# Monolithic Dual-Quantum-Well 10 Gb/s Mach-Zehnder Transmitter

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*Abstract*— **A 10 Gb/s transmitter composed of a Sampled-Grating DBR (SGDBR) laser and Mach-Zehnder modulator was fabricated on a dual-quantum-well integration platform. The device exhibited error free operation and negative chirp.**

## I. Introduction

Transmitters play an important role in fiber optic communication systems. The monolithic integration of the laser and modulator reduces packaging cost and insertion losses while eliminating polarization dependance. Widely tuneable transmitters have the additional advantage of reducing the inventory requirements for providers. While, negative chirp provides the benefits of high bit rates and longer transmission distances.

It is well known the use of quantum-wells within the Mach-Zehnder allows for higher index changes [1]. Previously, a sampled-grating DBR laser (SGDBR) and a Mach-Zehnder modulator has been successfully integrated using bulk InGaAsP in the modulator regions [2]. Building upon this work the first widely tuneable Mach-Zehnder transmitter on a dual-quantum-well integration platform has been fabricated. This devices implements a SGDBR laser and a series-push-pull Mach-Zehnder modulator-as shown in Fig. 1.

## II. Device

The transmitter's epitaxial structure is comprised of two sets of quantum-wells identical to that in [3]. A set of offset quantum-wells (photoluminescence = 1550 nm) are used in the gain section of the SGDBR and the SOAs. A separate set of seven quantum-wells (photoluminescence = 1465 nm) centered in the InGaAsP waveguide aid the modulator efficiency. The fabrication of this device requires a single blanket regrowth of the InP cap and InGaAs contact layer following the selective removal of the offset quantum-wells from the passive sections and the etching of holographically defined sampled gratings.

The modulator has a traveling wave electrode segmented into 8-50 $\mu$m long T-sections to capacitively load the transmission line allowing for better impedance matching. The ridge width is reduced from 3 $\mu$m in the laser and SOA regions to 2 $\mu$m within the modulators. In addition to the thinner ridge widths, BCB is used underneath the modulator electrode to reduce the capacitance. An integrated 50 $\Omega$ NiCr resistor provides on chip termination. The 400 $\mu$m long Mach-Zehnder

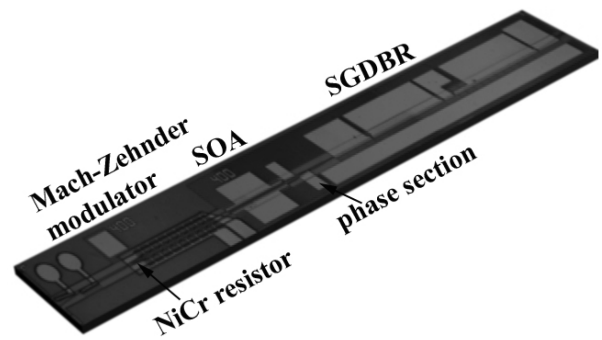


Fig. 1. Diagram of integrated widely tuneable transmitter chip

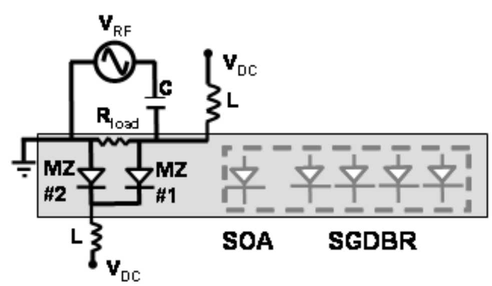


Fig. 2. Schematic of series-push-pull biasing scheme

is operated in a series-push-pull fashion with the RF signal applied across the modulator electrode (Fig. 2). This configuration allows for improved bandwidth, lower modulation voltages and small chirp values [2], [4].

In each arm of the Mach-Zehnder there is a 400 $\mu$m SOAs to increase the output power of the device and compensate for propagation losses. Phase sections within the interferometer arms are implemented to allow for biasing to $\pi$-phase-shift. A flared and curved output waveguide as well as an AR coating was used to reduce optical reflections and to aid in fiber coupling.

## III. Experiments

Following fabrication the devices were thinned, cleaved and mounted onto an aluminum nitride carrier for testing. All DC contacts were wirebonded to the carrier and contacted via a

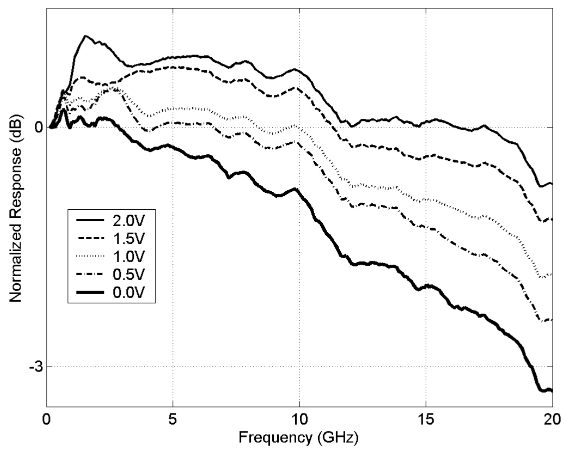


Fig. 3. Bandwidth of transmitter of different Mach-Zehnder biases

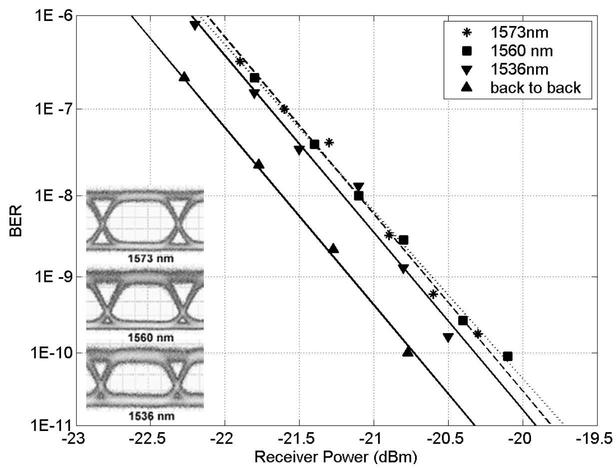


Fig. 4. BER for various wavelengths.

probe card. The modulator was directly probed with a CPS probe to prevent any parasitic effects from wirebonds.

Bandwidth measurements have been taken for various modulator biases. These measurements clearly show greater than 20 GHz bandwidth for all modulator biases greater than 0 V (Fig. 3).

Bit Error Rate testing at 10 Gb/s with a NRZ $2^{31}$-1 pseudorandom bit sequence was done for both back-to-back and transmission through 25 km and 50 km of Corning SMF-28 fiber. The modulator was biased at -1 V across each arm and driven with a 1.87 $V_{p-p}$ electrical signal from a HP 70843B BERT. The optical signal from the device was amplified with a high power Erbium Doped Fiber Amplifier (EDFA) followed by an optical filter, fiber for transmission and finally an attenuator before being detected by an HP 83434A 10 Gb/s photoreceiver. Error free operation (better than 1e-9 BER) and extinction ratios in excess of 10 dB were achieved for a wavelength range greater than 35 nm (Fig. 4). Transmission measurements show negative chirp across the wavelength range with a trend towards more negative chirp at

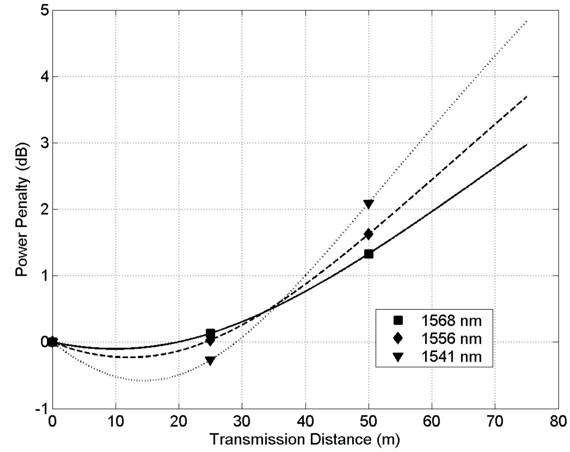


Fig. 5. Power penalty vs. transmission distance for various wavelengths. BER measurements were taken for transmission through 0 km, 25 km and 50 km of Corning SMF-28 fiber

lower wavelengths (Fig. 5).

## IV. Conclusion

For the first time a widely tunable Mach-Zehnder transmitter has been fabricated on a dual-quantum-well platform using a single blanket regrowth. The device demonstrates over 35 nm of tuning and bandwidth in excess of 20 GHz. The low DC bias of 1 V for this device means there is minimal insertion losses and low power consumption. Error free operation has been demonstrated for up to 50 km of transmission through fiber and all wavelengths have negative chirp with a 1.87 $V_{p-p}$ drive voltage.

## Acknowledgment

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## References

[1] W. Bardyszewski, D. Yevick, L. Yong, C. Rolland, and S. Bradshaw, “Theoretical and experimental analysis of mach-zehnder quantum-well modulators,” *Journal of Applied Physics*, vol. 80, pp. 1136–41, July 1996.

[2] J. S. Barton, M. L. Masanovic, A. Tauke-Pedretti, E. J. Skogen, and L. A. Coldren, “Monolithically-integrated 40gbit/s widely-tunable transmitter using series push-pull mach-zehnder modulator soa and sampled-grating dbr laser,” in *Optical Fiber Communication Conference and Exposition and The National Fiber Optic Engineers Conference*, Anaheim, CA USA, March 2005, paper OTuM3.

[3] M. N. Sysak, J. S. Barton, J. W. Raring, M. Dummer, A. Tauke-Pedretti, D. J. Blumenthal, and L. A. Coldren, “10 gb/s photocurrent driven, widely tunable electroaborption modulator based wavelength converter,” in *Optical Fiber Communication Conference and Exposition and The National Fiber Optic Engineers Conference*, Anaheim, CA USA, March 2005, paper OTuM4.

[4] R. G. Walker, “High-speed iii-v semiconductor intensity modulators,” *IEEE J. Quantum Electron.*, vol. 27, pp. 654–667, Mar. 1991.