Optik 127 (2016) 9259–9263

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

A comparative study of the performance of graded index perfluorinated plastic and alumino silicate optical fibers in internal optical interconnections

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ARTICLE INFO

Article history:
Received 11 January 2016
Accepted 1 July 2016

Keywords:
Optical fiber communication
Optical fiber dispersion
Optical interconnections
Optical computing
Optical fibers
Optical fiber applications
Optical losses
Optical polymers

ABSTRACT

This paper theoretically investigates a comparative analysis of the performance of both graded index perfluorinated plastic optical fiber and alumino-silicate optical fiber in internal optical interconnections operation, where these materials have low dispersion at the operating wavelength 1.3 μm. Temperature dependence of total dispersion coefficient is deeply investigated for these fibers. The temperature variations range from −50 °C to 100 °C. The obtained results show the dramatic effects of increasing ambient temperature variations on the signal quality degradation. The effects of increasing optical fiber length on optical interconnections performance efficiency and operation speed. A comparative study shows that, perfluorinated plastic optical fiber overcomes the alumino- silicate in operation performance efficiency and installation flexibility.

1. Introduction

Optical communication systems using Plastic Optical Fibers (POFs) have not reached their potential for a number of reasons: the rapid growth of glass optical fiber technology and because POFs have been relegated low speed and short distance applications. Graded index (GI) POFs are in a great demand in customer premises to deliver high-speed services due to their high bandwidth, single-mode operation and suitability for optical amplification. There are new POF materials with low loss, higher power and faster sources have been developed. Low-loss graded-index perfluorinated plastic optical fibers (GI PF POFs) are investigated for 100 m distance multi-Gb/s data transmission in premise networks, short-reach telecom, and computer interconnections. Several low-cost, uncooled, unisolated data communication sources, data transmission in premise networks, short-reach (<100 m) telecom and computer interconnects are dominated from copper interconnections up to 1 Gb/s data rates [1,2].

The next future will create a huge demand for high data rate, short distance and low cost interconnections. POFs are well known as solutions for low speed data links in cars, buildings and automation. Besides its robustness to mechanical stress

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http://dx.doi.org/10.1016/j.ijleo.2016.07.002

Table 1
Sellmeier coefficients of different materials [6,8–10].

Coefficient	Perfluorinated	Alumino silicate
A	1.495313456	1.4136733
B	0.918345 (T/T_0)	0.8503994 (T/T_0)
C	0.0170330	0.01324901
D	0.97915 (T/T_0)	0.9044591 (T/T_0)
E	150	100

and electromagnetic interference, the POF benefits from easy installation, low-cost connectors and a low price [3]. The large core of the POF allows the use of inexpensive injection-molded plastic connectors, which make it possible to dramatically decrease the cost of interface devices and installation.

The most important characteristic of the optical fiber; the bandwidth, is limited by the signal dispersion within the fiber. Therefore, once the attenuation was reduced to acceptable levels attention, was directed towards the dispersive properties of fibers [4,5]. Intermodal dispersion is one of these properties which act as a critical factor in optical fiber data transmission. POF assemblies possess special characteristics that make them an ideal solution for applications where additional glass optical fiber products are not well suited. For applications requiring a very tight bend radius [6]. POF assemblies have a core size; in some cases 100 times that of glass fiber. The increased core diameter allows 96% of the core to transmit signal from point-to-point, making it an ideal material for very high bandwidth which is the case of interconnections, signal transmission over very short distances. Also, the ease of installation and low system cost give the POFs strong advantages in computer interconnections and local area networks. Graded-index perfluorinated plastic optical fiber (GI-POF) has been developed to offer low losses (<50 dB/km) and high bandwidth at data communication wavelengths (0.85 μm, and 1.3 μm) [7].

2. Theoretical analysis

The core refractive index, n, as a function of the operating signal wavelength, λ, is defined through the Sellmeier equation which has the mathematical form [8]:

$$n = \sqrt{A + \frac{B\lambda^2}{\lambda^2 - C} + \frac{D\ \ \lambda^2}{\lambda^2 - E}} \tag{1}$$

where the Sellmeier coefficients of chosen materials are listed in Table 1 as functions of temperature (T in °C) and ambient absolute temperature (T_0 in °C).

The propagation constant, β, for graded index optical fibers is given by Raheem [8]:

$$\beta = \sqrt{\frac{V^2}{2\,\Delta a^2} - \frac{6\ V}{a^2}} \tag{2}$$

where a is the fiber core radius in μm, Δ is the relative refractive index difference and V is the normalized frequency. The total dispersion of a fiber is expressed as temporal broadening per unit length of the fiber per unit width of the light source used. The total dispersion parameter, D_T, is can be defined as in Ref. [8]:

$$D_T = D_m + D_w \tag{3}$$

where D_m and D_w are the material and waveguide dispersion coefficients, respectively, given by Raheem [8]:

$$D_m = -\frac{\lambda}{c}\left(\frac{d^2n}{d\lambda^2}\right) \tag{4}$$

$$D_w = -\frac{V^2}{2\pi\, c}\ \left(\frac{d^2\beta}{dV^2}\right) \tag{5}$$

where c is the free space speed of light and $(d^2n/d\lambda^2)$ is the second derivative of core refractive index and can be expressed as listed in Ref. [8]. Moreover, $(d^{2\beta}/dV^2)$ is the second derivative of the propagation constant and is shown in Ref. [8]. The fiber bandwidth, BW, characterizes the transmission capacity of a fiber for the graded index Gaussian-shaped pulses [1]:

$$BW = \frac{0.4484}{\Delta\tau} \tag{6}$$

where $\Delta\tau$ is the total pulse broadening due to dispersion effects, which is given by Rashed [9]:

$$\Delta\tau = \Delta\lambda\ D_T\, L \tag{7}$$

Table 2
List of parameters used in study [1,2,7,8].

Parameter	Value
Room temperature, T_0	27
Ambient temperature, T (°C)	−50 to 100
Refractive index difference, Δ	0.02
Fiber core radius, a (μm)	25
Input optical power, P_i (mW)	100
Noise figure, NF (dB)	0.5
Wavelength, λ (μm)	1.3
Optical loss at 1.3 μm, α (dB/km)	(Al_2SiO_5):0.28 (GI-POF):0.25
Fiber length, L (m)	0.1–10
Source spectral linewidth, Δλ (nm)	0.1

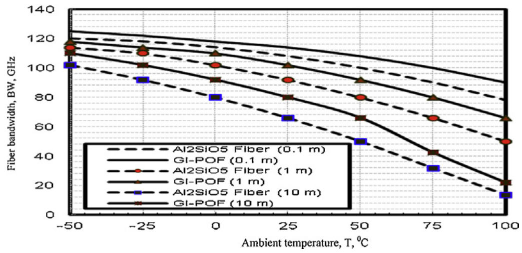

Fig. 1. Fiber bandwidth versus to ambient temperature at different optical fiber interconnection lengths.

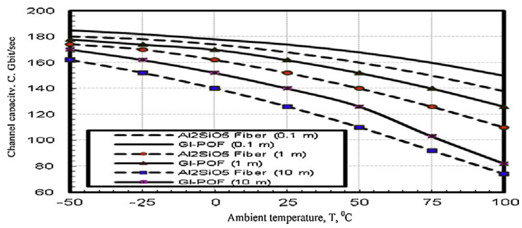

Fig. 2. Channel capacity versus ambient temperature at different optical fiber interconnection lengths.

where Δλ is the spectral linewidth of the light source in nm and L is the fiber length. Assuming the receiver side is at the room temperature, and feeds a matched preamplifier with noise figure (NF), then for a transmitted input optical power P_i, the signal to noise ratio at the receiver (SNR) can be expressed by El-dokany et al. [10]:

$$SNR = \frac{P_i\, L}{NF\, k_B\, T\, \alpha} \tag{8}$$

where k_B is the Boltzmann's constant, and α is the total attenuation coefficient in dB/km.The bit error rate (BER) in relation to signal to noise ratio can be estimated [11,12]:

$$BER = \left(\frac{2}{\pi \;\; SNR}\right) \quad \exp\left(-\frac{SNR}{8}\right) \tag{9}$$

Moreover, the Shannon channel capacity is given by Rashed [13]:

$$C = BW \log_2 \left(1 + SNR\right) \tag{10}$$

3. Results and discussions

We have deeply investigated a comparative performance study analysis of the graded index perfluorinated plastic and alumino-silicate optical fibers in internal optical fiber interconnections over a wide range of the affecting operating parameters that are listed in Table 2.

Based on the mathematical analysis and the list of operating parameters, the obtained results including BW, SNR, BER and C are displayed, respectively, in Figs. 1–4. From these figures, one can write:

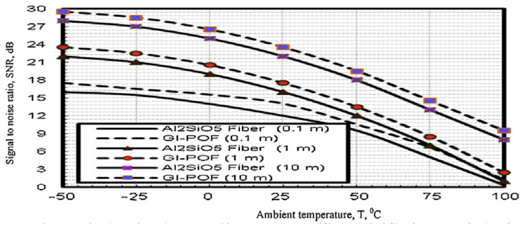

Fig. 3. Signal to noise ratio versus ambient temperature at different optical fiber interconnection lengths.

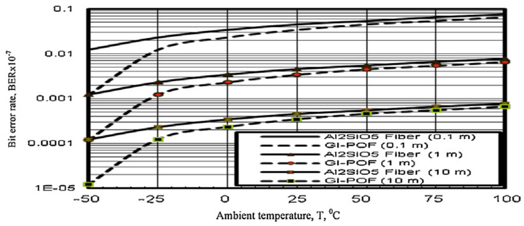

Fig. 4. Bit error rate versus ambient temperature at different optical fiber interconnection lengths.

i) Figs. 1 and 2 assures that optical fiber interconnection bandwidth and channel capacity decrease with both ambient temperature and optical fiber interconnection length variations for both materials. It is observed that, GI-POF has presented higher bandwidth when compared with alumino-silicate under the same operating conditions. The temperature dependent of refractive index has a positive linear relation with temperature. Thus, the increase in the refractive leads to a material dispersion increase and consequently, a decrease in both bandwidth and bit rate.

ii) As shown in Fig. 3, the signal to noise ratio decreases with ambient temperature and increases with optical fiber interconnection length for both materials. Again, the GI-POF has presented higher signal to noise ratio. This can be clarified from Eq. (8).

iii) Fig. 4, demonstrates that, bit error rate increases with the decrease of ambient temperature and optical fiber interconnection length for both materials. It is observed that, the GI-POF has presented lower bit error rate as compared with that of alumino-silicate under the same operating conditions. This can also be clarified from Eqs. (8) and (9).

4. Conclusions

The influence of both ambient temperature variations and optical fiber interconnection length variations on the performance of alumino-silicate and GI-POF been deeply investigated over a wide range of the affecting parameters. As expected, increasing ambient temperature decreases the fiber bandwidth, channel capacity and signal to noise ratio and increases the bit error rate. Moreover, it is indicated that, increasing optical fiber interconnection length results in decreasing bit error rate and consequently increasing signal to noise ratio. The obtained results reveal that, the GI-POF interconnection overcomes alumino-silicate in information bandwidth, signal to noise ratio enhancement and consequently decreasing bit error rate under the same operating conditions. So, GI-POF is recommended for optical internal interconnection due to operation flexibility and its high performance efficiency.

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