Broadband Rate-Equation Model including Many-Body Gain for WDM Traveling-Wave SOAs

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Abstract – **We present a traveling-wave rate-equation model for wavelength-division multiplexing (WDM) semiconductor optical amplifiers (SOA) which utilizes many-body gain spectra. Good agreement with measurements is obtained across a broad wavelength range.**

I. INTRODUCTION

Broadband semiconductor optical amplifiers (SOAs) are of great interest for wavelength-division multiplexing (WDM) and other multi-wavelength optical communication systems. The wavelength sensitivity of the device performance is of special concern, in our case for a wavelength range from 1525 nm to 1565 nm.

We here present an SOA rate-equation model which gives good agreement with measured device characteristics over a broad wavelength range due to the inclusion of many-body gain spectra. To demonstrate and validate this model, we investigate ridge-waveguide devices with an InGaAsP multi-quantum-well (MQW) active region grown on top of the waveguide layer.[1] Our example SOA is 400μm long and the waveguide ridge is 3μm wide. More device details are given elsewhere.[2]

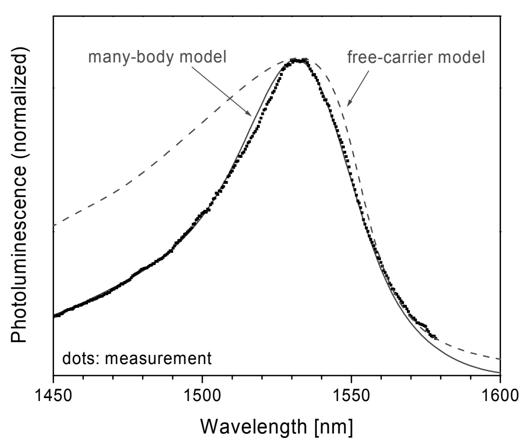

Fig. 1 Photoluminescence spectrum (dots: measured, dashed: free carrier model, solid: many-body model).

II. GAIN MODEL

The accurate modeling of quantum well properties, in particular the optical gain is prerequisite for a realistic simulation of broadband devices. We initially employed the free-carrier gain model by Chinn et al. [3] including 4x4 kp band structure calculations and a Lorentz energy broadening function.[4] However, this approach did not give consistent agreement with experimental results, especially the measured wavelength dependence was not reproduced correctly. This becomes clear from comparison to the measured photoluminescence spectrum (Fig. 1) which exhibits discrepancies on both sides of the spectrum. The many-body gain theory by Koch et al. [5] provides a much better agreement across the entire spectrum (solid curve in Fig. 1). Gain spectra from both models are shown in Fig. 2 which reveal substantial differences not only in shape but also in magnitude. In strong contrast to the free-carrier model, the many-body spectra indicate relatively uniform SOA performance across the C-band, which is in agreement with our experimental observations.

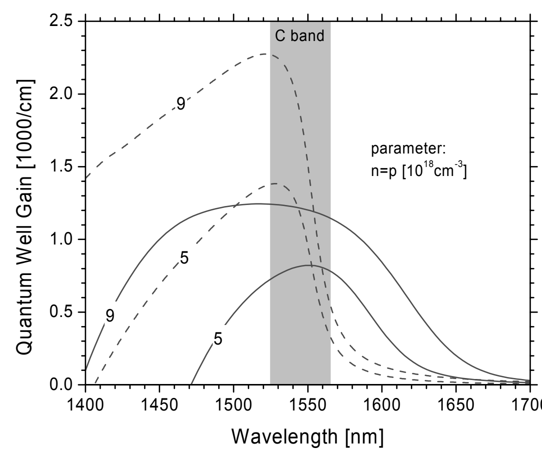

Fig. 2. Calculated gain spectra at two different carrier densities (dashed: free carrier model, solid: many-body model).

III. RATE-EQUATION MODEL

We employ a traditional rate-equation model for the quantum well carrier density and the photon density including non-radiative and spontaneous recombination.[6] As the carrier and photon densities are longitudinally non-uniform in our traveling-wave SOA, we break the active region into a number of much smaller sections, within which we can approximate the densities as uniform. The optical gain in each section is a function of the local carrier density and the signal wavelength.

It is extracted from many-body gain tables purchased from Nonlinear Control Strategies (Tucson, AZ)[7] that have been adjusted to our photoluminescence measurements as described elsewhere.[8]

The rate-equation model employs a number of material parameters which are critical to obtain good agreement with measurements. We assume typical values for the defect recombination lifetime (τ_{SRH} = 20 ns), the spontaneous emission coefficient (B = 0.8 10^{-10} cm^3/s), and the modal loss (α_i = 10 cm^{-1}). The injection efficiency η_i = 82% and the optical confinement factor Γ = 0.06 are extracted from an advanced device simulation.[8] The only fit parameter used here is the Auger coefficient C = 2.4 x 10^{-29} cm^6/s which lies well within the range reported in the literature.[9] Amplified spontaneous emission (ASE) effects are negligibly small.

IV. RESULTS

The fabricated device has a monolithically integrated photodetector at the output of the SOA, which was used to measure the output power.[1] This allows us to measure the output power easily and accurately, eliminating any coupling losses that would results if the detector was off-chip. Figure 3 shows the measured SOA gain (dots) as a function of wavelength along with the simulation result (line). The input power P_{in} is kept low to avoid saturation effects. The simulation is in good agreement with the measured data across a broad wavelength range. The deviation seen at the short-wavelength side may be attributed to slight inaccuracies in the calculated gain spectrum. The injection current density of j = 7.5 kA/cm^2 is sufficiently low to exclude self-heating effects and to assume room temperature in the simulation.

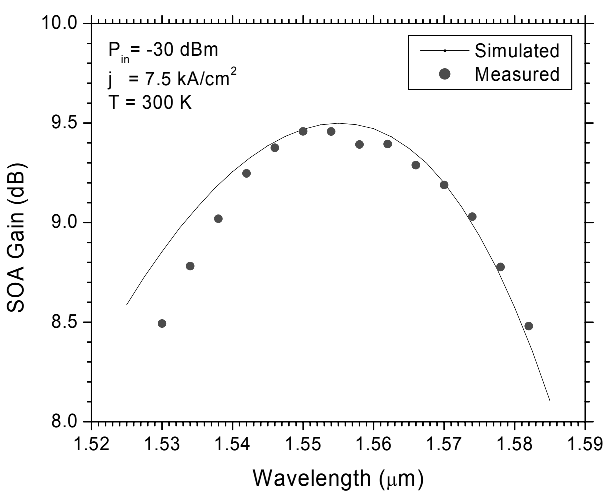

Fig. 3: Unsaturated SOA gain vs. wavelength at low injection current.

Figure 4 shows the output power at 1558 nm as a function of the input power. The measurement is very well reproduced by the model up to about 3 mW output power. Above this power level, saturation sets in as the photon density near the output facet becomes high enough for the stimulated recombination to substantially increase the total carrier recombination rate in the quantum well. Consequently, the carrier density drops and so does the SOA output power. The slight high-power deviation in Fig. 4 shows that the saturation is somewhat stronger in the measurement than calculated, which can be attributed to a slight overestimation of the carrier density in the simulation.

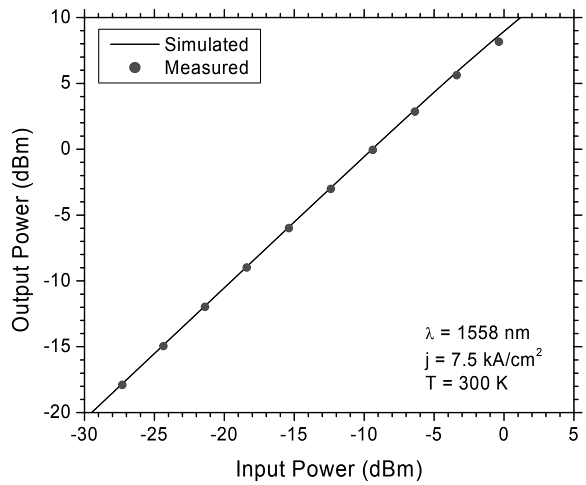

Fig. 4: SOA output power vs. input power.

In summary, we have demonstrated that relatively simple rate-equation models for traveling-wave semiconductor optical amplifiers can deliver realistic performance characteristics across a broad wavelength range by employing an advanced many-body model for the optical gain spectrum.

ACKNOWLEDGEMENT

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