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Multigigabit short-reach communication over microstructured polymer optical fiber

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ABSTRACT

In contrast to conventional polymer optical fibers (POF) microstructured POF (mPOF) provide an additional opportunity to control the optical properties of the propagating signals. A particular arrangement of the air holes allows to reduce the number of waveguide modes and thus overcome the bandwidth limitation which is inherent for step-index POF. In this paper we report on the implementation of a 50 m data transmission link based on mPOF with a single ring of holes and a core diameter of 180 μm. A bit rate of 7 Gb/s was achieved at a bit-error ratio (BER) of 10^{-3} employing on-off keying modulation technique and an offline-processed symbol-spaced decision feedback equalizer. Discrete multitone modulation provided a bit rate of 8.07 Gb/s at BER of 10^{-3}.

1. Introduction

Polymer optical fibers (POF) are highly suited for automotive and in-home networks because they offer easy handling, small bending radii, robustness against mechanical stress and electromagnetic interference. Data transmission performance of widely used step-index POF (SI-POF) is mainly limited by high attenuation and intermodal dispersion which leads to bandwidth reduction [1]. This bandwidth limitation may be overcome by microstructured polymer optical fibers (mPOF), which use an arrangement of air holes to control the optical field localization, and also the number of waveguide modes. Thus, mPOF offer a much wider range of optical properties and potential applications in comparison to conventional POFs.

Previous publications show that polymethylmethacrylate (PMMA) mPOF with a particular hole structure can provide a bandwidth of more than 10 GHz over a 50 m link [2]. A successful demonstration of 9.5 Gb/s on-off keying (OOK) data transmission over a 50 m mPOF link was reported in [3], using a simplified structure consisting of a single ring of holes to define the core. However, the use of expensive optical components, a high fiber-coupled power of +18 dBm, and a wavelength conversion required for the optical signal generation impede a cost-effective implementation of such a system. A 7.3 Gb/s gross data rate at a bit-error ratio (BER) of 10^{-3} was also achieved over a 50 m mPOF link using the same structure with a core diameter of 140 μm and discrete multitone (DMT) modulation [4]. Thus, mPOF offer a much wider range of optical properties and potential applications in comparison to conventional SI-POF.

Graded-index POF (GI-POF) offers a comparable or better performance in terms of transmission bandwidth and attenuation. PMMA GI-POF provides a bandwidth of more than 3 GHz over a 50 m link [1]. A data transmission at a bit rate of 10 Gb/s was realized over 60 m 1-mm core-diameter PMMA GI-POF [5]. A 47.4 Gb/s data rate was achieved over 100 m 50-μm core-diameter perflourinated GI-POF using a 1300 nm distributed feedback (DFB) laser with DMT modulation [6]. The capacity of 112 Gb/s over 100 m GI–POF were demonstrated by exploiting single-mode fiber components like 1550 nm external cavity laser, external modulator, as well as optical fiber amplifier [7]. These superior results, however, cannot be directly compared with mPOF-based systems, since a perfluorinated GI-POF has a smaller core diameter and operates in the infrared range. A fabrication process of GI-POF is rather complicated in contrast to the single-material mPOF with an index profile performed by the holes structure. Furthermore, the bending loss in mPOF depending on the hole configuration in the cladding

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[8] can be lower than commercial GI-POF and SI-POF [9]. Design and production features of mPOF [1,8] allow to control waveguide characteristics of the fiber and expand the range of possible applications including tunable components for sensor application, filters, data transmission.

This paper focuses on the implementation of PMMA mPOF short-reach communication link using off-the-shelf components which includes 650 nm edge-emitting laser diode and commercially available optical receiver with an avalanche photodiode. Since the fiber under test has an equivalent step-index profile, it should be further compared with PMMA SI-POF. The system performance was tested with a simple OOK and DMT modulation schemes. To show the potential of mPOF with the single ring of holes structure, an additional investigation of the optical signal transformation along the fiber was carried out. For different launch conditions and different fiber lengths the following parameters were measured: signal attenuation, intensity distribution in the fibers cross-section, numerical aperture at the output and pulse shape transformation. mPOFs are not standardized for data transmission and most fibers available on the market are specially designed to meet specific customer requirements. In this context, a further investigation of the mPOF as a transmission media supplements the previously published results [2–4,8] offering an efficient solution for short-reach communication.

2. Fiber characterization

The structure of the PMMA mPOF under test is composed of 32 holes with a diameter of 20 μm each, which define a 180 μm core. The bridge thickness does not exceed 200 nm. The outer diameter of the fiber is approximately 500 μm. The guiding properties of the fiber are determined by the hole structure and an additional layer of optical cladding is not required. A loss spectrum shown in Fig. 1 was measured under overfilled launch conditions using cut-back method from 20 m to 10 m with a spectral resolution of 8 nm. The attenuation minimum of 440 dB/km is achieved at 650 nm.

An optical field transformation along the fiber was investigated with a pulsed laser diode operating at 650 nm (PicoQuant LDH Series). The uniform beam profile within required input NA was adjusted by the optical system including a set of pinholes and microscope objectives. A LEPAS-11 Optical Beam Measurement System was used for capturing of the far-field optical power distribution at the fiber output. The numerical aperture (NA) of the output, determined at the 5% level of the far-field pattern, is shown in Fig. 2. An equilibrium mode distribution (EMD) is formed after 5 m and the output NA remains constant at 0.1 [10].

The total attenuation coefficient measured at different fiber lengths under different excitation conditions is shown in Fig. 3. For excitation with a high NA a large number of high-order and cladding modes are launched which attenuate rapidly, bringing the total attenuation to a constant value. By under-filled launch with NA < 0.1 the low-order modes are excited primarily. These waveguide modes are strongly concentrated in the core and characterized by the minimal radiative attenuation. With an increase of the fiber length the mode coupling effects lead to the energy flow into high-order modes which have higher radiation losses. It results an increase of the total attenuation coefficient which tends to the constant value. A fiber excitation with NA = 0.1, corresponding to the EMD (see Fig. 3), leads to a steady attenuation of 450 dB/km. This result agrees sufficiently with a data shown in Fig. 1.

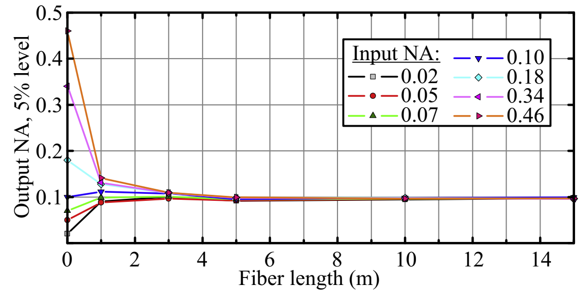

Fig. 2. Numerical aperture of the output signal under different excitation conditions (values at 0 m fiber length represent NA of the launch beam).

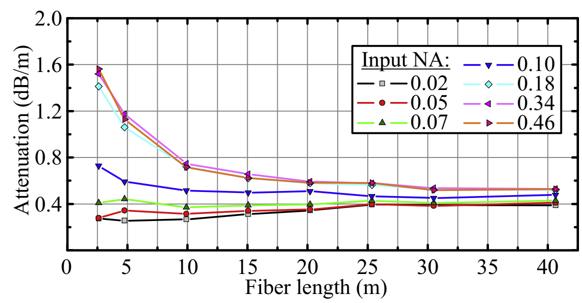

Fig. 3. Total attenuation under different excitation conditions.

Similar fibers with NA = 0.18 and core diameter of 140 μm were reported in [4] to have a loss of 190 dB/km at 650 nm under overfilled launch conditions using cut-back method from 15 m to 3 m. Also, in [11], such fibers with 140 μm core diameter were reported to have a loss of 160 dB/km at 650 nm using a similar cut-back measurement.

The smaller NA of the present 180 μm core mPOF most likely indicates that high-order modes suffer a higher attenuation leading to an increase of the total loss, with another factor possibly arising from the thermal history of the sample [11]. This behavior leads also to a higher bandwidth and thus to a smaller pulse broadening.

Pulse shape transformation along the fiber was measured by an optical sampling oscilloscope HAMAMATSU OOS-01 (see Fig. 4). It depends weakly on the excitation conditions. Pulse broadening measured by full width at half maximum did not exceed 80 ps over the 50 m link.

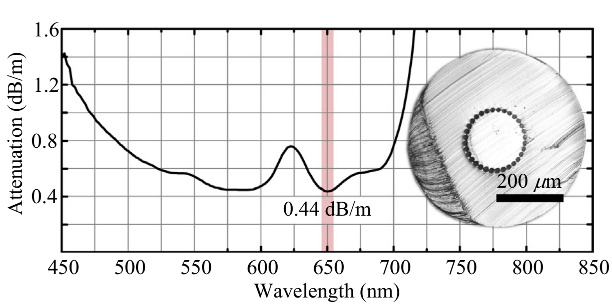

Fig. 1. Loss spectrum and cross section of mPOF.

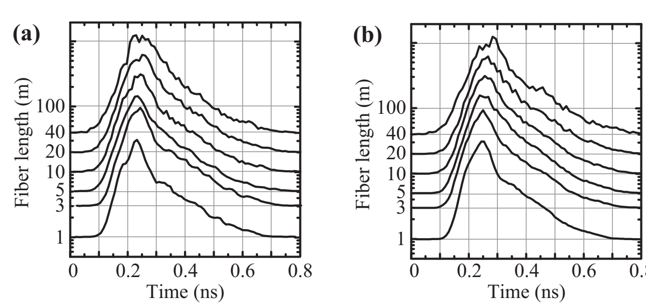

Fig. 4. Pulse shape transformation over the fiber length from 1 m to 40 m under different excitation conditions: input NA = 0.02 (a); input NA = 0.46 (b).