Coupling Ratio and Power Transmission to Core and Cladding Structure for a Fused Single Mode Fiber

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Abstract

The development of Single Mode Fiber (SMF) greatly expands in industrial purposes to reach high efficiency and its performance on communication and computer devices. One of important effects is described in this paper namely the fabrication of SMF by unstable fire torch at range temperature 800°C to 1300°C injected by hydrogen gas flowing at pressure of 1 bar. A coupling ratio of SMF with different ranges is investigated for both core and cladding structure before and after fusion. The pulling length and power transmission are compared to coupling ratio to obtain interesting phenomena which are split by the Y junction. This result is used to develop a wave model propagating along the fiber to core and cladding. The model is used to identify the fractional power of the core and cladding.

***Keywords*:** single mode fiber, coupling ratio, power transmission, pulling length

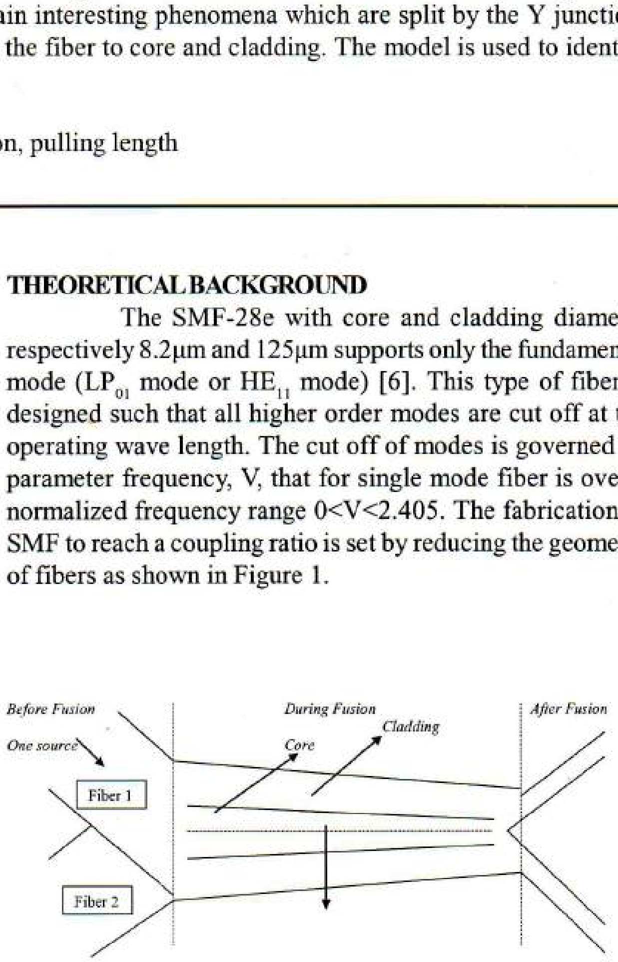
INTRODUCTION

In the past two decades, single-mode fibers (SMF) have emerged as a visible means for fiber optic communication. They have become the most widely use fiber optic type, especially for long-haul communications [1,2]. The major reason for this is that they exhibit the largest transmission bandwidth, high quality transfer or signals because of the absence of modal noise, very low attenuation, compatibility with integrated optics technology, and long expected installation lifetime. Several applications for SMF have been proposed and used as a coupler, such as an optical power divider, a combiner, an optical switch and a modulator. Couplers are devices that are used to combine and split optical signals [3]. A simple 1x2 coupler consists of one input port and two output ports, as shown in figure 1. It can be made by fusing two optical fibers together in the middle and then stretching them so that a coupling region is created. Such devices can be made wavelength independent over a wide spectral range. Thus an optical signal launched at input port 1 may be split into two signals that can be collected at output ports 1 and 2. The fraction of power available at output power is called the coupling ratio in the range 1:99 to 50:50.

A fabricated SMF by flame greatly expands for industrial purposes in communications and computers. Beside the power can be split, the excess loss and insertion loss are very low. However, a mechanism process to obtain the coupled SMF is always described at initial input and output result, whereas the wave source transmitting to a photo detector has not been explained in more details. When a coupling ratio is achieved a process will stop. The processes are to fire the coupled two fibers to soften them, to stretch fibers by a vacuum pump to reach a line and to pull the length of fibers to reduce the diameter size. A process to fabricate SMF is most important effect to reach good results [4,5]. This paper describes how the diameter of fibers influences coupling ratio in Y junction.

THEORETICAL BACKGROUND

The SMF-28e with core and cladding diameter respectively 8.2μm and 125μm supports only the fundamental mode (LP_{01} mode or HE_{11} mode) [6]. This type of fiber is designed such that all higher order modes are cut off at the operating wave length. The cut off of modes is governed by parameter frequency, V, that for single mode fiber is over a normalized frequency range $0<V<2.405$. The fabrication of SMF to reach a coupling ratio is set by reducing the geometry of fibers as shown in Figure 1.



Boundary between Fiber 1 and Fiber 2
Figure 1. Illustration of Y junction

The coupling mechanism is normally analyzed using electromagnetic theory for dielectric waveguides. Laser diode [7] (E and H) travels to a fiber as a cylindrical waveguide to both core and cladding diameter. Scalar wave (E, H) fulfills the wave equation $\nabla^{2}\Psi = \varepsilon_{0}\mu_{0}n^{2}\, [“^{2}\Psi\, /\, “t^{2}]$ with a general solution is $\Psi(r, \phi, z, t) = R(r)\, e^{il\varphi}\, e^{i(\omega t- z)}$. Since the fiber has different refractive index n (for core n_1=1.4677 and cladding n_2=1.4624), Ψ can be simplified by:

$$\Psi(r,\phi)=\frac{R(a)}{J_l(u)}\,J_l\left(\frac{ur}{a}\right)\ \cos l\phi;\ r<a\ (\text{for core})$$

$$\Psi(r,\phi)=\frac{R(a)}{K_l(w)}\,K_l\left(\frac{wr}{a}\right)\ \cos l\phi;\ r>a\ (\text{for cladding}) \qquad (1)$$

where r is a radius of fiber, J_l and K_l are Bessel and Hankel function [8] and $\cos l\phi=1$ for SMF-28e $l=0$. The electromagnetic wave brings power as a scalar approximation which can be calculated for core radius,

$$P_{core} = (\text{constant}) \int_{r=0}^{a}\int_{\phi=0}^{2\pi} |\psi(r,\phi)|^2\, r\,dr\,d\phi$$

The solution of above integral is power in the core then can be written by

$$P_{core} = C\pi a^2 \left[1-\frac{J_{l-1}(u)J_{l+1}(u)}{J_l^2(u)}\right] \qquad (2)$$

Similarly, the power distribution in the cladding can be obtained by

$$P_{cladding} = C\pi a^2 \left[1-\frac{K_{l-1}(w)K_{l+1}(w)}{K_l^2(w)}\right] \qquad (3)$$

P is power, C is constant. Adding equation (2) and (3), the total power P_{total} is as follows:

$$P_{total} = P_{core} + P_{cladding} \quad (4)$$

Dividing equation (2) or (3) to equation (4), the fractional power propagating in the core is $P_{core} / P_{total} = 1 - P_{cladding}$. Similarly, the fractional power for cladding is

$$P_{cladding} / P_{total} = 1 - \left[\, w^2/V^2 \left(1-\frac{J_l^2(u)}{J_{l-1}(u)J_{l+1}(u)}\right)\right] \quad (5)$$

The symbol of V is normalized frequency, $V=(u^2+w^2)^{1/2}$, as defined u^2 a" $(k^2n_1^2 - \beta_{lm}^2)a^2$, and w^2 a" $(\beta_{lm}^2 - k_2n_2^2)a^2$; $\beta_1 = kn_1$; $\beta_2 = kn_2$, where β, k are propagation constant and wave number [9,10]. The normalized propagation constant is calculated by $b_{lm} = [\beta_{lm}^2 - \beta_2^2] / [\beta_1^2 - \beta_2^2]$.

EXPERIMENTAL WORK

A coupled SMF is set by a schematic below as shown in Figure 2. Two fibers are twisted once to have tightly coupling when pulling by a vacuum pump. Laser diode (LD) transmitting along fiber 1 is detected by a photo detector at a monitor, if the fibers reach the coupling ratio set the system will stop. The vacuum pump pulls the fibers smoothly in micrometer while the fire on torch heats twisted fibers.

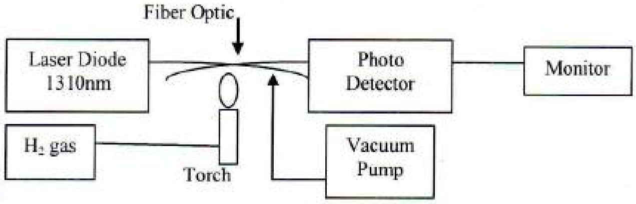


Figure 2. The schematic of SMF coupler process

A fire torch is produced by the hydrogen gas at 1 bar at temperature range of 800°C to 1300°C which is measured by thermocouple type K [11]. A monitor shows the pulling length and coupling ratio as illustrated in Figure 3.

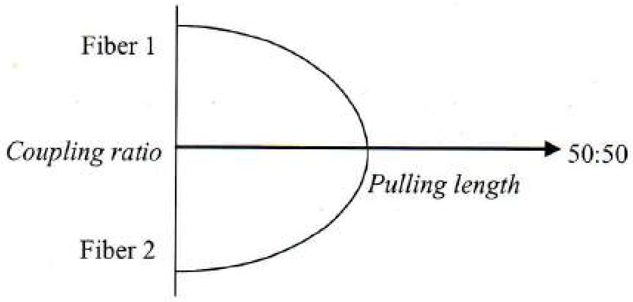


Figure 3. Illustration of coupled fiber: Pulling Length versus Coupling Ratio

Fiber 1 gives up the power to fiber 2 until 50%. Exponential function of the graph is due to the heat of fibers requires some times to become softened, which at a few first time is longer than the last. The Figure 3 can be modeled as power by a function of time and position using continuity equation:

$$\partial P/\partial t + \nabla . Pv = 0 \qquad (3)$$

Let $\partial P/\partial t$ is proportional to $-P/\alpha$, where α is a coefficient of power decay. Hence by integration for time dependence, $P_{decay} = P_{in}\, e^{-\alpha t}$. Thus $P_{out} = P_{in} - P_{decay}$. The power is simplified to $P_{out} = P_{in}\,(1 - Ae^{\alpha t})$. The symbol of α is negative, and time dependence for constant A=1. By knowing the coupling ratio of each fiber, P_{out}/P_{in} and time range from 1 to 10 seconds, so α can be determined.

RESULTS AND DISCUSSIONS

There are two measurements which have been done, a temperature of torch and SMF-28e geometry after fusion. Figure 4 shows the highest temperature is at the centre of the torch where the fiber is heated. The temperature is unstable due to the air flow and flux velocity at the circumstances. It results the momentum of H_2 gas to form a flame into air which is fluctuated at certain position. The 2 fibers are fused at highest temperature at y=2mm and y=3mm. At x=1mm temperatures vary because they are influenced by air flow rather than the hydrogen flow. However, at x=5mm the temperature of gas tends to be constant. Along the x position, the momentum of the gas will excite the atoms and molecules of air hence the flame readily occurs by increasing the temperatures.

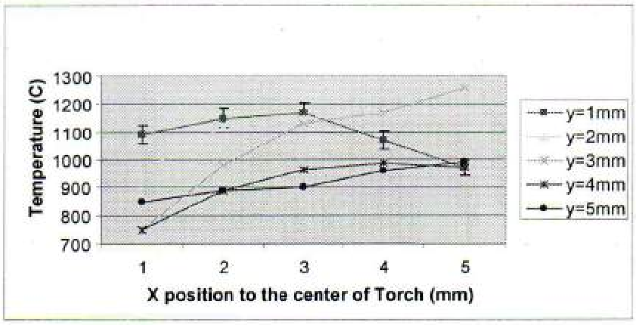


Figure 4. Temperature Position of Torch at Pressure 1bar, horizontal (x) and vertical (y) versus Temperature

The core and cladding diameter of SMF-28e references are shown in Figure 5(a); however, Figure 5(b) is the diameter of light radiating from core to cladding which the cladding diameter is not clearly measured with a microscope by magnification factor 20. Both figures after fusion for core and light diameter are reduced from 83% to 92% respectively by a factor 3.96 and 12.5, as shown in Figure 5(c).

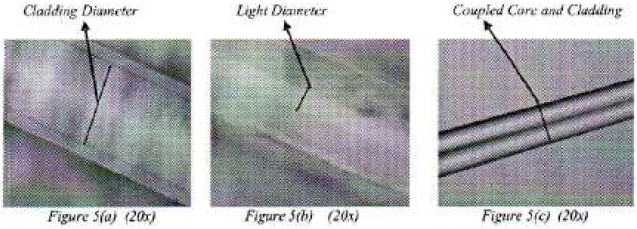


Figure 5(a) (20x) *Figure 5(b) (20x)* *Figure 5(c) (20x)*

Figure 5. The Cladding and Light Diameter in SMF28-e

The light diameter radiating from core to cladding is shown in Figure 6. This light has some modes then it can radiate to cladding. Nevertheless, the core diameter can be comparable as shown in Figure 7. The coupling ratio can not determine that the cladding diameter must constant even though the LP_{01} diameter position achieved. It is of course, the decrease of the refractive index of the Y junction fibers to reach the coupling ratio, while the 2 cores distance is closer than the radius of those of two claddings. Therefore LD can travel to both core and cladding. At x>50 the diameter of cladding tends to increase from 18μm, it is heated longer time and fiber 1 has to supply more than 50% power to fiber 2.

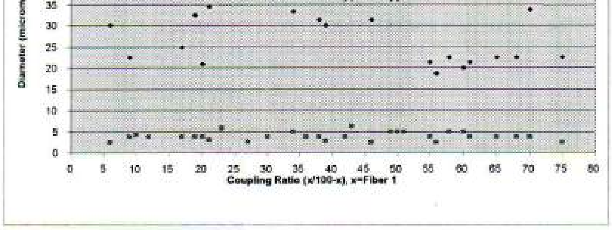


Figure 6. The Diameter of Light and Two Combined Claddings

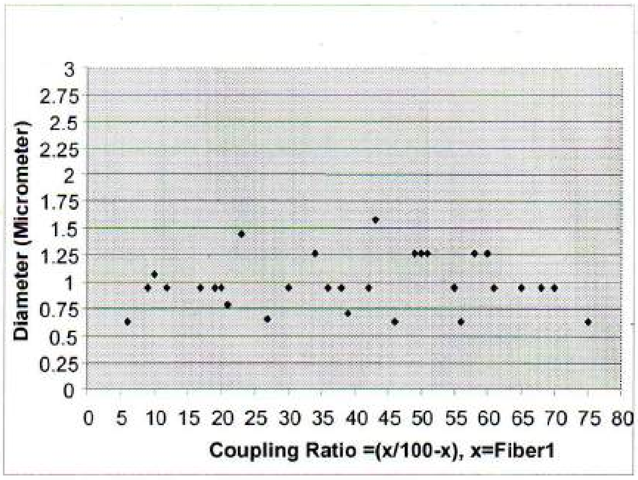


Figure 7. Core Diameter after Fusion

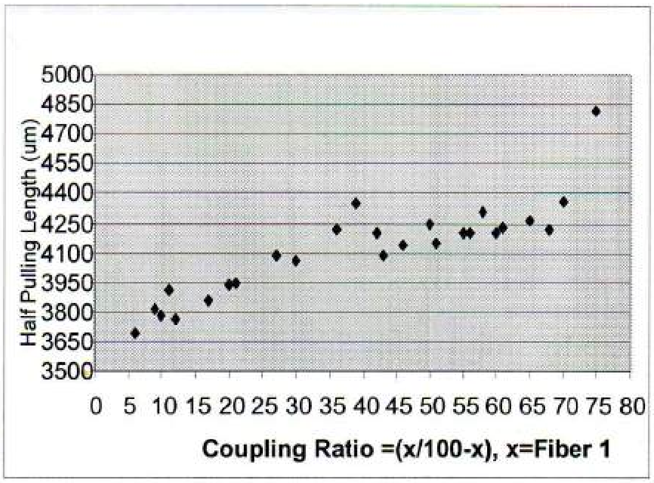


Figure 8. Pulling Length of Two Fibers

The SMF-28e core after fusion is reduced from 80.5% to 94% in a range of 35 to 45 seconds. The core diameter is also fluctuated because the flame heating fibers is unstable and refractive index changes; however, in general the core is in a narrow range. Half pulling length of fiber coupler increases significantly over coupling ratio. It is of course, not only the fiber becomes softened to reach certain diameter where power can travels, but also the power from fiber 1 moves to fiber 2 requires longer time.

In order to explain the experimental results above, the wave in fibers is calculated. The wave travels along the one fiber is shown in Figure 9 and critical beam propagation with angle 4.86°. The core power is nearly 83% corresponding to 8.3×10^{-4}W and cladding is 17% corresponding to 1.7×10^{-4}W. The wave at core and cladding respectively is in Bessel and Hankel function. At boundary, waves are influenced by refractive index changes; there is a displacement that the function is not completely continuous due to refraction.

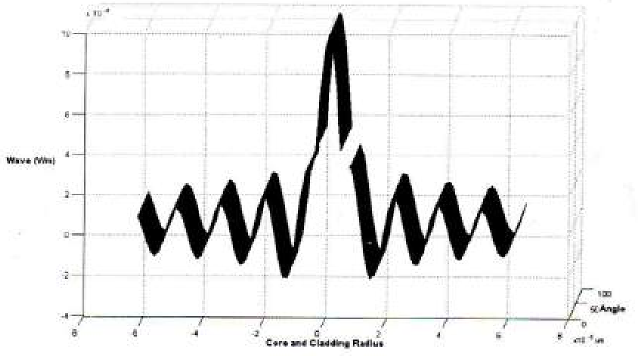


Figure 9. Electric Field Wave as a function of Core and Cladding Radius

Due to the fundamental mode, the electric field wave is higher at core radius than cladding radius. Waves traveling to cladding cannot be neglected. Although the power in cladding radius is weak, this range gives a reason during fusion to reach certain radius of coupled fiber in order that the power can travel to another fiber.

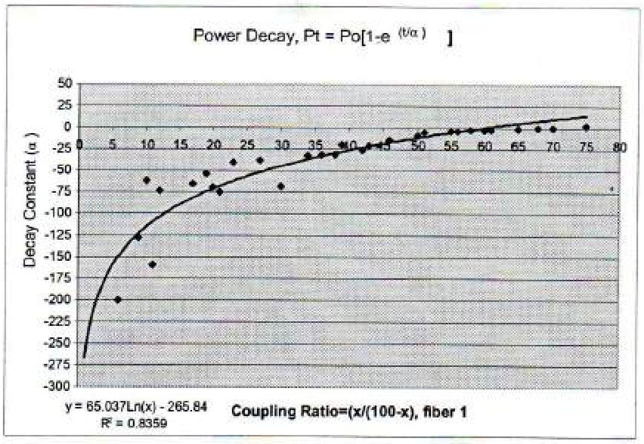


Figure 10. Coefficient of Power Decay versus Coupling Ratio

A coefficient of α is not constant by increasing the coupling ratio. There are a power loss and refractive index changes at the fusion region. At coupling ratio 50 and more, α has negative imaginer number and real positive at the last three coupling ratio. This occurs since the power has to give up more than 50% of power input to another fiber. The changes of diameter fiber are faster than refractive index in the range of 20 to 40μm (LP_{01} region). At the same region, power tends to propagate to both core and cladding at the lower refractive index changes. In addition, the higher coupling ratio, the more power propagates to another fiber. Therefore, power decay change is inverse proportional to coupling ratio.

CONCLUSION

The coupling ratio can be obtained by unstable torch, where the core and cladding radius are reduced from 83% to 94% in order to achieve the new radius of both core and cladding at LP_{01} region. This would allow the power to transmit from one fiber to another fiber during fusion. By increasing the coupling ratio, it is observed that the process of coupling requires a longer time in the range of 35 to 45 seconds. The coefficient of α exponentially increases at Y junction; it is due to lower refractive index and power loss.

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