International Conference on MEMS and Nanotechnology, ICMN'06
14-15 March 2006, Kuala Lumpur, Malaysia

MDD9

MEMS OPTICAL SWITCH BASED ON FIBER DISPLACEMENT

C. W. Leow and A. B. Mohammad

Fakulti Kejuruteraan Elektrik
Universiti Teknologi Malaysia, 81310 Skudai. Johor
Cheahwei.leow@gmail.com, bakar@utm.my

ABSTRACT

A MEMS optical switch based on fiber displacement is presented. The switch consists of an arrangement of electrostatic actuated cantilever beams. A movable fiber is attached to the cantilevers as such that it gets displaced as the cantilevers are actuated. By aligning another fiber towards the end of this movable fiber, a simple on/off switch is achieved. The switch can be extended to 1x2 by aligning 2 fibers at the receiving end. Design and modeling of the switch is done using a mixture of finite element and boundary element method, utilizing Coventor, a commercial MEMS modeling software. The switch can be utilized in optical monitoring and test equipment subassembly system.

1. INTRODUCTION

Low port count MEMS optical switch is used in the field of optical test and measurement equipment as well as optical channel monitoring in telecommunication network. The optical switch itself is also a core component in all optical switching networks [1]. In this work, a novel and simple MEMS optical switch is fabricated using Polymumps process. It consists of an array of electrostatically actuated cantilevers. A fiber is attached to these cantilevers such that it gets displaced as the cantilevers are actuated. By aligning another at the receiving end, a simple switch can be achieved by controlling the displacement of the movable fiber from up and down position, as shown in the schematic in Fig. 1. Prototype of the switch (Fig. 2) has been fabricated and tested. Although the switch has been only tested for on/off operation, it can be extended to become a 1x2 switch if 2 fibers are aligned at the receiving end. The switch can also be equipped with integrated 1 fiber or 2 fibers fiber alignment microstructures (Fig. 3) to provide easy and precise fiber alignment process during packaging [1] . Result shows that design of the switch is economically and functionally viable to be used in real world applications. Compared with other published works on fiber displacement based switches [4]-[7], which have operating voltage up to 100 V, the switch in this paper operates at a lower voltage of 60 V. This significantly makes the driving electronic circuitry simpler, cheaper and safer.

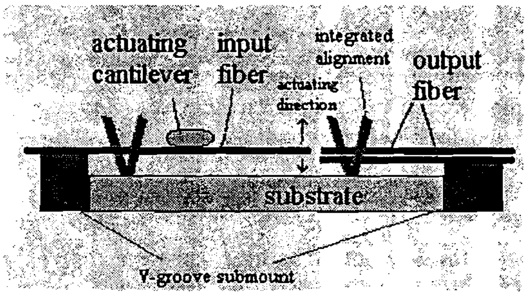
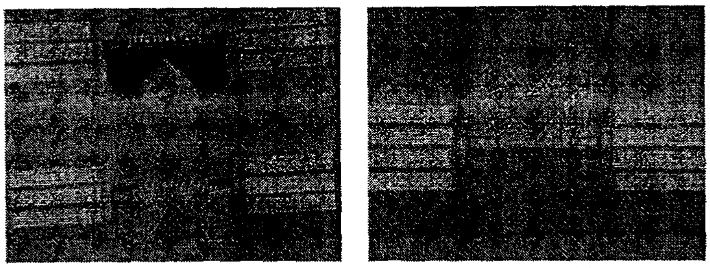


Fig. 1 The fiber alignment microstructure is aligned to an optical switch prototype.

Fig. 2 The switch prototype



(a) (b)

Fig. 3 The integrated fiber alignment microstructure for alignment of 1 fiber (a) and 2 fibers (b) can be used for the switch

2. DESIGN AND WORKING PRINCIPLE

The switch is fabricated using a commercial surface micromachining MEMS process known as PolyMUMPs [8]. In PolyMUMPs, different layers of materials and sacrificial materials are stacked upon each others using thin film deposition. With a combination of lithography patterning and sacrificial material etching (known as release), complex movable micromechanical devices can be fabricated.

In this work, the switch works by mechanically aligning the transmitting and receiving fibers between two positions as depicted in Fig. 1. This can then be configured as on/off switch or 1x2 switch. The core actuating mechanism of the switch is a bimorph cantilever. A bimorph cantilever is a cantilever formed by stacking two layer of different material in surface micromachining fabrication technology. In this design, a thin layer of gold is stacked onto polysilicon cantilever beam. Due to difference of thermal expansion coefficient between gold and polysilicon, residual stress is formed in the bimorph beam during deposition process. After the release process, the cantilever will curl upward as shown in (a) of Fig. 4.

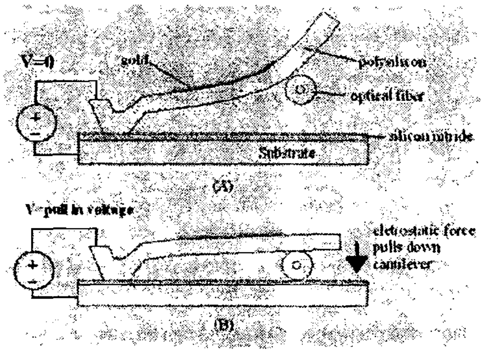


Fig. 4 The integrated schematic showing side view of how the fiber tets displaced by moving cantilever as the actuation voltage is applied

When a voltage is applied across the cantilever beam and the grounded substrate, the electrostatic force acting on the cantilever is strong enough to pull the cantilever towards ground. At a threshold voltage level known as the pull-in voltage, the cantilever will touch the ground, as shown in

(b) of Fig. 4. A thin layer of silicon nitride is used as insulator between the cantilever and grounded susbtrate to prevent short circuit. As the cantilever gets actuated, the fiber, which is underneath the cantilever, is moved along. By controlling the position of input fiber, an on/off switch or 1x2 switch can be realized. A photo of the switch is shown in Fig. 5.

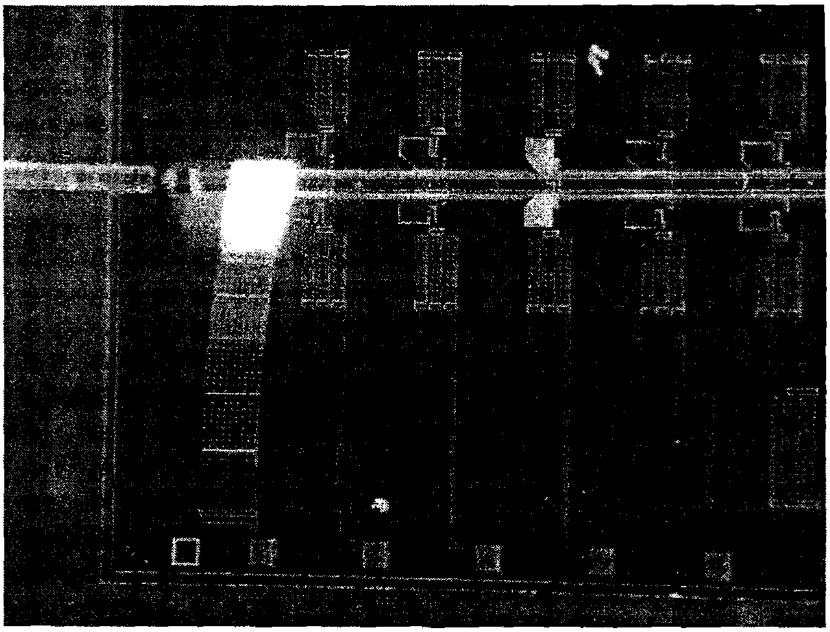


Fig. 5 Microscopy view of the switch prototype with its actuating cantilever and integrated fiber alignment microstructure

3. MODELING AND SIMULATION

There are a few design parameters to be modeled and simulated, which affect some main characteristics of the switch. Firstly, the cantilever should be able to curl up at least 250μm, as to accommodate at the input fiber over the entire on/off travel range. Secondly, the switch should have a proper actuating voltage (as low as possible).

Actuating voltage is inversely proportional to cantilever length. The longer the cantilever is, the lower the actuating voltage. However, long cantilever tends to stick easier to substrate as compared to its shorter siblings. As such, it is crucial to design the proper length of the actuating cantilever.

Design of the switch involves cross disciplinary study of electrostatic actuation in micro mechanical device. Firstly, an analytical model named as partially curl cantilever model (Fig. 6 and equation 1) developed by the authors is used to approximate the needed length.

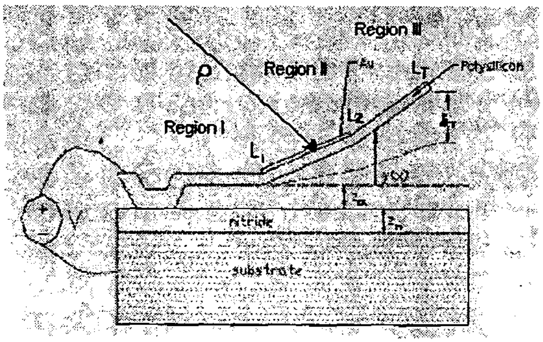


Fig. 6 Schematic showing the partially curl cantilever

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

where $Z_m = Z_n + Z_a$

In (1) the total tip deflection of the cantilever, δ_T, is related to the applied voltage across the cantilever and the silicon substrate.

A typical plot of (1) is shown in Fig. 7. From (1) and from analysis of a typical graph as in Fig. 7, a cantilever with desired pull in voltage and dimension can be designed.

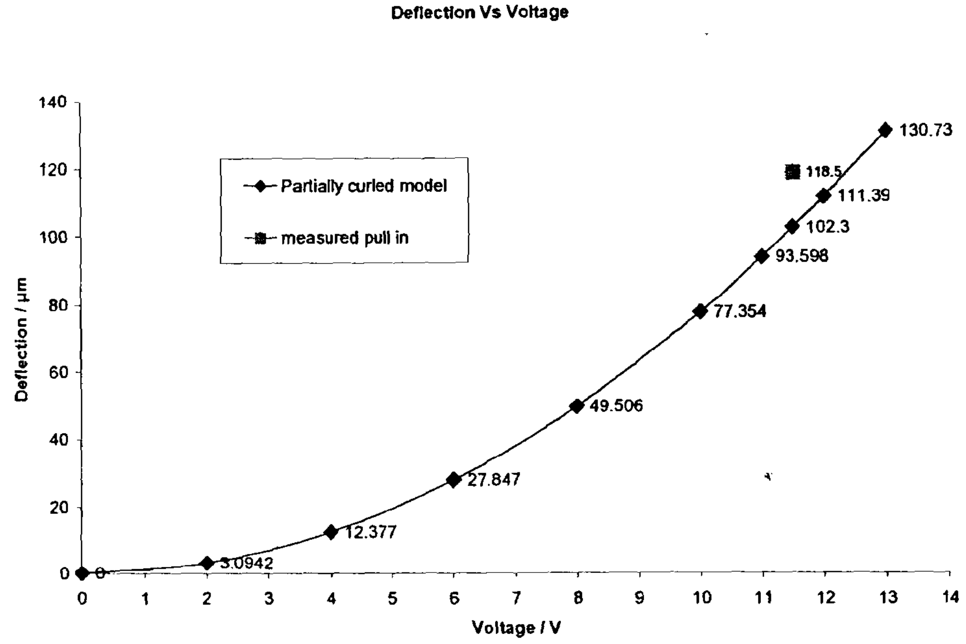


Fig. 7 Deflection of cantilever tip δ_T increases as voltage applied across the cantilever and substrate is increased

Detailed mathematical derivation of this model is covered in [9] and is not reiterated here. The analytical model does not include fringing field effect and irregularity in the cantilever shape (i.e. cantilever is buckled at the end). Fringing field contributes significantly to actuating voltage of a MEMS actuator. As such, finite element (FEM) and boundary element method (BEM) is used to numerically simulate the cantilever in a full 3D model, taking into account the fringing field and irregularity in the cantilever shape. A commercial MEMS simulator, Coventor [10], is used.

Based on result approximated by analytical modeling and verified using Coventor simulation, the proper length of the cantilever is determined. In this work, the length chosen is 730µm. This length ensures that a gap between the tip of the cantilever and the substrate is more than 250µm, which is sufficient to cover the entire actuation range needed by an optical fiber (125µm diameter). A length of 730µm will also ensure that the cantilever is less likely to stick on the substrate. Stiction is expected to affect cantilever with length greater than 1000µm, through observation of previous fabricated cantilevers by the author.

4. RESULTS AND DISCUSSION

From the design, the corresponding mask layout of the chip is then drawn using the built in layout editor in Coventor. Fabrication is outsourced to Memscape, using its Polymumps process [8].

Post fabrication of the MEMS bare dies, a simple chip on board packaging is done whereby the die is attached to a printed circuit board using epoxy and wirebonded. Initial test is carried out by connecting actuation control signal to the chip through the bonded wire as well as microprobing on some non-bonded probe areas. This is shown in Fig. 8. Pull-in voltage of the cantilever is measured using an impedance analyzer. Subsequently, switching operation is measured using a combination of a tunable laser source and optical power meter. The entire setup is shown in Fig. 9.

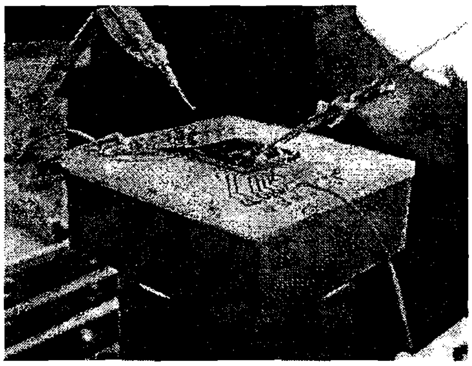


Fig. 8 Initial testing and microprobing

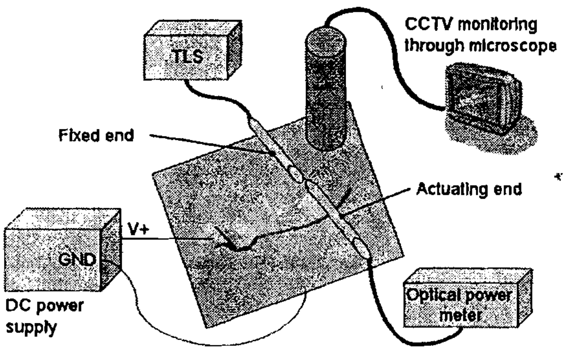


Fig. 9 Setup used for characterization of the switch

Fig. 10 shows the switching operation of the switch as measured, before the switch is fully packaged with V-groove submount. The pull-in voltage is found out to be higher than the measured pull-in voltage without the fiber attached and before the die attachment process, which is at 12V. It is deduced that the fiber has added some obstacle to the actuating cantilever. It is also deduced that the increase of voltage is due the extra curling observed on the cantilever after the die attach process. This is due to the relatively high temperature baking needed to cure the thermal curable expoxy used as die attach epoxy.

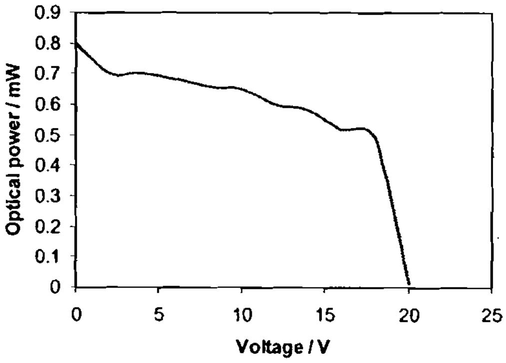


Fig. 10 Switching operation of the switch.

The final packaged switch with v-groove submount fitted is found to have a higher operating voltage at 60V. This is due to the increased stiffness of fiber as shorter length of fiber is protruded onto the actuation mechanism in the final packaged switch. It is deduced that the switching operation of 20V should be achievable in future by using UV curable epoxy as well as by optimizing the package design.

5. CONCLUSION

A simple and novel MEMS optical switch is successfully fabricated and tested. This voltage can be further lowered to 20V in future, with enhancement in the packaging process to reduce the stiffness of the fibers as well as to use UV-curable epoxy rather than thermal curable epoxy in die attach process. The switch has applications in network protection switching and monitoring in which switching times in the ms range are commonly used.

ACKNOWLEDGEMENT

This research was funded by the Malaysian Ministry of Science, Technology and Environment (MOSTE), Vot numbered 74211. The first author is sponsored under the National Science Foundation (NSF) scholarship.

REFERENCES

[1] E. Ionnone, and R. Sabella, "Optical Path Technologies: A Comparison Among Different Cross-Connects Architectures," *J. Lightwave Technol.*, vol. 14, pp. 2184-2196, 1996.

[2] M.R. Matthews, B.M. MacDonald, K.R. Preston, "Optical components-The new challenge in packaging," IEEE Trans. Comp., Hybr., Manufact. Tech., vol. 13, no. 4, pp. 798-806, 1990.

[3] C.W. Leow, A.B. Mohammad "MEMS On/off and 1x2 Optical Switch with Integrated Fiber Alignment Capability", *Proc. 2004 IEEE International Conference on Semiconductor Electronics ICSE2004,* Mines Resort, Malaysia.

[4] Hara, Hane, Kohl (1999). "Si Micromechanical Fiber-Optic Switch with Shape Memory Alloy Actuator." *Proceedings of Transducers 99*, June 7-10, 1999. Sendai, Japan: IEEE. 790-793.

[5] Oilier, E.; Chabrol, C.; Enot, T.; Brunet-Manquat, P.; Margail, J.; Mottier, P.. "1×8 micro-mechanical switches based on moving waveguides for optical fiber network switching," *Proceedings of IEEE/LEOS international conference on optical microsystems and technologies,* August 21-24 2000. Kauai, Hawaii: IEEE, 2000: 39-40.

[6] Field, L. A., Burriesci, D. L., Robrish, P. R. and Ruby, R. C. "Micromachined 1x2 optical fiber switch," *Sensors and Actuators A*, 1996, 53(1): 311-316

[7] Yasseen, A.A., Mitchell, J., Streit, T., Smith, D.A. and Mehregany, M. "A rotary electrostatic micromotor 1×8 optical switch," *J. of Selected Topics in Quantum Electronics*, 1999, 5: 26-32.

[8] PolyMUMPSs Design Handbook, Rev 10.0, Memscap, 2003

[9] C.W. Leow, A.B. Mohammad, N.M. Kassim, "Analytical Modeling For Determination Of Pull-In Voltage For An Electrostatic Actuated MEMS Cantilever Beam," *Proc. 2002 IEEE International Conference on Semiconductor Electronics ICSE2002*, Penang, Malaysia.

[10] http://www.coventor.com