行政院國家科學委員會專題研究計畫　期中進度報告

新穎全光纖型主被動元件之研究(1/2)

計畫類別：個別型計畫
計畫編號：NSC91-2215-E-009-062-
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計畫主持人：祁甡

計畫參與人員：陳南光,蔡馥宇,林峰生,連偉志

報告類型：精簡報告
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行政院國家科學委員會補助專題研究計畫 □成果報告 🗋期中進度報告

新穎全光纖型主被動元件之研究 (1/2)

The studies of novel all-fiber active and passive components (1/2)

計畫類別：🗋 個別型計畫　　□ 整合型計畫
計畫編號：NSC 91－2215－E－009－062
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計畫主持人：祁甡教授
共同主持人：
計畫參與人員：陳南光、蔡馥宇、林峰生、連偉志

成果報告類型(依經費核定清單規定繳交)：🗋精簡報告　□完整報告

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中華民國 92 年 5 月 28 日

行政院國家科學委員會補助專題研究計劃期中報告

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一、中文摘要

全光纖型波長多工元件的波長通道間隔與極化效應是攸關光纖通訊能否成功邁向高密度及高碼速 OG-768 (40 Gb/s) 傳輸系統的最主要因素之一。本計劃第一年的研究方向即在於製作高性能之光纖消逝場型側磨光纖元件並用以製作極化等向窄波道光纖元件及光塞取多工器。光纖元件的製作方法是利用自行研發之電弧式光纖熔燒拉錐機來完成，除可以有效避免傳統方法中氫氧基離子所造成的損耗外並可以成功地製作機械強度穩固之光纖耦合器。基此，可任意操作於光通訊全頻帶範圍 (1260 nm ~ 1675 nm) 及應用於 CWDM 或 DWDM 通訊系統的全光纖型窄波道元件即將可以輕易地實現。

關鍵詞：極化等向波長多工器、光塞取多工器、熔合-側磨光纖耦合器、電弧熔燒拉錐機

Abstract

Polarization isotropy is crucial to achieve all-fiber narrow channel wavelength separation WDM couplers that are the key access to high density and high-bit-rate, e.g., 40 Gb/s, fiber-optic communication systems. The aims of this project are to fabricate polarization isotropic narrow channel separation fiber devices and the add-drop multiplexers based on high-performance side-polished fiber components. The fabrication method of the fiber devices is based on our newly designed arc fusion tapering station. The advantages are to make fiber devices free from the diffused OH$^-$ ions induced losses introduced by conventional flame fusion and capable of operating over all the transmission windows, namely the O, E, S, C, L, U bands and, potentially, in CWDM or DWDM systems.

Keywords：polarization isotropy WDM couplers、add-drop multiplexers、fused-polished fiber couplers、arc fusion tapering station。

二、緣由與目的

In fiber-optic communication systems, various kinds of passive components are employed for certain functions. Among them, fiber couplers are the most essential components. They usually serve as power dividers and wavelength multiplexers while those specially made can act as spectral filters [1] or polarization beamsplitters [2]. All-fiber add-drop multiplexer is also another kind of important component. It can be fulfilled based on the fiber couplers [3-5] and plays the role as a simple form of a wavelength router where a specific wavelength is added to or dropped from incoming signal streams. It has significantly improved the flexibility in signals routing and system managements for fiber-optic networks.

In contrast to integrated-optic devices, all-fiber components are intrinsically advantageous to prevent extra coupling losses derived from waveguide discontinuity, alleviate substantial polarization birefringence originated in non-cylindrical symmetry and are free of the sophisticated alignment works during fabrication. Nowadays, fiber couplers are able to operate anywhere from 1.2 μm to 1.7 μm wavelength region due to the advent of zero-OH fibers [6]. To make efficient use of the transmission capacity, narrow channel separation WDM couplers and add-drop multiplexers are important and, indeed, their characters are respectively relevant to the retained polarization birefringence and the excited cladding modes of the couplers and, of course, the fabrication methods.

Generally, three major fabrication methods have been demonstrated to make fiber couplers [7-9]. The first method is to fuse by using flame and then to adiabatically taper two adjacent unjacketed fibers being allied [7]. As a result, these couplers are named fused-tapered couplers and are typically with insertion loss below 0.5 dB and channel isolation below 30 dB contingent upon the operating wavelength. However, higher order core modes are converted to cladding modes due to the guiding structure of the reduced cladding. This could make some troubles to, for example, the fused type all-fiber add-drop multiplexers, where a tilted Bragg grating inscribed with a critical angle is considerably an issue for fabrication [3-4]. Moreover, the form birefringence induced polarization anisotropy [10-11] and the diffused OH^- ions caused losses [12] are also non-negligible problems for long elongated fused-tapered couplers. This is disadvantageous to achieve narrow channel wavelength separation fiber couplers capable of using in high-bit-rate, e.g., 40 Gb/s, fiber-optic communication systems and over all the transmission widows.

The rest of methods are based on fiber side-polishing [8] and laser microstructuring [9], respectively. For the former, fibers are partially polished to access evanescent field and such two polished half-couplers are then superposed as a full-coupler. But, both in controlling a precise polishing depth and working on the subsequent alignment are time-consuming and tedious. Also, the essential index-matching fluid is an ill for stability [8]. For the latter, a fiber micro-coupler with an interaction length of 200 μm based on tapered fibers by a focused CO_2 laser beam was reported [9]. However, a long interaction length is absolutely needed for narrow channel wavelength separation couplers.

Fused-polished couplers are exempt from the aforementioned issues and had been proposed by means of an abrasive wheel and an oxy-butane flame [13]. Nevertheless, a thin layer of sol-gel made silica filling was recommended to be deposited inside the interface of the fiber assembly for a successful fusion. Accordingly, insertion loss, mechanical strength and a long interaction length turned out to be difficult. Here, we report on fabricating fused-polished fiber couplers with a long interaction length by a unique arc processing method. Based on this, fused-polished fiber couplers not only show promising in advanced WDM components fabrication but also exhibit potential as excellent sub-components for all-fiber devices, e.g., the add-drop multiplexers.

三、結果與討論

(I) High performance polished fiber half-couplers

A long effective interaction length is crucial to achieve narrow channel separation WDM couplers but is not easy to acquire, typically around 2 ~ 3 mm [8, 14], for polished fibers based on glass substrates. As a good substitute, we choose silicon wafers as our polishing substrates where multiple, precision curved V-grooves are made using standard microelectronic techniques. Corning SMF-28 standard fibers are bonded into these grooves with a specific curvature. By using our home-made polisher, the exposed cladding of the unjacketed part is then polished away until the strong evanescent field is accessed. The remained cladding thickness is normally set to be around 0.5 μm and the extinction ratio was tested above 70 dB at 632.8 nm wavelength. The insertion loss of these half-couplers is typically measured below 0.1 dB and the detailed characterizations of these polished half-couplers are referred to [15]. Since our continuous devotions to these works, we are able to simultaneously fabricate 6 well-polished fibers within 20 minutes. An effective interaction length as long as 20 mm at 1.55-μm [15] and their surface roughness, examined by AFM, better than a few tenths of nanometers were also achieved.

(II) WDM couplers

Mating two side-polished fibers together can achieve an evanescent-field device and details of the coupling and wavelength multiplexing principles were described well by Digonnet *et al.* [8]. Our interesting devices are 1310/1550-nm and 1480/1550-nm WDM couplers. Based on our simulation, L_{eff} is around 4~5 mm for 1310/1550-nm combiners and is around 2 cm for 1480/1550-nm. We choose R of curved-fibers of 800cm and 5,000 cm for 1310/1550-nm and 1480/1550-nm combiners, respectively. The curvatures are much larger than any radius of curvature of side-polished fibers ever been reported [8,13]. On our silicon wafers, there are two sets of patterns: one for fibers to be side-polished and another for alignment purpose. The width of the former pattern is gradually widened from its central region [16]. The width of the latter pattern, located on both sides of the former pattern, is constant. Two pieces of these samples are to be assembled as a WDM coupler. In either of them, we load two unjacketed fibers into each of the two straight alignment grooves as the locking mechanism. Note that the depth of alignment grooves is so accurately designed and fabricated that exactly a half of the locking fiber is beneath the silicon surface. Next, we take another piece of the sliced wafer and then put it onto the top of the former wafer with their polished surfaces in contact.

A 1310-nm and a 1550-nm laser diode are used as our light sources and the outputs are monitored by an optical spectrum analyzer. For a WDM coupler, three power levels are measured. First, we measure each of the transmitted ports of the two side-polished fibers and then measure these two mated side-polished fibers to be acted as a WDM coupler. Because the flatness of our samples are good, we can achieve good contact between these two mated side-polished fibers without difficulty. Owing to photolithography and anisotropic etching, the accuracy of the transverse alignment of our devices two patterned wafers can be better than 0.5 μm and thereby we immediately observe the coupling of from one port or the adjacent port and vice versa when two polished-fibers are mated together. We tune the device along its longitudinal direction to get the optimal coupling. The whole alignment and tuning procedures can be finished in minutes. Our experimentally measured results are given in Fig. 1 and Fig. 2 where the two side-polished fibers are mated and tuned as a WDM coupler. Our measured results agree quite well with our simulation results [16]. We also measured PDL by using the polarization controller and found the polarization dependent loss is below 0.02 dB.

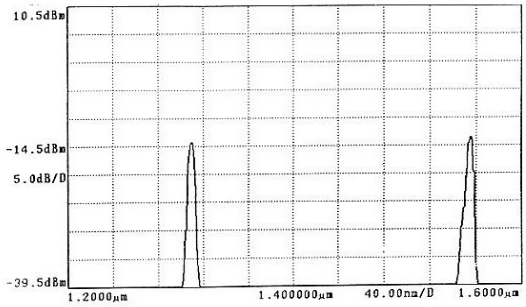

Fig. 1. Output spectrum of the 1310/1550-nm WDM coupler.

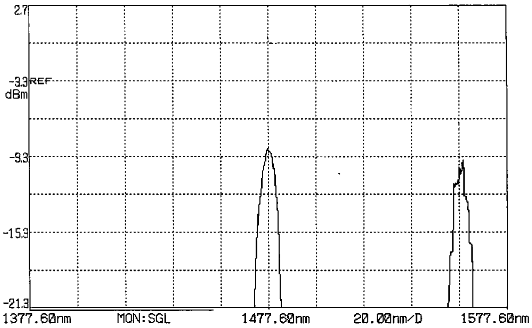

Fig. 2. Output spectrum of the 1480/1550-nm WDM coupler.

(III) Fiber demultiplexers

Fiber de-multiplexers can be realized by introducing a Bragg grating into the coupling section of a fused-tapered coupler or a side-polished coupler. Fabricating fiber Bragg gratings onto the elongated waist of a fused coupler were reported [3,4]. Although such a device could show low insertion loss, the cleanness of the drop channel was in question owing to the intrinsic nature of the elongated waist. To achieve a large reflectance, gratings should be tilted by a small and precise degree with respect to the axial direction.

Instead, we polish fibers in silicon V groves having radii of curvature of 800 cm and 1,200 cm where the single-mode, photosensitive fibers for 1.55 μm with a numerical aperture of 0.13 are used. Some of them have UV-induced intra-core fiber Bragg gratings of reflectance of about 98.5% and with $L_g \cong 10$ mm long. In polishing, a fiber should be glued in the groove of a certain radius of curvature of a substrate. Such curved fibers have a position dependent interaction, thereby degrading the light spectra of the assembled filter. To alleviate this negative effect, a long radius of curvature is helpful. We choose two side-polished fibers with the same photosensitive fibers, with and without a Bragg grating, respectively. The C-band ASE light source is injected into the fiber with a Bragg grating and the reflected light spectra taken from another leading port, acted as the drop port and without a Bragg grating, are scanned and recorded.

The measured characteristics of de-multiplexers made of 800-cm and 1,200-cm curved side-polished fibers look similar and the insertion losses can be negligibly small, e.g., less than 0.1 dB. Figure 3 shows transmission spectrum of the half coupler with 800-cm curvature and a Bragg grating inside, before mating to be a de-multiplexer. Apparently, this device is featured with a much smaller bandwidth of filtered signals, shown in Fig. 4, when compared with those using glass or quartz polishing substrates [5]. This result is expected due to our longer interaction length. The present devices can act as fiber add/drop multiplexers provided that two fibers are identical and the phase condition for a non-Bragg signal can be met simultaneously. However, our devices cannot act as good add/drop multiplexers, shown in Fig. 5, because a right L_g [5] to meet the demands for phase-matching condition among output ports cannot be obtained from our supplier, currently.

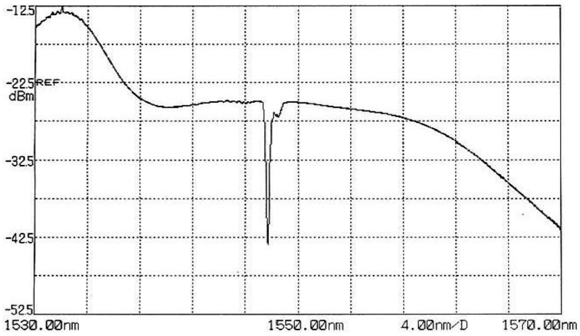

Fig. 3. Transmission spectrum of the half coupler with Bragg grating inside.

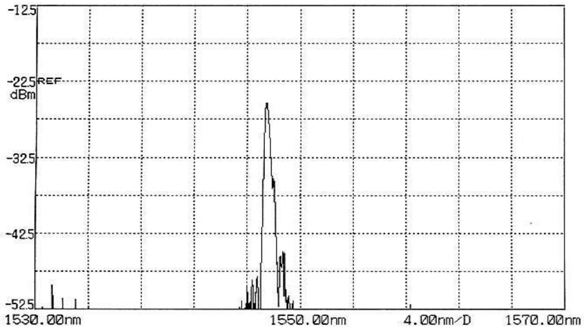

Fig. 4. Dropped signal spectrum of our filters.

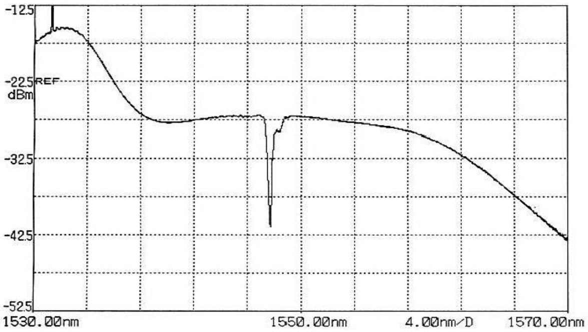

Fig. 5. Transmission spectrum of our filters.

(IV) Fused-polished fiber couplers

Fused-polished fiber couplers own the individual advantages of fiber couplers made from fused-biconical-tapering and side-polishing technique, respectively. The polarization isotropy, long interaction length and strong mechanical strength can achieve high-performance novel WDM components. The fabrication processes are as follows. The bilateral leading fibers of the polished fibers are point-bonded onto an alignment jig while each polished orientation is exactly kept upward. Silicon substrate is taken away by chemicals and the polished fibers should be thoroughly cleaned and dried. Then, superpose such two samples together as a full-coupler and finely adjust the bonded positions to make the polished fibers slightly curved. In this way, the polished surfaces can be made closely contact and the polishing induced stresses [13] can be then nullified during heating processes. Except the contact issue, polished surfaces can transversely lie alongside owing to the designed alignment jigs. Afterwards, this fiber assembly is loaded onto the stage of our home-made fusion station for further treatments of arc.

In our fusion station, the specially made electrodes are carried by a precision stepping motor and can be used in oxidizing atmosphere for a long time. The discharging intensity and duration can be programmed and adjusted in rapid cycles by PLC (programmable logical controller) circuits. The diameter of the discharging field is about 1 mm with the temperature of higher than 1500°C when releasing energy to fibers. It’s worthy noting that unlike the flame fusion, arc will not produce large quantity of moisture [12], give rise to a regional airflow and will not have the long elongated fibers to be bending downward by gravity.

In the beginning of processing, we use a fast-moving, 6.8 mm/s, and intensity-adequate, ~ 1200°C, arc to clean fiber assembly and then gradually elevate the current to reach 1500°C for thorough fusion between silica fibers. A He-Ne laser light is launched into the two input ports for monitoring. Continuously, the intense arc is moving along the interface of the fiber assembly at the speed of 410 μm/s, back and forth, until the in situ monitored He-Ne laser light fade out to extinguish, observed from the side-view of the fused region. This means that the polished surfaces are completely merged and no defect-derived scattering is existed any more. Again, the fused region is re-bathed in a moderate arc, ~ 900°C, at the speed of 350 μm/s, for annealing purpose which eliminates potential stresses. Fiber coupler with a fusion length of around 2 cm is therefore accomplished and it totally takes about 3 minutes for each round of arc processing by our preliminary recipes. Eventually, the unjacketed part of the fused fiber assembly is recoated with UV-curable acrylate as a package. The side-view and the cross-sectional view of the fused-polished fiber couplers are shown in Fig. 6 and Fig. 7, respectively.

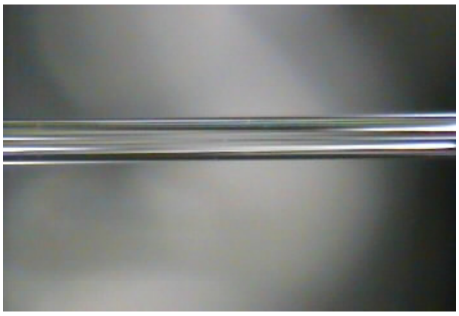

Fig. 6. Side-view of the fused-polished region.

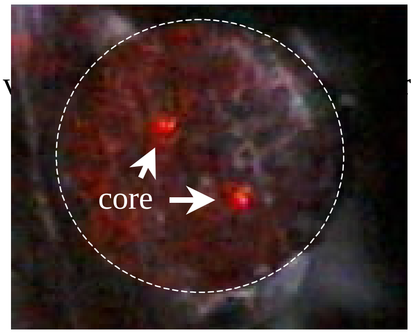

Fig. 7. Cross-sectional v r coupler.

四、成果自評

本計劃執行期間，我們成功地製作出高品質且有效側磨長度高達 20 mm 的側磨光纖元件，相較於目前歐美各學術研究單位及商業公司的 2 ~ 3 mm 長度，我們擁有極佳的潛力製造各式新穎全光纖型元件。此外，由我們實驗室獨力研發的新穎電弧式光纖熔燒拉錐機亦成功地驗證用以製作光纖耦合器的高度可行性及其相較於火焰熔燒方法的諸多優點。基此，電弧式熔燒拉錐機具有極強的競爭力來取代目前普遍使用的火焰式機台。在此計劃期間，我們亦提出了三個台灣/美國專利及一個中國大陸專利的申請，一篇國內期刊論文以及兩篇國際期刊論文被接受。因為研發新穎光纖製作工具極其耗費時間的關係，我們相關的論文目前正在改寫並準備投稿 SCI 論文當中，但我們已經成功地驗證了製作適用於高密度及高碼速通訊系統的新穎全光纖型元件之高度可行性。

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