Simulation of the Spectral Behavior in High-Power Distributed Feedback Lasers above Threshold

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***Abstract*—We report on the simulations of mode hopping behavior in semiconductor distributed feedback lasers with asymmetric facet reflectivities above threshold and its dependence on the phase between the grating and the high reflective facet.**

***Index Terms*—Semiconductor Diode Lasers, Distributed Feedback Lasers, Simulation, Spectral Behavior**

I. Introduction

Compact, efficient and robust tunable single frequency laser diodes emitting with small linewidths are key components for a broad range of sensing applications. Especially quantum technology applications need wavelengths easily accessable by GaAs-based devices which cover a wavelength range from about $600\,\mathrm{nm}$ to $1200\,\mathrm{nm}$. Integrated devices with internal frequency selective elements are ideally suited for this purpose. Distributed Bragg Reflector (DBR) and Distributed Feedback (DFB) lasers are able to match those requirements as long as the applications do not require laser sources with very high coherence which might only be satisfied by more sophisticted systems as e.g. external cavity diode lasers. However, such systems as well as DBR lasers suffer from mode hops when operation conditions like the voltage applied to the devices or the device temperature are changed. Unfortunately, the operation condition dependent characteristics of the longitudinal modes supported by their resonators differ from the corresponding frequency drift of the frequency selective elements used within these designs. In contrast, properly designed DFB lasers with anti reflction (AR) coated facets and gratings containing phase shifts can be continously tuned over a wide range of operating parameters. DFB lasers with the front facet being AR coated and the back facet being highly reflective (HR) offer the advantage of a higher optical output power at the front facet and share most often the well-behaved tuning behavior. However, it is an unsolved technological challenge to this day to efficiently control the phase ϕ_{rear} between the grating and the rear facet which leads to DFB lasers with gratings incorporating an uncontrolled phase shift which can lead to unstable operation. Within this work we want to explore the mode hop behavior of such HR-AR coated DFB lasers above threshold by traveling wave based simulations to get a better understanding of the nature of these processes and possible device parameters and operation conditions to prevent the occurence of mode hops.

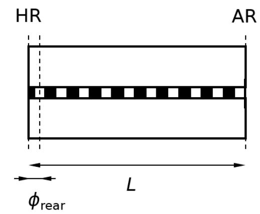

Fig. 1. Simulated HR-AR coated DFB laser devices with varied rear facet phase with respect to the grating.

II. Device Under Study and Simulations

The DFB lasers analyzed have uniform gratings along the entire resonator. The coupling coefficient of the grating is $\kappa = 4.5\,\mathrm{cm}^{-1}$ at a resonator length of $L = 1500\,\mu\mathrm{m}$ to achieve a rather uniform longitudinal intensity distribution along the resonator. The rear power reflectivity is set to 0.95. The front facet power reflectivity is set to 0 in order to exclude any pertubations from additional phase variations between the grating and the front facet. The Bragg wavelength is set to $783\,\mathrm{nm}$. The basic design is described in [1].

For comparison the devices were simulated at threshold using stationary coupled wave equations [2], [3] to get a basic overview of the spectral characteristics at first varying the phase of the rear facet a full cycle from 0 to 2π. The main simulations were done using the BALaser software kit orignally written to simulate the dynamics in edge emitting broad area semiconductor lasers [4]. Its optical model is based on time dependent traveling wave equations with slowly varying amplitudes for the forward and backward propagating optical fields $u^{\pm}(x, z, t)$ where x and z describe the lateral and longitudinal coordinates, respectivly. In addition BALaser is able to account for the spatially and temporally varying carrier densities [5], current spreading in p-doped layers as well as self-heating [6]. For the simulations ϕ_{rear} was varied from 0 to 2π ins steps of $0.1 \times 2\pi$ with applied voltages ranging from $1.7\,\mathrm{V}$ to $2\,\mathrm{V}$ in steps of $0.05\,\mathrm{V}$. Those voltages correspond to operating currents from well above threshold to slightly above $200\,\mathrm{mA}$ – a typical range applied to real devices.

III. Results

From the simulations with stationary coupled wave equations at threshold one sees that the lasing mode switches at $\phi_{\mathrm{rear}} = 0.75 \times 2\pi$ when the relative threshold gain Δg of

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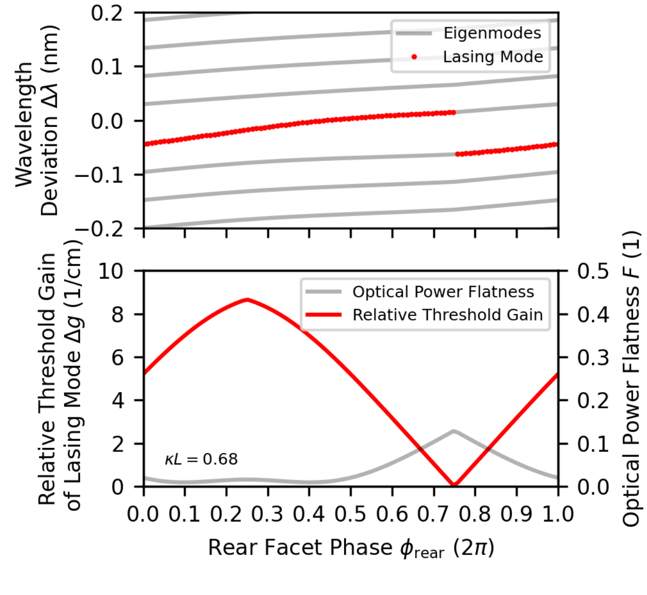

Fig. 2. Eigenmodes of the device at threshold as well as the relative threshold gain difference of the lasing mode to the next most favored one and the optical power flatness as a function of the rear facet phase.

the lasing mode with respect to the next most favored one vanishes. Actually, at this rear facet phase the reflected field is just in antiphase with the incoming field. In contrast, at $\phi_{\text{rear}} = 0.25 \times 2\pi$ the relative threshold gain is at its maximum and the laser should be in stable single mode operation. In this case the back reflected field from the facet is just in phase with the incoming field. One can define an optical power flatness $F = \int_{\text{cavity}} (\hat{I}(z) - 1)^2 \mathrm{d}z/L$ to describe how uniform the field intensity distribution $I(z)$ is to account for spatial hole burning with $\hat{I}(z) = I(z)L/\int_{\text{cavity}} I(z)\mathrm{d}z$ beeing the normalized intensity distribution along the resonator [7]. Actually, this measure peaks at $\phi_{\text{rear}} = 0.75 \times 2\pi$ as well for the device. Based on the optical power flatness and the relative threshold gain of the lasing mode one may define margins for single mode operation.

The simulation results above threshold obtained with BALaser are presented in Fig. 3. The simulations were done with self-heating turned off to differentiate between electrical and thermal effects. One can clearly identify a discontinuity of the emitting peak wavelength as function of the applied current at a rear facet phase of $0.6 \times 2\pi$. However, no mode hops are observed for devices with other rear facet phases within the chosen operating range except for $0.7 \times 2\pi$ at about $50\,\mathrm{mA}$ near to threshold (not shown here). The mode hop width of about $0.07\,\mathrm{nm}$ corresponds to the stopband width of the DFB laser. A more detailed analysis of the time averaged carrier density distribution of the devices with a rear facet phase of $0.6 \times 2\pi$ reveals actually a stronger local increase near the back facet compared to the other devices which even rises with higher currents applied. The induced reduction of the refractive index by the elevated carrier density is consistent with the observed mode hops from the lower to the higher stopband mode.

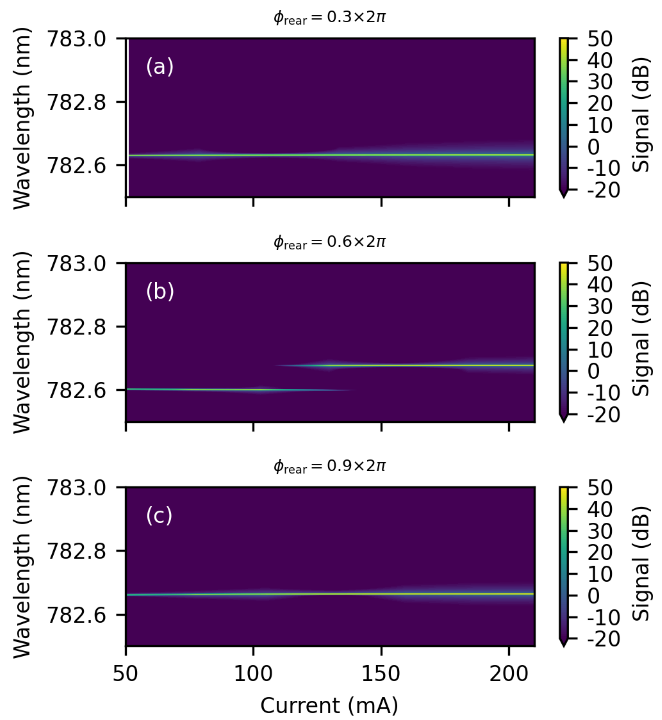

Fig. 3. BALaser simulations of the spectra emitted by HR-AR DFB lasers as function of applied current for a selction of rear facet phases ϕ_{rear} of (a) $0.3 \times 2\pi$, (b) $0.6 \times 2\pi$ and (c) $0.9 \times 2\pi$.

These results are given as an outlook on the talk which will include further simulation results including the spectral behavior considering self-heating as well.

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