Technical University of Lodz

Department of Semiconductor and Optoelectronics Devices

Laboratory of Optoelectornics

Instruction 4

Measurement of fiber attenuation.

1. Goal

To acquaint students with the parameter of attenuation of optical fibers and the method of its measurement

2. Theory

Attenuation is the loss of optical power as light travels along the fiber and it is caused by absorption, scattering, and bending losses. Signal attenuation is defined as the ratio of optical input power (Pi) to the optical output power (Po). Optical input power is the power injected into the fiber from an optical source. Optical output power is the power received at the fiber end or optical detector. The following equation defines signal attenuation as a unit of length:

$$\text{attenuation} = \left(\frac{10}{L}\right)\log_{10}\left(\frac{P_i}{P_o}\right)$$

Formula 1. Fiber attenuation

Signal attenuation is a logarythmic relationship. Length (L) is expressed in kilometers. Therefore, the unit of attenuation is decibels/kilometer (dB/km). As previously stated, attenuation is caused by absorption, scattering, and bending losses. Each mechanism of loss is influenced by fibermaterial properties and fiber structure. However, loss is also present at fiber connections.

ABSORPTION is a major cause of signal loss in an optical fiber and it is defined as the portion of attenuation resulting from the conversion of optical power into another energy form, such as heat. Absorption in optical fibers is explained by three factors:

- Imperfections in the atomic structure of the fiber material
- The intrinsic or basic fiber-material properties
- The extrinsic (presence of impurities) fiber-material properties

Imperfections in the atomic structure induce absorption by the presence of missing molecules or oxygen defects. Absorption is also induced by the diffusion of hydrogen molecules into the glass fiber. Since intrinsic and extrinsic material properties are the main cause of absorption, they are discussed further.

Intrinsic Absorption is caused by basic fiber-material properties. If an optical fiber were absolutely pure, with no imperfections or impurities, then all absorption would be intrinsic. This kind of absorption determines the minimum level.

In fiber optics, silica (pure glass) fibers are used predominately. Silica fibers are used because of their low intrinsic material absorption at the wavelengths of operation. In silica glass, the wavelengths of operation range from 700 nanometers (nm) to 1600 nm. Figure 1. shows the level of attenuation at the wavelengths of operation. This wavelength of operation is between two intrinsic absorption regions. The first region is the **ultraviolet** region (below 400-nm wavelength), the second region is the **infrared** region (above 2000nm wavelength).

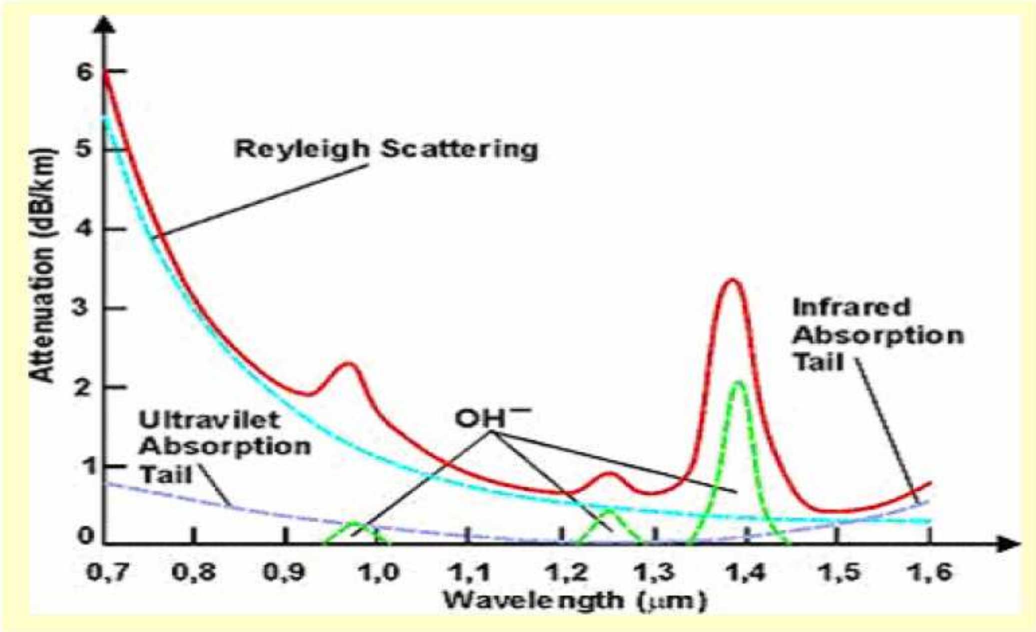

Fig 1. Quartz fiber attenuation dependence on the wavelength

Intrinsic absorption in the ultraviolet region is caused by electronic absorption bands Basically, absorption occurs when a light particle (photon) interacts with an electron and excites it to a higher energy level. The tail of the ultraviolet absorption band is shown in Figure 1. The main cause of intrinsic absorption in the infrared region is the characteristic vibration frequency of atomic bonds. In silica glass, absorption is caused by the vibration of siliconoxygen (Si-O) bonds. The interaction between the vibrating bond and the electromagnetic field of the optical signal causes intrinsic absorption. Light energy is transferred from the electromagnetic field to the bond. The tail of the infrared absorption band is shown in Figure 1.

Extrinsic Absorption is caused by the electronic transition of metal impurities ions (such as iron, nickel, and chromium, are introduced into the fiber during fabrication) from one energy level to another. Extrinsic absorption also occurs when hydroxyl ions (OH-) are introduced into the fiber.

Water in silica glass forms a silicon-hydroxyl (Si-OH) bond. This bond has a fundamental absorption at 2700 nm. However, the harmonics or overtones of the fundamental absorption occur in the region of operation. These harmonics increase extrinsic absorption at 1383 nm, 1250 nm, and 950 nm. Figure 1 shows the presence of the three OH- harmonics. The level of the OH- harmonic absorption is also indicated. These absorption peaks define three regions or windows of preferred operation. First window is centered at 850 nm, second window is centered at 1310 nm and third is centered at 1550 nm. Fiber optic systems operate at wavelengths defined by one of these windows.

The amount of water (OH-) impurities present in a fiber should be less than a few parts per billion. Fiber attenuation caused by extrinsic absorption is affected by the level of impurities (OH-) present in the fiber. If the amount of impurities in a fiber is reduced, then fiber attenuation is reduced.

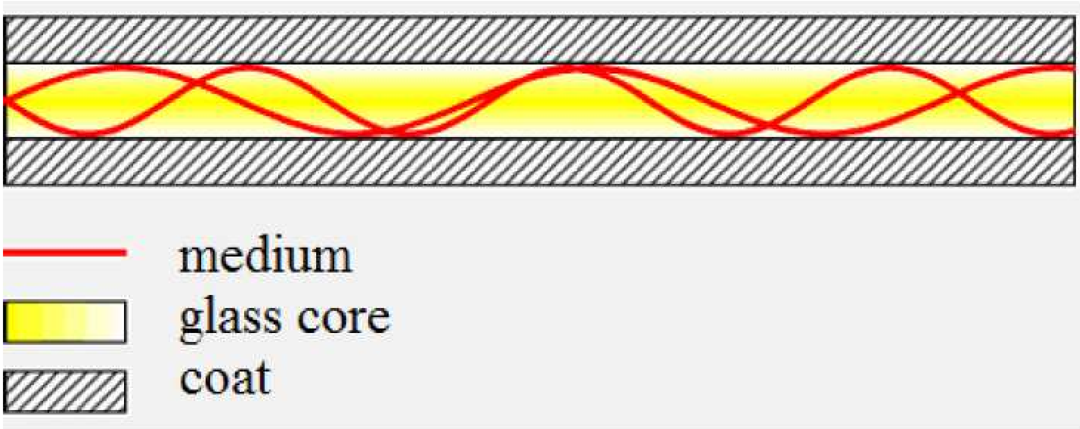

Fig. 2. Graded index fiber

Certain optical fibres (gradient- or graded-index fibres) are also made with a radially-varying refractive index profile; this design strongly reduces the modal dispersion of a multi-mode optical fiber.

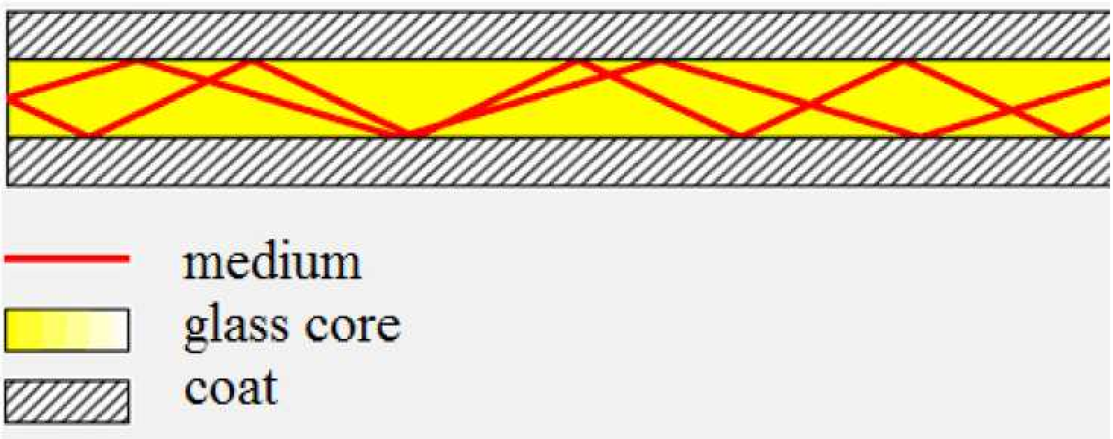

Fig.3. Step index fiber

For an optical fiber, a step-index profile is a refractive index profile characterized by a uniform refractive index within the core and a sharp decrease in refractive index at the corecladding interface so that the cladding is of a lower refractive index. The step-index profile corresponds to a power-law index profile with the profile parameter approaching infinity. The step-index profile is used in most single-mode fibers and some multimode fibers.

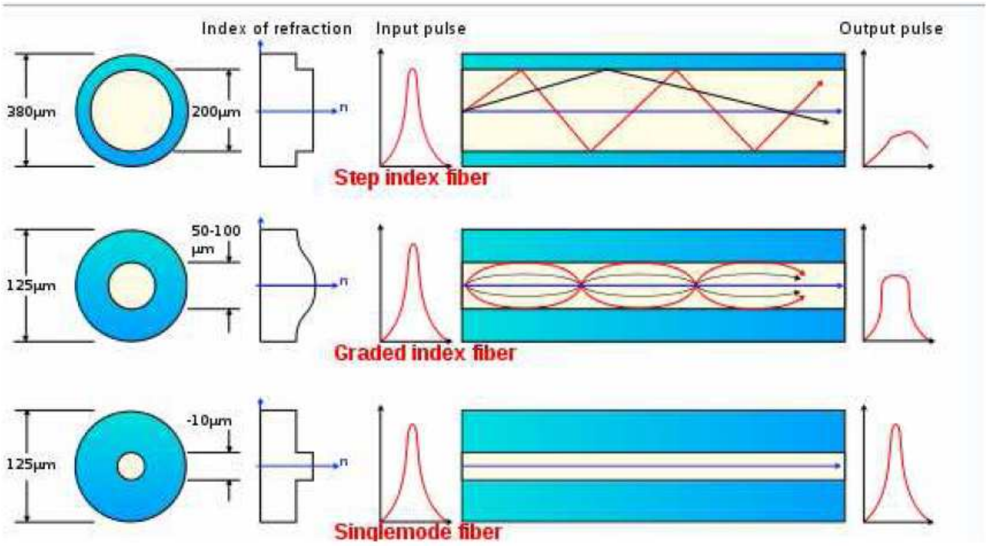

Fig. 4. Optical fiber types

Multi-mode fiber

Fiber with large core diameter (greater than 10 um) may be analyzed by geometric optics. Such fiber is called multi-mode fiber, from the electromagnetic analysis (see below). In a step-index multi-mode fiber, rays of light are guided along the fiber core by total internal reflection. Rays that meet the core-cladding boundary at a high angle (measured relative to a line normal to the boundary), greater than the critical angle for this boundary, are completely reflected. The critical angle (minimum angle for total internal reflection) is determined by the difference in index of refraction between the core and cladding materials. Rays that meet the boundary at a low angle are refracted from the core into the cladding, and do not convey light and hence information along the fiber. The critical angle determines the acceptance angle of the fiber, often reported as a numerical aperture. A high numerical aperture allows light to propagate down the fiber in rays both close to the axis and at various angles, allowing efficient coupling of light into the fiber. However, this high numerical aperture increases the amount of dispersion as rays at different angles have different path lengths and therefore take different times to traverse the fiber. A low numerical aperture may therefore be desirable.

Single-mode fiber

Fiber with a core diameter less than about ten times the wavelength of the propagating light cannot be modeled using geometric optics. Instead, it must be analyzed as an electromagnetic structure, by solution of Maxwell's equations as reduced to the electromagnetic wave equation. The electromagnetic analysis may also be required to understand behaviors such as speckle that occur when coherent light propagates in multi-mode fiber. As an optical waveguide, the fiber supports one or more confined transverse modes by which light can propagate along the fiber. Fiber supporting only one mode is called single-mode or monomode fiber. The behavior of larger-core multi-mode fiber can also be modeled using the wave equation, which shows that such fiber supports more than one mode of propagation (hence the name). The results of such modeling of multi-mode fiber approximately agree with th predictions of geometric optics, if the fiber core is large enough to support more than a few modes.

3. Exercise

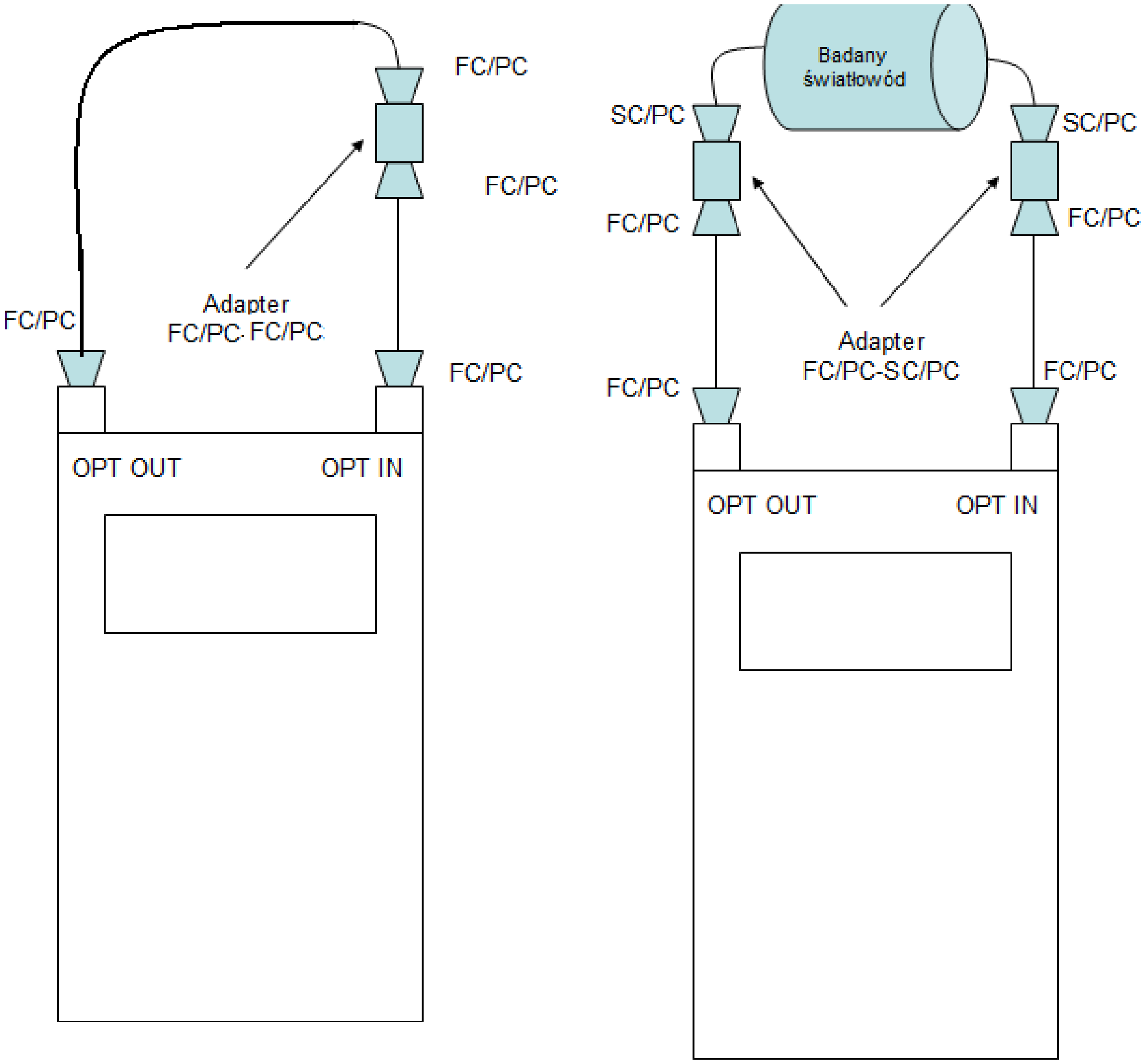

Fig.5.a) meter calibration b) measurement of fiber attenuation

1. Ask the teacher about MS9020B meter, and a set of test fiber.

   WARNING! During the calibration and measurement do not look at the output of connectors, light sources, and meters!

2. Examine under the microscope all fronts of optical fibers to avoid damaging input of measured detector or output of the light source on the meter.

3. In case of impurities on the front of fiber, it is obligatory to remove them using a tissue soaked in alcohol. After re-checked, tested fibers combine with the meter (Fig.5.a) **Do not switch on the meter during this point!**

4. Prepare the meter and set the wavelength at 1250 nm as stated in points 5-7.
5. Set the switch to "set-meas" on the side of the meter housing on "set".
6. Set the switch of sensor input on "1.3".
7. Turn on the meter.
8. Press the "REL / LIGHT" button and turn on the set of wavelengths.
9. Press the "MOD" and "AVG" button and set the needed wavelength.
10. Set the switch to "set-meas" on the side of the meter housing on “meas. "
11. Set the "offset" as in points 10-11.
12. Check after step 8 if on the meter screen displays the message "-7. LO " if not block the sensor input by pressing the" OPTOUT " button.
13. Press the "SHIFT" button and then "OFFSET" button. The meter will automatically assume the zero level.
14. Again press the "OFFSET" button and on the meter screen you will see the value of attenuation expressed in dBm or nW. If it is necessary change the Units by pressing the "LOSS" button.
15. Write dwon the measured attenuation for each fiber and wavelength. Then turn off the meter and connect the diagram shown in Figure 5.b).
16. Write dwon the value of the attenuation and subtract it from the value received in point 15.
17. Do the measurements for wavelengths 1280 nm, 1310nm, 1350nm doing everything described in points 5-13.
18. Do the measurements for wavelengths 1450nm, 1500nm, 1550nm doing everything described in points 5-13.

WARNING! Turn off the meter, and then switch the light source at wavelength "1.55"!

19. Do the measurements for other types of optical fiber according to the above points

4. Raport

The report should include:

- Results of measurements for the tested optical fiber in table.
- Conclusions and observations about the dependence of attenuation on wavelength.