

# First Experimental Transmission over 50 m GI-POF at 40 Gb/s for Variable Launching Offsets

Stefan Schöllmann (1), Christoph Wree (2), Abhay Joshi (2) and Werner Rosenkranz (1)

(1) Chair for Communications, University of Kiel, Kaiserstrasse 2, 24143 Kiel, Germany, [sts@tf.uni-kiel.de](mailto:sts@tf.uni-kiel.de)

(2) Discovery Semiconductors Inc., 119 Silvia Street, Ewing, NJ 08628 USA

**Abstract** We show by BER measurements the first 40 Gb/s transmission over 50m GI-POF. The robustness towards launching offsets, polarisation changes and fibre bending is investigated for MMF and POF with 33GHz multi-mode coupled photo detector.

## Introduction

Silica multi-mode fibre (MMF) and plastic optical fibre (POF) systems are characterized by easy handling and robustness towards strong bending compared to single mode fibre (SMF) systems. Therefore, both are promising candidates for the increasing market of high speed local area networks (LANs) and short optical interconnects in high performance computing (HPC) environment up to 40 Gb/s [1,2].

First experimental results based on eye diagrams were presented up to 40 Gb/s over GI-MMF [2] and up to 30 Gb/s over GI-POF [3]. However, all these publications were limited by multi-mode coupled photo detectors either with a small bandwidth or a small active detection area. For this type of fibre links, no BER measurements focused on the robustness towards launching offsets and polarisation changes were presented. In contrast to that, we are using a 33 GHz multi-mode coupled photo detector with an active detection area of 20  $\mu\text{m}$  diameter. This photo detector is the key element for our experimental investigation by BER measurements of robustness towards mode dispersion, polarisation and bending effects at a high data rate of 40 Gb/s over 50 m GI-POF and 100 m GI-MMF.

## Experimental Setup

The experimental setup is shown in fig. 1. The light of the DFB laser ( $\lambda=1540$  nm) is externally modulated by a Mach Zehnder Modulator (MZM). This is driven by a PRBS of length  $2^{31}-1$  with a data rate of 40 Gb/s (multiplexed in the electrical domain from 10 Gb/s to 40 Gb/s). Afterwards the signal is amplified by an EDFA and attenuated with a variable optical attenuator (VOA) to vary fibre input power. The polarisation of the signal can be changed with a polarisation controller. Variable restricted launch positions are realised by a micropositioner. Thereby, the light is launched with different offsets in horizontal as well as vertical direction from SMF (thin line) into the graded index MMF/POF (thick line). Afterwards, the signal is transmitted over 50 m GI-POF (loss: 14dB – would be reduced to 3 dB by transmitting at 1300 nm) or 100 m GI-MMF (loss: 0.5 dB; bandwidth at 1300 nm: 4 GHz km) with core diameters of 50  $\mu\text{m}$ . The signals are detected by a high speed (33 GHz 3 dB bandwidth) multi-mode coupled (50  $\mu\text{m}$  core, 1 m length) photo detector with an active area of 20  $\mu\text{m}$

diameter. This signal is afterwards amplified by an electrical amplifier (bandwidth: 48GHz; gain: 20dB). Bending influences for POF transmission are investigated by turning the fibre around a screw with a diameter of 8 mm. Finally, the robustness of the system is analysed after 1:4 demultiplexing in the electrical domain by a bit error ratio tester at 10Gb/s (measuring all four tributaries) or an oscilloscope.

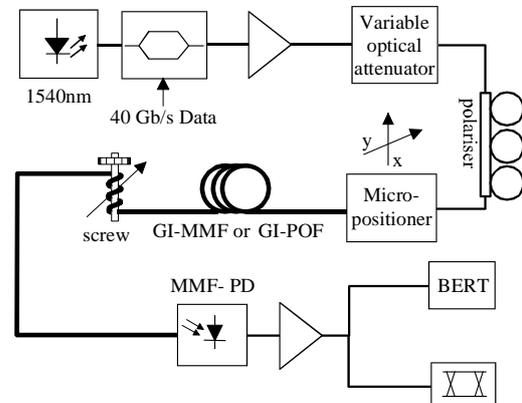


Fig. 1: Experimental setup: variable input power, polarisation states and launching offsets, different fibre types (GI-MMF and GI-POF) and bending influences

## Experimental Results

Fig. 2 shows the BER curves versus input power values for four investigated setups: back to back (b2b), 100 m GI-MMF and 50 m GI-POF (with and without bending influences). Thereby, the launching offset is set to zero between SMF and MMF/POF.

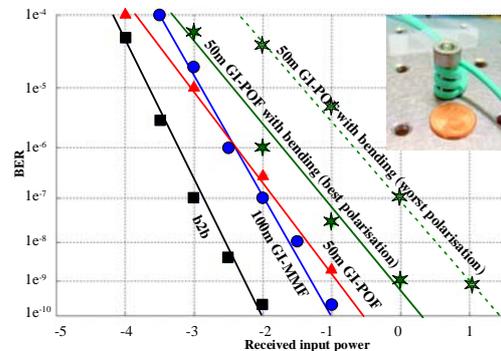


Fig. 2: BER measurements versus received input power for four cases: b2b, 100 m GI-MMF and 50 m GI-POF with and without bending influences

In addition, each of these setups is investigated in an

optimum and in a worst state of polarisation. This means that the optimized BER (changing the polarisation controller) is measured for this setup. In a next step, the polarisation is changed to find the worst BER. Following results are extracted from fig. 2.

Firstly, for all 4 setups a BER of  $1e-10$  (no error floor is observed) is achieved. This is, to the best of our knowledge, a new record over 50 m GI-POF at a data rate of 40 Gb/s. Secondly, for all investigated setups we observe only a small influence of polarisation changes (for simplicity of the diagram, only the largest difference of 1 dB between best and worst polarisation (50 m GI-POF with bending) is shown). Thirdly, the minimum received power at the photo detector for a BER of  $1e-10$  is found to be -2 dBm for the b2b setup, -1 dBm for 100 m GI-MMF transmission line, -0.7 dBm without bending and 0.3 dBm with bending over 50 m GI-POF. Thereby, the curves representing silica based systems own a higher gradient compared to POF based systems. This behaviour might be explained by a higher influence of mode coupling and modal noise in POF compared to MMF due to imperfections at the core cladding interface. Nevertheless, we observe a high robustness towards strong fibre bending (three times around a screw (8mm diameter) – see picture in fig. 2) for the GI-POF because we see only a degradation of approximately 1 dB between the system with and without bending.

Our experimental results concerning launching offsets for transmission (fixed polarisation, without bending influences) over 100 m GI-MMF and 50 m GI-POF are shown by three dimensional plots (BERs over horizontal and vertical offsets) in fig. 3a and fig. 3d, respectively. Thereby, we set our received input power at the optimum detection position to 3 dBm. Afterwards, the launching position is varied in steps of 2  $\mu\text{m}$  from -20 $\mu\text{m}$  to +20 $\mu\text{m}$  in the horizontal as well as in vertical axis. This means that each of the BER distributions is based on 400 measured data points. An error free transmission for offset variations of approximately  $\pm 3 \mu\text{m}$  from central launching position over 100 m GI-MMF (eye diagram in fig. 3b) is achieved. For higher offsets of approximately 10  $\mu\text{m}$  we observe a strongly degraded BER up to  $1e-1$  which is based on the limiting influence of mode dispersion. This is underlined by the eye diagram in fig. 3c. For even higher offset (ca. 13  $\mu\text{m}$  – 18  $\mu\text{m}$ ) the BER is slightly improved again due to a lower influence of dispersion. These results agree with previous published results for 10 Gb/s systems limited by mode dispersion [4,5]. In summary, the 40 Gb/s setup with the MMF is mainly limited by mode dispersion.

For the POF transmission setup, we observe a significant higher tolerance of approximately  $\pm 10 \mu\text{m}$  in respect to launching offsets for error free transmission. This is explained by the shorter

transmission distance and by the excellent transmission performance with respect to mode dispersion influences. This is underlined by an undistorted eye for an offset of 10  $\mu\text{m}$  where only the amplitude is reduced compared to optimum position. This reduction is explained by excitation of high order modes which are travelling predominantly in the outer region of the core [5]. Only for higher offsets than 15  $\mu\text{m}$  we see the limiting effect of mode dispersion (fig. 3f). In summary, this means that the POF transmission system is very robust against launching offsets.

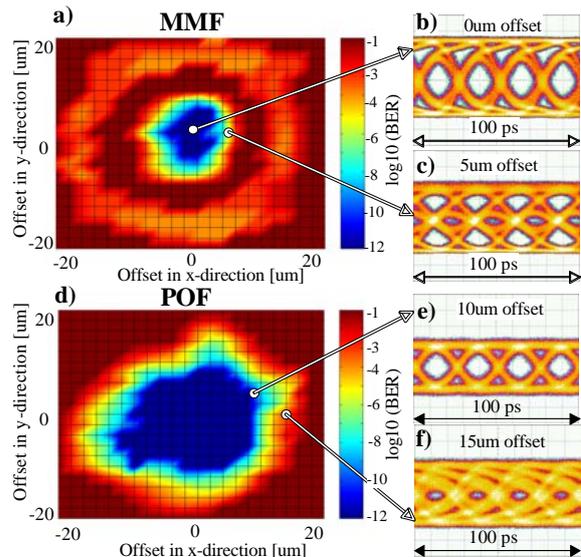


Fig. 3: BERs for vertical and horizontal launching offsets: a) 100m GI-MMF, d) 50m GI-POF; eye diagrams for 0  $\mu\text{m}$  and 5  $\mu\text{m}$  offset over MMF (b, c) and 10  $\mu\text{m}$  and 15  $\mu\text{m}$  offset over POF (e, f)

## Conclusions

The feasibility of error free transmission over 50 m GI-POF and 100 m GI-MMF at 40 Gb/s with a 33 GHz multi-mode coupled photo detector (active area of 20  $\mu\text{m}$  diameter) is shown by BER measurements for the first time. In addition, a high robustness towards bending influences and polarisation changes is demonstrated. Finally, the tolerable launching offset is found to  $\pm 3 \mu\text{m}$  for MMF and  $\pm 10 \mu\text{m}$  for POF. Thereby, the MMF transmission is limited due to mode dispersion influence whereas the mode dispersion tolerance of the POF system is significantly higher.

## Acknowledgement

We thank Chromis Fiberoptics for providing the GigaPOF50SR-PC-SM plastic optical fibre.

## References

- 1 P. Pepeljugoski et al., OFC 2007, OMR 4
- 2 P. Matthijsse et al., OFC 2006, OWI 13
- 3 A. Polley et al., OFC 2007, OMR 5
- 4 C. Xia. et al., Journal of Lightwave Technology (JoLT), June 2005, pp. 2001-2011
- 5 L. Raddatz et al., (JoLT), March 1998, pp.324-331

