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Generation of 1.5 Gbps Pseudo-random Binary Sequence Optical Signals by Using a Gain Switched Fabry-Perot Semiconductor Laser

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Recently, polymethyl methacrylate based plastic optical fibers (POFs) have attracted considerable attention as a potential medium for local area network (LAN) and home network applications. Since the POFs have very low optical loss at around 650 *mm*, in particular, it becomes quite important to develop *GHz* transmitters operating at this wavelength for high bit rate optical transmission applications of the POFs. In this paper, we present generation of ≥ 1.5 *Gbps* pseudo-random binary sequence optical signals by using a gain switched InGaAlP Fabry-Perot semiconductor laser with a high frequency filter, operating at 650 *mm*, and the application of these signals to bandwidth measurement of POFs.

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I. INTRODUCTION

Single mode optical fibers based on silica have been widely used for core metropolitan area networks because of their ability to provide high bandwidth, low attenuation, and long-term stability. However, silica fibers may not be ideal media for high bit rate data communication in home and office network applications because high cost and skilled labor are required to install silica fibers [1],[2]. In this point of view, plastic optical fiber (POF) has particular advantages such as low costs related to its ease of coupling and splicing due to its large core, its flexibility and ductility enabling fast installation. Therefore, POF has long been considered as an alternative to the silica based fiber for short distance communications, even though it has strong attenuation [3],[4].

In the beginning of 1990's, polymethyl methacrylate (PMMA) based high-bandwidth and large-core graded-index (GI) POF was reported for the first time [5]. After then, low loss and high quality PMMA based POF has been developed and even commercialized by a couple of companies for short distance data transmission [6],[7]. In particular, it has been successfully utilized for the highest comfort model of up-market in-vehicle network applications [8], [9]. Since it has very low optical loss at around 650 *mm* wavelength, there has been a growing interest of developing ultrafast transmitters for the high bit rate data communications at this wavelength. In this paper, we present demonstration of a gain switched InGaAlP Fabry-Perot semiconductor laser diode (LD) operating at 650 *mm* wavelength, generation of ≥ 1.5 *Gbps* pseudo-random binary sequence (PRBS) optical signals based on the gain switching technique with a high frequency filter, and their application to *GHz* bandwidth measurement of the POFs.

II. GAIN-SWITCHED FABRY-PEROT SEMICONDUCTOR LASER

Gain switching can be achieved by driving a LD with an electrical current pulse to excite only the first peak of the relaxation oscillation. This can be achieved by applying a short current pulse to a LD to generate relaxation oscillation of the laser. If the width of the current pulse is shorter than the period of relaxation oscillation of the laser, we may obtain a single optical pulse for a given current pulse [10]. The pulse width of this gain switched optical pulse becomes shorter for a larger gain cross-section of a lasing medium and for a shorter length of a laser cavity. Shorter pulses can be obtained if the reflectivity of the end faces of a laser is lowered.

Fig. 1 shows the experimental setup for a gain switching technique. Voltage Controlled Oscillator (VCO) was used as a major electric signal source to generate a sinusoidal RF signal. Its power was around 10 *dBm* and its frequency can be varied from 500 *MHz* to 1 *GHz*. An electronic amplifier with 20 *dB* gain was used just after the VCO. Then, the output signal of the amplifier was used to drive a commercial comb generator that provides a short electrical current pulse to a semiconductor laser. The comb generator consisted of step recovery diode and filtering reactive element [11]. The 125 *ps* electrical pulse was generated whenever the sine signal passes through from the positive to the negative half-cycle. The output pulse repetition rate of the comb generator was the same as the input signal repetition rate. The generated short electrical pulse was combined with the DC bias current through a bias-tee to drive the semiconductor laser. The DC bias current, I_B, was needed to cause population inversion of the gain medium more easily with a lower intensity current pulse.

The LD used in this experiment was a commercially available InGaAlP Fabry-Perot semiconductor laser, operating at 650 *mm* wavelength. Its continuous (CW) threshold current I_{th} was about ~30 *mA*. The optical pulse widths of the gain switched operation of the laser as a function of DC bias current is given in Fig. 2. It shows that the measured optical pulse width (full-width-at-half-maximum) gradually decreases as the bias current increases and eventually it is saturated [12]. When the bias current was increased too much, there rises a second pulse just after the first pulse. At modulation frequency of f_m = 600 *MHz*, the shortest pulse width of 33 *ps* was achieved when I_B/I_{th} = 2.353. When f_m = 350 *MHz*, the shortest optical pulse width of 40 *ps* was obtained at I_B/I_{th} = 1.773.

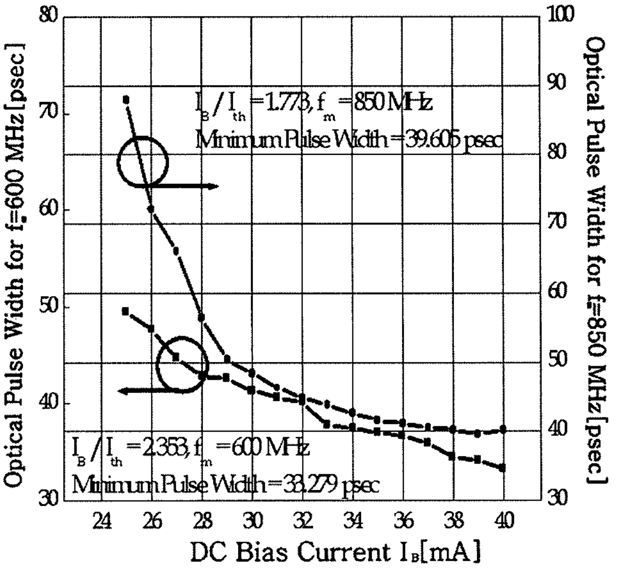


FIG. 2. FWHM of optical pulses for various DC bias currents.

III. Generation of ≥ 1.5 *GHz* PRBS-NRZ Pattern Optical Signals

Even if we show that ≤ 50 *ps* laser pulses can be produced as shown above, we should be able to generate *GHz* modulation of light, encoded by binary code, to measure the bandwidth of the PMMA based POF for *Gbps* digital light communication. In order to get the square and binary optical signals, at first, pseudo random binary sequence (PRBS) electrical signals of ~ 1.5 *Gbps* were obtained by a pattern generator. Fig. 3 displays an eye-diagram of our PRBS electrical signals obtained by using a digital sampling oscilloscope. It is quite clear from this eye-diagram that our electrical signal has rising time of ~ 120 *ps*.

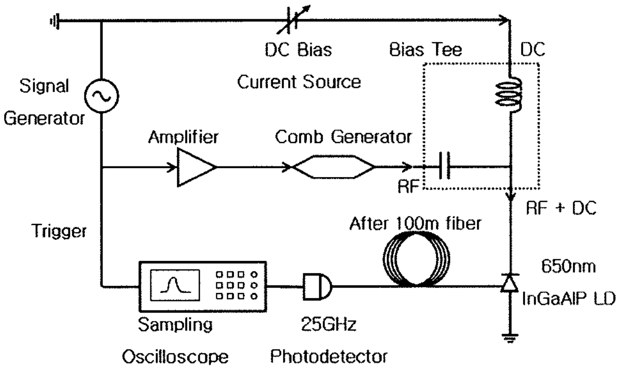


FIG. 1. Schematic diagram of gain switching technique.

Before delivering the PRBS electrical signal to the semiconductor laser diode (LD) with the gain switching mechanism, we have investigated the rising time of the laser diode by using a periodic square wave. Fig. 4 (a) shows the rising characteristics of InGaAlP LD from

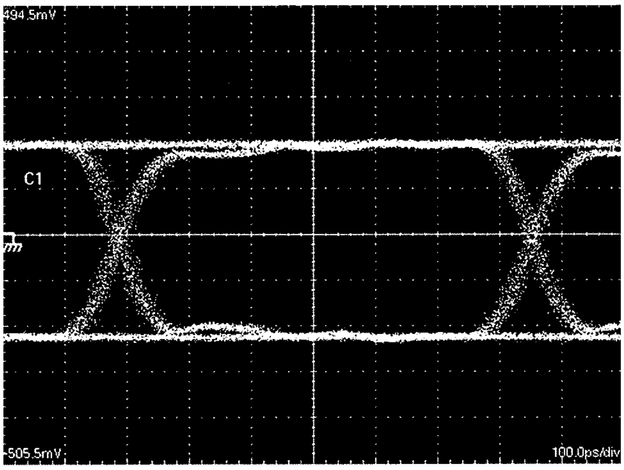
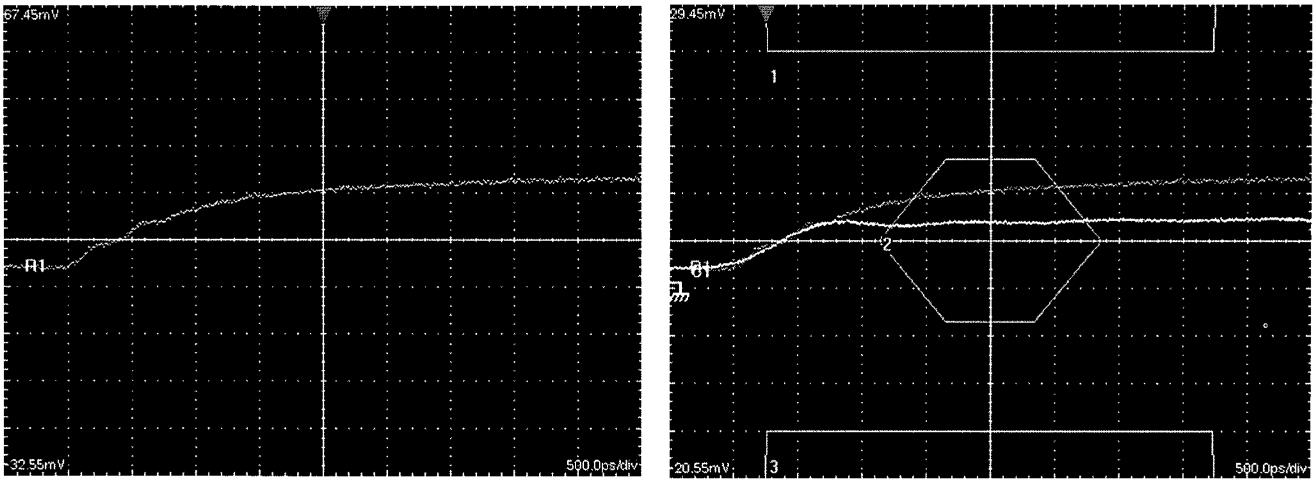


FIG. 3. Eye-diagram of PRBS electrical source.



(a) (b)

FIG. 4. Rising time of laser diode (a) without and (b) with a high pass filter.

low to high optical power levels. The rising time was observed to be ~ 2 *ns*, indicating no possibility of operation of ≥ 500 *Mps* as a digital communication source. Here, DC current of ~ 22 *mA* and AC current of 3 *mA* were applied. As shown in Fig. 2, we can decrease the rising time by increasing the DC bias current. In general, however, PMMA based POF is expected to have the bandwidth of only ~ 1 *Gbs* over 100 *m*. Instead of increasing the DC bias current to reduce the rise time, therefore, we have employed a high pass filter in order to get long-term stability of LD operating at 650 *nm*. Fig. 4 (b) shows that the rising time can be greatly improved to as low as ~ 500 *ps* by employing a high pass filter (see Fig. 5) without increasing the DC current level.

By applying PRBS electrical signal to these gain-switched LD with the high pass filter, as shown in Fig. 5, the PRBS non-return to zero (PRBS-NRZ) optical signal was successfully generated. It was confirmed by observing the back-to-back eye-diagram of the generated optical signal. Fig. 6 displays the back-to-back eye-diagram obtained by sending the generated PRBS-NRZ optical signal to the 2.3 *GHz* Si-APD detector directly without positioning the POF, indicating the possibility of ≥ 1.5 *Gbs* bandwidth measurement of a POF.

In addition, by placing the POF between the PRBS-NRZ optical signal and the detector, we have measured the bandwidths of POFs. Fig. 7 (a) and (b) display an example of measuring the bandwidth of a commercially available POF (Mitsubishi Rayon GH4001) with a specification of 40 *MHz* · 50 *m*. A opening eye was clearly observed at 44 *Mbps* but closed at 250 *Mbps*, as expected.

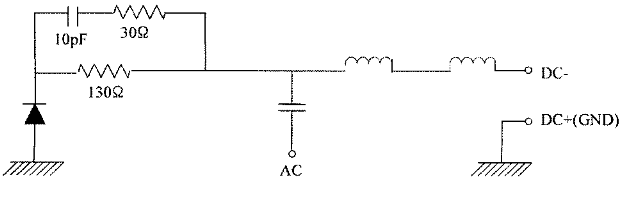


FIG. 5. Transmitter circuit with high pass filter.

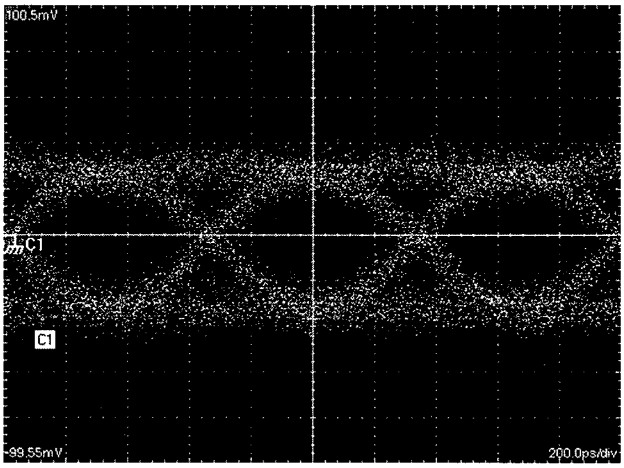
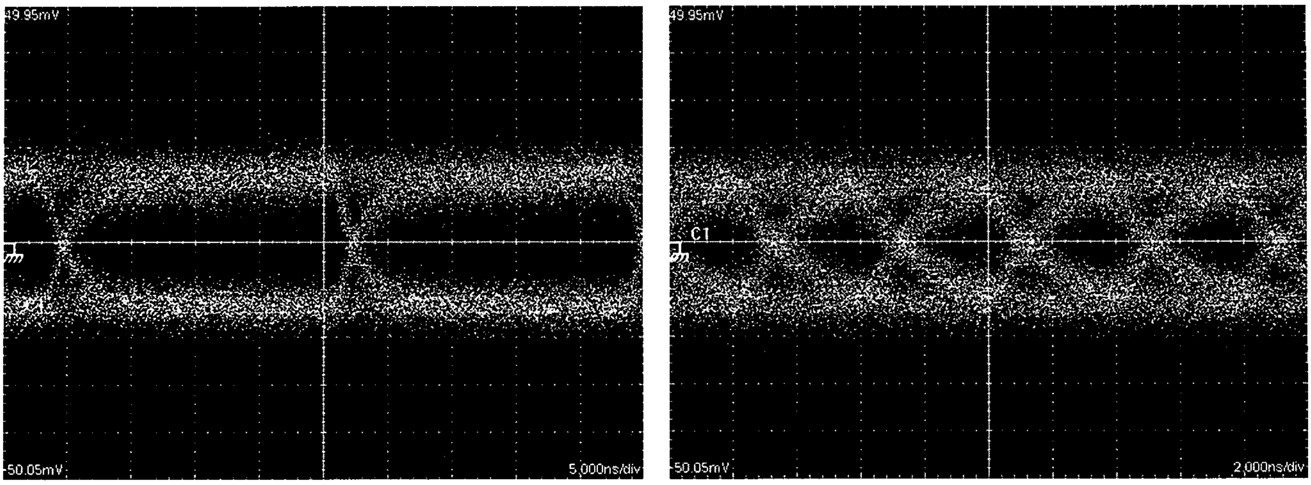


FIG. 6. Gbps back-to-back eye-diagram.

IV. CONCLUSIONS

The PRBS-NRZ optical signals of ≥ 1.5 *Gbs* were successfully generated by using a gain switched mechanism in InGaAlP Fabry-Perot semiconductor laser and a high frequency filter. In addition, back-to-back eye-diagram and bandwidth measurement of the commercially available POF with the generated Gbps PRBS-NRZ optical signals were presented. We believe that our experimental results are quite useful for bandwidth measurement of the PMMA based POFs operating at 650 *nm* wavelength.



(a) (b)

FIG. 7. Eye-Diagram of POF at (a) 44 Mbps and (b) 255 Mbps

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