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Optical Data Transmission over Large Temperature Range Using Highly Efficient Oxide-Confined GaAs VCSEL Sources

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Abstract: GaAs based selectively oxidized vertical-cavity surface-emitting lasers (VCSELs) are highly attractive devices for parallel optical fiber interconnect data transmission. Here we demonstrate 1 Gbit/s pseudo-random bit sequence (PRBS) transmission over 100 m graded index fiber in the temperature range from 20 to 100 °C applying constant 2.5 mA bias and 0.5 V_{pp} voltage swing for modulation.

I. Introduction:

The performance of VCSELs has improved significantly over the past years. Record high power conversion efficiencies of 57 % at room temperature, a cw operation range from -80°C up to +185°C, and threshold currents below 500 μA from -40°C to +80°C have been obtained [1]. The combination of low threshold current with superior thermal and optical performance allows efficient high speed data generation under low or bias free conditions [2].
Light emission perpendicular to the wafer surface due to the vertical-cavity geometry enables simple on-wafer automatic probe testing of individual VCSEL arrays [3] and provide simple coupling of the light into fibers with uniquely high coupling efficiencies. These characteristics are essential for low cost optical interconnect systems. Fundamental mode lasing is favorable in order to avoid mode competition noise in high speed fiber transmission. VCSELs with optimized index guiding show single-mode operation up to several milliwatts [4]. Excellent modulation characteristics [5] with record high data transmission of 10 Gbit/s for a single device [6] have been achieved.

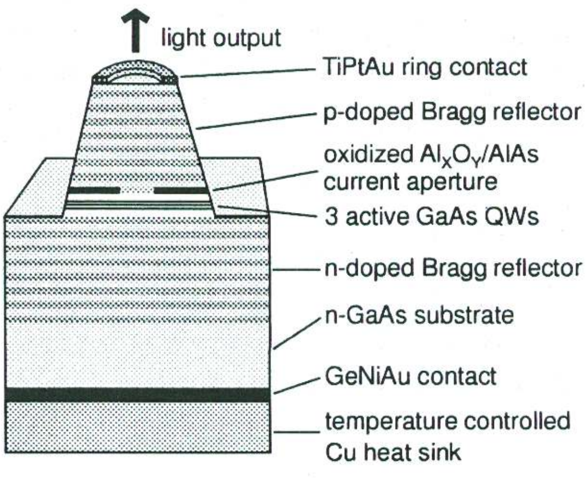


Fig. 1: Cut-away view of an oxidized VCSEL mounted junction up on copper heat sink.

II. Layer Structure:

We have fabricated GaAs based 850 nm emission wavelength oxide confined VCSELs using solid source MBE with Carbon as p-type dopant. Fig. 1 shows a schematic cut-away view of the fabricated oxide confined GaAs VCSELs. The epitaxial structures are grown using solid source molecular beam epitaxy (MBE). The bottom Bragg reflector consists of 30.5 n-type Silicon doped $AlAs/Al_{0.2}Ga_{0.8}As$ pairs. The active region contains three 8 nm thick GaAs quantum wells separated by 10 nm $Al_{0.2}Ga_{0.8}As$ barriers. The p-type top DBR consists of 26 Carbon doped $Al_{0.2}Ga_{0.8}As$ / $Al_{0.9}Ga_{0.1}As$ pairs. A 30 nm AlAs layer is used for subsequent selective oxidation and is integrated in the lowest p-type top DBR pair. Using wet chemical etching, mesas with diameters of 38 μm are formed. The etching process is stopped below the AlAs layer. Oxidation in an N_2/H_2O atmosphere at a temperature of 400°C defines the active area of the lasers, typically a few μm in diameter. On the top side TiPtAu ring contacts and on the bottom side broad area GeNiAu n-contacts are deposited. After 2.2 μm thick polyimide passivation a TiAu bondpad is evaporated.

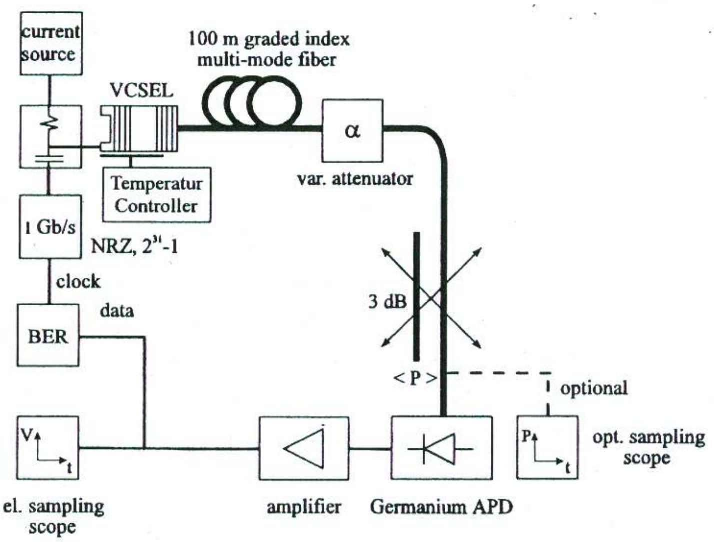
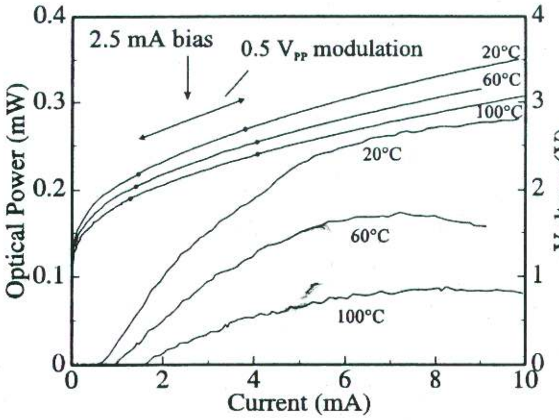


Fig. 2: Experimental setup for data transmission experiments.

III. Experimental Setup:

The light output is measured using a Newport optical power meter with a calibrated Silicon diode, which is directly illuminated. The spectra were measured using an Anritsu optical spectrum analyser. The setup for the transmission experiments is shown in Fig. 2. The laser is mounted on a Peltier element for temperature control and wire bonded to an SMA socket to keep feeding lines as short as possible. For data transmission experiments the laser is driven by a constant bias source combined with the signal of a pattern generator with a pseudo-random bit sequence (PRBS) with 2^{31}-1 wordlength at 1 Gbit/s non-return-to-zero (NRZ) data rate. To guarantee stable alignment the multimode fiber is attached to the VCSEL using an index matching glue. The transmitted signal is passed though a variable attenuator and detected with a 2 GHz bandwidth Germanium avalanche photodiode (APD). The preamplified bit sequence is monitored with an electrical sampling oscilloscope and analyzed with a bit error rate (BER) detector.



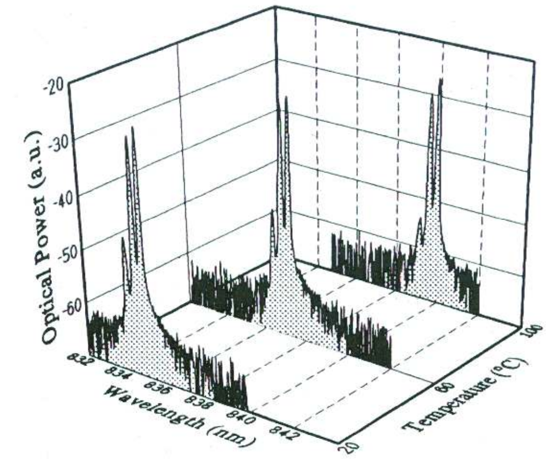


Fig. 3: Temperature dependent characteristics of a 5 μm diameter oxidized GaAs QW VCSEL with indicated bias point and modulation range for PRBS data transmission.

Fig. 4: Temperature dependent spectra under 1 Gbit/s PRBS 0.5 V_{pp} modulation at 2.5 mA bias current.

IV. Device Characteristics:

Highly efficient devices with low internal heating due to the low resistance of the DBR stacks and minimum optical absorption are favorable for operation over a wide temperature range. A VCSEL of about 5 μm active diameter has been used for data transmission. Fig. 3 depicts light output and current-voltage characteristics at 20°C, 60°C, and 100°C heat sink temperatures. Fig. 4 shows temperature dependent spectra under 1 Gbit/s PRBS modulation from the various temperatures. The modulating PRBS data signal of the VCSEL has a peak-to-peak voltage swing of 0.5 V_{pp}. The corresponding current modulation ranges from 1.3 to 4.0 mA. Eye patterns are illustrated in Fig. 5 which are symmetrical with an on-off ratio of larger than 10 dB and negligibly small turn-on delay at 20°C. At higher temperatures the off-state is below threshold resulting in a turn-on delay of 160 ps and 360 ps for 60°C and 100°C, respectively. Bit-error rate (BER) measurements shown in Fig. 6 are performed after 100 m fiber transmission. For 20°C a BER of 10^{-11} is obtained at a received power of –29 dBm. At 100°C a minor 1 dB penalty in received power is observed.

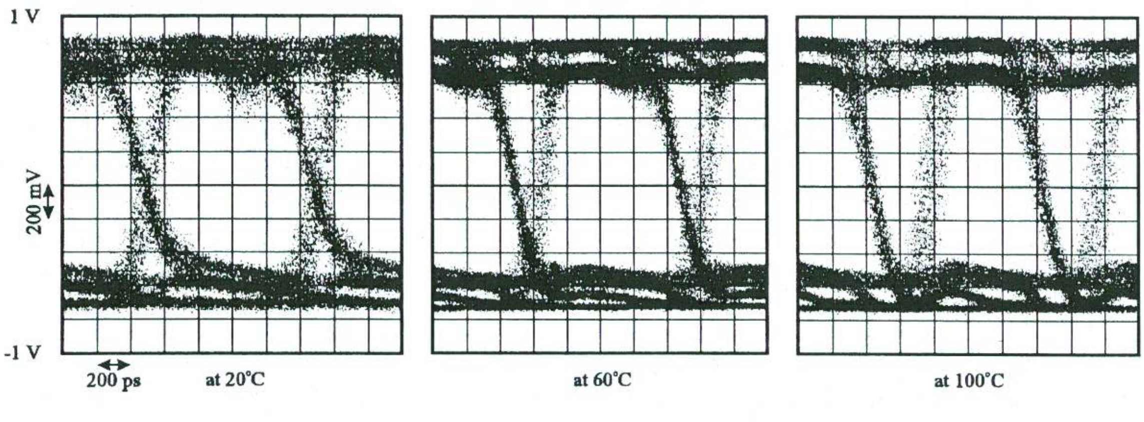


Fig. 5: Eye diagrams for 1 Gbit/s data transmission at various temperatures.

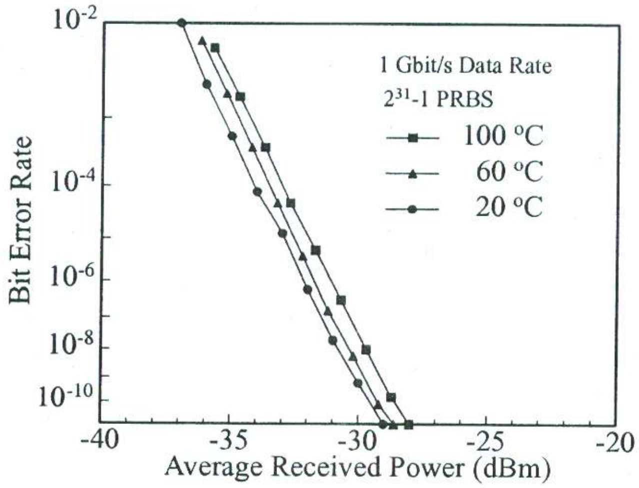


Fig. 6: Temperature dependent BER curve corresponding to the spectra in Fig. 4.

V. Summary:

We have successfully demonstrated 1 Gbit/s wide temperature range (20°C to 100°C) optical data transmission over 100 m graded index fiber using high performance oxide-confined VCSELs emitting at 850 nm wavelength. These results cleary demonstrate that high performance VCSELs may very well fulfill environmental requirements of optical interconnect systems.

Acknowledgments:

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