes (MUMPS), a surface micromachining process. It is a moving fiber based design which works by mechanically aligning the transmitting and receiving fibers between on and off state. Compared with other published works on moving fiber based switches [2]-[7], which have voltage up to 100 V, the switch in this paper operates at a much lower voltage of 20 V. This significantly makes the driving electronic circuitry simpler, cheaper and safer. The switch also features an integrated fiber alignment capability for optimizing the assembly of fiber onto the device. Conventionally, external submount or silicon v-groove fiber array is used in alignment of fiber into and out of the switch. Other features of the switch are low insertion loss (0.97 dB at 1550 nm, 1mW input power source), wavelength independent (as light travels entirely in fiber and air, which has effect on all communication window laser source), low power consumption, compact size and low cost bulk fabrication through surface micromachining process.

The switch has applications in network protection switching and monitoring in which switching times in the ms range are commonly used. In addition, the same design presented in this paper can also be utilized as integrated passive or active fiber alignment microstructure, whereby it can be integrated onto the same target MUMPS optical MEMS chip or used as external submount for in-package optical MEMS packaging.

II. DESIGNING AND MODELING

The switch consists of an array of curled cantilevers arranged in an intersecting pattern as shown in Fig. 1. These cantilevers are made up of 2 layers of stacked polysilicon and coated with gold. The stacking of different material layer creates an out-of-plane cantilever due to thermal mismatch between polysilicon and gold during fabrication. These cantilevers can be actuated electrostatically through application of a voltage difference between the cantilevers and the substrate. Fig. 2 shows the schematic of the optical switch. An input fiber is to be fixed onto an electrostatic actuated cantilever beam. At the receiving end, two fibers are assembled in such a way that the input fiber is always precisely aligned to any of the output fiber at their associated on or off position (i.e. pull-down or rest position).

Chip on board (COB) packaging has been chosen to be used in this work for testing of the prototype. The entire MUMPS die is attached onto a gold plated printed circuit board and then wire bonded with gold wire. A completed prototype is shown in Fig. 3. The assembly of fiber onto the device is made easier with the unique cantilevers formation in this design, which forms an integrated v-groove for easy passive alignment. In fact, a limited active alignment of the fiber can be performed in one axis for fine tuning any optical positioning mismatch caused by the crude passive alignment. The fiber is to be permanently fixed onto the fibers using UV curable epoxy.

Fig. 1 The intersecting cantilevers array forms a "V-groove" in which the fiber can be placed.

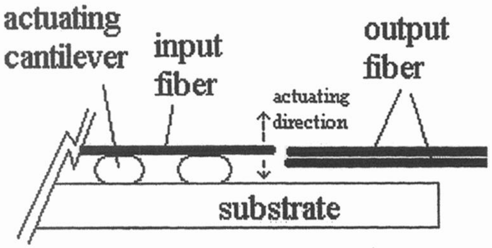

Fig. 2 Schematic of the optical switch

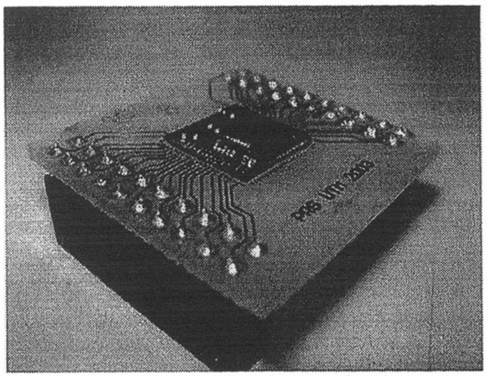

Fig. 3 Chip on board packaging for the prototype

Electrostatic actuation is a highly nonlinear is still widely unknown in details in the research world, albeit a variety of reported work in the modeling of similar electrostatic actuated devices. The modeling of electrostatic actuation can be separated into numerical and analytical method. For numerical method, the Finite Element Method (FEM) is widely employed and is the engine behind all major MEMS simulation softwares. Analytical method, on the contrary, gives a clearer picture on such relationship. However, it is very difficult to derive an exact analytical model which is applicable to different MEMS devices. Electrostatic pull-in modeling is still a continual work elsewhere in the research community [8]-[12]. However, all these analytical models have their limitations and not too suitable for use in this work. [8] is too simple and not suitable for most MEMS devices. Fully distributed load condition is assumed in [9]. In [10], [11] and [12], curvature of the cantilever is not modeled. As the cantilever used in this work has a very large curvature, a new analytical has been developed to catered for this need. This analytical model, with closed expression describing the pull in voltage of a single cantilever, has been reported in [13]. A closed form analytical model comes in very handy for the design of the switch in this work as it provide insight at an early phase of designing of MEMS without the need for using computing intensive numerical simulation tools. In this work, the controlled displacement of the fiber is enables the realization of an on/off switching function.

Schematic of the cantilever design used in this work is depicted in Fig. 4. The cantilever is made of polysilicon. The entire structure sits on a silicon substrate. It consists on 3 separate regions. Region I and III are straight polysilicon region. In region II, a thin layer of metal is deposited onto the polysilicon layer. This makes region II to be curling upward. This design is known as the partially curled cantilever in this work. When a voltage is applied across the cantilever and the substrate, electrostatic force pulls the cantilever down towards the substrate. A silicon nitride layer acts as an insulator, preventing voltage short between the cantilever and the grounded substrate.

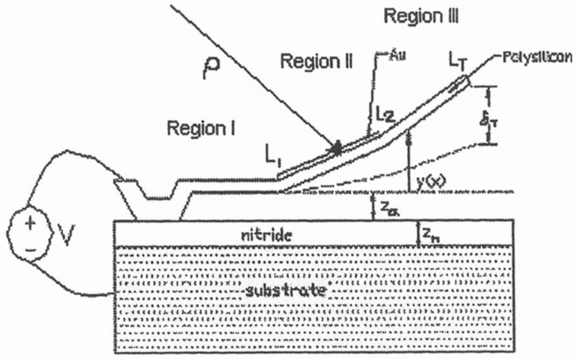

Fig. 4 Schematic showing the partially curl cantilever model.

Equation (1) is the partially curled cantilever model developed for the modeling of this partially curled cantilever and is reported in details in [13]. In (1) the total tip deflection of the cantilever, δ_T, is related to the applied voltage across the cantilever and the silicon substrate.

$$\delta_T = \frac{L_T w k \varepsilon_0 V^2}{4EI}\left[\int_0^{L_1}\left(\frac{x}{Z_m - (x/L_1)^2 - Z_a}\right)^2 dx + \int_{L_1}^{L_2}\left(\frac{x}{Z_n + \rho\left(1-\cos\left(\frac{L_2-L_1}{\rho}\right)\right)}\right)^2 dx \right.$$
$$\left. + \int_{L_2}^{L_T}\left(\frac{x}{Z_n + \rho\left(1-\cos\left(\frac{L_2-L_1}{\rho}\right)\right) + (x-L_2)\sin\left(\frac{L_2-L_1}{\rho}\right)}\right) dx\right] \quad \ldots(1)$$

where

$$Z_m = Z_n + Z_a$$

A typical plot of (1) is shown in Fig. 5. From (1) and from analysis of a typical graph as in Fig. 5, a cantilever with desired pull in voltage and dimension can be designed.

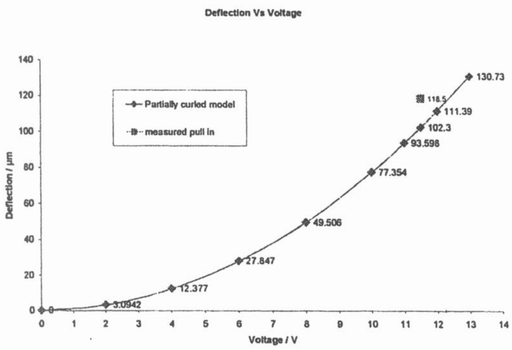

Fig. 5 Deflection of cantilever tip δ_T increases as voltage applied across the cantilever and substrate is increased.

In this work, a prototype of the switch has been successfully tested and the concept of the design has been verified.

III. EXPERIMENT AND PRELIMINARY RESULT

The setup as shown in Fig. 6 is used for insertion loss measurement of the switch prototype. As can be seen in Fig. 7, the cantilevers of the switch pull in at 24 V. However, a voltage of 20 V is sufficient for the switch to operate. The optical power is reduced to near zero as the cantilevers get actuated, thereby achieving an on/off switching operation. Insertion loss of the switch is measured to be 0.97dB at 1550nm at 1mW power. This is usable for optical network protection switching and monitoring requirement.

Due to limitation of our laboratory equipment, the actual actuating range of the cantilever is not measured, but it is estimated to be at 300µm based on observation on microscopy image. As such, the switch can be extended to become a 1x2 switch by arranging two fibers at the receiving end, considering that the diameter of single mode fiber (SMF) is 125µm. This is shown in II. Fig. 2. However, this has not been tested yet.

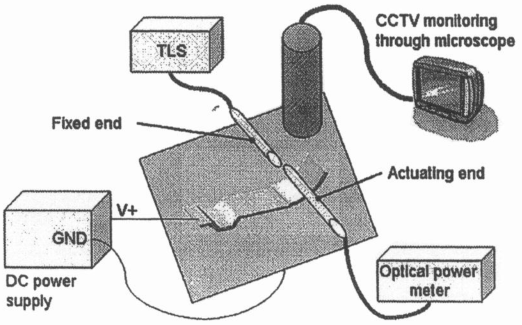

Fig. 6 Experimental setup for insertion loss measurement

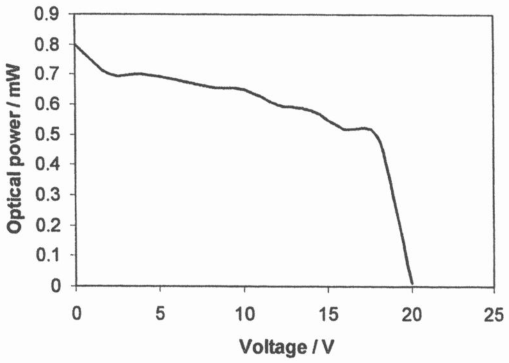

Fig. 7 Optical power observed at the receiving fiber versus actuation voltage.

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IV. CONCLUSION

A novel and simple design of a MEMS optical switch is presented. Although preliminary result is based on 1X1, it should be possible to extend the switch to become a 1X2 switch. In fact, the switch can even be extended to become a variable optical attenuator [14]-[16]. The switch design should makes the assembly straight forward and can be achieved in lab. Modeling effort has covered area not previously covered by other reported works [8]-[12], in specific the effect of cantilever curvature on the pull-in voltage. The analytical model developed should can assists the author and future MEMS designer in designing the optimal dimension of the switch before any time consuming numerical simulation is applied.

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