Simulation challenges for distributed feedback semiconductor lasers

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Distributed feedback (DFB) semiconductor lasers are the workhorses of optical communications providing single wavelength and narrow linewidth optical sources for demanding dense wavelength division multiplexing applications. The theory of DFB lasers is well understood with many excellent texts devoted to the subject [1]. Correspondingly most commercial simulation tools include some support for DFB laser design. Despite the advanced state of DFB laser theory and modeling, optical component manufacturing companies face challenges mass producing DFB lasers. Small processing variations can have a large effect on device yield. DFB laser designers must take these small processing variations into consideration when working on a design, ensuring that device performance is robust across the largest region of manufacturing fluctuations. This paper focuses on three current challenges associated with manufacturing DFB lasers: 1) analyzing DFB laser performance as function of grating/facet phase, 2) including gain coupled grating effects, and 3) allow the simple extraction of DFB laser parameters from experimental data.

DFB lasers are described by the usual laser rate equations for the forward and backward fields [1]:

$$\begin{aligned} \frac{1}{v_g}\frac{\partial E^{\pm}}{\partial t} \pm \frac{\partial E^{\pm}}{dz} &= (g - i\delta)E^{\pm} + i\kappa E^{\mp}, \\ E^{+}(z=0) &= \rho^{-}E^{-}(z=0), \\ E^{-}(z=L) &= \rho^{+}E^{+}(z=L), \end{aligned}$$

where $E^{\pm}$ is the forward/backward propagating field, v_g is the group velocity, g is the carrier dependent effective gain, δ is the carrier dependent effective refractive index, κ is the effective field coupling, L is the cavity length, and $\rho^{\pm}$ is the front/rear facet reflectivity. Usually κ and $\rho^{\pm}$ are taken to be real. However these coefficients are more likely to be complex with variations in the imaginary parts strongly effecting the laser performance.

The first challenge come from the misalignment of the grating plane with the facet plane resulting in a grating/facet phase mismatch (Fig. 1). This can me modeling as complex using complex values of $\rho^{\pm}$. Stability of the selected bragg mode depends on the relative grating/facet phase mismatch [2]. A laser may designed to pick one bragg mode based on a single facet/grating phase value only to yield poorly in manufacturing as the facet phase varies across a bar. The ability to sweep the grating/facet phase over all possible values and calculate laser properties is sorely needed.

The second challenge arises from using gain coupled gratings. Gain coupled gratings have been demonstrated as a means of achieving high single mode yield, while also providing other advantages, such as high intrinsic bandwidth and improved reflection immunity. Small changes in the gain coupling can change laser characteristics dramatically (Fig. 2). Gain coupling can easily be included with a complex κ term in the rate equations. Again the ability to investigate laser performance as a function of gain coupling is desired.

The third challenge is a self consistent way of determining the optimal laser parameters from an existing working design. Sometimes a few devices of a given design work while the rest fail. Because of process variations the true values of the working devices may be far from the intended value. Using the measured data from these devices to calculate the true laser parameters [3] can point to the correct design space and decrease the design time required.

[1] J. Carroll, J. Whiteaway, and D. Plumb, “Distributed feedback semiconductor lasers”, IEE Press (1998).

[2] D. M. Adams et al., “Yield enhancement due to carrier injection behavior in truncated-well gain-coupled DFB’s”, *CLEO ’96*, CMF3 (1996).

[3] G. B. Morrison et al., “Extraction of gain parameters for truncated-well gain-coupled DFB lasers”, *IEEE Phot. Tech. Lett.*, vol. 11, pp. 1566-1568 (1999).

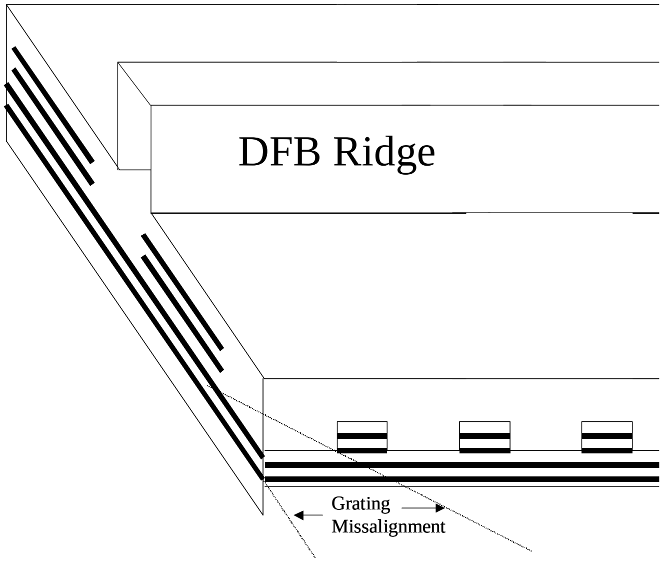

Fig. 1: Misalignment of the grating plane with the facet plane results in a grating/facet phase mismatch. This can me modeling as complex using complex values of $\rho^{\pm}$. Etching into the active region results in gain coupling which can be modeled with complex values for κ.

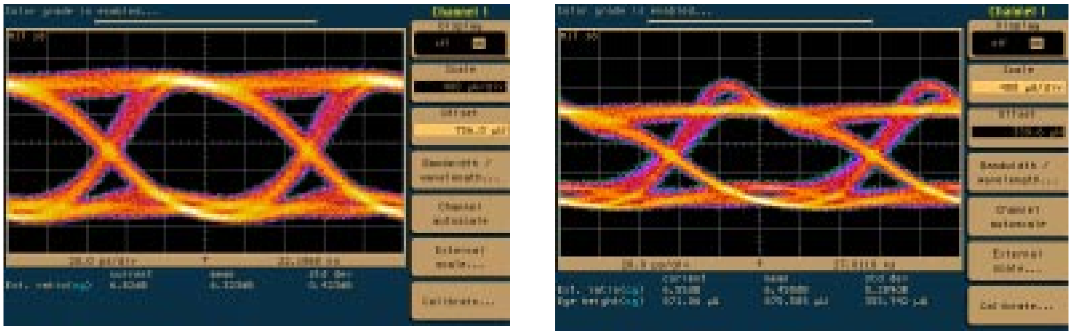

Fig. 2: Measured 10 Gbit/s directly modulated eyes of gain coupled DFB lasers. Re(κ), as measured from the stopband, is roughly equal. However Im(κ) is larger for the left eye than the right eye. All other measured laser parameters are similar.