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Module Assembly Technology for Optical Multi-Interconnection Devices —InP Based 4 × 4 Optical Switch—

Takeshi KATO, Fumio YUUKI, Hiroaki INOUE,
Ken'ichi MIZUISHI and Koji ISHIDA

Central Research Laboratory, Hitachi Ltd.,
1-280, Kokubunji, Tokyo 185, Japan

ABSTRACT. With an original fiber-coupling method, an InP-based 4 X 4 optical switch array (OSA) module is fabricated. In assembly, precise alignment and secure attachment of fiber-array to the OSA is essential. Presented here is a novel method where the fiber-array is inserted into a Si attachment containing photolithographically defined pyramidal through-holes. This method qualifies as a assembly process suitable for precise alignment and time-saving. To ensure the stability, mechanical strength test and temperature storage test are performed, with promising results.

1. INTRODUCTION

Optical integrated module assembly technology is essential for the successful deployment of optical devices in real systems. Presently, there is a growing demand to increase the throughput of the high speed optical devices. To meet this demand, optical interconnections are multiplying more. For hybrid integration of these devices, technologies for precise alignment and secure attachment between multiple interconnects are being required.

As a key component for optical interconnections, the fiber-array aligned by pyramidal through-holes (APT fiber-array) is presented here. This paper first discusses our original fiber attachment method. This method qualifies as a process suitable for a module assembly. Preliminaly results obtained about mechanical and thermal stability are encouraging for practical use of the fabricated module.

2. MODULE ASSEMBLY PROCESS

2.1 Optical Switch Array

As an optical multi-interconnection device, the InP-based 4 X 4 optical switch array (OSA) was used 1),2). A schematic view of the OSA is shown in Fig.1. All waveguides were single mode InGaAsP/InP ridge waveguides with an estimated mode spot size of $(2.5 \pm 0.5) \times (1.0 \pm 0.2)\ \mu m^2$ for 1.3-μm wavelength. To couple the single-mode fiber-array, the waveguides are spaced 160 ± 0.5 μm apart. The total device size is 1.5-mm wide and 8.1-mm long. Details of the fabrication process have been published elsewhere 1).

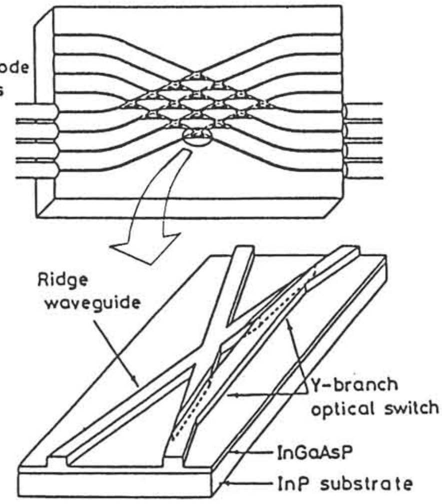


Fig.1 Schematic view of the single slip structure optical switch as a unit cell of an InP-based 4 X 4 optical switch array.

2.2 Fiber-Array Attachment

A Schematic view of the proposed fiber array aligned by pyramidal through-holes (APT fiber-array) is depicted in Fig.2.

Tapered fibers are first located in Si V-grooves, and then the entire fiber array is aligned to interconnect using a Si fiber-array attachment with truncated pyramidal through-holes. The fiber-array tips of the hemispherical lenses are inserted into the through-holes. The single-mode fibers to the OSA had a mode spot size of 5.0 μm, a lens radius of 15 ± 2.5 μm, and a taper angle of 30 ± 1 ° .

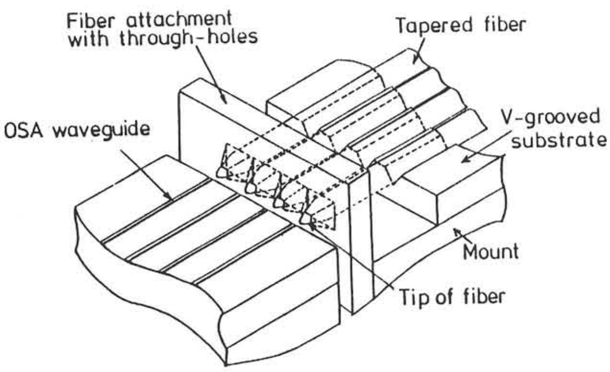


Fig.2 Schematic view of a fiber-array aligned by pyramidal through-holes (APT fiber-array) to OSA waveguides.

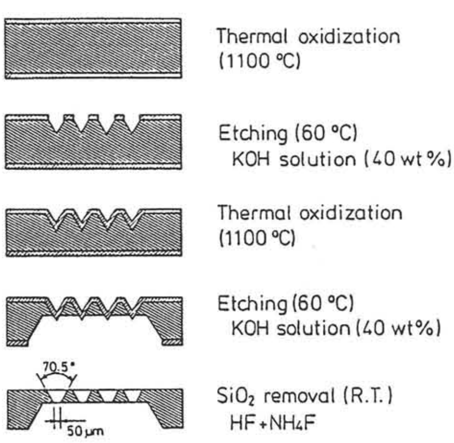
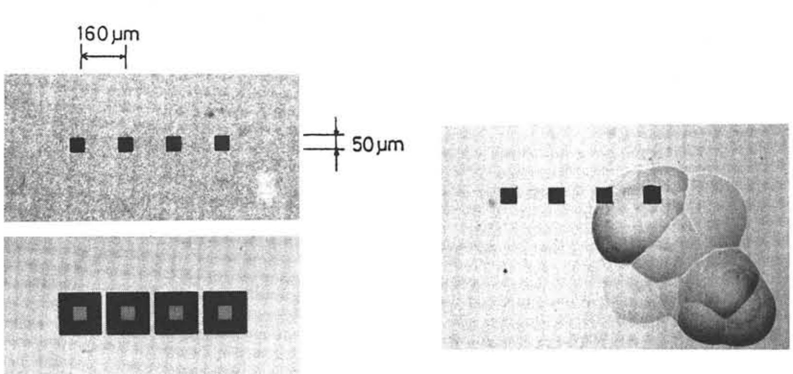


Fig.3 Fabrication process of pyramidal through-holes on a Si substrate.



(a) (b)

Fig.3 Photographs of formed pyramidal through-holes. (a) normal. (b) with irregurarly etched portions.

As shown in Fig.3, the pyramidal through-holes were formed by anisotropic etching of a Si substrate using a thermally oxidized Si (100) surface as a mask. Using a KOH etchant, the pyramidal shaped through-holes surrounded by (111) planes were formed. The fabricated taper angles were 70.5 ° and the through-holes were specified at 50 ± 0.5 μm^2, as shown in Fig.4(a). Since periodic positioning of fibers was determined by a photolithographic process, less than ± 0.5-μm precision alignment was readily attained. Fluctuations in periodicity of the through-holes were within ± 0.2 μm, which corresponded to the accuracy of the photomask used. This technique allowed the alignement of all fibers by adjusting only two fibers of the attachment, even if the fiber-array had a 2-dimensional structure; the other fibers were automattically aligned provided the array was properly fabricated. Thus, manufacturing time can be minimized.

Figure 4(b) shows an example of through-holes with spherically concave portions. These were etched irregurarly due to defects in Si crystal, which lowered the accuracy of the through-holes. Therefore, care must be taken of quality of Si and process conditions.

As seen in Fig.2, the through-hole area of a fiber-Si attachment joint seems to be quite

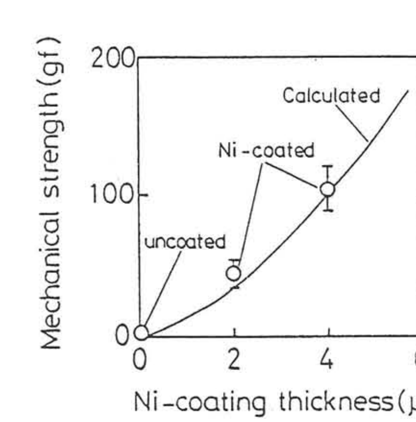


Fig.5 Comparison of mechanical strength between Si attachments with and without Ni-coating. Solid line is a calculated results based on Ni-layer deformation model.

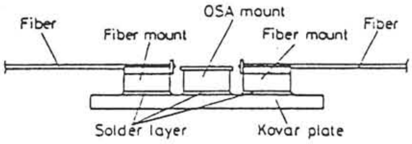
fragile. This is because only four points in the through-hole area are in contact with a fiber tip. To reinforce the mechanical strength, a new method was devised in which the Si surface was plated with Ni. Figure 5 compares the mechanical strength values of individual Si attachments, with and without Ni coating. The results show that Ni-coated (4-μm thick) samples are two orders of magnitude stronger than those without coating. It was found that this improvement was a result of the enlarged contact area caused by the deformation of the Ni layer. That is, the solid state line in Fig.5 is a calculated result which well explanes the experimental results.

Mechanical stress induced by a thermal expantion of the module in the range 25 to 100℃ was estimated at 15 gf. Therefore, Ni-coated Si attachments are expected to have a much higher mechanical stability.

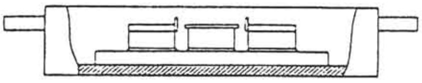
2.3 Fiber-Array Aligning and Attaching Process

A process of aligning and attaching the fiber-arrays to the OSA is shown in Fig.6.

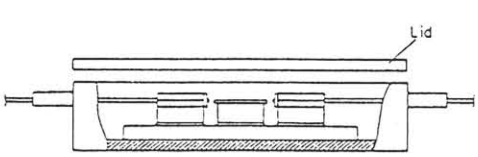
First, a through-holed Si substrate and a V-grooved Si substrate were soldered (with In-Sn eutectic alloy) to a Kovar mount, called a "fiber mount". An OSA chip was also soldered to another Kovar mount, called an "OSA mount".



(a) Alignment by micropositioners



(b) Mount assembly installed in package



(c) Reinsertion of fibers into package

Fig.6 Process of aligning and attaching fiber-arrays to OSA.

These fiber mounts and OSA mount were roughly positioned and soldered to a Kovar plate, prior to the precision alignment process.

While the solder layer on the Kovar plate was still molten, the fiber mounts and OSA mount were independently adjusted by micropositioners.

After obtaining peak power through the fiber-waveguide-fiber in process (a), the temperature was lowered below the eutectic temperature of the solder. When the solder solidified, the fibers were detached from the fiber mounts, and, in process (b), the mount assembly was installed in a package (15-mm wide, 10-mm high, 50-mm long). Finally, the fibers were reinserted into the through-holes of the fiber mount via the holes on each side wall of the package (process (c)).

Figure 7 is a photograph of the complete module without a lid. One may notice that, in the above process, it is unnecessary to adjust multiple fibers in a package. This implysthat the process is more productive and time-saving than the conventional ones, and makes it feasible to use a small package.

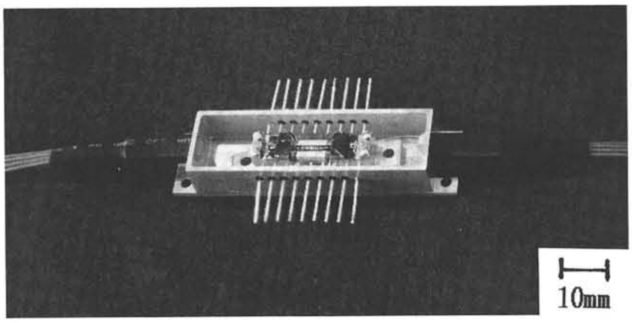


Fig.7 Photograph of complete optical switch module without a lid.

3. OPTICAL SWITCH MODULE CHARACTERISTICS

3.1 Optical Characteristics

The fundamental coupling characteristics of the fabricated module was measured. At a 200-mA injection current, the extinction ratio reached 23.9 dB, the minimum total insertion loss was 23.7 dB, including Fresnel reflection loss.

As shown in Table 1, a coupling loss through fiber-waveguide-fiber was calculated to be 2.8 dB, assuming a hemispherical lens radius of 15 μm, a waveguide-fiber spacing of 25.5 μm, and zero deviations in lateral and longitudinal waveguide-fiber positioning. The calculation formula was based on reference3). With expected and measured values of total insertion loss, an excess loss was found to be less than 1.9 dB. This is a satisfactory figure compared to the results of one input and one output fiber precisely aligned with the conventional method.

Table 1 Classification of insertion loss.

Propagation loss	> 10 dB
Scattering loss	> 6
Fresnel reflection	> 1.5 X 2
Coupling loss	> 1.4 X 2
Total loss (expected)	> 21.8
Total loss (measured)	> 23.7
Excess loss	< 1.9

3.2 Temperature Characteristics

The difference in thermal expantion coefficients between components assembled in a module is a primary cause of mechanical strain. Since a crystal fiber has the lowest thermal expantion coefficient (3.5×10^{-7} deg^{-1}), care must be taken to absorb mechanical strain in the axial direction of the fiber. For this, the section of inside the package was slightly bent as a means of absorbing mechanical strain (see Fig.7).

As an initial temperature storage test condition, temperature characteristic (5- 80℃) of total insertion loss was measured for a complete module, and the result is shown in Fig.8. The result of a 60 ℃ storage test is shown in Fig.9. Deviations were found to be within ± 1 dB.

To gain more insight into the above results, it would necessitate to investigate the reliability of an optical switch itself. Hence, the present study has not yet reached a final conclusion because of a lack of experimental data concerning distinguishable degradation modes of the entire module. However,we believe that the preliminaly data described so far suggest the absence of critical deterioration in the modules developed, which is encouraging for the practical use.

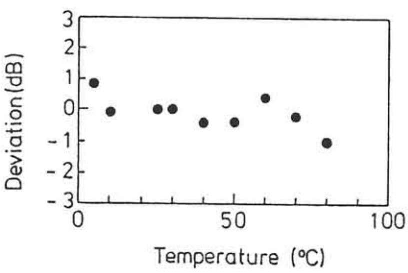


Fig.8 Temperature dependence of total insertion loss for the module.

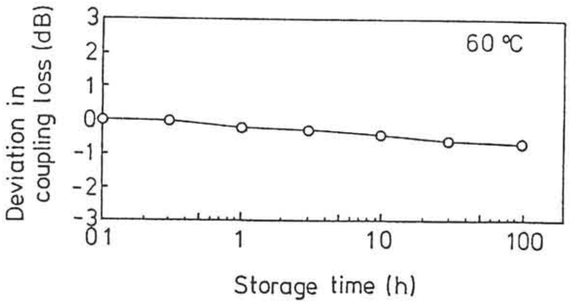


Fig.9 Variation in total insertion loss of the module during 60℃ storage test.

4. CONCLUSION

A novel fiber attachment method was proposed for the assembly of a module composed of an InP-based 4 X 4 optical switch array aligned with single-mode fiber-arrays. Fundamental characteristics of a complete module and several aspects on reliability were described.

This relatively time-saving method was found to be appliciable to efficient fiber-waveguide coupling in single mode with an excess loss of less than 2 dB for a packaged version.

To ensure improved mechanical stability of the fiber-waveguide joint and to examine thermal stability of the solder as adhesive for key components, high temperature storage test(60℃) were conducted, with promising results.

Finally,we believe that the fiber-array attachment, which can align a number of fibers by truncated pyramidal through-holes, will be utilized for future large-scale optical ICs.

5. REFERENCES

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