3. Mode Field Diameter of Single Mode Fiber

(Dated: January 4, 2021)

I. OBJECTIVE

To determine the Mode Field Diameter(MFD) of fundamental mode in a given single mode fiber (SMF) using far field measurement.

II. APPARATUS

1. Optical breadboard
2. He-Ne Laser and Laser aligner
3. Microscopic objective (20X) and holder
4. xyz-translational stage
5. Pin hole photodetector with multimeter and holder
6. Two fiber chucks
7. 2 post bases and 3 posts
8. Single-mode (NA = 0.1) fiber of appropriate length
9. Fiber cleaver
10. Rotation stage

III. THEORY

In a single mode fiber, the transverse distribution of propagating mode is more important than numerical aperture in determining the performance characteristic of these fibers. Mode field diameter is a measure of transverse extent of the modal field distribution of LP_{01} mode (linearly polarised mode with transverse symmetry), i.e. the fundamental mode having a gaussian field profile.

Mode field diameter is used to measure different characteristic and quantities such as joint loss, coupling efficiency, cutoff wavelength, microbending losses, and even waveguide dispersion.

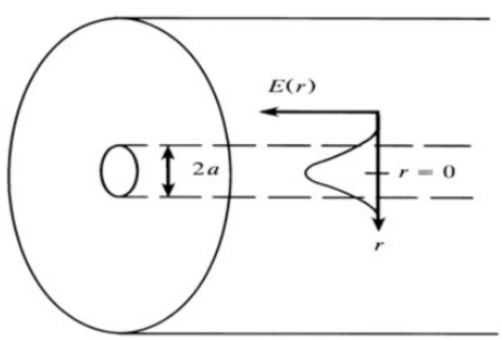

FIG. 1. Mode distribution inside single mode fiber

Now, as said earlier, LP_{01} mode can approximated to a gaussian distribution, therefore, the fundamental mode is given by :

$$\psi(r) = Ae^{-\frac{r^2}{w_0^2}} \quad ...(1)$$

where w_0 is referred as the spot size of the mode field pattern, the quantity d=$2w_0$ is referred to as the mode field diameter or MFD. The criteria choose the value of w_0 which leads to the maximum launching efficiency of the exact fundamental mode field by an incident Gaussian field- that is, one mximises the quantity:

$$\eta = \frac{\int_0^\infty e^{-r^2/w_0^2} R(r) r\, dr}{[\int_0^\infty e^{-r^2/w_0^2} r\, dr \int_0^\infty R^2(r) r\, dr]^{1/2}} \quad ...(2)$$

where $R(r)$ represents the exact modal field. For example, for a step index fiber $R(r)$ can be expressed in terms of Bessel functions and one has the following empirical expression for w_0, explained by Marcuse.

$$\frac{w_0}{a} \approx \left(0.65 + \frac{1.619}{V^{3/2} + \frac{2.879}{V^6}}\right) \quad ....(3)$$

Here, far field properties acts, therefore, it is a diffracting field with Fraunhoffer diffraction pattern (unlike near field diffraction which is Fresnel diffraction),which is Fourier transform of its near field. It can be shown that the far field pattern of a Gaussian mode distribution given by the above equation is again a Gaussian distribution and the corresponding intensity distribution is given by:

$$I(r, z) = \frac{I_0}{[1 + \gamma^2(z)]} exp[-2r^2/w_0^2(z)] \quad ....(4)$$

where, $w(z) = w_0[1 + \gamma^2(z)]^{1/2}$ and $\gamma(z) = \frac{\lambda z}{\pi w_0^2}$.

Equation 4 gives the farfield intensity distribution. $w(z)$ is the far field mode field radius (MFR) of the Gaussian amplitude distribution, The far-field distribution refers to the angular dependence of the output field intensity, sufficiently far from the output end of the fiber. For practical purposes, z is such that $z >> w_0^2/\lambda$, observation plane is said to be in the far-field. For such large values of z

$$w(z) = \frac{\lambda z}{\pi w_0} \quad .....(5)$$

Now, the Gaussian MFD ($2w_0$ of a single mode fiber can be easily obtained from a measurement of the angular distribution of its far field measurements. Using eq.(5), the far field intensity distribution of a Gaussian field is approximately given by,

$$I(r) = Bexp\left[-\frac{2\pi^2 r^2 w_0^2}{\lambda^2 z^2}\right] = B\left[\frac{-2\pi^2 w_0^2}{\lambda^2} tan^2(\theta)\right] \quad ....(6)$$

Where, B is a constant of r and $tan(\theta) = r/z$, θ being the far-field diffraction angle. The angle θ_c at which far-field intensity drops down by a factor of e^2 from its maximum value at $\theta = 0$ would then be given by:

$$tan(\theta_c) = \frac{\lambda}{\pi w_0}$$

which yields

$$w_0 = \frac{\lambda}{\pi tan(\theta_c)} \quad .....(7)$$

IV. PROCEDURE FOLLOWED

Light was coupled into the single mode fiber in the similar manner as it was done in the 1^{st} experiment to obtain maximum coupling.
After obtaining maximum coupling, the photo detector was mounted on the rotation stage, and the rotation stage was fixed on the optical breadboard in such a way that the distance between the fibre end and the detector is about 3-4 cm, so that it is far enough to observe the far field but not too far as then detector would not have been able to detect much of the output.
After setting this up, the rotation stage was rotated upto small degree and then the reading of multimeter was recorded. This process wass repeated starting from multimeter reading of 0 to the maximum value and then again 0. Finally, the readings are plotted in a graph and at $1/e^2$ of the total normalized power, θ_c is obtained, from which MFD was calculated.

V. EXPERIMENTAL DATA

A. MFD for Single Mode (NA = 0.1)

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TABLE I. Scanning method for Single-mode fiber with NA = 0.1

Reading on the rotation stage (degrees)	Voltage of multimeter (mV)	Normalized Power
-6.8	0	0
-5.4	0.1	0.02778
-4.4	0.2	0.1111
-3.2	0.3	0.25
-2.2	0.4	0.44444
-1.2	0.5	0.69444
0	0.6	1
1.2	0.5	0.69444
2.2	0.4	0.44444
3.2	0.3	0.25
4.2	0.2	0.11111
5.4	0.1	0.02778
6.6	0	0

VI. GRAPHS AND CALCULATIONS

Using appropriate values from Table I, graph between normalized power and angle obtained from rotation stage is plotted as below:

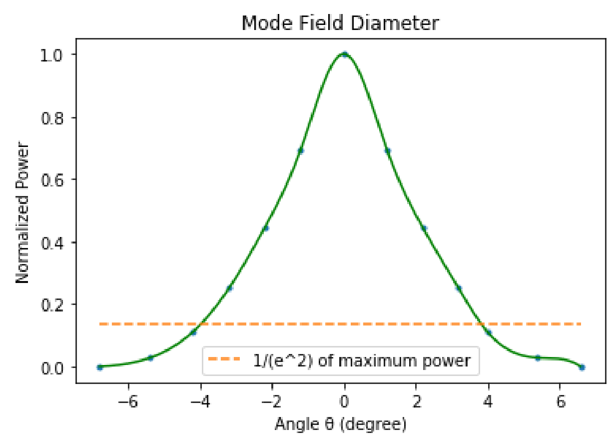

FIG. 2. Normalized Power vs Angle

Now, from the graph, we get $\theta_c = 3.9^o$. Using this value in eq.(7), we get:

$$w_o = \frac{0.633}{\pi * tan(4.2^o)} \mu m$$

$$w_o = 2.744 \mu m$$

Now, we can calculate MFD as follows:

$$MFD = 2 * w_o = 2 * 2.744 = 5.48 \mu m$$

So, the Mode Field Diameter of the given Single Mode Fiber is $5.48 \mu m$

VII. RESULT AND DISCUSSION

The value of Mode Field Diameter obtained experimentally is $5.48\mu m$, which is in close range to the value provided by the manufacturer i.e. $5.1\mu m$.

[1] Solid state Physics Lab Manual,*School of Physical Sciences,NISER*

[2] https://slideplayer.com/slide/4213519/

[3] https://www.newport.com/t/fiber-optic-basics#:~:text=The%20Numerical%20Aperture%20(NA)%20of,radiation%0modes%20of%20the%20fiber.