Data Transmission Using GaAs-Based InAs-InGaAs Quantum Dot LEDs Emitting at 1.3 $\mu$m Wavelength

Max Kicherer

We use vertical emission light-emitting diodes (LEDs) based on long-wavelength, self-assembled InAs-InGaAs quantum dots (QDs) grown on GaAs substrate to demonstrate up to 1 Gbit/s digital data transmission. The devices are characterized in terms of small-signal modulation, showing bandwidths beyond 1 GHz.

1. Introduction

There is an increasing interest in the development of GaAs-based active materials emitting at 1.3 and 1.55 $\mu$m wavelength for telecommunication applications. Since the first realization of lasing using self-assembled InAs-GaAs quantum dots on GaAs substrate, great advances have been made yielding laser diodes with remarkably low threshold current densities [1, 2, 3, 4]. QD-based LEDs may represent efficient and cheap sources for low data rate links at 1.3 $\mu$m [5]. To our knowledge, this letter presents the first demonstration of data transmission using 1.3 $\mu$m QD LEDs.

2. Device Structure

In this experiment we use single-mirror QD LEDs operating at around 1.3 $\mu$m wavelength. Devices are grown on Si-doped (001)-oriented GaAs substrate using solid source molecular beam epitaxy. A $\lambda/2$-thick layer of AlGaAs is grown first for carrier confinement, followed by a GaAs spacer layer. For the active QD region InAs is deposited directly on the GaAs surface and covered by an InGaAs layer. A successive low-index Al$_{0.97}$Ga$_{0.03}$As layer is intended for wet oxidation to serve as a current aperture. It is sandwiched between two Al$_{0.3}$Ga$_{0.7}$As barriers and forms a single Bragg period with the following high-index GaAs layer. To phase match the reflection from the gold layer deposited on top, a highly p-doped GaAs cap layer is grown, serving as a contact layer as well. Layer thicknesses are chosen such that radiation reflected by the top mirror constructively interferes with emission from the QD region, resulting in a fourfold increase in optical output at the substrate side [6]. Device fabrication consists of mesa etching, lateral wet oxidation of the Al$_{0.97}$Ga$_{0.03}$As layer, contact evaporation and annealing. Using this structure we previously demonstrated an external quantum efficiency of 1% at low current densities [5].
3. DC Characteristics

In Fig. 3, the optical output power is plotted versus the injected current for three different device sizes denoted by their oxidized aperture size. The inset shows electroluminescence (EL) spectra taken for CW operation of a 84 $\mu$m-size device. As the injection density increases, ground state emission at 1285 nm saturates due to state filling in the QDs, and two peaks corresponding to emission from excited states are observed. Total output power also saturates since carriers on excited states are more easily lost due to escape to the wetting layer and nonradiative recombination.

4. Small-Signal Modulation

We use a scalar network analyzer for the small-signal modulation measurements. The modulation signal out of the 50 $\Omega$ impedance source is combined in a bias-T with the DC-bias current and fed to the LED. The device is contacted by a ground-signal-ground configuration high-frequency probe head to ensure signal integrity during on-wafer testing. The optical signal is collected using a microscope objective with a numerical aperture of 0.4 and focused onto an InGaAs PIN detector of 100 $\mu$m diameter using another objective. All optical components are anti-reflection coated for the emission wavelength. The electrical signal is amplified by 25 dB prior to detection. The bandwidth of the setup is limited to 1.5 GHz by the photodiode (PD). All measurements have been performed at room temperature with no temperature stabilization of the device.

Fig. 4 shows the modulation response curves of an 84 $\mu$m device for different bias currents, normalized to the value at 20 MHz. Periodic modulations in the curves are caused by reflections on the feeding lines due to the impedance mismatch between LED and driving source. The modulation power was set to –11 dBm out of the 50 $\Omega$ system for all currents. The 3 dB decay is indicated by a horizontal line. We observe the modulation depth to increase with bias current up to about 4 mA, while for higher currents it decreases. Furthermore we observe a continuous increase in bandwidth with increasing bias, leading to rather flat response curves for high driving currents. The maximum bandwidth reached for 20 mA of bias is 860 MHz.
This behaviour can be attributed to state filling, as observed in the DC characteristics. The modulation depth is related to the slope of the light-current curve, which is seen to decrease at high currents in Fig. 3.. On the other hand, at high bias the modulation mostly affects carrier population on excited states, which have shorter carrier lifetime due to both increased nonradiative recombination and an alternative relaxation channel to lower states [7]. This shorter carrier lifetime, also observed independently by time-resolved photoluminescence measurements, results in the observed increase of the modulation bandwidth with bias.

The same setup was used to investigate 35 and 186 µm-size devices. At a bias of 20 mA, the 186 µm devices showed a maximum bandwidth of about 400 MHz, while for the 35 µm devices we found a maximum bandwidth of above 1 GHz at 8 mA of driving current.

5. Data Transmission Experiments

For digital modulation, the scalar network analyzer is replaced by a pulse pattern generator on the transmission side. In the detection circuit the same PD was used. After two amplifiers, totaling about 50 dB of gain, the bit pattern was viewed on a digital sampling oscilloscope.

We use the 84 µm device presented above at a bias of 12 mA. The generator is set for a modulation voltage of 2V_{pp} out of the 50 Ω impedance port. With a pseudo-random bit sequence of $2^7 - 1$ word length at 300 Mbit/s we could detect an open, but somewhat asymmetric eye diagram. Using a repetitive 1-0-bit sequence at a data rate of 1 Gbit/s we recorded the eye diagram shown in Fig. 5.. Again we use the 84 µm device biased at 12 mA of DC current. The modulator output was set for 1.6V_{pp}. The resulting eye diagram is wide open and symmetric.
6. Conclusions

In conclusion, we have demonstrated up to 1 Gbit/s data transmission employing single-mirror vertically emitting LEDs operating around 1.3 µm wavelength from self-assembled InAs-InGaAs quantum dots on GaAs substrate. This shows that QD LEDs may be suitable as low-cost sources for short-distance 1.3 µm optical links.

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References


