Toward Si photonics based transceivers using directly modulated heterogeneously integrated DFB lasers

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High speed directly modulated single mode lasers are becoming important optical components for the short reach communication. On the other hand, Si photonics opens up new opportunities to explore the transceivers for the short reach applications. We have fabricated a heterogeneously integrated DFB laser on a Si photonic circuit as a transmitter. For the receiver, a low voltage Si waveguide-coupled Ge avalanche photodetector has been used. We have successfully demonstrated error free transmission of a 10 Gb/s NRZ-OOK signal over 20 km single mode fiber using a silicon on insulator (SOI) based transmitter and receiver.

Introduction

Passive optical network (PON) technologies are being upgraded constantly to meet the ever increasing bandwidth demand for the next generation of fiber access networks [1, 2]. The recommendation G.989 suggests that next generation passive optical network stage 2 (NG-PON2) will be established based on time and wavelength division multiplexing (TWDM) architecture. Four channels 10G-PONs are combined to provide 40-Gb/s aggregate capacity [3].

Light modulation can be done externally or through current (direct) modulation. As compared to external modulation (EM) schemes such as electro-absorption modulation (EAM) or Mach-Zehnder interferometric modulation (MZM), direct modulation is considered simple and generally cost-efficient, and thus more suited for cost-sensitive metro and access optical links. However, in directly modulated lasers (DMLs) the intensity modulation is always accompanied by frequency modulation. Two different types of frequency modulation (called chirp) are distinguished: transient chirp and adiabatic chirp [4].

In DML based PON systems, the chirp results in spectral broadening that severely limits the maximum achievable transmission reach due to fiber dispersion, especially for the long reach applications. The transient chirp can be suppressed by biasing the laser far from its threshold current. On the other hand, the adiabatic chirp can be used to enhance the transmission distance by a technique called Chirp Managed Laser (CML). High performance CML directly modulated DFB lasers based on an InP platform have been demonstrated recently [4, 5].

At the same time, silicon photonics is emerging as the platform of choice for the fabrication of photonic integrated circuits because of its potential for low cost fabrication and dense integration capacity. Intensive research is going on towards the integration of photonic active components such as laser diodes, photodiodes and modulators on the hybrid Si platform. Heterogeneous integration has emerged as an attractive approach to realize this integration, as it is relatively easily scaled to large arrays of devices [6].

In this paper, we will present our recent 10G-PON CML results based on a Si based transceiver. At the transmitter side, a heterogeneously integrated directly modulated DFB laser was used. The receiver was constructed using a low-voltage Ge waveguide APDwire-bonded to a 130nm BiCMOS trans-impedance amplifier (TIA) [7].

DFB laser structure and characteristics

The DFB laser is fabricated using adhesive bonding technique. The epitaxial structure consists of 8 InGaAlAs quantum wells as an active region. A SEM image of the cross section of the laser is shown in Figure 1. The structure is similar to that reported in [8], except that the two 200 μm long InP tapers on either side of the DFB laser are electrically isolated and can be separately biased. This helped to suppress the strong low frequency response that was observed earlier in [8] and to flatten the small signal response of the laser. The bonding layer thickness can be controlled by changing the rotation speed of the spin coating or by partially etching a planarization SiO_2 top layer. Using these methods we have demonstrated a bonding layer thickness less than 10 nm. A thinner bonding layer helps to increase the light interaction with the Si passive grating underneath the active InP waveguide. A stronger interaction results in a higher coupling coefficient and lower threshold current which is beneficial for a low cost transmitter for PON application. This sample is passivated by 600 nm thick SiNx layer and 2 μm thick BCB polymer.

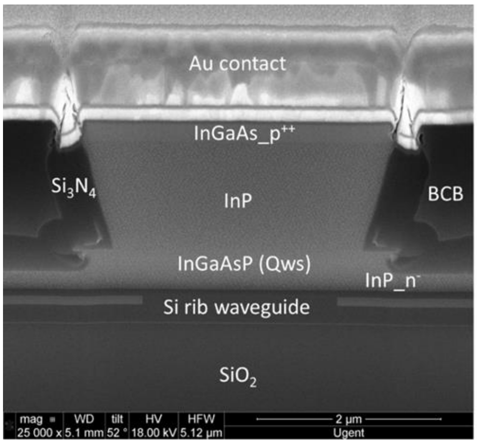

Figure 1: SEM picture of the cross section of a fabricated device

Threshold currents at room temperature of 20 mA, output powers in the silicon waveguide above 3 mW at 100 mA, and a series resistance of 7 Ω were measured for the lasers. The optical spectra show a wide stop band and a side mode rejection of over 40 dB.

10G-PON measurement

The set up used for the large signal modulation is given in Figure 2. An RF signal of 0.6 V from an SHF-PPG was applied for the modulation, but because of the impedance mismatch between the laser and the 50 Ω transmission line, around 0.2 V was actually applied to the laser.

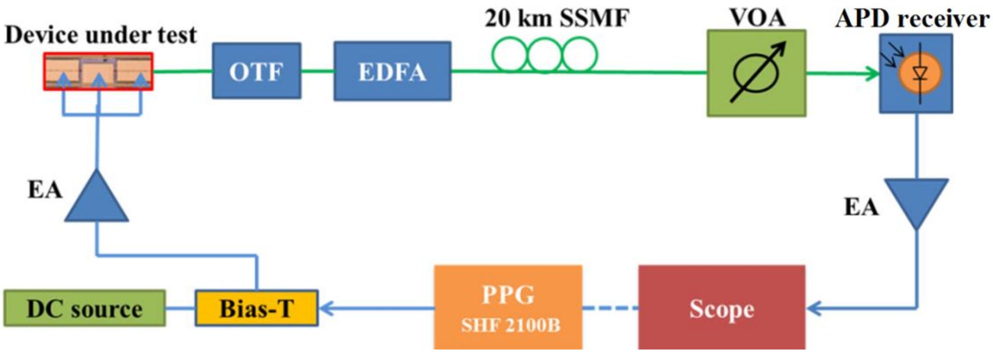

Figure 2: Schematic of the large signal measurement set-up for the 10G-PON measurement.

In order to increase the reach distance we have inserted a Santec-350 optical filter that is tunable in wavelength and bandwidth after the laser diode for the chirp management. Because the ‘1’ bits are blue shifted with respect to the ‘0’ bits due to the adiabatic chirp, the optical signal was aligned at the longer wavelength slope of the filter as shown in the Figure 3. The laser was biased at 50 mA. The large signal measurement has been done in two configurations: for back-to-back and after transmission over a 20 km SSMF. On the receiver side, a 10 Gb/s Ge/Si APD wire bonded on an electronics control board with a TIA was used.

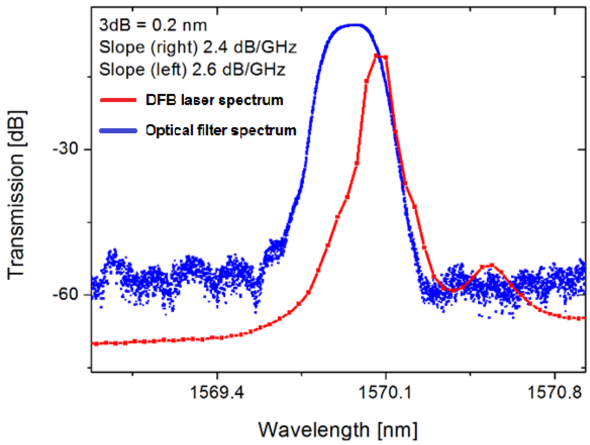

Figure 3: Optical spectrum of the laser with respect to the filter transmission spectrum.

Figure 4 shows the eye diagrams at 10 Gb/s for the back to back case and after transmission over 20 km of SSMF. The extinction ratio of the signal was increased from 5.9 to 16.3 dB by the application of the optical filter. The BER curves at 10 Gb/s are given in Figure 5. Two different PRBS pattern lengths of 2^7-1 and 2^{31}-1 were used in order to check the link pattern dependency. We did not observe any noticeable power penalty for two different patterns. However we measured 1.5 dB power penalty for transmission over 20 km SSMF.

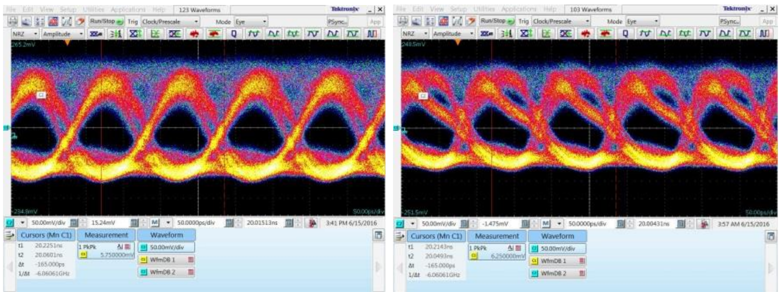

Figure 4. Eye diagrams at 10 Gb/s for the back-to-back case and after transmission over 20 km SSMF.

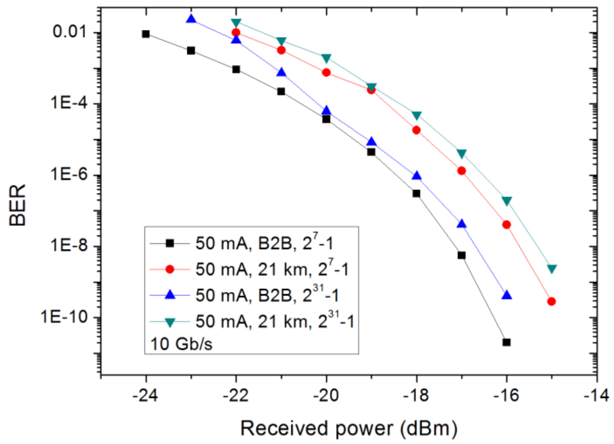

Figure 5: BER vs received optical power at 10 Gb/s for two different PRBS patterns lengths and for a 50 mA bias current to the DFB laser.

Conclusion

We demonstrated 10G-PON transmission based on a directly modulated, heterogeneously integrated InP-on-Si DFB laser and a Ge APD. Although the filter was a commercial one, in principle we could use ring resonators on a Si platform. In this case, the full link could be considered as a Si transceiver for 10G-PON system.

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