Single-Chip 40Gb/s Widely-Tunable Transceivers with Integrated SG-DBR Laser, QW EAM, UTC Photodiode, and Low Confinement SOA

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Abstract

We present the first single-chip, widely-tunable 40Gb/s transceivers. The devices integrate sampled grating DBR lasers with electroabsorption modulators, low optical confinement semiconductor optical amplifiers, and uni-traveling carrier photodiodes.

I. Introduction

The generation, detection, modulation, amplification, and transport of light on a single chip allows for a new generation of high-functionality photonic integrated circuits (PICs) with reduced cost, size, and power dissipation. For these high-functionality PICs to replace discrete components in optical networks, high-yield fabrication methods must be developed to facilitate the optimization of the individual components contained on the chip. In this work we present 40Gb/s monolithic transceivers integrating widely-tunable sampled grating DBR (SG-DBR) lasers with quantum well electroabsorption modulators (QW-EAM), high and low optical confinement semiconductor optical amplifiers (SOA), and uni-traveling carrier (UTC) photodiodes on a single chip. These component structures represent the state of the art technologies for even discrete devices. The fabrication method couples a robust quantum well intermixing (QWI) technique with simple blanket MOCVD regrowth steps and avoids the difficulties associated with selective area growth or butt-joint regrowth [1]. The transmitters demonstrate over 30nm of tuning, low drive voltages (1.5-2.5V_{PtoP}), and low power penalty transmission through fiber at 40Gb/s [2]. The SOAs within the receivers provided up to 28dB of gain with saturation powers in the 18.5dBm range while the UTC photodiodes facilitated 40Gb/s operation under high photocurrent conditions. Chip-coupled receiver sensitivity better than –20dBm was demonstrated at 40Gb/s.

II. Fabrication

Device fabrication begins with the MOCVD growth of a centered multiple quantum well (c-MQW) base structure consisting of ten 6.5nm InGaAsP QWs and eleven 8.0nm InGaAsP barriers centered within a 1.3Q waveguide to yield a maximized optical confinement factor of 12.6%. Using the QWI method illustrated in Fig. 1a and detailed in [3], the as-grown c-MQW band-edge (λ_{PL}= 1540nm) was blue-shifted in the EAM (λ_{PL}= 1505nm) and passive regions (λ_{PL}= 1440nm). Following the QWI process, a blanket MOCVD growth was performed for the deposition of a low-confinement offset MQW (o-MQW) gain region. The o-MQW (λ_{PL}= 1550nm) contained 5 wells and was designed to have an optical confinement factor of ~1.4%. The

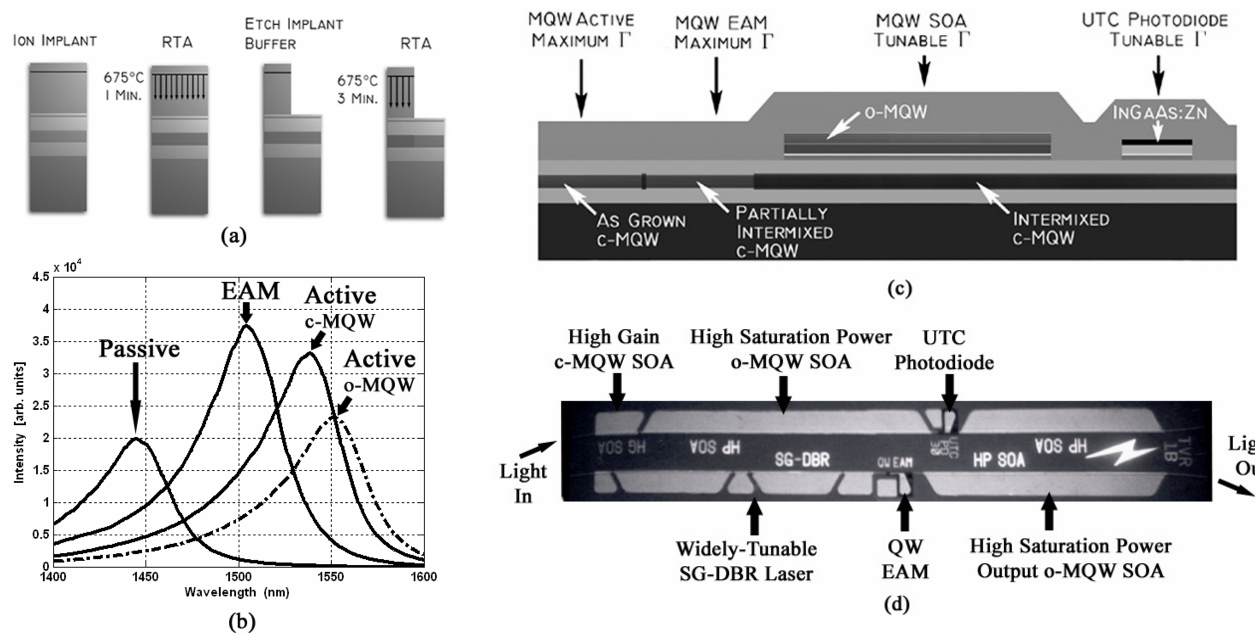

FIGURE 1. (a) QWI sequence used for controlled shifting of the c-MQW band-edge. (b) Photoluminescence of the as-grown c-MQW active, partially intermixed c-MQW EAM, severely intermixed c-MQW passive, and regrown o-MQW active regions. (c) Side view schematic of the high confinement c-MQW, low confinement o-MQW, and UTC photodiode regions. (d) Top-view SEM image of 0.5 by 3.5mm^2 transceiver device.

photoluminescence (PL) results from all four QW band-edges on the single-chip are shown in Fig. 1b. The o-MQW structure was defined in low confinement SOA regions with wet etching and a second blanket MOCVD regrowth was performed for the deposition of the UTC photodiode structure. The details of the growth sequence used for the o-MQW and UTC structures can be found in [4, 5]. Wet etching was used to define the UTC layer structure in the photodetector regions. A final MOCVD regrowth was performed for the upper InP:Zn cladding and InGaAs:Zn contact layers. Standard processing techniques were used to define surface ridge waveguide devices. A schematic side view illustrating the high confinement c-MQW regions, QW-EAM regions, low confinement o-MQW regions, and UTC photodiode regions on a single-chip is presented in Fig. 1c.

III. Transceiver Design

The single-chip transceiver devices were fabricated on the same wafer and employed a parallel ridge waveguide architecture with different transmitter and receiver designs. The transmitters consisted of a five section widely-tunable SG-DBR laser as described in [3] and a QW-EAM with a length of 125µm or 175µm. Select transmitters made use of an SOA positioned after the SG-DBR laser for increased output power. Two receiver designs were explored. Each design consisted of a dual section SOA and a UTC photodiode. The first design (#1) employed a 250µm high gain c-MQW front-end followed by a 1650µm high saturation power o-MQW gain section with a 30µm UTC photodiode. The second design (#2) consisted of a 400µm long high gain c-MQW front-end followed by a 1500µm long high saturation power o-MQW gain section and a 40µm UTC photodiode. A scanning electron micrograph (SEM) image of a transceiver with a footprint of only 0.5 by 3.5mm^2 is shown in Fig. 1d.

IV. Device Results

The SG-DBR lasers demonstrated threshold currents of 35mA, over 30nm of tuning, and output powers up to 35mW at a laser gain section current of 150mA. The EAMs demonstrated an optical 3dB bandwidth of 34 and 39GHz for 175µm and 125µm long devices, respectively. In Fig. 2a we present 40Gb/s broadband transmitter eye diagrams from a 175µm long EAM using a 2.5V_{PtoP} drive. The eye diagrams are open and demonstrate 10-12dB of signal extinction. The SOAs of receiver design #1 demonstrated a chip gain of over 22dB and a saturation output power of 18.6dBm while the SOAs of design #2 demonstrated over 28dB of gain and a saturation output power of 18.2dBm. In both cases the c-MQW high gain region was biased at 15kA/cm^2 and the o-MQW high saturation power section was biased at 6kA/cm^2. The internal quantum efficiency of the UTC photodiodes was limited to 30-35% due to a fabrication issue. Frequency response measurements of photodiodes terminated with a matched 50Ω resistor demonstrated less than 1dB of roll-off at the 20GHz of our testing capability with a 3V reverse bias and 20mA of average photocurrent. In Fig. 2b we present 40Gb/s eye diagrams taken from a receiver using design #2 positioned adjacent to the 40Gb/s transmitter of Fig. 2a. The open eye diagrams demonstrate output amplitudes up to 500mV.

Bit error rate (BER) testing was performed on transmitters and receivers at 40Gb/s using a non-return to zero format. A pseudo random bit sequence of 2^7-1 was used due to a noise floor in the bit-error rate test set-up at longer word lengths. The transmitters reported in [2] and fabricated on the same chip made use of a 125µm long EAM and exhibited only 0.2dB and 3.0dB of power penalty (1.5V_{PtoP}) for transmission through 2.3km and 5km of standard fiber, respectively. The 40Gb/s BER versus received power results for the two receiver designs are presented in Fig. 2d. Design #1 demonstrated error-free operation (1E-9) with a chip-coupled power of –16.8dBm and design #2 required only –20.3dBm for error-free operation.

V. Conclusions

We have demonstrated 40Gb/s widely-tunable transceivers consisting of SG-DBR lasers, QW-EAMs, high and low optical confinement SOAs, and UTC photodiodes. A high-flexibility integration scheme coupling a robust QWI technique with simple blanket MOCVD regrowth steps was used for device fabrication. The transmitters demonstrated low drive voltage 40Gb/s operation and low power penalty transmission through standard fiber. The two receiver designs exhibited –16.8dBm and –20.3dBm sensitivities at 40Gb/s. The SOAs within the receivers demonstrated up to 28dB of chip gain and saturation powers in the 18.5dBm range while the UTC photodiodes demonstrated 40Gb/s operation under high photocurrent conditions.

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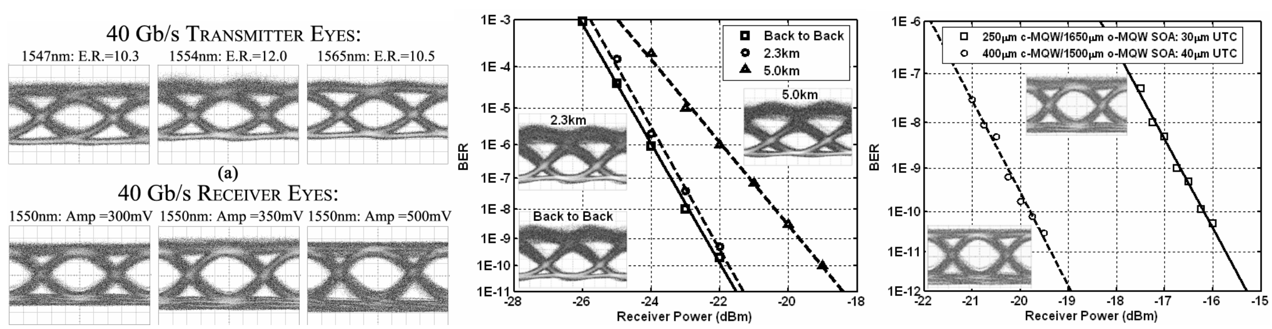

FIGURE 2. 40Gb/s eye diagrams from (a) transmitter and (b) receiver on a single 0.5mm by 3.5mm chip. (c) Bit error rate from a 125µm EAM at 40 Gb/s with a 1.5 V_{PtoP} drive and a wavelength of 1553nm. The back to back eye diagram along with the eye diagrams after transmission are shown as insets. (d) BER versus received power for the two dual section SOA/UTC photodiode receiver designs with inset eye diagrams.