Optical Switch Usign Large Core Optical Fiber(大口径コアア光ファイバを用いた光スイッチ)

	モハメッド　モイヌル　イスラム　ブイヤン
氏　　　　　名	Mohammed Moinul Islam Bhuiyan
授　与　学　位	博士（工学）
学位授与年月日	平成17年3月25日
学位授与の根拠法規	学位規則第4条第1項
研究科，専攻の名称	東北大学大学院工学研究科（博士課程）機械電子工学専攻
学位論文題目	Optical Switch Using Large Core Optical Fiber （大口径コア光ファイバを用いた光スイッチ）
指　導　教　員	東北大学教授　江刺　正喜
論文審査委員	主査　東北大学教授　江刺　正喜　東北大学教授　羽根　一博 東北大学教授　桑野　博喜　東北大学助教授　芳賀　洋一

論 文 内 容 要 旨

POF (Plastic Optical Fiber) is suitable for indoor LAN (Local Area Network), for example, in-home or office networks, because of its flexibility and its ease of connection due to its relatively large core diameter. A 1×2 optical switch for indoor LAN using POF and an SMA (Shape Memory Alloy) coil actuator with magnetic latches was successfully fabricated and tested. In this paper, the design concept and the characteristics of this switch are described.

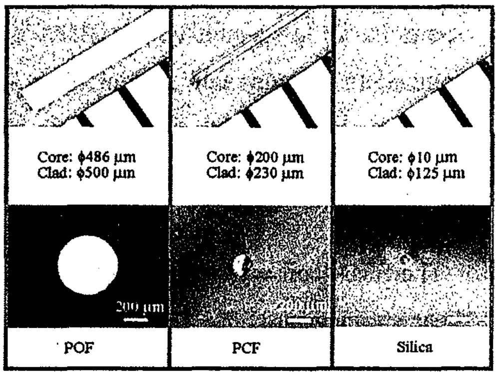
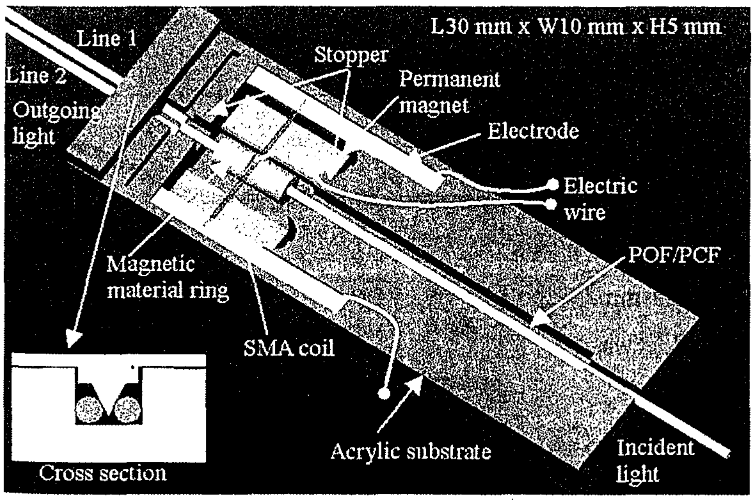
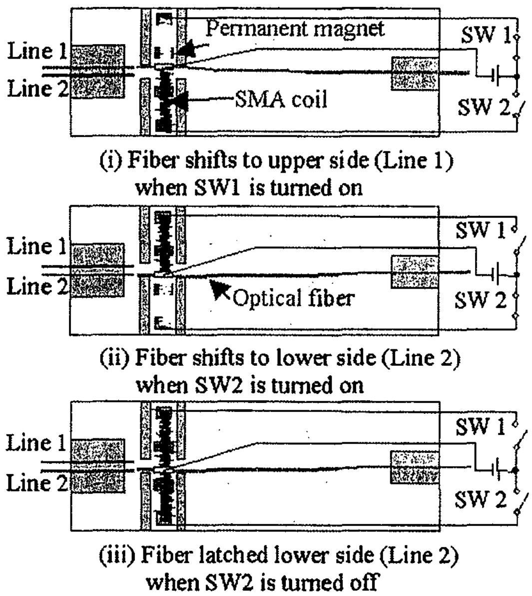


Fig. 1. Large diameter optical fiber (POF/PCF) and conventional silica fiber

To achieve switching by the movement of a POF, large displacement is necessary because the core diameter is large (e.g., 0.486 mm). A SMA coil actuator is used for large displacement and a magnetic latching system is employed for fixing the



(a)



(b)

Fig. 2. (a) Structure of optical switch and (b) switching mechanism

position of the shifted POF. For this design, the insertion loss is 0.40 to 0.50 dB and cross talk is more than –50 dB without index-matching oil. Switching speed is less than 0.5 second at a driving current of 80 mA. A cycling test was performed 1.4 million times at room temperature. Another optical fiber switch was fabricated and successfully actuated using PCF (Plastic Clad Fiber). PCF also has a large core diameter (e.g., 0.20 mm) and optical switches using PCF will be useful for short distance networks between buildings.

The structure of the optical switch is shown in Figure 2(a) and the switching mechanism is shown in Figure 2(b). On the right side is a movable POF attached to the SMA coil and on the left are two fixed POFs. The fiber end on the left side and those on the right side face each other. The switch is operated by moving the POF. A large displacement of 0.5 mm is needed because the outer diameter of the POF is 0.5 mm. To achieve such a large displacement, an SMA coil actuator was used. If switch SW 1 in Figure 2(b) is turned on, an electrical current flows through the upper half of the SMA coil, which is heated by Joule heat. When the upper half of the SMA is heated beyond a certain transition temperature, it contracts. A fiber, which is attached to the SMA, moves upward and light passes into the upper left side fiber (Line 1). If switch SW 2 in Figure 2(b) is turned on, the same change occurs in the lower half of the SMA coil and the POF is moved to the lower side (Line 2). A magnetic ring is attached to the movable optical fiber and two permanent magnets are placed at both sides of the fiber. The permanent magnets attract and fix the location of the magnetic ring when the fiber moves to the upper or lower side. Because the magnetic latch fixes the position of the shifted POF, a continuous current supply is not necessary.

The SMA coil was stretched from memorized shape and shear strain was 4.3%. The acrylic substrate, which is the base for all the parts, was fabricated using a high-speed milling machine. The fibers on the left side were placed in the groove of the substrate and properly fixed by pressing them into a V-shaped extension as shown in the cross section of Figure 2(a).

In order to consider minimal insertion loss of optical switch, an appropriate alignment should be necessary. F_{max} should be lower than 250 mN for SMA actuation and service life considerations as previously mentioned in the discussion of SMA coil design. For the calculation of L, the following values were used: a = 4.5 mm and v = 0.5 mm. For a long lifetime of SMA, Fmax was set at 40 mN. L was 24 mm as shown in Figure 3.

In order to get low insertion loss of fabricated switch, we have considered many types of fiber processing method. Mechanical polishing method is the superior than other

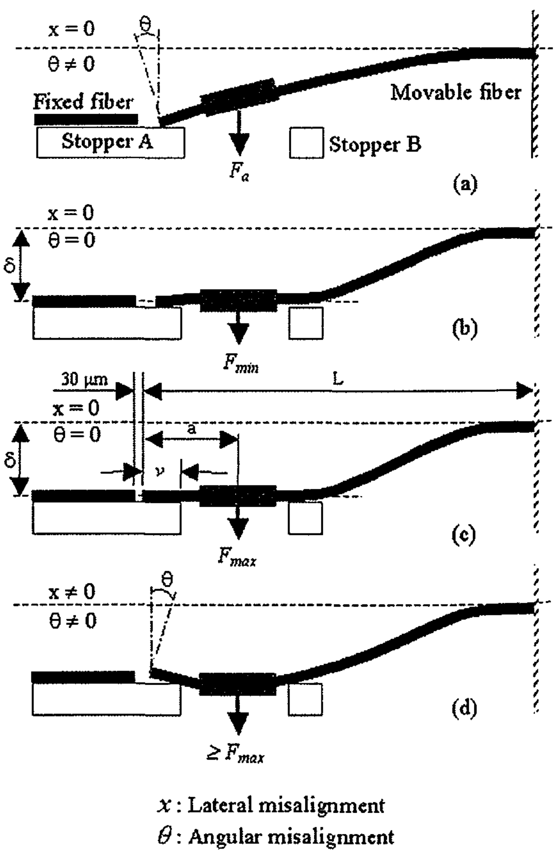


Fig. 3. Optical coupling condition for low loss of switch

processes. A polishing Jig was fabricated for polishing fiber ends without permanent fixing method. Using these methods, an excellent fiber surface with stable reproducibility was gained in this study as shown in Figure 4.

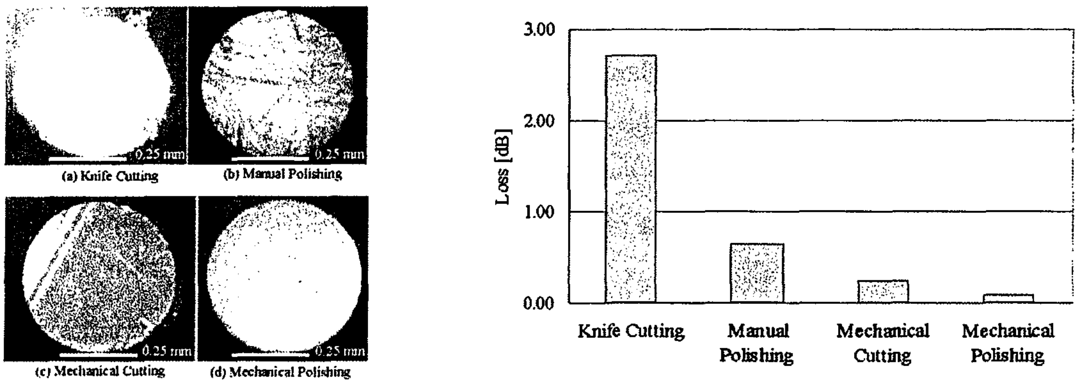


Fig. 4. Fiber end processing methods and results

A high-speed milling machine was used for cutting the acrylic substrate. The fabricated POF switch is shown in Figure 5. The above-mentioned parts were assembled on the processed acrylic substrate as follows:

1) Cu electrodes for driving of the SMA were attached to the substrate with adhesive.
2) The middle of the SMA coil was fixed to a ring made of magnetic material and connected to the electric wires.
3) Two permanent magnets were fixed to each predetermined position of the substrate.
3) The movable side of the POF was inserted into the magnetic ring and fixed using adhesive.
4) Two fibers were placed in the grove of the substrate and properly fixed by pressing from upper side using a V-shaped outward extension as shown in Figure 5.
5) The gap between the opposed POF ends was adjusted under a microscope.

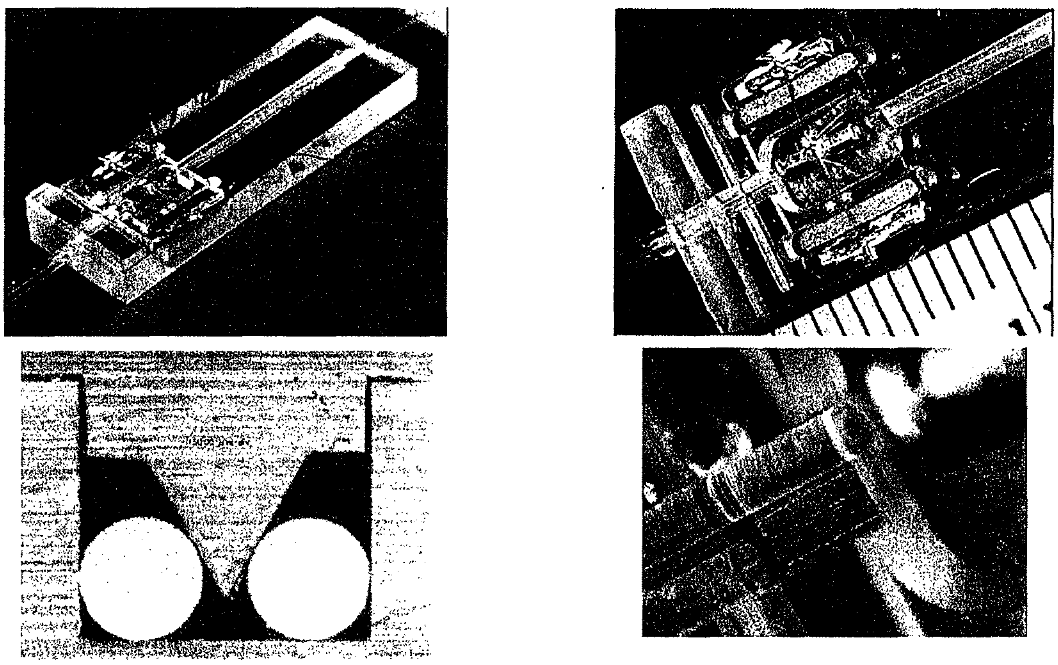


Fig. 5. Fabricated optical switch

Insertion loss of fabricated optical switch was less than 1 [dB] without using index-matching oil. When index-matching oil was used, insertion loss was less than 0.15 [dB]. Cross talk was more than –50 dB without index-matching oil. A continuous switching test was performed and 1.4 million cycles of switching were realized at room temperature. Switching speed was less than 500 ms for POF switch, and 260 ms for PCF switch at a driving current 80 mA. In this study, a highest switching speed was measured. At 180 mA, POF and PCF switches speeds are 160 and 80 ms, respectively. This value is near of commercial optical switch. It can estimate from this result that, in future when it will apply to the single mode fiber switch, this value become smaller. This speed is sufficient for indoor LAN or short distance network applications. As shown in Figure 6 there are some optical characteristics and a packaged switch.

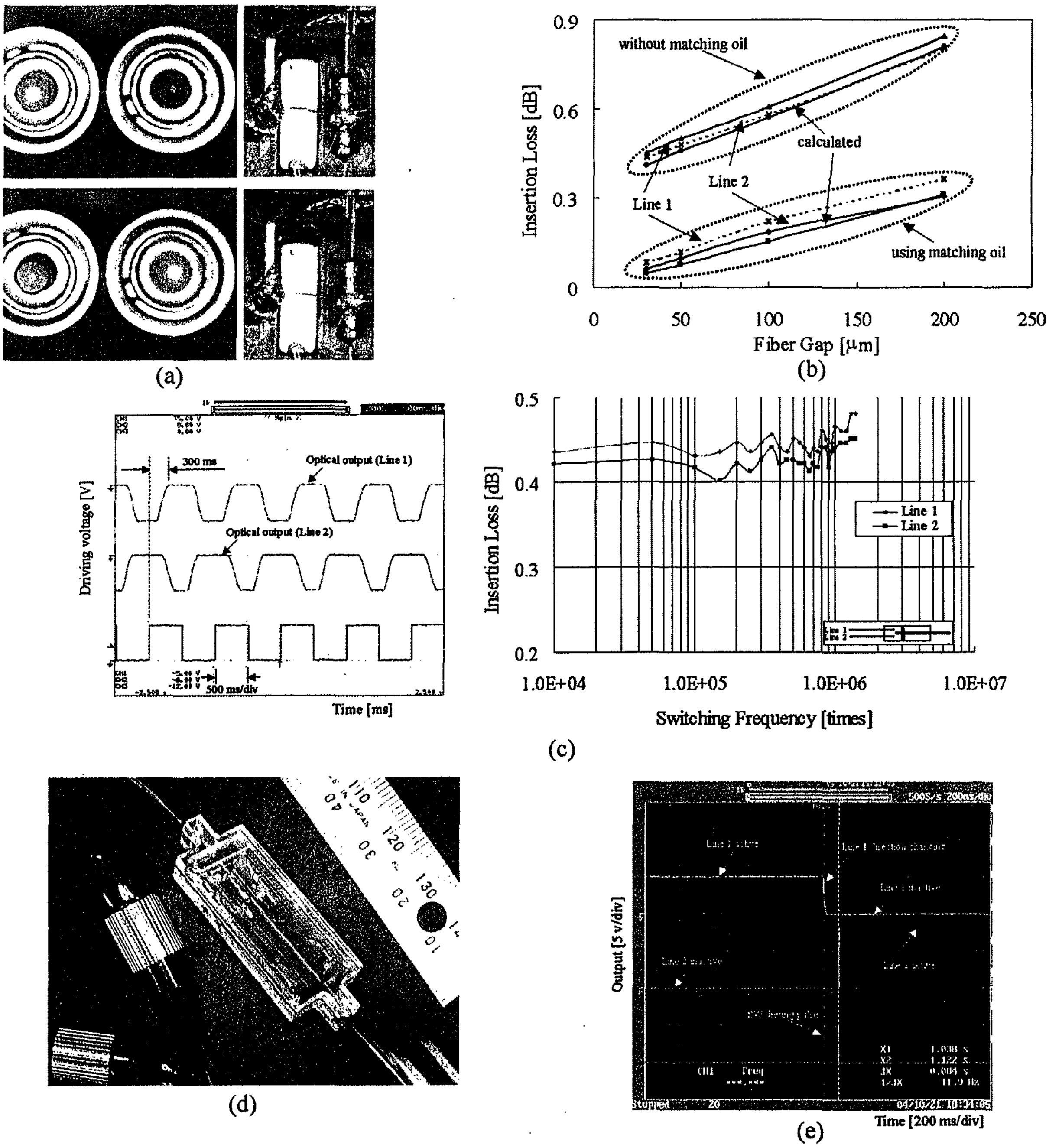


Fig. 6. (a) Actuation and latching confirmation test, (b) Insertion loss, (c) Continuous switching test, (d) Packaged switch, and (e) Switching speed of PCF switch at 180 mA

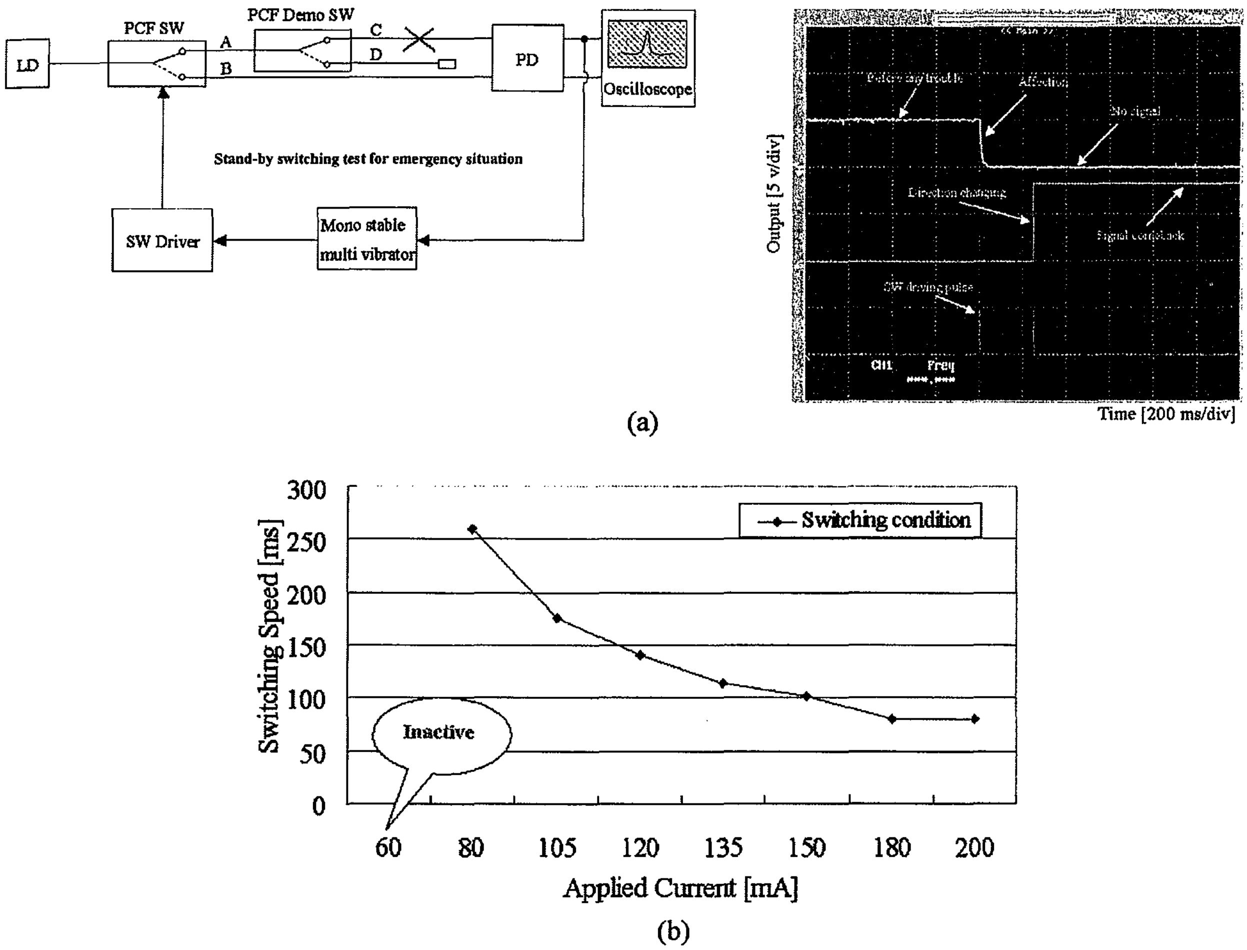


Fig. 7. (a) Application test, and (b) Recovery time at several current of PCF switch

We have discussed about packaging process and problem of fabricated optical switch. An appropriate adhesive is selected for fixing the main boy and cover of optical switch. A high viscosity adhesive is suitable for fixing. The packaged size was L30 mm × W15 mm × H5 mm. The outer dimension of our fabricated optical switches is not larger than commercial optical switches, which were described before. Cover structure for packaging was simple and it was suitable to fabricate using injection-molding process with mass production. Packaged fabricated optical switches actuation was confirmed.

In this study, we applied a simple stand-by application test for emergency trouble. At emergency situation fabricated switch can response with changing its previous position to another position. Switching speed was less than 350 ms for POF switch, and 260 ms for PCF switch at a driving current 80 mA as shown in Figure 7. Furthermore, if applied current is less than 70 mA, SMA actuator will be not active. Relation between switching speed and current were determined.

In future by adding several 1×2 optical switches, it is possible to use at 1×8 optical switch application. As the insertion loss is very low. 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 that will help to fabricate polymer optical switch with low insertion loss in future.

論文審査結果の要旨

インターネットに代表される光通信システムは高度情報化社会を支えており、家庭などの末端にまで光ファイバによるブロードバンド化が進行している。プラスチック光ファイバのような大口径コアの光ファイバは、太いため接続が容易になり末端で使用するのに適している。このシステムで接続を切り替えるため、大口径コアの光ファイバに使える光スイッチに関する試作研究を行った。回線数が少ない場合は、光ファイバを機械的に動かしてその端面を合わせる方式が優れているが、光ファイバが大口径の場合には大きく動かす光スイッチを製作しなければならない。大きく動かすアクチュエータには形状記憶合金が適しているので、それに通電加熱して動かすものを考案した。電力消費や発熱を少なくするため、磁気を用いた保持機構と組み合わせ、切り替え時にだけ通電すればよいようにしている。

本論文は、この磁気保持機構付き形状記憶合金アクチュエータを用いた、大口径光ファイバ用の光スイッチを製作する研究を行い、その成果をまとめたもので全編8章よりなる。

第1章は序論であり、研究の背景、大口径コアの光ファイバとその応用、光スイッチの現状や本研究で要求される課題などについて述べている。

第2章では、光スイッチの設計に関し、形状記憶合金コイルを用いたアクチュエータ、磁気的な保持機構、挿入損失のような光学的な特性などについて述べている。大口径光ファイバには全てがプラスチックのPOF(Plastic Optical Fiber)、および光が通るコアは石英で周囲のクラッドがプラスチックのPCF(Plastic Clad Fiber)の2種類があり、それぞれのスイッチを設計製作した。

第3章では、光ファイバの加工やスイッチの製作について述べている。光ファイバの端面の研磨、機械加工によるスイッチ本体の製作と組立などを説明した。実用レベルの光スイッチを実現できたことは優れた成果と言える。

第4章は、製作した光スイッチを光ファイバシステムに使用し、その性能試験を行った結果について述べている。光の挿入損失、クロストーク、繰り返し使用に対する耐久性、温度特性などに関し、POF用およびPCFの2種類の光スイッチについて評価している。

第5章では、挿入損失を減らすために、光ファイバの端面に反射防止膜を形成する方法に関して述べている。

第6章では、製作した光スイッチのパッケージングについて述べている。

第7章では、製作した光スイッチを応用し、動作速度などを評価した結果について述べている。

第8章は結論である。

以上要するに本論文は、家庭などの末端で用いられるプラスチック光ファイバのような、大口径コアの光ファイバに使う光スイッチの試作研究を行ったもので、光通信工学ならびに機械電子工学に寄与するところが少なくない。

よって、本論文は博士（工学）の学位論文として合格と認める。