Linewidth and Threshold Calculations for a Slotted, Fabry-Perot Semiconductor Laser

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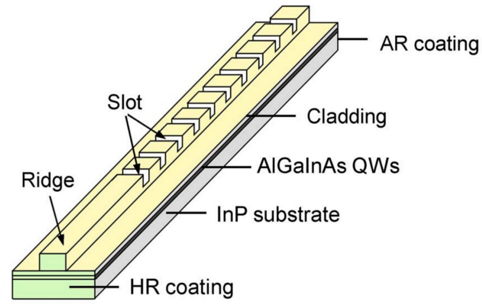
***Abstract*-Linewidth and threshold calculations are made for a current-injected, partially 'slotted' semiconductor laser while including the effects of noise with an explicit derivation of photon-current coupling and varying reflectivities as a function of slot depth. Calculations are demonstrated to show good agreement with experiments.**

I. Introduction

Within the past decade, partially slotted feedback lasers have been etched in Fabry-Perot cavities that allow for single mode lasing with a good SMSR above 40dB[1]. For applications in coherent communications systems, lasers will also require very narrow linewidths with a target of 100 kHz. We are developing a detailed model of the linewidth behaviour of our slotted laser platform so as to be able to design a laser with a predetermined linewidth. The slotted laser presented incorporates the selectivity of a periodic Bragg grating implemented throughout the active region, however on only one side of the cavity. It has been shown to be robust in regards to slot position and size thus allowing its fabrication to be done with more conventional photolithography and avoiding complex regrowth techniques generally required for traditional DFB lasers[2]. In additon, the slots could be optimized so that cleaved facets are no longer necessary at both ends of the cavity allowing integration with optical devices[3].

II. Device and Theoretical Method

The model of the partially-slotted Fabry-Perot (FP) laser shown in Fig.(1) includes noise and temperature fluctuations within multimode theory while taking into consideration the grating's reflectivity as a function of slot dimensions. The system's threshold behavior and linewidth are retrieved in 2 steps. Initially the scattering matrix method (SMM) is utilized in order to solve for the reflection coefficient due to the given slot width (ds), depth, and periodic spacing (dp) as previously described in references[2,3]. This research focuses specifically on the effects of slot depth with the width and period initially optimized to excite a Bragg wavelength of 1550 nm. Secondly, the reflection coefficients are then considered when implemented within the semiclassical rate equations and eventual extraction of the linewidth from the electric field spectrum. In particular, this implementation is done by considering the number of longitudinal modes that must be included as well as adjustments to the photon loss and mirror reflectivity[4]. The simulations include the coupling of Langevin fluctuations between the injected current, $F_N(t)$, and photons, $F_P(t)$. The method introduced by Marcuse quantifies the coupling with the cross-correlation of the quantum noise terms by,[5]



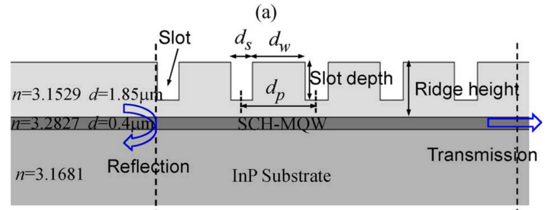


Fig. 1: (a) 3D schematic representing the slotted ridge waveguide. (b) 2D representation with the effective indices of refraction used in the simulations. d_s and d_p are optimized in order to excite a Bragg wavelength of 1550 nm.

$$\langle F_N(t)F_P(t')\rangle = 2C_{NP}\sqrt{D_N D_P}\delta(t-t'), \qquad (1)$$

with C_{NP} being the cross-correlation coefficient and $D_{N(P)}$ being the corresponding diffusion term due to the injected current (photon) fluctuations. This definition allows an analytic solution for the coefficient. which has been plotted as a function of injection current in Fig(4).

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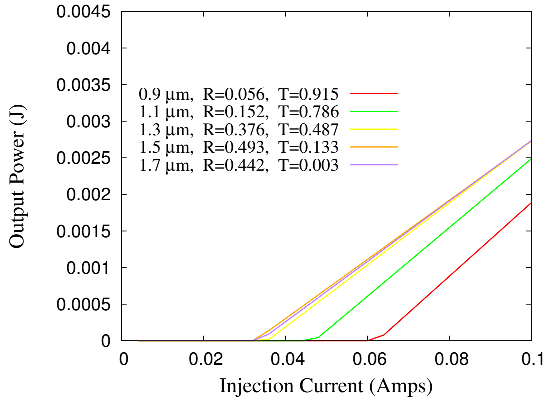

Fig. 2: Simulated results for optical power vs. injection current are presented for various slot depths along with reflection (R) and transmission (T) values calculated via the implemented SMM model.

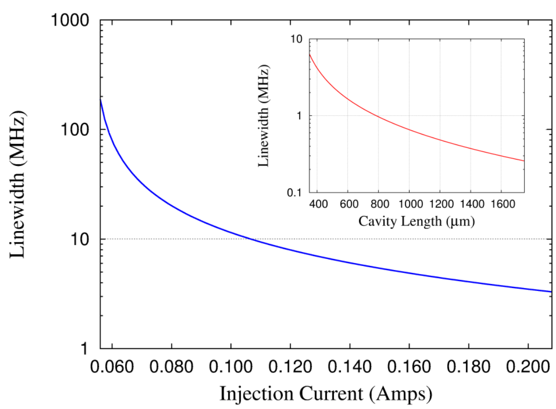

Fig. 3: Shown is the FWHM calculation extracted from the $\vec{E}$-field spectra. A linewidth of a few megahertz is able to be resolved as function of injection current for a slot depth of 1.35 μm and cavity length of 350μm. Comparable results for the FWHM as a function of cavity length for a similar slot depth and injection current of 200 mA is given in the inset.

III. Results

Fig.(2) shows the optical power output vs. threshold current as a function of slot depths ranging from 0.9→1.7 μm. Results shown are for a cavity length of 550μm along with reflection and tranmission coefficients of the slotted end of the cavity calculated using SMM theory. Fig.(3) is a best-fit curve of the FWHM showing the expected linewidth behavior as injection current and cavity length (inset) are increased for a sample cavity length of 350 μm. Typically, as we move above threshold, a linewidth of a few MHz is able to be resolved in addition to SMSRs above 50 dB comparing well with previously reported experimental data[6]. Fig.(4) includes a steady-state relative $\vec{E}$-field noise spectrum (REN) analogous to the relative intensity noise with phase information included. The nearest side peaks of the simulated spectrum (black) are due to random noise fluctuations as opposed to relaxation oscillations or longitudinal modes. Below a certain injection current the level of cross-correlation (inset) has a negligible effect on noise while well above threshold the coupling becomes comparable to the uncorrelated noise terms. This leaves us with a preferred range of injection current in order to reduce these coupled fluctuations. Altogether, the results demonstrate that partially-slotted FP lasers have the capability to serve as efficient single-mode sources while furthermore being highly integrable with other photonic devices.

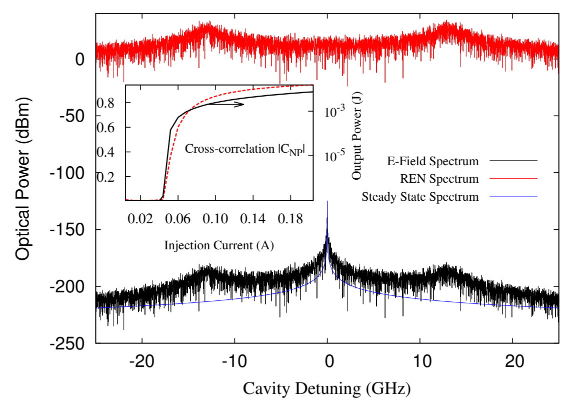

Fig. 4: Plotted are the $\vec{E}$-field spectra (black) and REN spectrum for an injection current of 100 mA and cavity length 350μm. Within the steady state the closest side peaks are calculated to be solely due to quantum noise fluctuations. The cross-correlation coefficient (inset-dashed red) is shown to increase as the sytem goes above threshold.

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