Reconfigurable 43 Gb/s Optical Link Test Based Upon On-Wafer Probes of GaAs Photodetectors and VCSELs up to 85ºC

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Abstract

Reconfigurable testing of a high-speed optical link based upon on-wafer probing of an oxide-confined 850 nm vertical-cavity surface-emitting laser (VCSEL) and a GaAs P-i-N photodetector (PD) is demonstrated at a non-return to zero (NRZ) modulated data rate up to 50 Gb/s at room temperature and 43 Gb/s at 85℃ over back-to-back distance. Without any impedance matching network, trans-impedance amplifier, or equalization technique present at the received side, the optical link has not only shown robustness but also achieved outstanding signal-to-noise ratios (SNRs) over the operating temperature range.

INTRODUCTION

The growing demand for high performance and more energy-efficient short-haul optical fiber links has driven the development of 850 nm oxide-confined VCSEL based transceivers for data center and supercomputing applications. Transceivers operating at 25 Gb/s per channel have become the most commonly deployed in today's short-haul communication. In order to push the date rate further toward 50 Gb/s per lane, lots of strategies such as four-level pulse amplitude modulation (PAM4), forward error correction (FEC) and equalizing schemes have been widely implemented in the development of optical links. Nevertheless, these techniques consequently increase power consumption from additional electronic circuitry in addition to added latency that limits the performance of optical links. However, non-return to zero (NRZ) signaling offers the advantage of low power consumption, less complex electronic circuitry and better signal integrity. The major challenge for improving NRZ signaling is to extend the bandwidth and maintain high reliability of optical transceiver components such as VCSELs operating from room temperature up to 85°C, similarly for the photodetectors at the receiver side

VCSELs are widely deployed in the high-speed optical transceivers for short-haul communication owing to its low power consumption, low threshold and high reliability. In recent years, tremendous progress has been achieved not only at room temperature with 57 Gb/s error-free data transmission [3] but also at 85°C with 50 Gb/s error free operation [4] and 42 Gb/s error free data transmission via the 100 m multimode fiber (MMF) [5] without any back-end signaling techniques present. Such high-speed transmitters need to be integrated with receivers of adequate bandwidth and high sensitivity so that the realization of high-speed optical links becomes feasible.

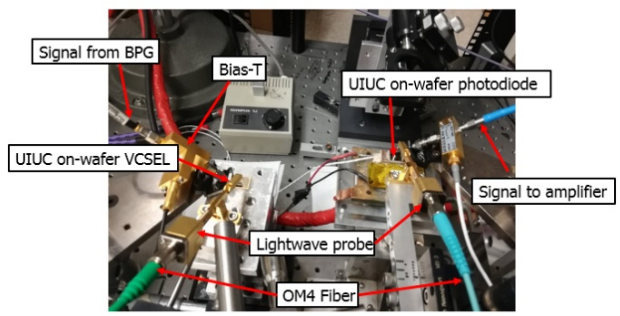

Fig. 1. Measurement setup for full optical fiber link consisting of 25 GHz UIUC on-wafer VCSEL and 26 GHz UIUC on-wafer P-i-N photodetector in BTB configuration.

In order to realize high-speed receivers in optical links for short-haul communication, GaAs and InGaAs based P-i-N photodetectors have emerged as promising candidates. Traditionally, GaAs and InGaAs P-i-N photodetectors have suffered from the trade-off between high responsivity and fast frequency response [1, 2]. Namely, thicker intrinsic layers will result in longer transit time but higher quantum efficiency and vice versa. Moreover, photodetectors with larger diameter benefit in higher responsivity, but at the expense of slowing down the frequency response due to increased capacitance. The reduction of the active area in photodetectors also makes it difficult to align with optical transmitters and fibers. These constraints make the simultaneous optimization of photodetectors speed and sensitivity necessary for the increasing data rate such as 56 Gb/s and beyond.

Previous works have been reported on an 850 nm P-i-N GaAs photodetector with 20 µm mesa diameter, 0.75 μm intrinsic layer thickness and junction capacitance of 60 fF

[6]. The parasitic-limited bandwidth was measured to be 26 GHz with the parasitic capacitance of 45 fF which is extracted from two-port S-parameter measurement with the aid of a Keysight PNA-X Network Analyzer. The intrinsic optical bandwidth can therefore be obtained by de-embedding the parasitic capacitance and resistance in the small signal equivalent model described in [1]. With such high-speed VCSELs and GaAs P-i-N photodetectors, we report the on-wafer characterization of the full optical fiber link for 50 Gb/s data transmission at room temperature and 43 Gb/s data transmission at 85℃ with back-to-back (BTB, around 3-meter) configuration.

Measurement Setup

The large-signal modulation measurement begins with a non-return to zero on-off keying (NRZ-OOK) data pattern from SHF 12103A bit pattern generator (BPG) with a 2^7-1 pseudorandom bit sequence (PRBS7). The RF signal is then combined with a DC bias via an Agilent BT65B 65 GHz bias-T before fed to the on-wafer VCSEL measured with a 50 GHz GSG-probe. The on-wafer photodetector is mounted on a temperature-controlled stage to allow high temperature operation. The optical output from a VCSEL is collected using a lensed OM4 fiber supported with a Cascade Lightwave probe followed by an OM4 multimode fiber patch cord in order to couple the light onto the on-wafer photodetector via another Cascade Lightwave probe. The fiber connector at the VCSEL side is chosen to be FC/APC type to minimize the back reflection. An unmatched 23-dB power amplifier is used to amplify the received signal from on-wafer photodetector to the Agilent DCA-J 86100C oscilloscope to measure the eye diagram. The measurement setup and block diagram are shown in Fig. 1 and Fig. 2, respectively.

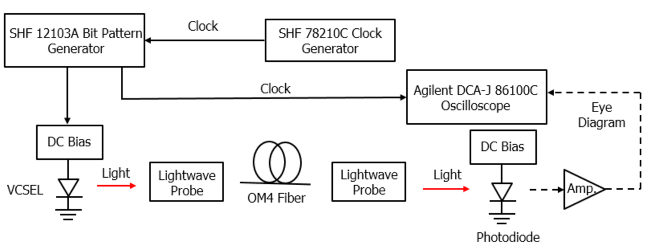

Fig. 2. The block diagram for the large-signal modulation measurement and eye diagram.

Characterization and Results

The large-signal modulation is carried out with a 5 µm aperture VCSEL and an un-packaged photodetector under a bias voltage of -3V. Figure. 3 shows the optical eye diagrams of the optical link at different data rates measured at room temperature in the BTB configuration. The corresponding SNRs are as shown. Up to the data rate of 50 Gb/s all eyes are clear and open. The eye amplitudes at 42, 46 and 50 Gb/s are 161 mV, 152 mV, and 146 mV, respectively. It is clearly seen that the eye opening becomes smaller and there is more noise present at 50 Gb/s, indicating the eye quality is significantly affected by imperfections of electrical signal such as jitters or the additional noise introduced by the measurement setup. For instance, the vibration of the lensed fiber during coupling at high speed could be one of the sources contributing the noise, which ends up distorting the eye diagram, especially at higher data rate. This needs to be addressed by re-aligning the VCSEL and photodetector repeatedly to optimize the quality of the optical eye diagram.

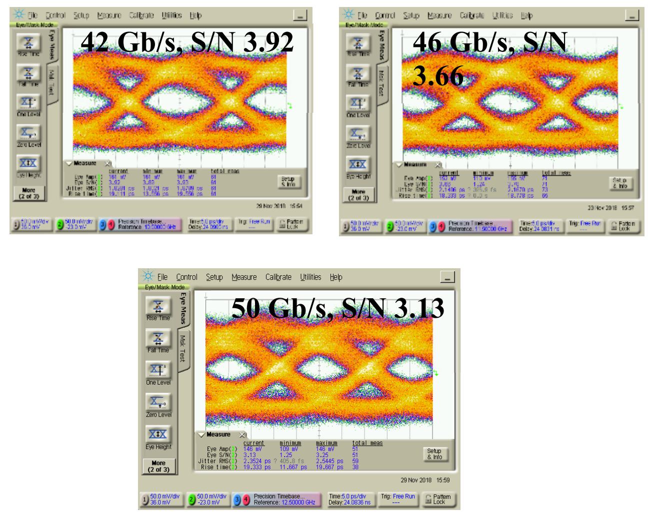

Fig. 3. The eye diagrams at 46, 48 and 50 Gb/s for the UIUC VCSEL + PD full optical link in the BTB configuration measured at room temperature with the scale of 50 mV/div. Corresponding SNRs are as shown. The bias current of VCSEL is 12 mA and the bias voltage of PD is -3V.

It should be noted that there is no impedance matching circuit between the on-wafer photodetector and the power amplifier, therefore it leaves a high potential for the SNR improvement and development of the receiver links. The SNR drops about 0.8 from 42 Gb/s to 50 Gb/s. However, the eye opening and SNRs shown in Fig. 3 are similar to the measurement results done separately with the Newport 1484-A-50 22 GHz high gain commercial photoreceiver module shown in Fig. 4. It is noted that the eye diagrams in Fig. 3 are a slightly noisier than that in Fig. 4 mainly due to the inevitable instability of the Cascade Lightwave probe at the photodetector side.

The eye diagrams from 50℃ to 85℃ for the optical fiber link consisting of on-wafer VCSEL and photodetector are shown in Fig. 5 at 43.5 Gb/s with corresponding measured SNRs. The eye openings in each diagram are about 20 mV on average and they are all clear throughout the temperature operation. However, the jitter becomes more significant at 85°C and therefore contributes to the reduction of SNR and the eye opening as shown in Fig. 5. The rise/fall time of this optical link is approximately 18/21 picosecond which is relatively stable throughout the temperature range.

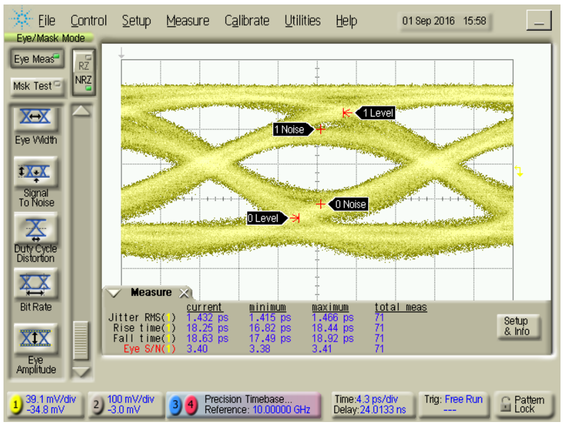

Fig. 4. 40 Gb/s eye diagram of the optical link composed of on-wafer UIUC VCSEL and Newport 1484-A-50 22 GHz high gain photoreceiver. This eye diagram was measured with free-space coupling techniques at room temperature. The SNR is about 3.4. The eye opening is about 50 mV.

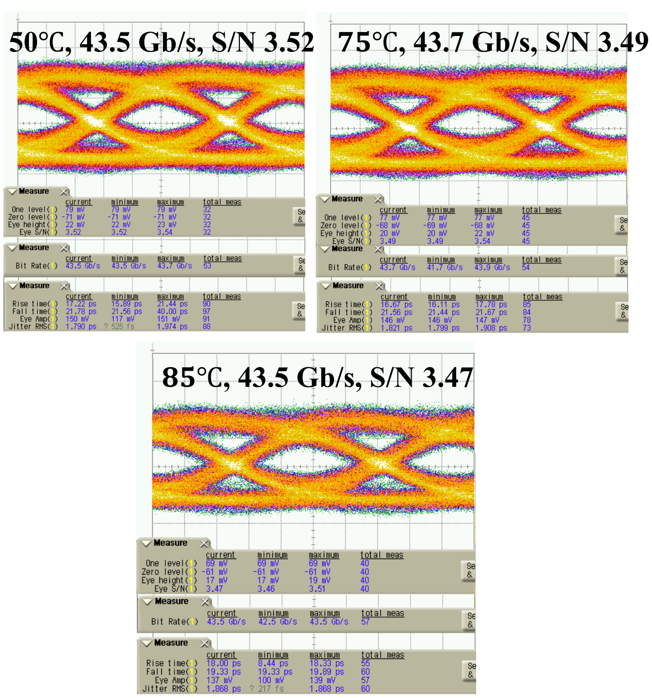

Fig. 5. Eye diagram of the full optical link from 50°C to 85°C at 43.5 Gb/s. The scale of each eye diagram is 20 mV/div.

Conclusion

In summary, we have shown the testing and characterization of the optical link based on 850 nm VCSEL and GaAs on-wafer photodetector for future high-speed application in optical fiber communication. The optical eye diagrams of 43 Gb/s from room temperature to 85°C have been shown with the SNRs close to 3.5 throughout the temperature operation. However, at this point we are not able to perform any meaningful bit-error ratio testing (BERT) because the technique of light coupling with on-wafer fiber probes introduces significant noise into the signal. Such noise would not exist if device-packaging is available. In addition, there is no impedance-matching between the on-wafer photodetector and the amplifier, thus the signal extraction efficiency is low. Furthermore, with no dedicated trans-impedance amplifiers present, it significantly limits the conversion ratio of current-to-voltage signal. Those results are reflected in the eye amplitude measurements in Fig. 5. All the factors described above limit the signal transmission bit-error-ratio around the level of 1E-11, which does not yet reach the error-free condition defined as when the bit-error-ratio (BER) < 1E-12. Nevertheless, the preliminary results shown in Fig. 5 suggest that it is very promising to achieve error-free at 43 Gb/s with appropriate receiver assembly.

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