Dual-wavelength Fibre Biconic Tapering Technology

W. L. Lim, E. C. Neo, Y. Zhang and C. Wen

Abstract – A novel technique used to improve current coupling workstations to fabricate dual-wavelength fibre couplers is presented. This new design can be added on any coupling fusion machine for the fabrication of wide-band fibre couplers. The detailed optical characterization of fibre couplers is presented together with the comparison between the existing coupling workstations and the developed new design.

Keywords: Fibre coupling, Dual wavelength, Fibre fabrication, Mode coupling

1 BACKGROUND

Over the past few years there has been a growing interest in the use of optical fibres for sensing, precision measurements, and information transmission. In order to improve the bandwidth and flexibility of manipulating optical signals, the industry responds with fabrication of multi-port fibre devices to divide or combine transmission signals, called wavelength-division multiplexing (WDM), which sends multiple wavelengths signals per fibre. As a building block component, fibre couplers play a critical role in the implementation of all optical WDM filters such as spectrum equalizers, optical time-delay lines, fibre interferometers, and so on.

In practice, fibre couplers are fabricated using the fused biconic taper (FBT) technology that is implemented on an automatic fusion coupling workstation [1-2]. Using the FBT technology, two pieces of fibres are stretched and fused. The coupling ratio is monitored through sending light at one end of fibres and detecting the output power at another ends. However, the conventional FBT process is designed for controlling a constant coupling ratio for one wavelength incident light. The resultant fibre couplers have different splitting ratios for other multiple-wavelengths input light, the output would suffer power unbalancing. Thus, ones expect to have fibre couplers with an identical coupling ratio for multiple wavelengths. This gives rise to the need to develop a new FBT technology to fabricate such fibre-couplers.

2 OBJECTIVE

This report presents a new FBT technology that is developed on a commercial fibre coupling workstation to fabricate dual-wavelengths fibre couplers. The proposed FBT technology is designed by using the mode coupling theory, and it is implemented by modifying the power analysing module and the fusion control process of a commercial fibre coupling station.

3 METHODOLOGY

An automatic FBT system usually consists of several modules including the laser source module, the fibre fusion process module, and the optical power analysing module.

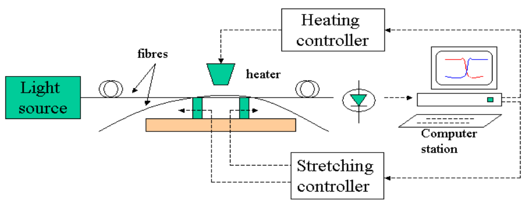

Fig. 1. Schematic illustration of fusing fibre couplers by the FBT technology.

The model of the fused biconic taper (FBT) process relies on a number of simplified assumptions. One of the most common assumptions is that the electromagnetic field of the light becomes detached from the core of the original fibre in the taper region indicated in Fig. 2 [3].

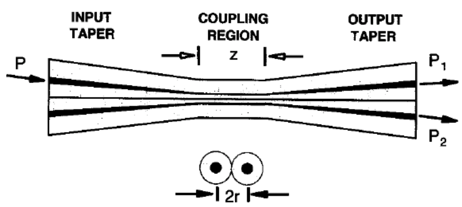

Fig. 2. Schematic diagram of a fused fibre coupler.

In the region between the two tapers, the former cores and the inner claddings of two fibres are melted as the core of the coupler and the outside claddings of two fibres form the cladding of the coupler. As the fibre is de-tapered, the process reverses and the light once again is bound in the original fibre. If the tapers are gradual enough, then the loss will be very low. The speed of the tapers will be controlled by the stretch speed of the FBT coupler workstation. This is because light is detached from the original core in the region between the tapers; the light is accessible from the outside. That means that the evanescent field of the light wave extends into the surrounding medium. If another similarly tapered fibre is brought into close proximity to the first fibre then light can couple from the first fibre to the second and from the second fibre to the first.

The key point to obtain the FBT technology for fabricating multiple-wavelengths fibre couplers is the design of a power analysing module to monitor the splitting ratios for each wavelength simultaneously when the fibres are being fused. The development of such a power analysing mechanism is illustrated as follows. First, we present the mode coupling theory that is fundamental to making fibre couplers by the FBT technology. Then, we will illustrate the design of the splitting ratio monitoring mechanism.

3.1 Mode coupling theory

As coupling of the fibres can be regarded as a beating of the two lowest order modes of the composite glass structure, Ankiewicz [4] showed that power transferred from the first fibre to the second is given by

$$P = F^2 \sin^2 (Kz / F) \qquad (1)$$

where F^2 is the maximum power transferred, K is the coupling coefficient, and z is the coupling length (elongation) [5].

As seen, the determination of the coupling coefficient K cannot easily be calculated. However, using the fact that the scalar approximation can be used in the taper waist region and due to the fact that the waist structure in highly multimode (large V number), T. A. Birks [1] approximates the coupling coefficient to be equal to

$$|K| = \frac{3\pi^3 \lambda}{128 r^2 \mathrm{k} n_{cl}} \qquad (2)$$

where r is the radius o f the taper waist and k is the propagation constant in vacuum.

If the composite structure is heated and stretched to further reduce the radii of the fibres, then the coupling coefficient as well as the maximum power transfer will change. Based on the assumption that two reduced cores are just in contact as in the Fig. 2 above and the radii of the fibres decrease exponentially with increasing elongation, one can show that the first complete power transfer from one output arm to the other one occurs for z = L with:

$$L = \frac{2}{\pi\, |K(L)|} \qquad (3)$$

$$F = \left[1 + \left(br^3 / \lambda^3\right)\left(\Delta r / r\right)^2\right]^{-1} \qquad (4)$$

where Δr is the difference in radius of the two fibres.

It should be noted that F=1 is the largest value when the two fibres are identical. For F = 0, the two couplers are tangent to each other and no coupling occurs. So if F is close to unity results in a strong coupling while a small value of F leads to a weak coupling, the degree of fusion depends on the tapering process duration and the speed of elongation stage used to pull the couplers.

Since the two fibres are fused together in the heating and elongation process, the coupling ratio achieved when the process is stopped is very stable against temperature since the configuration is frozen in the glass structure.

3.1.1 Power oscillations during coupling

This is only for the case when both fibres used are identical, therefore, F = 1, the power at the end of the fibres is:

$$P_1(z) = P \cos^2(\theta) \qquad (5)$$

$$P_2(z) = P \sin^2(\theta) \qquad (6)$$

where the coupling angle, **θ (z) ≈ |K|z**, and it can be seen from (2) that the output power (6) is dependent on the elongation z, the tapered waist r, the wavelength λ and the cladding refractive index n_{cl}. This makes the output power of the coupler an oscillatory function of these parameters that is mainly the wavelength as seen in Fig. 3 [5].

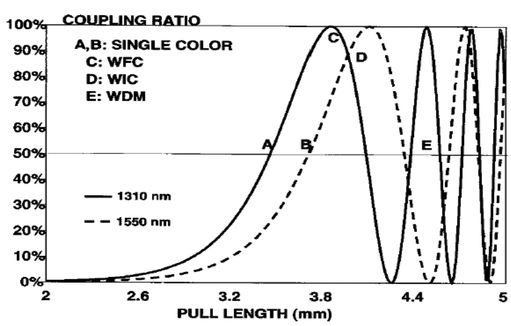

Fig. 3. Coupling ratio as a function of pull length for a fused biconical taper (FBT) coupler.

3.1.2 Frequency of power oscillations during coupling

The fused-fibre couplers described are dependent on the wavelength of light used to monitor fusion of the fibre coupler. The amount of light transferred depends on the length of the coupling region, as measured in wavelengths. Over some characteristic distance, the light transferred completely from one output to the other.

From (2), (5), and (6), we can calculate that during coupling for shorter wavelengths such as 1310 nm, the power at the output ports will experience more oscillations and for 1550 nm, the power will experience fewer oscillations. Therefore, it can be seen in Fig. 3 that the number of cycles for the 1310 nm is more compact than the cycles of 1550 nm. This opens a way to achieve a coupling ratio that will separate the wavelengths.

3.1.1 Coupling ratio for two wavelengths

The coupling ratio can be seen as a function of the pull distance for two different wavelengths as shown in the above Fig. 3. The coupling ratio is able to oscillate back and forth between zero and one hundred percent.

At point A, power is split equally (3 dB splitter) for wavelength 1 (for example, 1310 nm). At point B, power is split equally (3 dB splitter) for wavelength 2 (for example, 1550 nm), at the same time about 90% of the power has already been transferred to the second fibre at wavelength 1.

If the elongation stops at point E, then the coupling ratio is 0% at wavelength 2 and 100% at wavelength 1. Thus, this device can be use either as a wavelength division multiplexer (WDM) or as a de-multiplexer. If the two wavelengths are inputs to the device on different ports, then they will appear on the same output port. If they are inputs on the same port, then the two wavelengths will appear on separate output ports. This is what we want to achieve – separation of two wavelengths.

3.3 Setup for the WDM separators/combiners workstation

The schematic of the new FBT system proposed is shown in Fig. 4 and it is briefly described as follows: two laser beams with different wavelengths are combined into a single fibre, and each of the wavelengths will be split and emitted from the two outputs of the coupler under fusion. The two output lights are separated again through four specially designed fibre couplers and detected by photo-detectors (PD) respectively. The intensity distributions of the four detectors are then converted to digital signals, displayed in computer through LabVIEW programming, and used to control the coupling workstation.

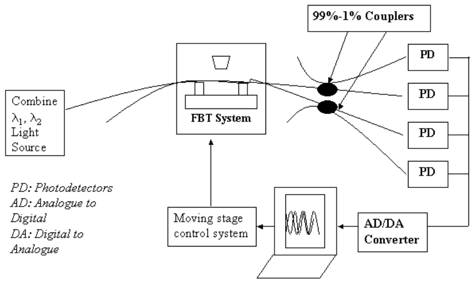

Fig. 4. Schematic illustration of the dual wavelength FBT system.

The key problem anticipated was to be able to effectively separate the two channel powers effectively. This would mean a maximum power for 1310 nm and a minimum power for 1510 nm in one channel and vice versa. The accepted standard adopted for our research was actually a 20 dB difference. In other words, one channel should contain 20 dB higher 1310 nm light than 1510 nm and vice versa. This would mean that for any one channel, it contains about 99% power of one wavelength and 1% of the other.

The use of the 99%-1% (Coupler 1 and Coupler 2) is important because the photo-detectors were not able to differentiate the power at 1310 nm or 1550 nm. It will only detect the power output on the whole, which is the summation of the power of both wavelengths. Thus, without the 99%-1% couplers splitting the light intensity according to their wavelengths, it would not be possible to monitor their respective splitting ratios.

The 99%-1% couplers were fabricated using the standard FBT technology for single wavelength. These two couplers will separate the light intensity of 1310 nm and 1550 nm from the output of the fabricated coupler. Thus, we are able to identify which different wavelengths for the different outputs.

Following, the photo-detectors at the outputs would be able to effectively convert the light intensities at their specific wavelengths: 1310 nm and 1550 nm to electric signals that can be acquired. The coupler can then be fabricated as the mechanism for monitoring their splitting ratios is achieved.

4 RESULTS & DISCUSSION

Based on the schematic design as shown in Fig. 4, the proposed FBT technology is implemented on a commercial fibre fusion coupling station. It is accomplished by developing a dual wavelength power analyser to monitor the output light power splitting ratios. This module consists of two 99:1 fibre couplers and four photo-detectors. Fig. 5 shows the outlook and the inside circuits of the prototype.

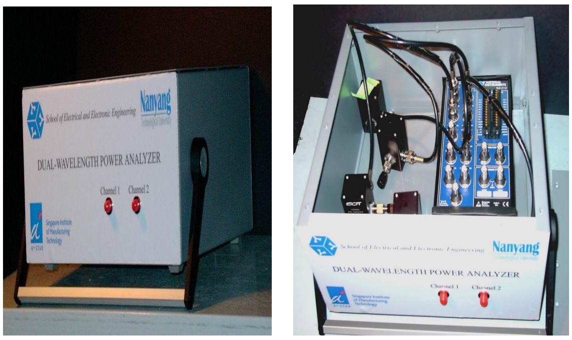

Fig. 5. Prototype of the dual-wavelength power analyser module.

To integrate the developed module with the existing station to form an automatic fibre fusion coupling workstation, a LabView based graphics user interface (GUI) is built as well. It provides a friendly interface to monitor and control the fusion progress. A typical environment is shown in Fig. 6.

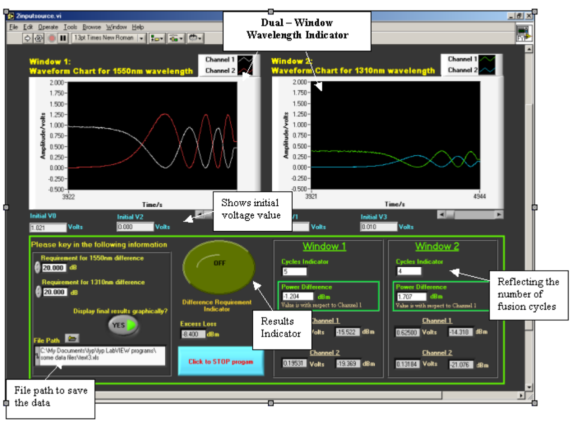

Fig. 6. GUI of the developed fibre fusion coupling workstation.

The effectiveness of the developed station is tested by fabricating dual-wavelengths fibre couplers with different ratios. The repeatability of the system is also performed by repeating the fabrication of fibre couplers with 99:1 coupling ration for 1550 nm and 1310 nm input lights. The coupling ratios of the couplers are also measured for each wavelength by an optical spectrum analyser. Table 1, Table 2 and Table 3 show some of the results for the 99%-1% couplers.

Table 1. Coupling power readings obtained by the proposed FTB and the OSA.

Difference of the interested power levels as seen on OSA					
Channels	1310	1550	Channels	1550	1310
1550-Input1	-40.11	-36.839	1310-Input1	-36.9	-15.23
1550-Input2	-52.74	-15.34	1310-Input2	-37.48	-39.27
Input 1 – Input 2		-21.499	Input 1 – Input 2		24.04
LabVIEW Reading					
Input 1 – Input 2		-20.35	Input 1 – Input 2		26.70

Table 2. Coupling power readings obtained by the proposed FTB and the OSA.

Difference of the interested power levels as seen on OSA					
Channels	1310	1550	Channels	1550	1310
1550-nput1	-44.21	-35.67	1310nput1	-37.2	-13.23
1550-input2	-50.17	-14.46	1310Input2	-38.68	-36.37
Input 1 – Input 2		-21.12	Input 1 – Input 2		23.14
LabVIEW Reading					
Input 1 – Input 2		-22.49	Input 1 – Input 2		25.60

Table 3. Coupling power readings obtained by the proposed FTB and the OSA.

Difference of the interested power levels as seen on OSA					
Channels	1310	1550	Channels	1550	1310
1550-nput1	-41.21	-36.96	1310-nput1	-37	-14.50
1550-nput2	-51.57	-15.69	1310-nput2	-37.68	-35.35
Input 1 – Input 2		-21.23	Input 1 – Input 2		20.15
LabVIEW Reading					
Input 1 – Input 2		-23.79	Input 1 – Input 2		23.41

The data in tables are not exhaustive but representative values obtained over the whole range possible. The results have shown that the differences in power obtained from LabVIEW and the OSA are about the same for each instance. Due to the restriction on the sensitivity and the performance of the equipment used, the results are considered acceptable. Also with the source and the output ports reversed, the results are also about the same. This implies that the couplers fabricated are bi-directional. These results also confirm that the developed workstation is stable and accurate and thus has the capability of being commercialised.

5 CONCLUSION

A new and efficient system to fabricate two wavelengths fused fibre couplers is presented. The results showed that accurate and repeatable coupling ratios of the dual-wavelength couplers can be achieved. In some cases, the results can be comparable or even better than commercial devices. Thus this technology has been proven to be effective and practical. The automatic FBT system achieved can help to reduce significantly the labour, time and costs required to manufacture dual-wavelength couplers.

Even though the presented FBT technology is designed and implemented with concentration on a two-window 2-by-2 fused fibre coupler, it serves only as a platform for more applications. With the same concept derived here, a similar approach can be undertaken to fabricate multiple window fused fibre couplers, WDM, and even broadband light source applications.

6 INDUSTRIAL SIGNIFICANCE

The presented FBT technology provides an effective means to fabricate fibre couplers with the same coupling ratios for multiple wavelengths. As the developed FBT technology can be implemented in an automatic way, it is of greatly meaning to enhance competence of manufacturing of fibre components.

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