<u>Exercice 2</u> : Measurement of a characteristic parameter of a step index fiber

Data and curves likely to be used in this exercise are given at the end .

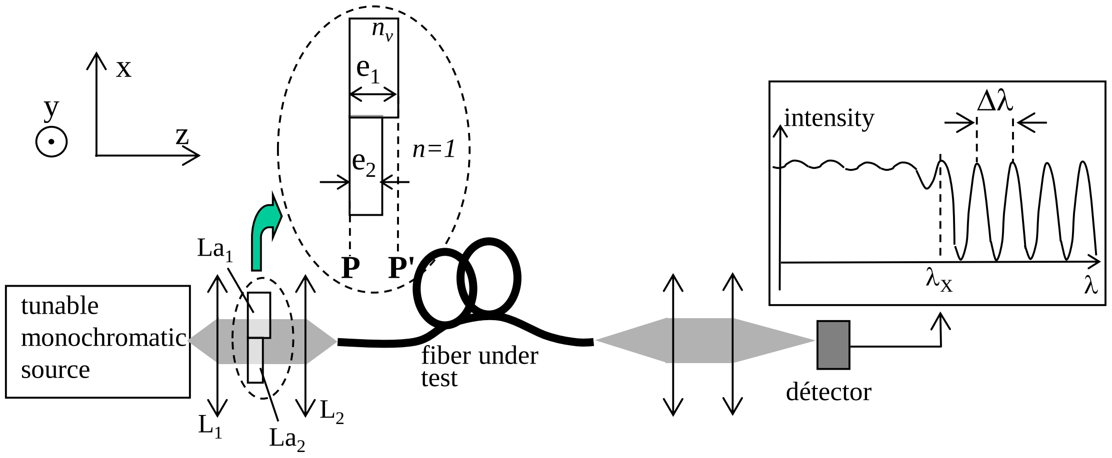
A piece of a cylindrical optical fiber of diameter 125µm is taken on a drum in order to achieve its characterization. We know that the fiber has been drawn homothetically, starting from a step index preform with an outer diameter of 3 cm. This preform is made of two concentric regions with different refractive indices. The external region Z_{ext} is made of pure silica and the internal region Z_{int} is made of Ge doped silica. At λ=633nm, the refractive indices of the two regions are respectively n_2=1,458 for Z_{ext} and n_1=1,463 for Z_{int}.

1- In the drawn fiber, to what correspond the regions Z_{ext} and Z_{int} ?

2- Calculate the numerical aperture of the fiber. In the following, we will assume that this numerical aperture does not vary versus the wavelength.

3- The length of the preform which has been used for the fabrication of the fiber is 50 cm. What is the length of fiber available on the drum ?

In order to characterize the fiber, we use the following setup :



The source is a monochromatic source, linearly polarized in the x direction. The emitted wavelength can be selected in the range [600nm, 1700nm]. The emitted power is supposed to remain constant whatever the selected wavelength. The output beam is collimated by a lens L_1 in order to provide a PLANE WAVE, with a quasi-gaussian spatial distribution of power. This plane wave is sent on an assembly of two glass plates set perpendicularly to the beam direction, and having a refractive index noted $n_v(\lambda)$ (index v stands for "verre" = glass in French), as described in the figure above. Half of the beam crosses the plate La_1 of thickness e_1 and the second half crosses the plate La_2 of thickness e_2. The operating wavelength is λ_T.

4- a) verify that LP modes can be considered in the tested fiber. What is the meaning of "LP" ? What does it physically means ?

b) Give the expression of the phase shift $\delta\varphi_1$ experienced by the first half of the beam between the plane P and the plane P', as a function of the data of the problem.

c) Considering that the index of the air is 1, give the expression of the phase shift $\delta\varphi_2$ experienced by the second half of the beam between the plane P and the plane P', as a function of the data of the problem.

d) Deduce that the phase difference $\Delta\varphi$ between the two parts of the beam is $\Delta\varphi = |\delta\varphi_1 - \delta\varphi_2| = \frac{2\pi}{\lambda_T}(n_v(\lambda) - 1)\Delta e$ where $\Delta e = (e_1 - e_2)$.

5- Around the operating wavelength, we consider in first approximation that the refractive index of the plates is constant and is n_v.

a) Calculate the expression of the derivative of $\Delta\varphi$ with respect to the wavelength.

b) From this expression, deduce the literal expression of the free spectral range $\Delta\lambda$ over which $\Delta\varphi$ varies by 2π.

c) We know that e_1=10mm and e_2= 9,5mm. Verify that $\Delta\lambda$ around λ_{T1} = 1100nm ($n_v(\lambda_{T1})$ = 1,5 =constant), approximately equals 4,8nm.

6- the beam exiting the assembly of plates is focused by means of the lens L_2 on the core of the fiber. It is perfectly centered on this core and there is no angular tilt. We still work at λ_{T1} = 1100nm. We know that, at λ_{T1}, the fiber is able to guide only two LP modes.

a) What are these modes ? Plot a schematic representation of the spatial distribution of the intensity of light in each of these modes.

b) Plot, for each mode, few lines of the electric field in the plane, at any moment.

7- we assume that, at λ_{T1}, $\Delta\varphi=2m\pi$ (m is an integer). What mode will be mainly excited in the fiber ? What will be the part of the energy which will be coupled in the LP_{11} mode ? Justify your answers.

8- The source now emits ligth at the wavelength λ_{T2}=1102,4nm. What is the value of $\Delta\varphi$? Now, what mode will be mainly excited in the fiber ? What will be the part of the energy which will be coupled in the LP_{01} mode? Justify your answers.

9- When the wavelength emitted by the source is increased little by little, we first note only little fluctuations of the detected power, with a period equal to $\Delta\lambda$. Then, beyond a wavelength λ_X, the fluctuations of the detected power become very large, and this detected power even reaches zero for certain wavelengths spaced by de $\Delta\lambda$ (see the inset in the figure above).

a) With the help of the answers to questions 7 and 8, explain the origin of these large fluctuations.

b) To what parameter corresponds λ_X ? Finally, what kind of characterization is achieved by means of the setup described on the figure ?

10- The cutoff wavelength of the second mode is λ_c = 1240nm.

a) What is the radius of the core of the fiber ?

We now work at λ_{T2} = 633 nm.

b) What are the LP modes able to propagate in the fiber ? Justify your answer.

c) determine the effective index of the lowest order mode and of the highest order mode able to propagate and calculate their respective phase velocities.

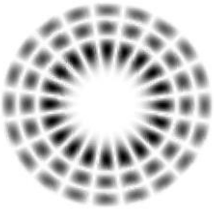
Data and curves likely to be useful for the exercise

π=3,14159 V= k_0.a.NA is the normalized spatial frequency

Relative index difference : $\Delta = \frac{NA^2}{2.n_1^2}$

Fonction→	J_0	J_1	J_2	J_3	J_4
1er zéro	2,405	0	0	0	0
2eme zéro	5,52	3,83	5,14	6,38	7,59
3eme zéro	8,65	7,01	8,42	9,76	11,06

First zeros of the first Bessel functions of the first kind J_ν



Transverse mode pattern for the $LP_{10,3}$ *mode of a step index fiber*

Curves B=f(V) for the first LP modes (modes of lowest orders), where V is the normalized spatial frequency, and $B = \frac{\beta^2 - k_0^2.n_2^2}{k_0^2.(n_1^2 - n_2^2)}$, β being the propagation constant of the considered mode.