Optics Communications 350 (2015) 178–188

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Polarization and modal dynamics of multimode vertical-cavity surface-emitting lasers subject to optical feedback and current modulation

Hong Lin [a,*], Aliza Khurram [a], Myles D. Black-Ingersoll [a,1], Angel Valle [b]

[a] Department of Physics and Astronomy, Bates College, Lewiston, ME 04240, USA
[b] Instituto de Física de Cantabria (CSIC-Univ. Cantabria), Avda Los Castros s/n, E39005 Santander, Spain

ARTICLE INFO

Article history:
Received 27 January 2015
Received in revised form
24 March 2015
Accepted 1 April 2015
Available online 3 April 2015

Keywords:
Polarization and transverse dynamics
Vertical-cavity surface-emitting lasers
Optical feedback
current modulation

ABSTRACT

Dynamics of a multi-transverse mode vertical-cavity surface-emitting laser is studied experimentally in a wide parameter range of optical feedback and current modulation. While the orthogonal polarizations manifest anticorrelated feedback dynamics, dynamics of different transverse modes with orthogonal polarizations do not exhibit a clear correlation property. This may be attributed to spatial hole burning effect. As the current modulation becomes strong, both polarization and modal dynamics are modulation dominated. When the modulation frequency is close to the external cavity resonance frequency or its harmonics, feedback dynamics is enhanced. For the modulation frequency close to half integer multiples of the external cavity resonance frequency, feedback feature can be suppressed. The minimum modulation amplitude for suppressing feedback dynamics is measured for each polarization and one of the transverse modes in the polarization, and the results are discussed. Interplay of relaxation oscillation, optical feedback, and current modulation is observed and measured. Our results are compared to the theoretical predictions.

1. Introduction

The vertical-cavity surface-emitting laser (VCSEL) has become a useful device in high bit-rate data communications because of its many advantages (e.g., single longitudinal mode operation, low divergence circular beam profile, low threshold current, ease for integrating two-dimensional arrays, and large bandwidth for modulation) over edge-emitting lasers. When the bias current is above the threshold, higher order transverse modes can start oscillation [1]. The key mechanism for oscillation of higher-order modes is attributed to spatial hole burning effect [2,3]. The operation of higher order transverse modes increases the output power and decreases the modal noise [4], which makes multimode VCSELs very useful for application such as high speed multimode fiber links [4] and high-power arrays [5].

Because of circular transverse geometry, polarization of VCSELs is intrinsically unstable. VCSELs can emit two linearly polarized lights which are along two crystallographic directions. These two linear polarizations are perpendicular to each other. Typically, a VCSEL is linearly polarized near the threshold. With increasing bias current, the VCSEL can suddenly switches to the orthogonally linear polarization. This phenomenon is termed polarization switching (PS). Depending on birefringence, the frequency difference of the two orthogonal polarizations can range from a few GHz to a few tens of GHz [6]. The polarization of higher order transverse modes can be orthogonal or parallel to that of the fundamental mode [7]. In the presence of optical injection a transverse mode can be elliptically polarized, often with one polarization component much stronger than its orthogonal counterpart [8,9]. Polarization properties of VCSELs (e.g., polarization switching, polarization coexistence, and polarization competition) and underlying mechanisms have attracted a great deal of attention [10–14].

In fiber–optic communications, lasers with a large modulation bandwidth are required. Modulation response of VCSELs is of importance for both fundamental and applied research [15–21]. Chaotic behavior appears in the multimode regime due to transverse mode competition, and different scenarios of polarization dynamics are identified [20,21]. Simultaneously, optical feedback caused by reflection from fiber tip or other surfaces in the network is unavoidable. Optical feedback can broaden or reduce the spectral linewidth [22,23], select transverse modes [24,25], affect polarization switching process [26,27], and achieve linear polarization in a wide current range [28]. It can also induce low frequency fluctuations [29], self-modulation in polarizations [30], and

* Corresponding author.
E-mail address: hlin@bates.edu (H. Lin).
[1] Current address: Department of Electrical Engineering, Boston University, Boston, MA 02215, USA.

http://dx.doi.org/10.1016/j.optcom.2015.04.005
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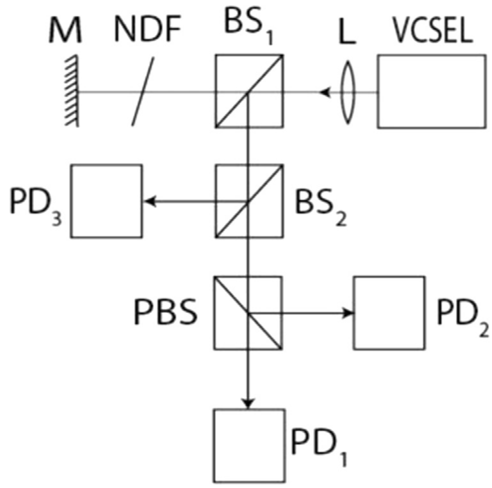

Fig. 1. Schematic diagram of the experimental setup. BS: nonpolarizing beam splitter; L: collimating lens; M: feedback mirror; NDF: neutral density filter; PBS: polarizing beam splitter; PD: fiber-coupled fast photodetector.

irregular pulsations [31,32]. Therefore, it is necessary to study interplay of modulation and feedback effects in VCSELs. In addition, semiconductor lasers subject to both optical feedback and current modulation can be used in chaos communications [33]. Torre et al. numerically studied transverse dynamics in directly modulated VCSELs subject to weak optical feedback, with polarization features neglected [34]. For increasing modulation amplitude, they found a transition from a regime governed by optical feedback to a regime governed by current modulation. This was verified by Hong et al. in a linearly polarized VCSEL with dc bias current near threshold [35]. The influence of low-frequency (1–100 kHz) modulation on PS was investigated in an external-cavity VCSEL [36]. Polarization dynamics was numerically studied around PS region in a single transverse mode VCSEL with GHz level modulation and weak optical feedback [37]. However, experimental work about dynamics in multi-transverse mode VCSELs has not been reported yet.

In this paper, we report an experimental study on the polarization and modal dynamics of a current-modulated VCSEL subject to optical feedback. Our study was conducted when the VCSEL operates with three transverse modes. The results are compared to the theoretical predictions.

2. Spectral and spatial features of the VCSEL

The VCSEL used in the experiment is proton-implanted (Honeywell HFE 4083-322). Operating at ~843 nm, its modulation bandwidth is larger than 1 GHz, and its aperture is 14 μm. The dc

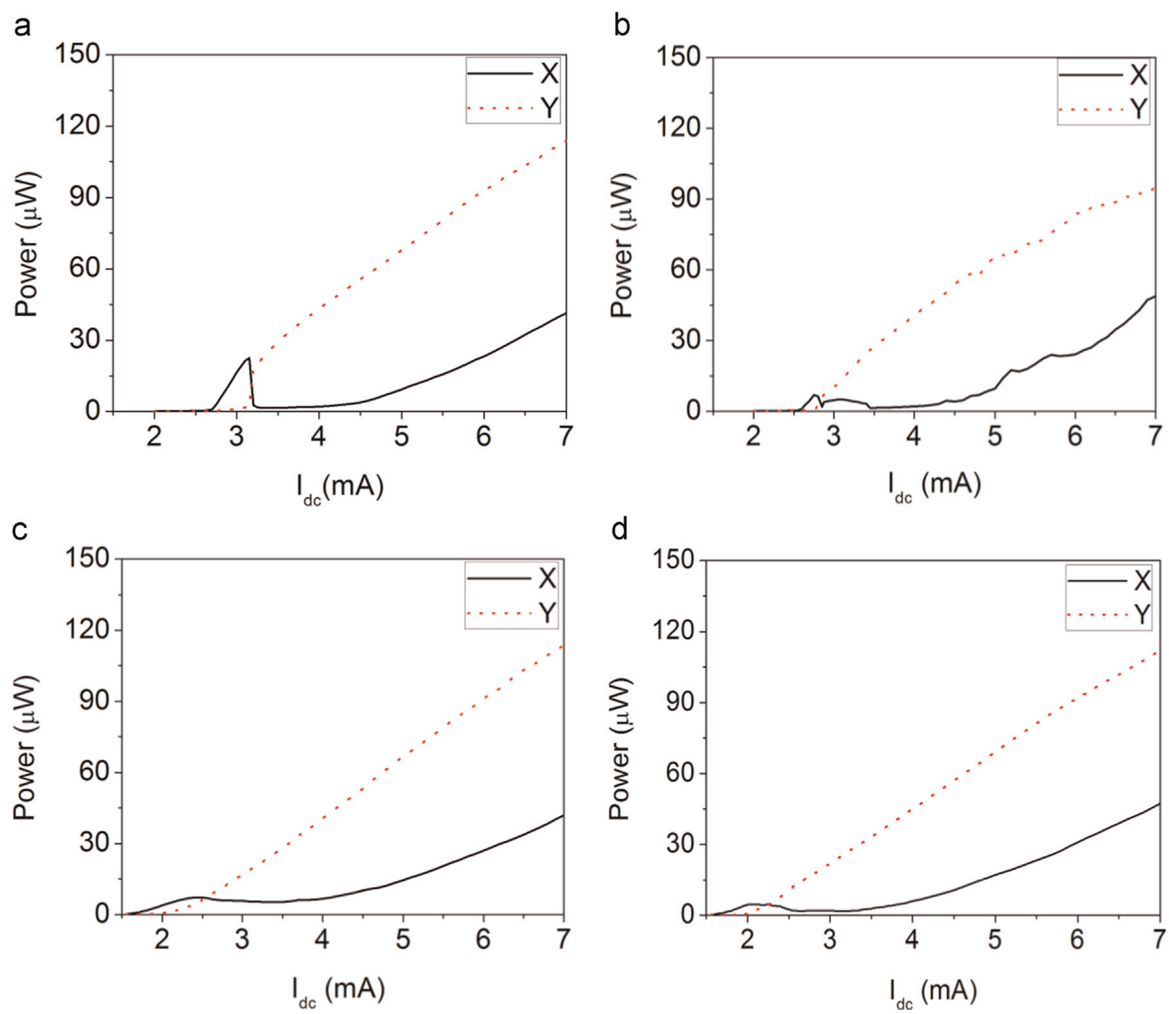

Fig. 2. Polarization resolved power versus dc bias current curves of (a) the solitary VCSEL, (b) the VCSEL subject to optical feedback, (c) the VCSEL subject to current modulation, and (d) the VCSEL subject to both optical feedback and current modulation. The experimental parameters are I_{dc}=5.5 mA, R_{ext}=17.1%, L=57 cm, I_m=2.0 mA, and f_m=100 MHz.