Single and Multiple Channel Operation Dynamics of Linear Quantum-Dot Semiconductor Optical Amplifier


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Abstract

Ultra linear quantum-dot semiconductor optical amplifiers at 1.3 µm provide high dynamic input power range for single and multiple channels with error-free amplification. Good burst-mode tolerance is observed.

Introduction

All-optical networks like extended reach CWDM based passive optical networks (PON) have a need for optical amplifiers. Bulk and quantum well (QW) semiconductor optical amplifiers (SOAs) offer polarization insensitive gain, high saturation output power and reasonably low noise figure (NF). This makes such devices promising for in-line amplification to increase the number of customers served by the same central office [1-3]. On the other hand, the slow gain dynamics even under moderate gain saturation limit their input power dynamic range (IPDR) and their multi-wavelength capability.

In contrast, quantum-dot (QD) SOAs are cost-effective candidates to overcome the aforementioned issues. Some of their advantages are the ultra-fast QD gain response, greatly expanded bandwidth, low noise figure, the enhanced multi-wavelength capability and the possibility of uncooled operation. Up to now, quite extended studies of the nonlinear capabilities of QD SOAs have been performed [4]. However, an in-depth characterization of the linear performance of QD-SOAs is still missing.

In this paper we demonstrate a wide and linear IPDR with error-free single and multi-wavelength amplification at bit rates from 2.5 to 43 Gbit/s. The 1.3 µm QD SOA devices are found to be burst tolerant.

QD SOA and Setup

The QD SOA used for this study is grown by molecular beam epitaxy. It contains 10 stacks of InGaAs/GaAs QDs having a dot in a well structure. The device length is 4 mm and the waveguide width is 2 µm. The applied current density is 6.25 kA/cm². A small-signal gain of up to 20 dB, a 3 dB bandwidth of 35 nm and a saturation output power of 10 dBm are found. The device shows polarization dependent gain of up to 10 dB. This intrinsic issue of the QD SOAs can be overcome by growth techniques or polarization diversity schemes [4].

The IPDR for amplification of single and multiple data signals with a 1.3 µm QD SOA is studied by evaluating the Q² factor. The experimental setup is shown in Figure 1. The optical power of two decorrelated data signals at 1290 nm and 1310 nm is adjusted before launching into the QD SOA. After amplifying both data signals in the QD SOA one channel is blocked by a tuneable filter while the Q² factor of the remaining data channel is analyzed with a digital communication analyzer (DCA) and a bit-error rate tester (BERT).

IPDR for Amplification of Data Channels

The sensitivity of the Q² factor to variations in the power launched into the QD SOA is shown in Figure 2. We investigated bit rates and modulation formats of 2.5 Gbit/s NRZ-OOK, 10 Gbit/s NRZ-OOK and 43 Gbit/s RZ-OOK in the presence of one and two data signals.

In the single channel case a large IPDR exceeding 25 dB for each bit rate is found, Figure 2 (a). For high input powers the quality of the signal decreases. This is due to patterning introduced by the slow QW confinement layer dynamics in the range of 200 ps [5]. At low launch powers the performance degrades as it is operated below the optical signal-to-noise ratio (OSNR) of the device.

Error-free amplification of multiple channels in a QD SOA at a wavelength of 1.3 µm is shown in...
Figure 2 (b). The IPDR remains large for all bit rates. At low input powers, the signal quality performance is similar to the single channel. Under deep gain saturation patterning and interchannel crosstalk degrade the signal quality. Table 1 summarizes the results of the IPDR with $Q^2$ factors of 15.6 dB and beyond.

Table 1: IPDR for QD SOA at different bit rates for 1 and 2 channels. For comparison a commercial available QW SOA has been tested at 43 Gbit/s.

Table 2: IPDR for QD SOA at different bit rates for 1 and 2 channels. For comparison a commercial available QW SOA has been tested at 43 Gbit/s.

Figure 3: Good burst-mode performance is found for a large IPDR in a QD SOA

Figure 3 shows the effect of a signal burst for different input power levels and an extinction ratio of 13 dB on a cw probe signal with the same power. No transient are induced onto the cw channel for low and moderate input power levels. This shows a high performance burst-mode capability of QD SOAs. If the input power levels are increased into deep saturation only a 3 dB transient is observed. The dynamics are driven by the QW time constant which shows long-term gain transients of 200 ps.

Conclusions

We found error-free amplification for a large input power dynamic range exceeding 25 dB in the single channel experiment at bit rates of 2.5, 10 and 43 Gbit/s. In the multi-channel case the IPDR is still large showing 19 dB at 43 Gbit/s. The ultra linear behaviour of the device also shows low magnitude and fast dynamics of transients. Such linear 1.3 µm QD SOAs are promising candidates for in-line amplification in future access networks.

This work was supported by the European project TRIUMPH (grant IST-027638 STREP), by SANDIE NoE (NMP4-CT-2004-500101), by the Center of Functional Nanostructures (CFN) within Project A4.4, and the Sonderforschungsbereich SFB 787.

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