# Polymer Y-branching Thermo-optic Switch For Optical Fiber Communication Systems


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## 1. Background

In recent years optical fiber communication systems have grown rapidly with Dense Wavelength Division Multiplexing (DWDM) technology. With the increasing of communication channels, optical switches will be in great demand for selection of optical paths. Many types of optical switching devices have been proposed and one of the promising switching devices is a polymer Digital Optical Switch (DOS). DOS is a kind of Planar Lightwave Circuit device (PLC) which uses the thermo-optic effect to select optical paths. It consists of a Y-branching polymer waveguide and thin metal film heaters on the surface of the waveguide. Without of employing FHD or P-CVD processes, polymer PLC devices are probably more cost effective than silica PLC devices. Only spin-coating and baking processes are needed to form polymer films.

In this paper, 1x2 and 2x2 DOSs are introduced with their optical characteristics. The 1x2 switch can be applied to the protection switching of a leased line. The 2x2 Cross-Bar switch is suitable to select add/drop channels in an Optical Add Drop Multiplexer (OADM) module.

## 2. One Input-Two Output (1x2) Thermo-optic Switch

### *2.1 Overview*

Firstly, the 1x2 switch has been designed and fabricated.[1][2] Photo.1 shows the overview of the switch. The switch device is formed on a silicon wafer using fluorinated polyimide waveguide[3] and Cr/Au thin metal heaters. The input and output Single-Mode optical Fibers (SMF) are bonded to the device as optical fiber arrays. The V-groove substrates of fiber arrays used are silica glass.

This DIP package size is compact enough to be installed onto a printed circuit board by soldering. The dimensions are 52mm x 14mm x 6mm. The material of package is KOVAR with Ni/Au plating.

The optical characteristics of the 1x2 switch at 1550nm are listed in table 1.

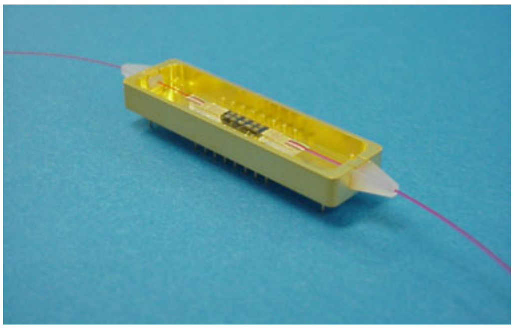

Photo. 1 The overview of 1x2 switch

Table 1 The optical characteristics of fabricated 1x2 switches at 1550nm

| | Insertion loss | Isolation | Return loss | PDL | Electrical power | Switching time |
|---|---|---|---|---|---|---|
| Typical | 1.8 dB | 23dB | 51 dB | 0.4 dB | 150mW | < 10ms |
| Best | 1.5 dB | > 25dB | > 55 dB | 0.3 dB | | |

### *2.2 Insertion loss*

The insertion loss value consists of the propagation loss, the connection losses of two connection points and the switching loss at Y-branching area. The propagation losses of fluorinated polyimide waveguide have been reported by J.Kobayashi et al.[3] which are 0.3dB/cm at 1310nm and 0.6dB/cm at 1550nm. In our device, the length of the waveguide is about 1cm so the material loss is estimated to be about 0.6dB at 1550nm. The connection loss is estimated to be 0.2dB per point typically. The switching loss has been estimated to be about 0.8dB using Beam Propagation Method (BPM) computer simulation.

The three dimensional BPM simulations were executed to design an optimum core pattern and a heater layout. Firstly, the steady state temperature distribution was calculated using difference calculus method computer simulation. Then the refractive index distributions were prepared based on its result and the core pattern. Finally, BPM simulations were executed using the refractive index distributions. After several trials, the heater layout was determined. Figure 1 shows the calculation results of the case. In figure 1(b) and (d), it can be seen that the light was guided to only one port. The insertion loss of the best result was 0.8dB.

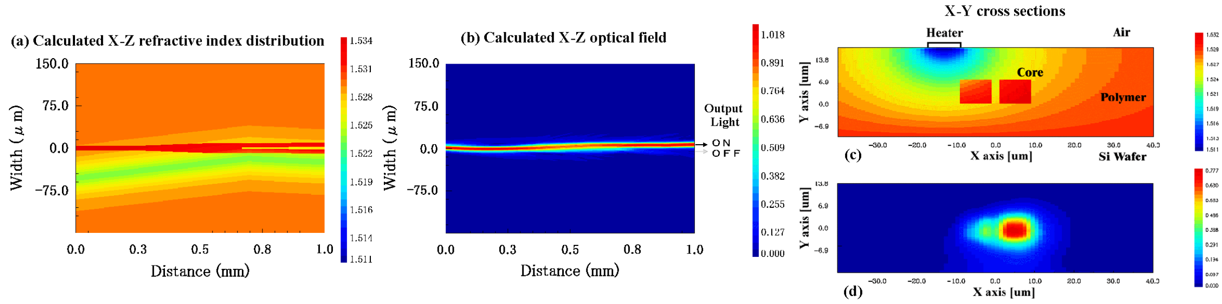


Fig. 1 The calculation results near Y-branching section. The one of two heaters heated. (a) and (c) are the refractive index distributions. (b) and (d) are the optical power distributions. (c) and (d) are the X-Y cross sections at Z=0.7mm, the input side of two output S-bend core.

## *2.3 Isolation and the improvement with partitioned heaters*

As far as we know, the isolation of 23dB in typical value is considered to be good for a one stage Y-branched switching device. It is 18~23dB for usual Y-branching devices and there are few reports about high isolation Y-branch design[4]. Nevertheless a higher isolation over 30dB is required for some applications.

For DOSs, the common way to obtain high isolation is to provide additional electrical power, which, however, leads the loss increase in ON state port. While the electrical power is suitably supplied, the insertion loss of the ON state port is low enough. On the other hand, when the additional electrical power is supplied, the excessive heat influences not only the OFF state port but also the ON state port. It brings about an increase in the insertion loss of the ON state port.

Figure 2 shows the schematic diagram of our proposal to suppress the undesirable increase in the insertion loss of the ON state port. The middle point electrodes 1B and 2B partition each heater into two areas. The heater 1-1 and the heater 2-1 are to switch the two optical paths. The heater 1-2 and the heater 2-2 are to attenuate undesirable light in the OFF state port. The electrical power provided to the heater area 1 is determined by the optimum condition to minimize the insertion loss of the ON state port. At the same time, more power can be

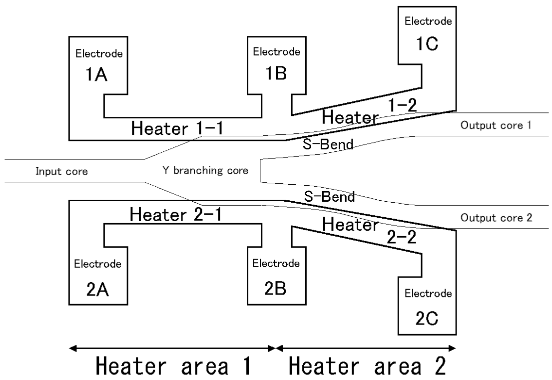


Fig.2 A schematic diagram of the isolation improved 1x2 switch with partitioned heaters.

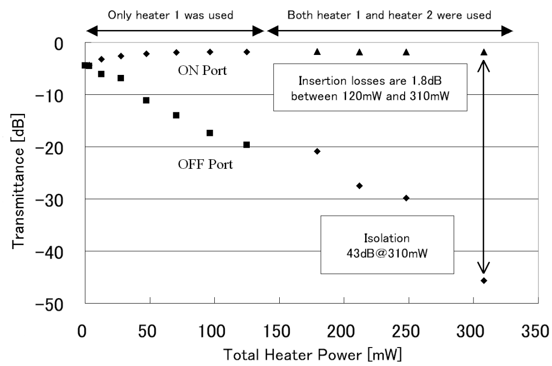


Fig.3 The switching characteristics of the isolation improved 1x2 switch. The high isolation value of 43dB is obtained and the insertion loss is still maintained low.

supplied to the heater area 2 to attain high isolation without affecting the insertion loss of the ON state port. In figure 3, the high isolation value of 43dB is achieved simultaneously with the low insertion loss of 1.8dB at 310mW electrical power. In this case, 120mW is supplied to the heater area 1 and 190mW is supplied to the heater area 2 respectively.

The position of electrode B is very important. For our device, over 40μm distance is suitable between the heater area 2 and the S-bend core of opposite side for sufficient thermal isolation.

### *2.4 Return loss*

The return loss of over 50dB is enough for most applications in the communication systems. In devices of this kind, the undesirable reflection of the signal light may occur at the bonding interface between the PLC device and the fiber arrays. The Y-branching core also has a possibility of reflecting the signal light.

To prevent the reflection at the bonding interface, the edges of the developed PLC and the fiber arrays are cut at the angle of 8 degree. The reflection at the tip of Y-branching core have been reduced by improving the process conditions of Reactive Ion Etching (RIE) and over cladding processes. The improved core pattern with low insertion loss[2] also contributed to the reduction of reflection.

### *2.5 Polarization dependent loss (PDL)*

The PDL of the device investigated here is mainly caused by the birefringence of fluorinated polyimide waveguide. The amount of PDL depends on the core patterns. The PDL of a 1cm long 1x2 Y-branching switch is about 0.4dB and less than 0.1dB/cm for a straight waveguide. The improvement to reduce PDL is still under investigation.

### *2.6 Electrical power*

The requirement of minimum electrical power depends on the temperature dependence of the refractive index and the thermal conductivity of the polymer materials adopted as the waveguide. The optimum temperature gradient should be realized in waveguide layer in steady state. The properties of fluorinated polyimide, such as the large dependence of the refractive index on temperature of $-1.3\times10^{-4}$ /K and the low thermal conductivity of 0.2W/m·K, are suitable to realize low power switches shown here.

### *2.7 Switching time*

The switching time depends on the thermal conductivity and the thickness of the polymer film layer. Because the thermal conductivity of polyimide is as low as about 0.2W/m·K, the switching time of this device is dominated by the thickness of the waveguide layer. We have estimated the switching time by difference calculus computer simulations of heat transfer[1]. When the thickness of fluorinated polyimide waveguide is assumed to be less than 60μm, the switching time can be less than 10ms. The measured switching time for our device is about 8ms. It can be reduced to 1~2ms by decreasing the thickness of the waveguide, but it is difficult to achieve the shorter switching time less than 1ms without the expense of insertion loss.

## 3. Two Input-Two Output (2x2) Thermo-optic Switch

### *3.1 Configuration and characteristics*

More complex optical switching devices can be built from the 1x2 switches. Figure 4 shows the schematic diagram of a 2x2 cross-bar type optical switch device consisting of four 1x2 switch units.

In the cross switching state, the electrical power should be provided to the four outside heaters. The input signal light from the input port #1 is guided to the output port #2 on the opposite side, while the light from the input port #2 is guided to the output port #1.

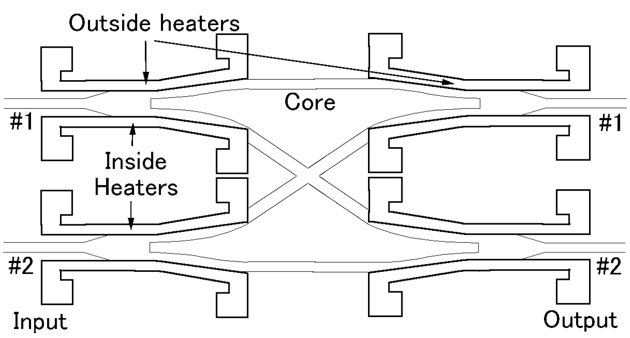

Fig.4 A schematic diagram of 2x2 cross-bar switch.

In the bar switching state, on the other hand, the electrical power is provided to the four inside heaters. The signal lights are guided to the output ports of the same number respectively.

The switching characteristics of the 2x2 switch fabricated are shown in figure 5. There are two switching states (cross and bar) and two input ports, therefore the results of all four measurements are dotted. All of the insertion losses are sufficient low at less than 2.7dB and the high isolations of over 40dB were obtained.

Because the device is a two stage Y-branching device, the switching loss at Y-branching area and the isolation are roughly two times as large as that of a 1x2 switch.

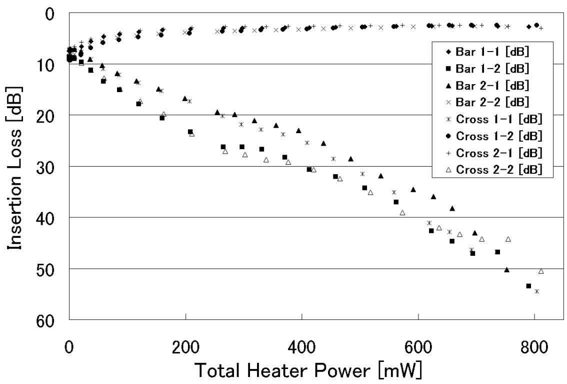


Fig.5 The switching characteristics of a 2x2 switch.

### *3.2 VOA integration*

A Variable Optical Attenuator (VOA) device can also be easily realized using thermo-optic effect. In some applications, VOAs are inserted into each channel in OADMs to equalize the optical powers. So the 2x2 optical switch with an integrated VOA is favorable for OADMs. In our experiment, it was confirmed that a VOA with the sufficient attenuation range of over 10dB can be introduced by adding a heater on the waveguide.

## 4. Conclusion

Polymer Y-branching thermo-optic switches 1x2 and 2x2 were investigated. The fluorinated polyimide 1x2 switch has been successfully demonstrated with the insertion loss as low as 1.8dB and other good optical characteristics. The idea of partitioned heaters has been employed to improve the isolation and over 40dB was achieved without increasing of the insertion loss. The 2x2 switch has been also realized with the low insertion loss of less than 2.7dB and the high isolation of over 40dB. The thermo-optic VOAs with the attenuation range of over 10dB have been integrated with these switching devices. These optical switches are applicable to optical fiber communication networks.

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