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Indoor optical free space networks – reflectivity of light on building materials

Abstract. *Over the past decade rapid development happened in the field of communication technologies based on optical fibers. Over the past decade rapid development happened in the field of communication technologies based on an optical fibers. These technologies become dominant in the field of the last mile networks as well (WDM-PON, GePON, EPON, etc.). As an alternative to the last mile networks can be considered the so-called free space optical networks (FSO). Currently, diffusion systems make an interesting concept into the future. They use secondary sources - building materials inside the room. Therefore it is necessary to pay attention to an issue of the light reflectivity on building materials.*

Streszczenie. *Ostatnia dekada przyniosła, w dziedzinie optoelektroniki, szybki rozwój technologii tele-informatycznych opartych na światłowodach. Technologie te zyskują znaczną popularność w sieciach ostatniej mili (WDM-PON, GePON, EPON, itd.). Jako alternatywę w stosunku do sieci ostatniej mili można przyjąć optyczne sieci bezwłóknowe (FSO). Z punktu widzenia przyszłości systemy dyfuzyjne prezentują się jako ciekawa koncepcja. Korzystają one ze źródeł wtórnych – materiałów budowlanych wewnątrz pomieszczeń, dlatego koniecznym jest poświęcenie uwagi problematyce wpływu odbić światła na materiałach budowlanych. (***__Wewnętrzne optyczne sieci bezwłóknowe – wpływ odbicia światła na materiałach budowlanych).__

Keywords: diffusion system, directional characteristic, polarization.
Słowa kluczowe: system dyfuzyjny, charakterystyka kierunkowa, polaryzacja.

Introduction

A luminous flux, which is emitted from the light source, impinges directly into the receiver or is reflected into the receiver from the surfaces of walls, floors, ceilings (in cause a room). The most of light active surfaces around us fall into a group of secondary light sources. The secondary sources reflect the light that fell on them from the other light sources. This reflection is caused by interactions between the incident light beam and the surface of light active material. It is important to note that the wavelength of reflected light is dependent on the incident wavelength, angle of incidence and type of material - roughness of the light active material and its electrical properties such as permittivity and conductivity.

The architecture of indirectly oriented systems NLOS (Non Line of Sight) is inherently based on the use of reflections of optical beam from walls and internal equipment (general building materials). In conjunction with the optical free space system it is called a diffusion system very often. The reason is the use of optical wide-angle resources. Nowadays, it is beginning to establish multi-point and quasi-diffusion systems, which are based on the basic diffusion system, but there is used a cellular technology with the partition of microcells.

Indoor optical free space network – diffusion systems

In classical diffusion networks [1] the base station is placed on a level of table (cabinet or shelf) and the optical transmitter is directed to the ceiling of the room (Fig. 1). The optical transmitter has usually a radiation pattern as Lambert radiation source, which allows the lighting around the room ceiling and part of walls. In effect, this distribution means that the optical signal is scattered around the room and by the help of one or more reflections it reaches the optical receiver (terminal). Therefore it is not required any direction and any line of sight to the receiver, but an enormous amount of transmission paths leads to signal distortion and may cause the intersymbol interference.

The other issue is power efficiency [2]. Generally, the scattered configuration is characterized by high losses in the signal path. Therefore it has to be applied an optical receivers with large effective collecting area and wide FOV (Field of View). Above mentioned aspects, the loss of signal and the multipath propagation (intersymbol interference), are limiting the achievable bit rates of tens Mbit.s^{-1}. On the other hand, NLOS system can be easily overshadowed by the barrier, the diffusion system is more resistant due to its distribution of optical signal.

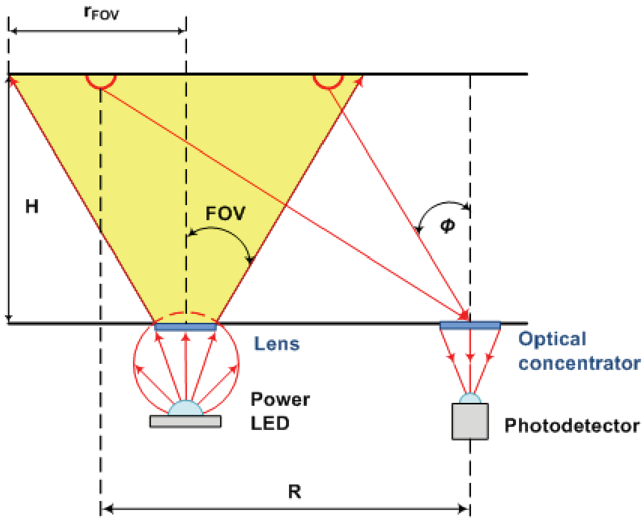

Fig. 1: Indoor FSO – diffusion system with Power LED

Incidence and reflection on building material surfaces

The optical properties of materials are especially important for the design and construction of light active parts of different devices. It has to be considered the possibility of directing the flux, its variance and eventually the restrictions of brightness in different directions, while the highest possible efficiency is achieved. In indoor FSO there are not only used the direct beams from the optical transmitter, but also the reflected beams from different material surfaces [3]. The surfaces may have a reflecting character as directional diffuse, diffuse or a combination of both (Fig. 2).

The luminous flux Φ, which incidents on the considered matter, is generally divided into three parts, namely a Φ_ρ, which is reflected, in part Φ_τ, which passes through a matter and in part Φ_α, which a matter absorbs. An outer limits correspond to absolute black body (α = 1), absolute white body (ρ = 1) and absolute transparent body (τ = 1). For non-transparent materials $\alpha + \tau = 1$ [4].

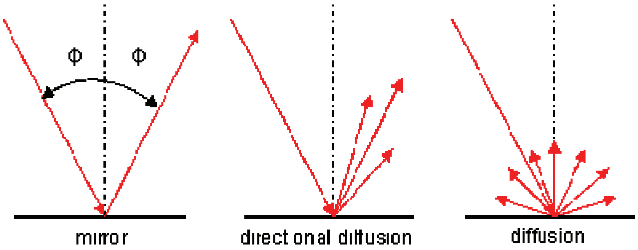

Fig. 2. Type of reflections on building material surface

Luminous flux Φ is determined by equation (4):

$$\Phi = K_m \int_{380nm}^{720nm} p(\lambda)V(\lambda)d\lambda \,, \quad (4)$$

where: $p(\lambda)$ – power spectral density of radiation, K_m – maximal value of spectral light efficiency with wavelength at λ_m = 555 nm (683 $lm.W^{-1}$), $V(\lambda)$ – relative spectral light efficiency of radiation with wavelength λ ($K(\lambda)/K_m$).

Directional characteristics of building materials

Directional characteristics connect points of the same intensity of power in space. It is determined as the dependence of optical power source of radiation on the active area of the receiver. It is shown as the dependence of light intensity on the direction angles from the central source. It is discriminated between the directional characteristics of the near and far fields. Directional characteristics of the near field affect a distribution of the radiation intensity on the source area. Directional characteristics of far field show the directional characteristics of emission. A block diagram of measuring system is shown in fig. 3.

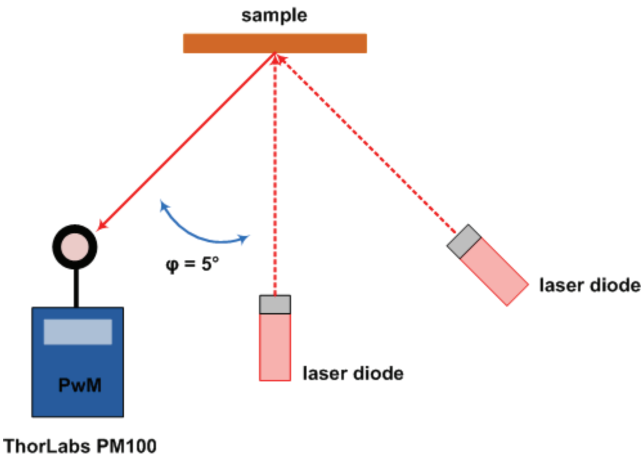

Fig. 3. Block diagram of measuring system of directional characteristics

The laser diode is connected to ThorLabs LDC 202 (Laser Diode Controller) and ThorLabs TED200 (Temperature Controller) for setting a constant optical output of 100 nW. The reflected optical beam (optical power 100 nW) of the sample is measured at different distances from the laser diode with an angle of rotation φ = 5°. Experiment measurement is performed in range 0 - 180°. The position of the laser diode was 90° and 45° (see Fig. 3) at wavelengths of 650 nm and 850 nm.

For the experimental measurement of the directional characteristics of building materials, two groups of samples have been created. The first group consists of coatings (hereafter NH) which was two-times applied to the plaster. The coatings are formed predominantly by samples from companies Primalex NH and Het. NH samples are in different shades. Colours were selected on the basis of the most common use in the interiors of the rooms, so that the measurements are closer to the reality (Fig. 4, Table 1). The second group consists of samples of tiling, building and structural materials. By selection of samples was emphasized the typical representatives of materials used in the interiors (Fig. 5, Table 2.).

Examples of the measured values of directional characteristics are shown in fig. 6 and 7. In this case, the samples were selected a whitewood no. 13 (natural colour) and HEAT CLASSIC no. 6. The measured values of the sample no. 13 exhibit that the directional characteristic is combined (diffuse and directional diffuse) and in the case of sample no. 6 directional characteristic is diffuse.

Fig. 4. The samples of coatings

Table 1. The description of samples of coatings

1	ROKO – INTERIER SUPER RK 400
2	HET KLASIK COLOR
3	PRIMALEX PLUS
4	PRIMALEX BONUS
5	HETLINE
6	HET KLASIK
7	PRIMALEX STANDARD (tinting)
8	EXIN EKO
9	Paste for tinting
10	PRIMALEX STANDARD

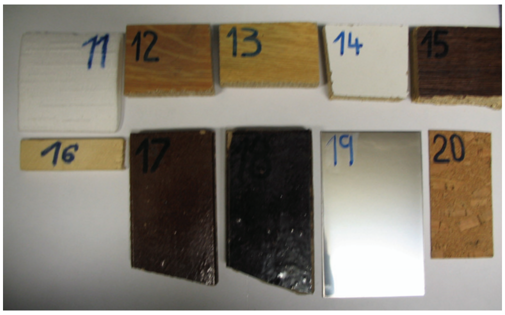

Fig. 5. The samples of building and tiling materials

Table 2. Building and tiling materials

11	POLYSTYREN
12	wooden board (light brown)
13	wooden board (ochre)
14	wooden board (white)
15	wooden board (dark brown)
16	spruce wood
17	clinker glossy (light brown)
18	clinker glossy (dark brown)
19	steel
20	cork

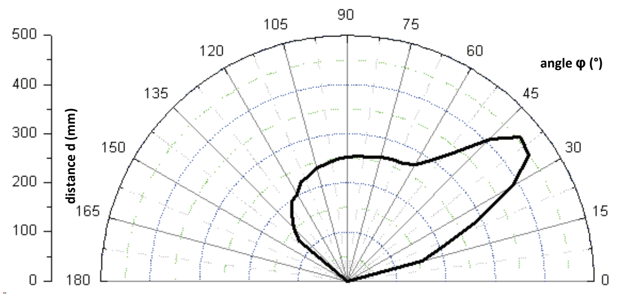

Fig. 6. Directional characteristic of sample no. 13, wavelength 650 nm, direction of laser diode 90°

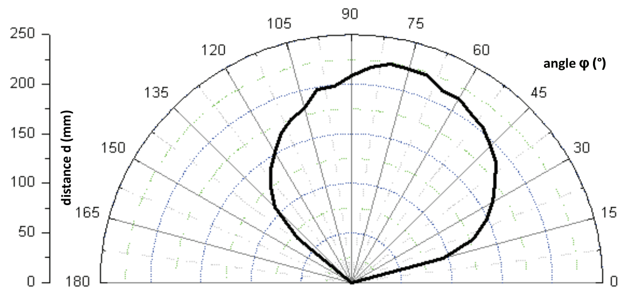

Fig. 7. Directional characteristic of sample no. 6, wavelength 650 nm, direction of laser diode 90°

The measured directional characteristics show a noticeable difference when using wavelength of 650 nm and 850 nm. When using larger wavelengths reflected optical radiation is able to cover a larger area and also achieves higher performance (Fig. 8).

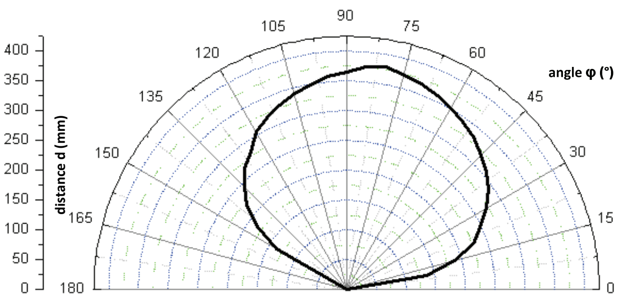

Fig. 8 Directional characteristic of sample no. 6, wavelength 850 nm, direction of laser diode 90°

Therefore it is evident that for diffusion systems in indoor FSO it is preferable to operate at higher wavelengths (infrared region).

Variance of reflectivity of building materials in dependence on polarization of light

Light is an electromagnetic wave and as such it has two components: the electrical component, which represents the vector of electric field intensity E and magnetic, which consists of a vector of magnetic induction B. The both components are perpendicular together and in addition they are both perpendicular to the direction of propagation of light. For the experimental measurement of the variance of the reflectivity in dependence on the polarization state of light was used a block diagram on Fig. 9.

A polarizer was placed before the laser diode, whereby it is possible to polarize the nonpolarized light falling on the polarizer from a laser diode. Angle of polarization was φ = 30°. Another steps are consistent with the procedure of the spectral characteristics measurement, respectively by the help of an optical detector the reflected light is coupled at first by semipermeable glass and then by the measured sample into fiber. The fiber is connected with the Ocean Optics USB4000 spectrometer. Examples of measured values at the wavelength of 650 nm and 850 nm are shown in fig. 10 and 11 for the sample no. 6.

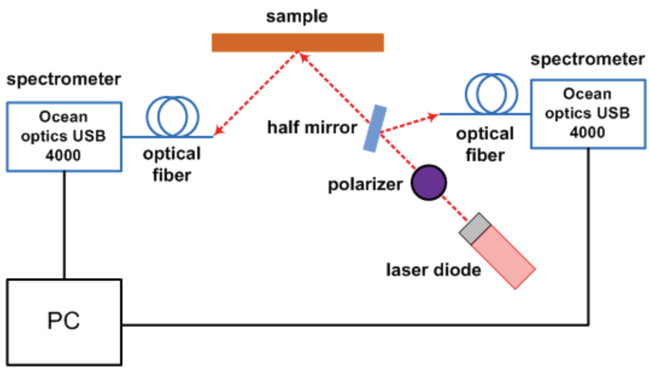

Fig. 9. Block diagram of experimental measurement of variance of reflectivity of building materials in dependence on polarization of light

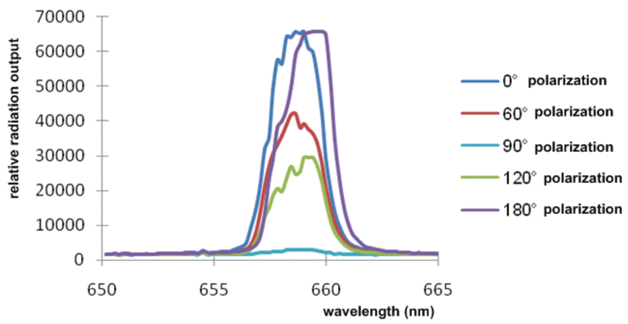

Fig. 10. Spectral characteristics in dependence on polarization of light of sample no. 6, wavelength 650 nm, direction of laser diode 45°

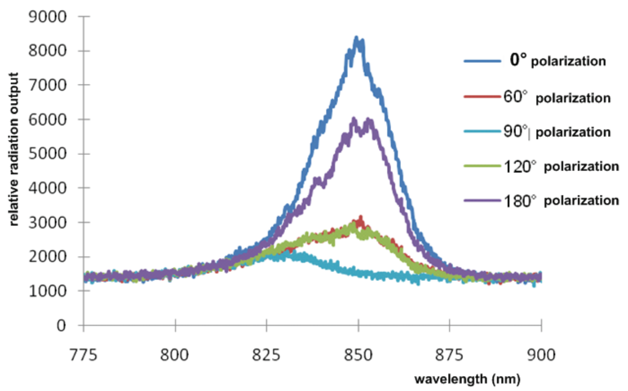

Fig. 11. Spectral characteristics in dependence on polarization of light of sample no. 6, wavelength 850 nm, direction of laser diode 45°

Measurement values of the sample no. 6 at wavelengths of 650 nm and 850 nm confirm that the polarized light has not any influence on the change of the spectrum after the reflection on the measured material. In dependence on the polarization changes only the value of the radiation power.

Conclusion

The diffusion systems are an alternative to the NLOS in indoor FSO. These systems are able to cover a larger area than NLOS. In experimental systems there was considered a primary source of radiation which can cover the whole room through a secondary sources of radiation (building materials inside the room). When using diffusion systems in indoor FSO it has to be paid attention to the building materials. The measured directional characteristics of building materials have confirmed the assumptions that matt surfaces have diffuse or directional diffuse character of the reflection - the typical example of the diffuse reflectivity is the sample no. 10 (PRIMALEX STANDARD). On the other hand, shiny, polished and glazed surfaces have a directional, almost mirror reflection - the typical example of the mirror reflection is the sample no. 18. The other finding was the influence of wavelength on the directional characteristics of building materials. It appears that the higher wavelengths are more suitable for diffusion systems, especially in the infrared region. The experimental measurements did not demonstrate (at wavelengths of 650 nm and 850 nm), that the polarization of light can affect the radiation spectrum. It changed only the value of the emitted power of secondary source, but this value is based on the principle of polarization.

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