CWDM Technology for Polymer Optical Fiber Networks

H.P.A.v.d.Boom, W. Li, G.D. Khoe

Cobra Institute, Technical University Eindhoven EH-12, P.O. Box 513, 5600 MB Eindhoven, Netherlands.
(h.p.a.v.d.boom@tue.nl)

Abstract
One of the most important features of polymer optical fiber is the possibility to adopt a large core diameter, thus allowing low installation and handling costs. This makes these robust optical fibers extremely suitable for in-home and LAN applications. 2.5 Gbit/s Graded Index Polymer Optical Fiber (GI-POF) link experiments over distances up to 550 meters have already been established. For flexible high capacity GI-POF optical networks, applying Wavelength Division Multiplexing (WDM) will be necessary. Perfluorinated polymer based GI-POF has a low loss wavelength region from 500 to 1300 nm, so a broad wavelength range is available for the implementation of CWDM (Coarse WDM as opposed to Dense WDM). In contrary to DWDM, CWDM can use low cost technology to separate the wavelength channels. Our recent records reaching 5 and 7.5 Gbit/s WDM transmission results using perfluorinated polymer based GI-POF will be reported.

Introduction
Silica based single mode optical fiber is widely utilized in the long distance trunk area for giga bit per second transmission and beyond, because of its high bandwidth. On the other hand, use of the silica based multimode fiber is a recent trend in the area of local area networks (LANs) and interconnection. This is because the large core diameter of silica based multimode fiber of 50 and 62.5 microns relaxes the tolerance required for connection compared with the single mode fiber whose core diameter is only 5 to 10 microns. However, even with the multimode silica fiber, an accurate alignment in the connection is still required. The large core diameter (100–1000 microns) of Polymer Optical Fiber, POF enables the use of inexpensive polymer connectors, which are prepared by an injection molding process, because a displacement of ±30 microns in the connection does not seriously influence the coupling loss [1-2]. Furthermore, a large core of more than 100 microns could reduce the modal noise, which disturbs systems with multimode silica fibers [3]. Polymethyl methacrylate (PMMA) has been generally used as the core material of commercially available step-index POF. Its attenuation limit is approximately 100 dB/km in the visible region. Therefore, the high attenuation of POF compared to the silica-based fiber has limited the POF data link length, even when the bandwidth characteristics are improved by the Graded Index-POF, GI-POF [4-5]. On the other hand, the perfluorinated (PF) amorphous polymer base GI-POF has a low loss wavelength region from 500 to 1300 nm [6], see Fig.1. The experimental total attenuation of the PF polymer based GI-POF decreases to 40 dB/km even in the near infrared region. In this paper, record 2 and 3 times 2.5 Gbit/s Coarse Wavelength Division Multiplexing transmission experiments using PF GI-POF will be reported.

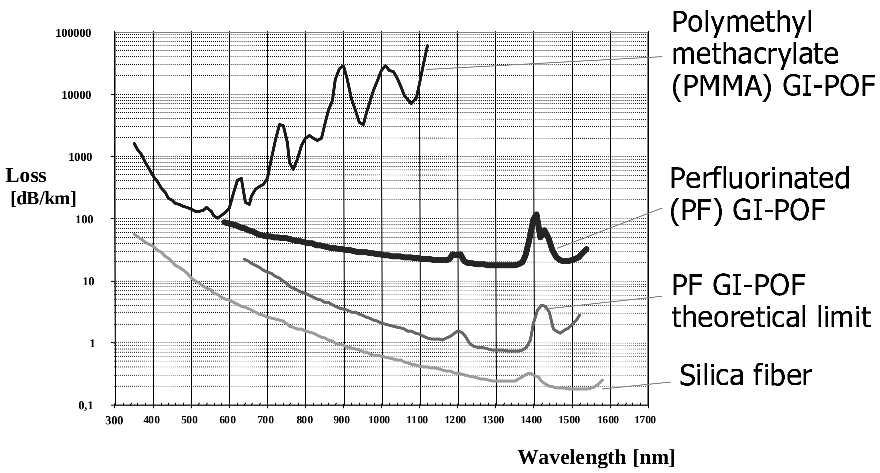

Fig. 1: Attenuation of GI-POF

Coarse Wavelength Division Multiplexing Experiments

As indicated earlier Perfluorinated polymer based GI-POF has a low loss wavelength region from 500 to 1300 nm, so a broad wavelength range is available for the implementation of CWDM (Coarse WDM as opposed to Dense WDM). In contrary to DWDM, CWDM can use low cost technology to separate the wavelength channels. We developed a 3 times 2.5 Gbit/s over 200 m GI-POF CWDM experiment using the wavelengths 645, 840 and 1310 nm and a 2 times 2.5 Gbit/s over 456 m GI-POF CWDM experiment using the wavelengths 840 and 1310 nm with a record bit rate times distance product. A block diagram of the 2 times 2.5 Gbit/s experiment is shown in Fig. 2.

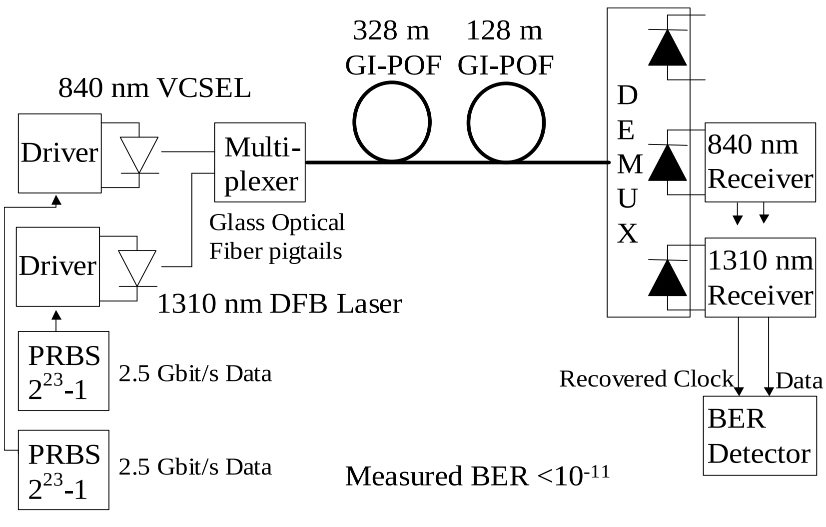

Fig. 2: Block diagram of the 2 times 2.5 Gbit/s over 456 m PF GI-POF CWDM transmission experiment.

Because the fiber samples have an attenuation of more than 100 dB/m at 640 nm, this wavelength could not be used. At the transmitter side for the 840 nm channel a Vertical Cavity Surface Emitting Laser (VCSEL) with a modulated output power of 2.1 dBm has been used and for the 1310 nm wavelength channel a Distributed FeedBack (DFB) laser with a modulated output power of 3.0 dBm has been used. To compensate for the insufficient bandwidth of the VCSEL, an electrical equalising circuit has been applied.

To multiplex both wavelength channels, a multimode glass fused fiber 850/1300 nm WDM has been used. The step index pigtails of the 850/1300 nm multiplexer have a core diameter of 50 micron and the losses of the multiplexer are 1.5 dB and 0.7 dB for respectively the 840 and 1310 nm channel. The 456 m PF GI-POF consists of a piece of 328 m and a piece of 128 m. The total losses of the GI-POF are 24.2 dB and 25.9 dB for respectively the 840 and 1310 nm wavelength. For splitting up the wavelength channels, a demultiplexer has been realized with planar interference filters [7]. The demultiplexer has been developed for the wavelengths 645, 840 and 1310 nm, so in this experiment the 645 nm output has not been used. In Fig. 3 the principle of operation of the demultiplexer is shown.

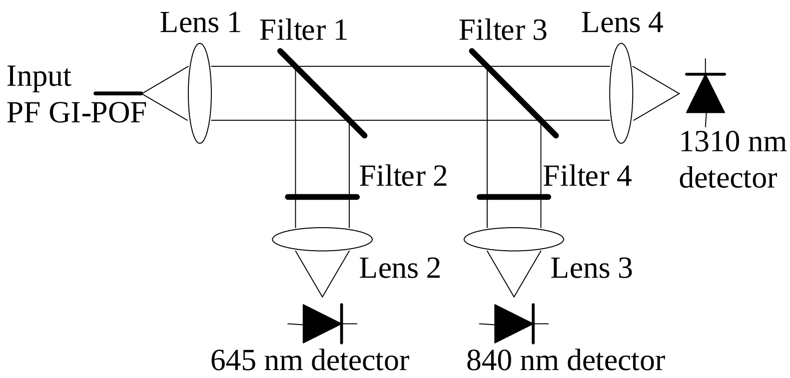

Fig. 3: Principle of operation of the 645, 840, 1310 nm demultiplexer.

First the light from the input GI-POF is transformed to a parallel beam by means of lens 1. Interference filter 1 deflects the light in the 645 nm wavelength region. The other wavelengths are passed through. To decrease cross-talk an extra filter 2 has been used which is only transparent for the 645 nm wavelength region. Lens 2 focuses the light at the photo diode of the 645 nm receiver. The light in the 840 and 1310 nm wavelength regions, which passed through filter 1, is split up by filter 3. Light in the 840 nm wavelength region is deflected by filter 3, filtered by filter 4 and focused on the detector of the 840 nm receiver by lens 3. The remaining 1310 nm light is focused on the 1310 nm detector by lens 4. The measured insertion losses for all three wavelengths, from GI-POF input to photo detectors are smaller than 1.6 dB. Measured cross-talk levels are smaller than -35 dB.

The detector in the 840 nm receiver is a Silicon Avalanche Photo Diode (APD) with a large active area of 230 μm in diameter. The sensitivity of the 2.5 Gbit/s 840 nm receiver is

–29.0 dBm for a Bit Error Rate (BER) of 10^{-9}. A key element used in the 1310 nm reveiver is an InGaAs APD with an active area of 80 μm in diameter. The sensitivity of the 2.5 Gbit/s 1310 nm receiver is also –29.0 dBm for a BER of 10^{-9} [8]. The measured BER for the 840 nm as well as the 1310 nm channel is smaller than 10^{-11}. All BER measurements were carried out using a Non Return to Zero (NRZ) Pseudo Random Binary Sequence (PRBS) with a pattern length of 2^{23}-1.

Conclusions

Applying WDM can further enhance transmission capacity via POF. WDM also increases the flexibility in POF networks. Perfluorinated polymer based GI-POF has a low loss wavelength region from 500 to 1300 nm, so a broad wavelength range is available for the implementation of CWDM (Coarse WDM as opposed to Dense WDM). In contrary to DWDM, CWDM can use low cost technology to separate the wavelength channels. A three times 2.5 Gbit/s over 200 m GI-POF and a two times 2.5 Gbit/s via 456 m GI-POF CWDM experiment have been developed. The experimental results show the applicability of Graded Index Polymer Optical Fiber for customer premises and local area networks. We believe that the record results reported here are important milestones that may encourage the development of polymer fiber systems and networks.

Acknowledgement

The presented work has been carried out within the framework of the Innovative Research Program IOP on Electro-Optics, subsidized by the Ministry of Economic Affairs.

References

[1] G.D. Khoe, Y. Yoike, T. Ishigure, P.K.v.Bennekom, H.P.A.v.d.Boom, W.Li, G. Yabre, “Status of GIPOF systems and related technologies", *25th ECOC '99*, 26-30 Sep. 1999, pp. II/274-II/277.
[2] F. Fredricx, Ch. Bouchat, P. Vetter, H.P.A.v.d.Boom, W. Li, “Polymer Optical Fiber for datacommunication: a feasibility study", *Symposium IEEE/LEOS Benelux Chapter*, November 15, 1999, Mons Belgium, ISBN 2-9600226-0-2, pp.115-118.
[3] R. E. Epworth, “The Phenomenon of Modal Noise in Analogue and Digital Optical Fiber Communication,” *Proc. of 4th European Conf. on Opt. Comm.*, Genoa, Italy, Sept. 1978, pp. 492-501.
[4] Y. Koike, T. Ishigure, and E. Nihei, “High-bandwidth graded-index polymer optical fiber,” *IEEE J. Lightwave Technol.*, vol. 13, no. 7, 1995, pp.1475-1489.
[5] W. Li, G. Khoe, H. v.d. Boom, G. Yabre, H. de Waardt, Y. Koike, S. Yamazaki, K, Nakamura, Y. Kawaharada, "2.5 Gbit/s Transmission over 200 m PMMA Graded Index Polymer Optical Fiber Using A 645 nm Narrow Spectrum Laser and a Silicon APD", *Microwave and optical technology letters*, Vol 20, No. 3, Febr. 5 1999, pp 163-166.
[6] G.D. Khoe, (invited), “Exploring the use of GIPOF systems in the 640 nm to 1300 nm wavelength area”, *Proc. 8th Intern. POF Conf.*, Chiba, Japan, 14-16 July 1999, pp. 36-43.
[7] W. Li, G.D. Khoe, H.P.A.v.d.Boom, "A Perfluorinated Based Graded Index Polymer Optical Fiber Demultiplexer for 645, 840 and 1310 nm", *Symposium IEEE/LEOS Benelux Chapter*, November 15, 1999, Mons Belgium, ISBN 2-9600226-0-2, pp.73-76.
[8] W. Li, G.D. Khoe, H.P.A. v.d.Boom, G. Yabre, H. de Waardt, Y. Koike, M. Naritomi, N. Yoshihara, "Record 2.5 Gbit/s 550 m GI POF transmission experiments at 840 and 1310 nm wavelength", *7th Microptics Conference/International POF Conference '99*, 14-16 Jul. 1999, pp 60-63.
[9] G.D. Khoe, W. Li, G. Yabre, H.P.A. van den Boom, P.K. van Bennekom, (Invited), "Progress in GIPOF systems and enabling technologies", *International Optoelectronics Symposium 2000*, Kyoto University, Japan, June 7-9, 2000, Vol. 55, No. 2, pp. 9-10.
[10] G.D.Khoe, L.Wei, G. Yabre, H.P.A.v.d.Boom, P.K.v.Bennekom, I.Tafur, H.J.S.Dorren, Y.Watanabe and T.Ishigure, (Invited), "High Capacity Transmission using GIPOF", *Proc. International POF 2000 conference*, Boston, Massachusetts, USA, September 5-8, 2000.