Optimizing POF/PCF based optical switch for indoor LAN

M M I Bhuiyan¹,⁴, M M Rashid¹,⁵, Sayem Ahmed¹,⁶, M Bhuiyan² and M Kajihara³

¹ Department of Mechatronics Engineering, International Islamic University Malaysia, Jalan Gombak, 53100 Kuala Lumpur, Malaysia
² SEGi University, Faculty of Medicine, No. 9, Jalan Teknologi, Taman Sains Selangor, Kota Damansara PJU 5, 47810 Petaling Jaya, Selangor, Malaysia
³ Department of Materials Science and Engineering, Tokyo Institute of Technology, Yokohama 226-8502, Japan
E-mail: ´moinul@iium.edu.my, ´mahbub@iium.edu.my, ´sayem7746@gmail.com

Abstract. For indoor local area network (LAN) the Polymer optical fiber (POF) is mostly appropriate, because of its large core diameter and flexible material. A 1x2 optical switch for indoor LAN using POF and a shape memory alloy (SMA) coil actuator with magnetic latches was successfully fabricated and tested. To achieve switching by the movement of a POF, large displacement is necessary because the core diameter is large (e.g., 0.486mm). A SMA coil actuator is used for large displacement and a magnetic latching system is used for fixing the position of the shifted POF. The insertion loss is 0.40 to 0.50dB and crosstalk is more than 50dB without index-matching oil. Switching speed is less than 1s at a driving current of 80mA. A cycling test was performed 1.4 million times. Polymer clad fiber optical (PCF) switch also fabricated and tasted.

Keywords: Optical switch, Shape memory alloy, Plastic optical fibre, Indoor LAN, Magnetic latch

1. INTRODUCTION

For office and home environment Polymer optical fiber (POF) is more suitable than the quartz optical fibre to construct LAN (Local Area Network) [1-3], because of its flexibility and ease of connection by relatively large core diameter. Demand of treating huge information in home or office is increasing and it is predicted that the huge information from the outdoors will be transmitted to various information terminals and AV equipment using an optical fibre through information consents in the near future (Figure 1).

In order to transmit the information from the outdoor to each information terminal, optical switches are needed in every bifurcation.
Small core Silica optical fibers are widely used for communication systems. However, such small core, only 0.01 mm optical fibers (Figure 1(b) shows the fiber diameter comparison) require high precision alignment between two fiber ends, and which is the main problem in indoor LAN connection area. In this research we approached POF/PCF (although higher optical attenuation than silica fiber but larger diameter) to overcome the problem. Because of larger core diameter, POF/PCF is selected for the LAN switch. A large displacement is required for switching. SMA [4-6] coil is preferred for actuation and power consumption is also considered.

![Figure 1: (a) Concept of future home network](image-a)

![Figure 1: (b) Large diameter optical fibre (POF/PCF) and conventional silica fibre.](image-b)

A magnetic latching system [7] is introduced in this device for holding the position of the shifted POF, and therefore a continuous current supply is not necessary. There are some optical fibre switches, which use solenoid coils and permanent magnets, which move and latch fibre magnetically. Such switches are for silica optical fibre and required small displacement of the fibre.

**2. Structure and Principle of Switch**

Structure of the optical switch is shown in Figure. 2(a) and a circuit diagram is shown in Figure. 2(b). There is a POF fixed to a SMA coil in the right side of the figure and two POF(s) are fixed in the left side. One of the fibre ends of the left side POF(s) and the fibre end of the right side POF are faced each other. If switch No.1 is turned on (Figure. 2 (b)), electrical current is applied to upper half of the SMA coil and the upper half of SMA is heated above a certain transition temperature by direct heating and contracts. POF, which is attached to the SMA moves towers upper side and the light is passed into the upper left side POF. If No.2 switch (Figure. 2(b)) is turned on similarly, the same change will be occurred in the lower SMA and the POF is moved lower side. For switching by movement of a POF, large displacement is needed because of large core diameter (in this case, Core diameter: 0.486mm, Outer diameter: 0.5mm) and this device needs displacement of 0.5mm. It is relatively difficult to get displacement of 0.5mm by micro actuator for example, electrostatic actuator, piezoelectric actuator etc. We chose SMA coil actuator for large displacement.
As shown in Figure 2(a), two pairs of stoppers are located both sides of the right side POF. The stoppers enable its fibre end and left side POF end (in Figure 2) to face correctly each other. However, the current must be applied continuously to maintain the displaced position in the case of using SMA actuator [1]. To solve this problem the magnetic material ring (nickel) is attached to the right side POF, and two permanent magnets are placed at the both side of the POF. This magnetic latch mechanism holds the position of the POF even if driving current is turned off. Moreover, this magnetic latch prevents upward displacement of the POF by pulling it down by embedding two permanent magnets in the substrate.

Acrylic substrate, which is carrying on all the parts, is fabricated using high-speed milling. The size of the whole switch is L25mm×W15mm×H5mm. The size of the permanent magnet was L4mm×W4mm×H2mm. Surface magnetic flux density was 320mT and magnetic force was 0.35kg. Ni-Ti SMA coil micro actuator was used. Its external diameter was 0.2mm and wire diameter was 0.05mm. External diameter, wall thickness and length of Ni magnetic material ring were 1.5mm, 0.5mm and 4.0mm respectively.

3. Fabrication
3.1 The processing method and result
In order to make precise alignment of the POF, it is necessary to fabricate with sufficient accuracy. The high-speed milling machine is preferred for cutting the acryl substrate. Before the processing, appropriate tool and processing conditions are chosen and checked using simulator as shown in Figure 3.
Three types of switches were fabricated using the POF of 0.5mm, 0.75mm and 1.0mm diameter respectively. Three types of acrylic substrates fabricated using high-speed milling machine are shown in Figure 4. Acrylic substrate was cooled by water to avoid deformation during high-speed milling. Firstly, a switch using 0.5-mm-diameter PMMA POF (Core diameter: 0.486mm, Outer diameter: 0.50mm) was fabricated and its performance was evaluated.

3.2 Processing of POF End
A parallel POF end with a smooth surface is beneficial in reducing insertion loss in an optical switch. In this study, a mechanical polishing technique [8] was used for POF to obtain the parallel end face with a lower roughness reproducibly. It is reported that the mechanical polishing technique could form a smooth surface with lowest loss compared to other techniques such as hot plate, hot cutter technique. Figure 5 compares the end face polished by a fibre polisher (Seikoh Giken SEP-7002) to that produced by a cutter. The insertion loss will be reduced further by alignment of POF(s) using the magnetic latch and the stopper (Figure 2(a)), gap control between the fibre ends (Figure 2(a)) and precise fixation of POF(s).
3.3 Assembly Process
The above-mentioned parts are assembled on the processed acrylic substrate as the following.

1. Cu electrodes for driving of the SMA were attached to the substrate with an adhesive.
2. The middle of the SMA coil was fixed to a metallic ring and connected to the electric cables.
3. Two permanent magnets were fixed to each predetermined position.
4. The right side POF was inserted into the metallic ring and fixed using the adhesive.
5. The fibres in the left side were placed in the groove of the substrate and properly fixed by pressing from upper side using a V-shaped convex. (See Figure.6).
6. Gap between the POF ends was adjusted under a microscope.
7. Finally, the magnetic material ring was attached around

![Figure 6: Fixation of left side POF(s)](image)

4. Results
4.1 Characteristics of SMA actuator
Comparison between coupling loss using index-matching oil and coupling loss without index-matching oil is shown in Figure 7. In this case mechanically polished ends were used. The insertion loss of the fabricated switch was 0.50 dB or less, namely, a minimum value of 0.40 dB to a maximum value of 0.50 dB when index-matching oil was not used. When index-matching oil was used, insertion loss was less than 0.10 dB, namely, a minimum value of 0.06 dB to a maximum value of 0.09 dB.

![Figure 7: Required release power from magnetic latch.](image)  
![Figure 8: Switching condition](image)
4.2 Evaluation of Switching Speed

650nm laser diode was used as the light source. The light intensity, which came out from the output side, was measured as shown in Figure 10. In this measurement, index-matching liquid was not used. To measure coupling loss, the intensity of outgoing light from the switch (Figure 9) was compared to that of reference POF (Figure 9). The entire pass lengths are 300 mm. Insertion loss was less than 1 [dB] (minimum value of 0.62 [dB] to maximum of 0.74 [dB]) (Figure 10). Almost insertion loss of conventional optical switch for communication is less than 1 [dB]. To reduce insertion loss further, antireflective-coated fibre end could be effective. This would also reduce back reflections. Index matching liquid is not preferable, because their surface tension prevents switching motion and the liquid have to be sealed in the device.

![Figure 9: Measurement method](image)

![Figure 10: Measurement of coupling loss](image)
5. Conclusion

Optical switch (1×2) using POF and SMA coil actuator with magnetic latch has been successfully fabricated and actuated. The continuous switching operation was confirmed and during this test switching speed was less than 1 second at driving current of 80mA. This speed is sufficient for indoor LAN.

The loss of the fabricated switch was less than 1 [dB] without using index-matching liquid. This value is almost equivalent to the conventional quartz fibre switch. This seems to be the firstly realized optical switch using large diameter (0.5mm) optical fibre.

Other large external diameter (for example, 0.5mm) plastic clad fibre (PCF) can be used for this device. To fabricate the substrate at low cost, injection moulding can be applied instead of high-speed milling machine.

Fabricated 1×2 switch can produce a good result at stand-by application. In future as the insertion loss is very low, by adding several 1×2 optical switches, it is possible to use at 1×8 optical switch application. To fabricate the substrate at low cost, injection molding can be applied instead of high-speed milling machining. We got new information by doing this research work, which will help to fabricate polymer optical switch with low insertion loss in future.

Acknowledgment

A part of this work was performed in Venture Business Laboratory in Tohoku University, Japan.

References

[1] Large, M. C J ; Blacket, D.; Bunge, C. -A, "Microstructured Polymer Optical Fibers Compared to Conventional POF: Novel Properties and Applications," Sensors Journal, IEEE , vol.10, no.7, pp.1213,1217, July 2010 doi: 10.1109/JSEN.2010.2041056

[2] Tao Geng; YuZhao Wang and HaiBin Wu, "Research on vision-based waveguide alignment of optical fiber," Measurement, Information and Control (MIC), 2012 International Conference on , vol.1, no., pp.286,289, 18-20 May 2012

[3] Horino M , Sato K , Hayashi Y, Mita M and Nishiyama T, “Plane Type Fiber Optic Switches,” The Institute of Electronics, Information and Communication Engineers Paper Magazine Vol.J83-C (2000), pp.681-688 (in Japanese)

[4] Bhuiyan M. M I; Haga Y and Esashi M., "Design and characteristics of large displacement optical fiber switch," Quantum Electronics, IEEE Journal of , vol.41, no.2, pp.242,249, Feb. 2005 doi: 10.1109/JQE.2004.839681

[5] Adelaide Nespoli, Stefano Besseghini, Simone Pittaccio, Elena Villa and Stefano Viscuso, “The high potential of shape memory alloys in developing miniature mechanical devices: A review on shape memory alloy mini-actuators, Sensors and Actuators”. A: Physical, Volume 158, Issue 1, March 2010, Pages 149-160, ISSN 0924-4247, 10.1016/j.sna.2009.12.020.

[6] Hoffman M, Member, IEEE, Kopka P and Voges E, “All-Silicon Bistable Micromechanical Fiber Switch Based on Advanced Bulk Micromachining,” IEEE Journal of Selected Topics in Quantum

[7] Bachman M, Yang Zhang, Minfeng Wang; Li, G., "High-Power Magnetically Actuated Microswitches Fabricated in Laminates," Electron Device Letters, IEEE , vol.33, no.9, pp.1309,1311, Sept. 2012 doi: 10.1109/LED.2012.2206553
[8] Bilro L, Alberto N, L. M. Sá, Pinto J. L and Nogueira R N, “Side-polished plastic optical fibre as refractive index, cure and viscosity sensor.” Proc. SPIE 8001, International Conference on Applications of Optics and Photonics, 800142 (July 26, 2011); doi:10.1117/12.892099