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Polarization Extinction Ratio Measurement Using CUBE-ER100

1. Polarization Extinction Ratio (PER) of a PM Fiber

When light transmits in a polarization maintaining (PM) fiber, it can be considered as a superposition of two orthorgonal linearly polarized lights. One is polarized along the slow axis of PM fiber and the other is along the fast axis. When the PM fiber is moved or bent within its specified range, the optical power of these two polarization components are theoretically conserved. However, crosstalk between these two polarization components can occur when an external mechanical force or thermal expansion of different materials introduce transverse stress on the PM fiber. The optical power ratio of these two polarization components at the output of a PM fiber is called the polarization extinction ratio (PER) and is represented by the following expression:

$$PER = 10\left|log\left(\frac{I_{slow}}{I_{fast}}\right)\right| \tag{1}$$

2. PER Measurement Using Broadband Light Sources

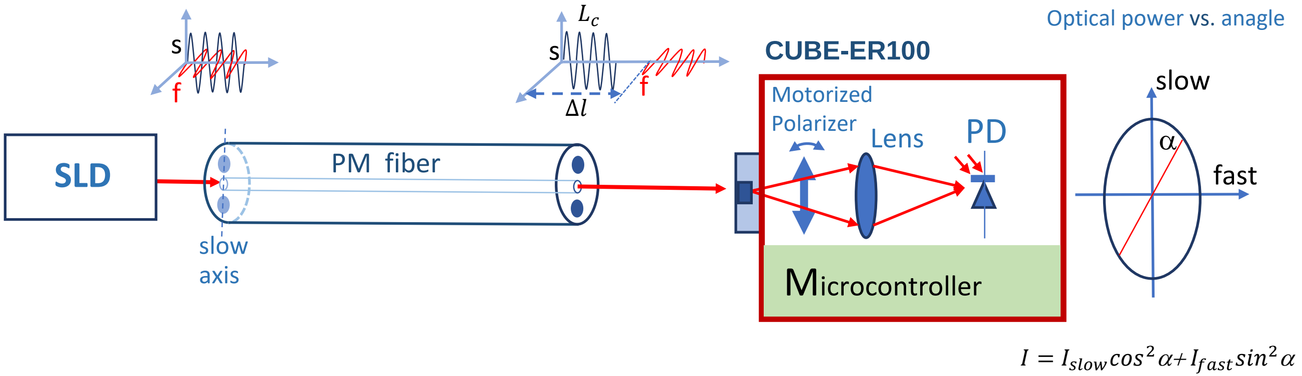


Figure 1. PER measurement using broadband light

As we know, PM fibers have a large birefringence, which introduces an optical path difference Δl between the two orthogonal linear polarization components polarized along the slow and fast axes. The Δl can be calculated according to the length l and beat length l_{beat} of the PM fiber as follows:

$$\Delta l = \frac{l}{l_{beat}}\lambda \tag{2}$$

where λ is the central wavelength of the light source. If the coherent length of the light source is shorter than the optical path length difference Δl, these two polarization components are incoherent at the PM output, and the optical power after the rotating polarizer can be simplified as:

$$I = I_{slow}cos^2\alpha + I_{fast}sin^2\alpha = I_{slow} + \left(I_{fast} - I_{slow}\right)sin^2\alpha \tag{3}$$

where α is the angle between the slow axis to the transmission axis of the polarizer. From Eq. (3), one can find

$$when\ I_{slow} > I_{fast}: \quad I_{max} = I_{slow}\ @\ \alpha = n\pi,\ and\ I_{min} = I_{fast}\ @\alpha = n\pi + \pi/2 \tag{4a}$$

$$when\ I_{slow} < I_{fast}: \quad I_{max} = I_{fast}\ @n\pi + \frac{\pi}{2},\ and\ \ I_{min} = I_{slow}\ \ @\alpha = n\pi \tag{4b}$$

$$when\ I_{slow} = I_{fast}: \quad I_{max} = I_{min} = I_{slow} = I_{fast} \tag{4c}$$

Substituting Eqs. (4) into Eq.(2) , we can rewrite the PER as

$$PER = 10\ log\frac{I_{max}}{I_{min}} \tag{5}$$

Thus, the PER measurement can be simplified to measure the ratio between the maximum and minimum optical power during the rotation of the polarizer.

3. Minimum Bandwidth of the Broadband Light Source Used for PER Measurement

As discussed in section 1, the coherent length L_c of the light source should be shorter than the optical path length difference Δl introduced by the PM fiber. L_c can be estimated by:

$$L_c = \frac{\lambda^2}{\Delta\lambda} \tag{6}$$

where λ is the center wavelength of the light source, and $\Delta\lambda$ is the 3dB spectral linewidth of the light soure. Substituting Eqs. (2) and (6) into $\Delta l > L_c$, one can find the following relationship:

$$\Delta\lambda > \frac{l_{beat}}{l}\lambda \tag{7}$$

For convenience, we list the typical coherent length of the light source vs. linewidth in Table 1 and the required minimum linewidth of the light source vs. beat length in Table 2.

Table 1 Coherent length vs. linewidth

Linewidth	Coherence Length @1550nm	Coherence Length @1310nm
1nm	2402µm	1716µm
10nm	240µm	172µm
20nm	120µm	86µm
30nm	80µm	57µm
40nm	60µm	43µm
50nm	48µm	34µm

Table 2 Minimum linewidth vs beat length for a 1m PM fiber

	1550nm		1310nm	
Beat length of PM fiber	Δl of 1m PM fiber	Minimum Linewidth of light source	Δl of 1m PM fiber	Minimum Linewidth of light source
2mm	775µm	3.1nm	655µm	2.6 nm
3mm	517µm	4.7 nm	437µm	3.9 nm
4mm	388µm	6.2 nm	328µm	5.2 nm
5mm	310µm	7.8 nm	262µm	6.6 nm
6mm	258µm	9.3 nm	218µm	7.9 nm
10mm	155µm	15.5 nm	131µm	13.1nm

4. PER Measurement of Narrow-band DFB or ITLA Lasers Using CUBE-ER100

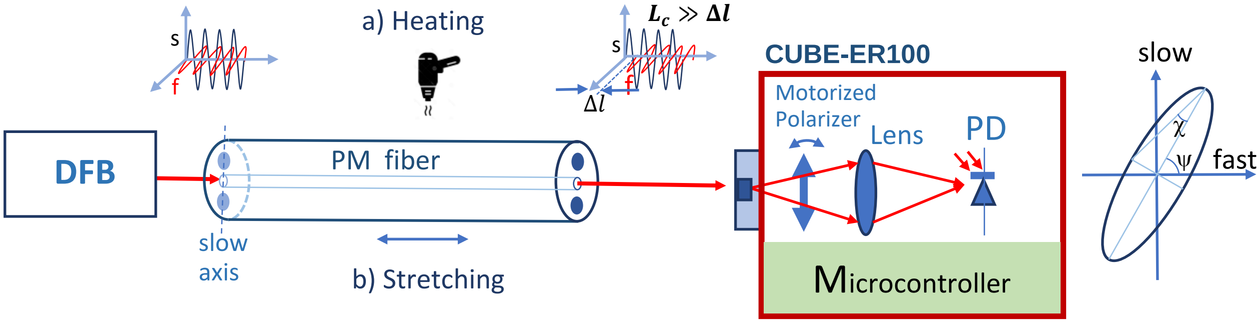


Figure 2. Measure PER of DFB or ITLA laser with PM pigtail

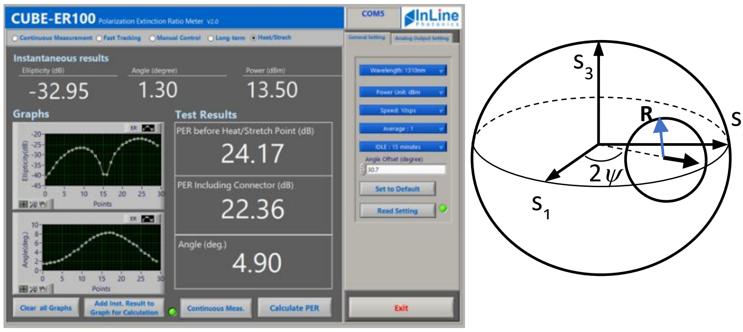
The PER measurement using a conventional rotating polarizer method requires a broadband light source of short coherent length. However, in some applications, such as coupling light from a narrow bandwidth DFB or ITLA laser into a PM fiber pigtail, as shown in Figure 2, one doesn't have the option of using a short coherent length light source. Generally, the coherent length of a DFB laser or ITLA laser is over tens of meters, which is much longer than the optical path difference between the slow and fast axes of PM fiber (see Table 2). In this condition, the polarization state at PM output is an ellipse, which depends not only on the power ratio between two orthogonal linear polarization states along the slow and fast axes, but also on their relative phase δ. The ratio of the maximum to the minimum power measured by the rotating polarizer method is the ellipticity of the polarization ellipse, which is not equal to the ratio between the optical power of the two polarization components polarized along the slow and fast axes. The angle corresponding to the maximum power is geneally not in the direction of the slow or fast axis.

The phase difference δ between the slow and fast axis is related to the length of the PM fiber l and the birefringence Δn of PM fiber as follows:

$$\delta = 2\pi \frac{\Delta \mathrm{n}\, l}{\lambda} \tag{8}$$

where λ is the central wavelength of the light source. δ changes λ when PM fiber is heated or stretched because heating or stretching causes changes in Δn and l. Therefore, while heating and stretching the fiber the ellipticity and orientation of the output polarization will change, and the corresponding SOP will draw a circle on the Poincare Sphere. CUBE-ER100 provides computer software to calculate the circle's radius R by fitting the ellipticity and angle curves as shown in Figure 3. From the calculated R, the PER of DFB or ITLA laser can be deduced by:

$$PER = -10\, log \frac{1-\sqrt{1-R^2}}{1+\sqrt{1-R^2}} \tag{9}$$


CUBE-ER100 Polarization Extinction Ratio Meter V2.0

COM5

○ Continuous Measurement ○ Fast Tracking ○ Manual Control ○ Long-term ● Heat/Strech

Instantaneous results

Ellipticity (dB)	Angle (degree)	Power (dBm)
-32.95	1.30	13.50

Test Results

PER before Heat/Stretch Point (dB): 24.17

PER Including Connector (dB): 22.36

Angle (deg.): 4.90

Wavelength: 1310nm
Power Unit: dBm
Speed: 10sps
Average : 1
IDLE : 15 minutes
Angle Offset (degree): 30.7

Figure 3. PER measurement results of DFB or ITLA laser while PM fiber is heated or stretched. The corresponding output SOP draws a circle on the Poincare sphere.