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VARIABLES EFFECTS ON TEMPERATURE DISTRIBUTIONS FOR COUPLED SINGLE MODE OPTICAL FIBERS FC

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Fiber Optic network and devices have found increasing usage in everyday life due to their immunisation of electromagnetic wave. Parallel with these development, coupled single fibers had emerged to be one of important aspect in fiber optic technology. Single mode fibers manage to capture many attentions because of their potential in high capacity data processing. In the early days, fibers are coupled using mechanical method but recently researcher had discovered that a more efficient way of coupling fibers that is by using fusion elongation method. Coupled fibers produced using this method was proven to have low excess loss and these coupled fibers were more stable mechanically. Excess loss of the fibers coupled using fusion method depends on the fused region. Since fusion elongation method is a new field in fiber optics, it was found that there are not many research had been done in this area,

particularly during the stage of fusing the fibers. It is obvious that during fusion process, heat transfer occur throughout the coupling region of the coupled fiber. Heat transfer occurs mainly through conduction since the fiber is in the form of solid. Using the heat equation in cylinder form, and neglecting the angular component in the equation, the temperature distribution of the fiber had been obtained. Several boundary conditions have been preset in order to obtain the constant values for the governing equation. To simplify the discussion and for the sake of better understanding, the equation for temperature distribution have been classified into three terms. Each of these terms were analysed. The results we obtained matched the physical change that occurs to the fibers. This research also shows that time is the most important component in the fusion coupling process.

1.1 OVERVIEW

Single mode fibers coupled using fusion process has generated much interest among researchers (Saktioto et. al, 2007). In the past, fusion coupling process has been done manually using highly skillful technique. This process has been improved by using computers to control all the steps involved in fusion coupling. Generally, fabrication methods for coupling fibers can be divided into two categories that are mechanical-polishing method and fusion elongation method.

In mechanical-polishing method, couplers are fabricated by polishing each of two fibers and placing the two polishing faces in contact by introducing a small amount of index-matching liquid between fibers. Disadvantages of this method are that the polishing technique needs to be extremely accurate and that coupler characteristics are unstable.

In the fusion-elongation method, couplers are fabricated by thermally fusing two fibers and elongating them. Resultant fiber couplers are mechanically stable so that the fusion-elongation method is regarded as the best at present (Juichi, 1987). The

disadvantages are first, excess loss of the fibers coupled using fusion method depends strongly on the fused region. The fused region need to be controlled precisely in order to produce good coupled fibers (Yablon, 2005). Secondly, during the heating process, the fibers are not heated homogenously. The third disadvantage is the heating element used in fusion method is not stable since torch flame is used.

Temperature distribution for fibers is a function of time, length and radius. Having an insight into this might able us to determine the correlation between temperature distribution and controlling fused region technique. However, there are not many publications relating to the temperature distribution of the fiber during fusion process.

For this investigation, it is necessary to start from general equation of heat transfer. This equation then will be derived and modeled until the appropriate equation that matches the condition of fusion coupling process is obtained. Using Matlab software as a platform, graphs will be generated from this equation. From the graphs we will see which of the variables involved in temperature distribution equation plays an important role in fusion coupling process.

1.2 HEAT TRANSFER OF FUSION COUPLING

When a fiber is heated, heat transfer occurs mainly through conduction (Incropera et. al, 2004) as fiber itself is in the form of solid. Conduction may be reviewed as the transfer of energy from more energetic to less energetic particle of substance due to interaction between particles (Incropera et. al, 2004). Transport of thermal energy may be due to two effects- the migration of free electrons and phonons. Since fiber is made of silica, phonon is the dominant contributor to conduction heat transfer (Incropera et. al, 2004). The general equation of heat transfer is (Yablon, 2005):

$$\frac{\partial T}{\partial t} = \kappa \nabla T$$

For cylindrical coordinate, the simple solutions of Equation (1.1), with assumptions that there is no energy generated inside the fibers, is

$$T(r, z, t) = c_1 e^{-\kappa \lambda^2 t} [c_2 J_0(\mu r) + c_3 Y_0(\mu r)] [c_4 e^{vz} + c_5 e^{-vz}].$$

Here, κ is the diffusivity coefficient while c_1, c_2, c_3, c_4 and c_5 are all constants. The solution for radius (r) component is in the form of Bessel function of the first kind with zeroth order. Solution for coupling region (z) is in the form of positive and negative exponential. Finally, the solution of time (t) is in the form of negative exponential. When r equal to zero, c_3 approaches zero and Equation (1.2) becomes

$$T(r, z, t) = e^{-\kappa \lambda^2 t} J_0(\mu r) [A e^{vz} + B e^{-vz}],$$

where λ, μ, v, A and B are all constants with $\lambda^2 = \mu^2 - v^2$ while κ is the diffusivity coefficient for silicon dioxide which is equal to $0.834 \times 10^6 \text{ m}^2 \text{ s}^{-1}$ (Incropera et. al, 2004). Using appropriate boundary conditions, the values of constants for Equation (1.3) can be obtained. Seven boundary conditions that had been preset earlier are

$$\begin{aligned} T(r, z, 0) &= 20, T(r, 0, t) = 1350, \\ T(r, -3750 \mu\text{m}, t) &= 1350, \\ T(r, 3750 \mu\text{m}, t) &= 1350, \\ T(20 \mu\text{m}, z, t) &= 1350, \\ T(62.5 \mu\text{m}, z, t) &= 1350 \text{ and} \\ T(r, z, 75 \text{s}) &= 1350. \end{aligned}$$

The values of the constants are shown in Table 1.1.

Table 1.1. List of constants.

No	Constant	Value
1	λ	$2.595 \times 10^{-4} i$
2	μ	$2.595 \times 10^{-4} i$
5	C	20.001

From the calculations in obtaining the constants value involved in Equation (1.3), it was found that the value of v is equal to zero thus eliminating the coupling length factor in temperature distribution equation. Substitution, Equation (1.3) becomes;

$$T(r, z, t) = e^{-0.0014 \times 10^6 (2.595 \times 10^{-4} i)^2 t}$$

It is stated earlier that radius (r) of the fiber after and before fusion are $20\mu m$ and $62.5\mu m$ respectively. Coupling region (z) $0 \leq z \leq 7500\mu m$ for t equal to $75s$. The value of diffusivity coefficient (α) changes during fusion coupling. The equation for α is given by

$$\alpha = k / \rho c_p, \tag{1.5}$$

where k is the thermal conductivity [W/m.K], c_p is the specific heat [J/kg.K] and ρ is the density [kg/m³]. When α changes with time, assuming that all parameters changes, the equation becomes

$$\frac{\partial \alpha}{\partial t} = \frac{\partial}{\partial t} \left[\frac{k}{\rho c_p} \right] = \frac{1}{\rho c_p} \frac{\partial k}{\partial t} - \frac{k}{\rho c_p^2} \frac{\partial c_p}{\partial t} - \frac{k}{c_p \rho^2} \frac{\partial \rho}{\partial t} \tag{1.6}$$

Table 1.2. Parametric changes during fusion.

Parameter (x)	Before fusion (at 20° C)	After fusion (at 1350° C)	$\left \frac{\partial(x)}{\partial t} \right $
k	1.38 W/m. °C	4.00 W/m. °C	0.0349 W/m. °C.s
c_p	745 J/kg. °C	1195 J/kg. °C	6.00 J/kg. °C.s
ρ	2.3588×10^6 g/m ³	1.1073×10^6 g/m ³	1.6687×10^4 g/m ³ .s

The value of c_p , ρ and k must be fixed at 745 J/kg. °C, 2.3588×10^6 g/m³, and 1.38 W/m. °C (Incropera et. al, 2004) respectively. These are thermophysical properties for SiO₂ at 20° C. Combining calculation results for each term, using Equation (1.6), the value of diffusivity coefficient change is 7.9801×10^{-12} m²s⁻¹. α at 20° C equal to 0.834×10^6 m²s⁻¹ (Saktioto et. al, 2007). From the calculations, it is shown that the change in diffusivity coefficient, compared to its initial value, is zero. The changes are too small, by the factor of -18, that it can be negligible.

1.3 HEAT TRANSFER TO FIBERS

For simplicity, the environment condition surrounding the fibers during fusion coupling is not considered. Fiber is heated by gas at temperatures ranging from 800 to 1350 (Saktioto et. al, 2007). Referring to Figure 1.1 of the profile of function I versus time, it can be clearly seen that function I increases over time. This happen as the fiber was continuously heated until it reaches its completion time. When it nearly reach 75 second , the slope of function I becomes steep, meaning that the fibers had become 'soft' and the formation of the coupled fiber nearly finish. The graph expected to continue increases over time until it reaches the maximum value that is relevant with the pre-set value of the fusion coupling process that is 1350 .

In function II, radius of the fiber is the variable involved in it. When function II was plotted versus radius, the profile produced

was a simple straight line. This is due to the value of the Bessel Function involved in function II remain constant throughout the range value of radius that is, in this case, it is equal to 1.

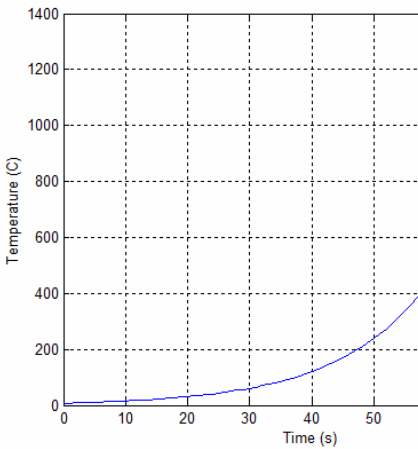
From all the profiles obtained (as shown in Figure 1.1 (a), (b) and (c)), it can be say that the first function that is

$$I = e^{-0.8934 \times 10^{-6} (2.595 \times 10^{-4} t)^2},$$

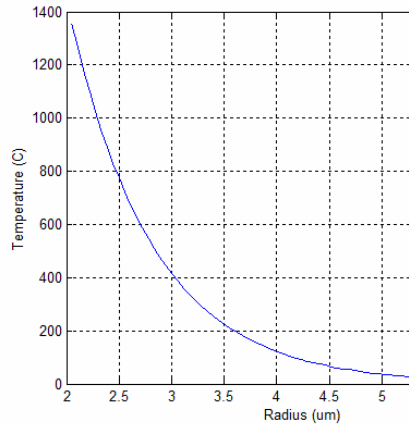
gives the most effect to the temperature distribution of the fiber compare to the other two functions and the second function.

$$II = J_0((2.595 \times 10^{-4} t)r)[20.001]$$

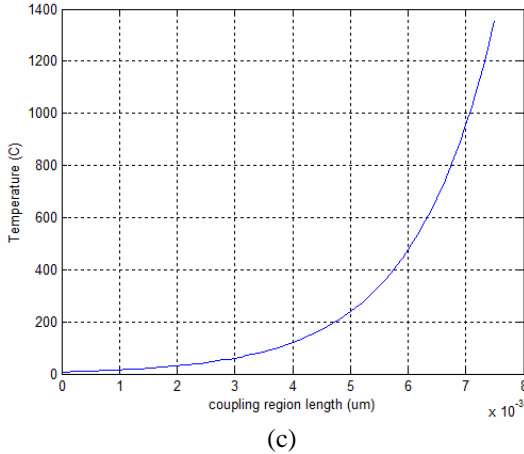
gives negligible effects on the temperature distribution. This also show that time is the most crucial variable in fusion splicing process while radius of the fiber is the less important variable in this process.



(a)



(b)



(c)
Figure 1.1. Profile of Temperature versus (a) time, (b) radius and (c) coupling region length.

1.4 CONCLUSION

The changes that occur in κ can be neglected in temperature distribution calculation as the changes are too small. From the Figure 1.1 it can be seen that the temperature increases quickly starting from $t = 60s$ until it reaches its completion time. By comparing three profiles showed in Figure 1.1, it can be seen that $I = e^{-0.0074 \times 10^6} (2.595 \times 10^{-4})$, gives the most effect towards the temperature distribution compare to the other the second term. In other words it means that time is the important variable in fusion coupling process.

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