A Quantum Well EAM-SGDBR Widely Tunable Transmitter Fabricated in a Novel Dual-Quantum-Well Integration Platform

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In this work we demonstrate for the first time a monolithically integrated, widely tunable, electroabsorption modulator (EAM) based sampled grating DBR (SGDBR) laser transmitter fabricated in a novel dual quantum well (DQW) integration platform that breaks the fabrication and growth barriers associated with integrating quantum well EAMs with laser sources. Compared with the well established offset quantum well (OQW) tunable transmitters [1,2], the DQW devices require no additional processing or growth steps, and demonstrate significant improvements in bandwidth, modulation efficiency, insertion loss, and chirp characteristics.

Monolithically integrated tunable transmitters containing EAMs are key components in next generation networks due their reduced packaging costs, small footprint, and their application to inventory reduction. Of particular importance are integrated transmitters with EAMs that utilize the quantum confined stark effect (QCSE) in quantum wells due to their large modulation efficiency and low chirp characteristics. Traditionally, integrated QCSE-based transmitters have required complex growth and/or processing techniques such as selective area growth (SAG), butt joint regrowth (BJG), or quantum well intermixing (QWI). As an alternative to these approaches, the OQW platform is attractive since it uses simple selective etch techniques to define active (gain) and passive (mirror tuning/EAM) regions and requires only a single blanket p-InGaAs/InP regrowth step [2]. However, until the work presented here intensity modulation in OQW integrated EAMs has been based on the Franz-Keldysh (FK) effect, which leads to limited modulation efficiency under low insertion loss conditions and positive chirp [3].

A diagram of the novel DQW platform is shown in Fig. 1. As in the OQW approach, fabrication consists of the selective removal of a set of quantum wells located above the optical waveguide layer to form gain and passive/EAM regions, followed by a blanket p-InP/InGaAs regrowth. In the DQW platform, an additional set of quantum wells consisting of 7x9 nm wells and 6x5 nm barriers is inserted into the center of the waveguide and utilized for modulation efficiency. Careful control of the emission wavelength of the waveguide wells (1480 nm) is used to manage band-tail absorption losses associated with the detuning between the waveguide and offset wells.

The DQW transmitter consists of a four section SGDBR laser [4], a 550 μm long semiconductor optical amplifier (SOA), and a 400 μm long EAM. A supermode spectrum from the transmitter along with an on-chip current versus optical power curve for the SGDBR is shown in Fig. 2 and Fig. 3 respectively. The on-chip laser power is extracted by measuring the photocurrent that was generated when the SOA that follows the SGDBR is reverse biased and the SGDBR laser is forward biased. At 1550 nm greater than 20 mW is generated from the SGDBR at 130 mA. Fiber coupled optical power levels ranged from 0 dBm at 1532 nm to 5 dBm at 1560 nm with both the SGDBR gain and SOA biased at 100 mA. Side mode suppression ratio (SMSR) measurements over 45 channels spaced at 100 GHz (Fig. 4) was > 30 dB.

Measurements of the integrated DQW EAM DC extinction, the 50 Ω terminated electrical to optical frequency response, and large signal time resolved chirp (TRC) are shown in Fig. 5, Fig. 6, and Fig. 7 respectively. DQW EAMs slope efficiencies ranged from 10 dB/V to 16 dB/V at 1560 nm and 1532 nm and modulation depths were up to 40 dB. The 3-dB bandwidth was in excess of 10 GHz and the chirp at 10 Gb/s reaches zero at a bias of -3.6 V. We have included data from the FK-EAMs in an OQW transmitter with a moderately Si-doped waveguide ($2x10^{17}$ cm^{-3}, 1.41 μm bandgap) in these Figures, along with a separate comparison of the slope efficiency at 1545 nm (Fig. 8). Using the DQW approach, EAM bandwidth is improved from 4 to 10 GHz, slope efficiency at 1545 nm is improved from 9 to 13.5 dB/V, and the chirp is clearly reduced.

In summary, we have demonstrated the first widely tunable transmitter fabricated on a DQW integration platform that utilizes the QCSE for modulation efficiency but maintains the simple fabrication requirements of the more traditional OQW approach. The DQW transmitters showed significantly improved modulation efficiency, bandwidth and chirp characteristics compared with the traditional OQW platform.

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[4] M. Sysak et al., *IEEE Photon. Technol. Lett.*, vol. 16, p. 2093 (2004).

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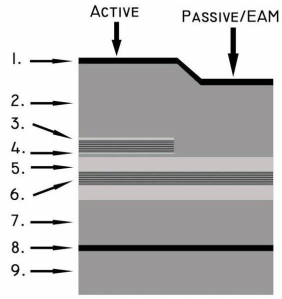

Region	Description
1	p-contact
2	p-cladding
3	Offset QWs
4	Stop Etch
5	Waveguide
6	Centered QWs
7	n-Buffer
8	n-contact
9	Fe-substrate

Fig.1. Epitaxial layer structure of the dual quantum well integration platform.

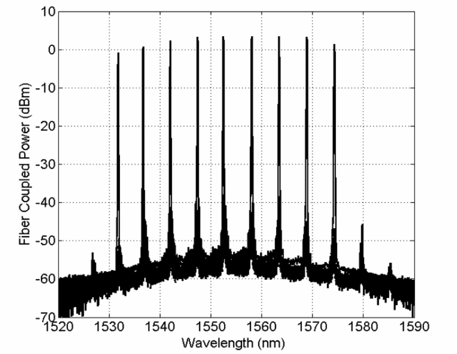

Fig. 2. Supermode spectrum of DQW SGDBR. Laser gain and SOA are at 100 mA bias.

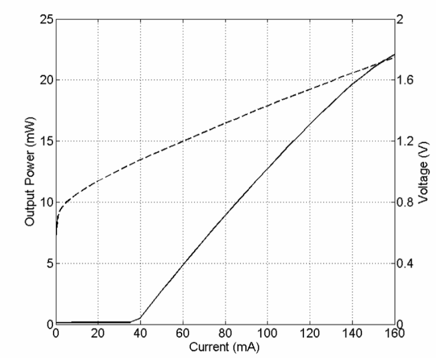

Fig. 3. Current vs. voltage (dashed line) and on-chip optical power (solid line) from the DQW SGDBR at 1550 nm.

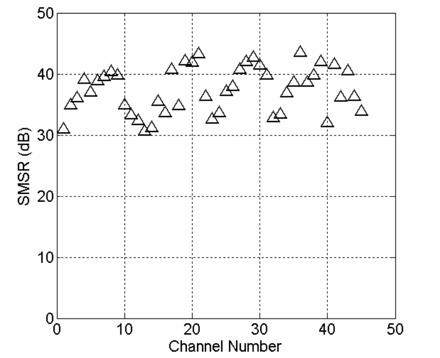

Fig. 4. SMSR measurements for DQW SGDBR over 45 channels spaced at 100 GHz. (1535 nm to 1570.2 nm)

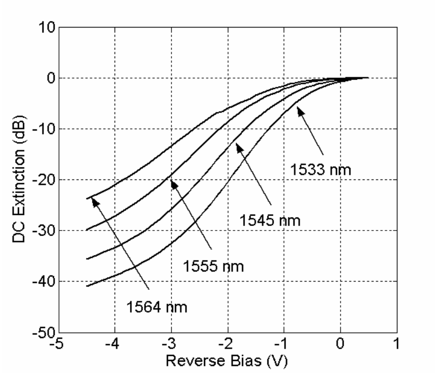

Fig. 5. DC extinction characteristics of the DQW EAM (400 μm).

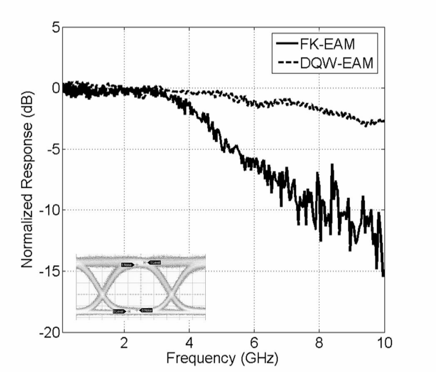

Fig 6. Frequency response of 50 Ω terminated QW-EAM and FK-EAMs. A 10 Gb/s eye diagram is embedded in the figure (1550 nm, -2 V bias, 1.2 V pp drive voltage)

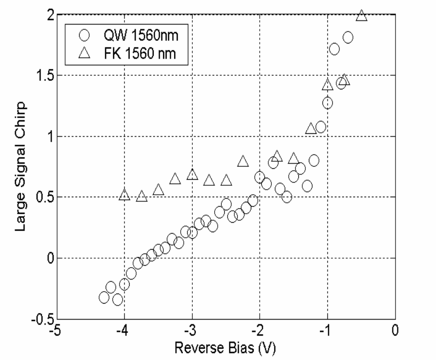

Fig. 7. Large signal chirp measured measurement for DQW-EAMs and FK-EAMs the Agilent Time resolved chirp software. Transmitter wavelength is 1560 nm.

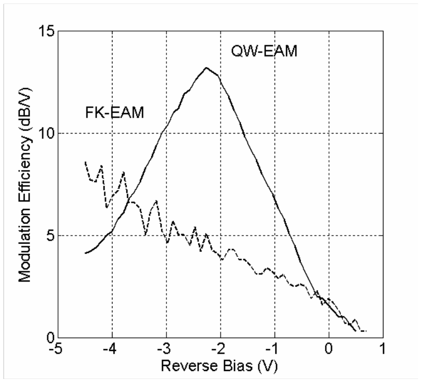

Fig. 8. Modulation efficiency comparison of OQW and DQW EAMs (1545 nm)

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