Opt Quant Electron (2009) 41:531–537
DOI 10.1007/s11082-009-9354-6

Improving the stability of distributed-feedback tapered master-oscillator power-amplifiers

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Received: 29 September 2009 / Accepted: 11 December 2009 / Published online: 6 January 2010

Abstract We report theoretical results on the wavelength stabilization in distributed-feedback master-oscillator power-amplifiers which are compact semiconductor laser devices capable of emitting a high brilliance beam at an optical power of several Watts. Based on a travelling wave equation model, we calculate emitted optical power and spectral maps in dependence on the pump of the power amplifier. We show that a proper choice of the Bragg grating type and coupling coefficient allows optimization of the laser operation, such that the laser emits a high intensity continuous wave beam for a wide range of injection currents.

Keywords High power lasers · DFB MOPA · Coupling coefficient · Continuous wave

Mathematics Subject Classification (2000) 35Q60 · 35B30

1 Introduction

During recent years, compact semiconductor lasers emitting single-frequency, diffraction limited continuous-wave (CW) beams at an optical power of several Watts have received considerable attention. Such lasers are required for many applications, e.g. frequency

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conversion (Fiebig et al. 2009; Jensen et al. 2009), laser display technology (Hollemann et al. 2001), and pumping of fiber lasers and amplifiers (Thomas et al. 2009). A device which is capable of maintaining a good beam quality and wavelength stability in the Watt range is the monolithically integrated master-oscillator (MO) power-amplifier (PA), where either a distributed Bragg reflector (DBR) (Wenzel et al. 2007) or a distributed feedback (DFB) (Spreemann et al. 2009) laser and a flared (or tapered) gain-region amplifier are combined on a single chip. Several groups presented such high-power systems (Schwertfeger et al. 2006; Chi et al. 2005) based on tapered laser devices (Sumpf et al. 2009) which promise a good beam quality and high output power at the same time. The narrow waveguiding MO part is responsible for the selection of a single lateral lasing mode, which is strongly amplified in the tapered PA part of the device. MOPA lasers are characterized by a large amount of structural and geometrical design parameters, and are subject to time-space instabilities like pulsations, self-focusing, filamentation and thermal lensing, which yield restrictions on output power, beam quality and wavelength stability. In many cases, changes in operating conditions (e.g. injection currents) of these devices imply destabilization of the desired continuous wave (CW) beams with a consequent occurrence of various dynamical states. To simulate the dynamics of MOPA devices, we apply a $2+1$-dimensional partial differential equation model based on the traveling wave (TW) equations for the complex slowly varying envelopes of the counter-propagating optical fields: see Spreemann et al. (2009), Radziunas et al. (2009), where a good qualitative agreement between experiments and simulations is demonstrated.

In the present paper, we consider the impact of the Bragg grating design on the dynamic performance of the DFB MOPAs discussed in Spreemann et al. (2009), Radziunas et al. (2009) with respect to the injection current in the PA part of the laser. We show that an increase of the coupling coefficient κ of a uniform Bragg grating allows stable CW emission without previously observed dynamic instabilities over a wide range of injection currents. We also show that improved wavelength selectivity and stabilization can be realized by introducing a quarter-wavelength ($\lambda/4$) shift into the grating of the MO DFB laser.

The paper is organized as follows. The device structure and mathematical model are described in Sect. 2. Section 3 discusses the wavelength stabilization of the MOPA device by selecting different coupling coefficients and the Bragg grating type. Conclusions are given in Sect. 4.

2 Laser structure and mathematical model

A schematic representation of a DFB MOPA device is given in Fig. 1. It consists of an index-guided DFB ridge-waveguide laser and a gain-guided tapered amplifier combined on a single chip. Both facets are anti-reflection coated with a residual reflectivity of $R \approx 10^{-3}$. This small reflectivity at the front (PA) facet has been shown to generate multiple compound cavity modes. The latter give rise to mode transitions and possible dynamical instabilities when the injection currents into the PA or MO are tuned (Spreemann et al. 2009; Radziunas et al. 2009).

To simulate the dynamics of the MOPA device we use a traveling wave model (Spreemann et al. 2009; Egan et al. 1998; Balsamo et al. 1996) based on the 2+1-dimensional TW equations for the complex slowly varying amplitudes of the counter-propagating optical fields $u^{\pm}$:

$$\frac{1}{v_g}\partial_t u^{\pm} = \frac{-i}{2k_0\bar{n}}\partial_{xx} u^{\pm} + (\mp\partial_z - i\beta(z, x, N, J))\, u^{\pm} - i\kappa(z, x)u^{\mp} + F_{sp}^{\pm},$$