

# Spectral stabilization of laser diodes by external Bragg resonator

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**Abstract:** Volume Bragg laser (VOBLA) with feedback produced by a reflective photo-thermo-refractive volume Bragg grating is used for narrowing spectral width and angular divergence of laser diodes. High-efficient, single mode and spectral width of 60 pm at power of 800 mW are demonstrated from 35 and 100  $\mu\text{m}$ -stripe laser.

The problem of high-brightness, high-efficient semiconductor laser sources with stable narrow emission spectra is important for different kinds of applications. Various constructions of external resonators for laser diodes (LD) were proposed and investigated, but up to now no successful commercial product resulted from those researches. First of all, no diffraction limited single lobe emission was obtained for external cavity semiconductor lasers under high pumping current [1-5]. The other reason restraining external cavity applications is an additional number of optical elements, which should be aligned with very high accuracy. Application of novel photo-thermo-refractive (PTR) glass Volume Bragg Laser (VOBLA) concept to semiconductor lasers allows simplifying an external cavity construction and obtaining narrow spectrum and near-diffraction limited divergence laser beam with no losses of original efficiency of LD.

A conventional method for selection of a single transverse mode with narrow emission spectrum is increasing of the aspect ratio (length/aperture) of a resonator by placing an aperture to provide a single Fresnel zone on a wavelength selective feedback element. Actually, this diaphragm in geometrical space means limiting of a maximum angle of light propagation in a resonator. Volume Bragg gratings because of their strong angular selectivity provide selection directly in space of wave vectors. In other words, transmitting and reflecting volume Bragg gratings serve as a slit and a diaphragm in angular space, respectively. It is important that both of them provide additional spectral selectivity. The current level of PTR-glass technology enables fabrication of transmitting and reflective volume gratings with angular selectivity better than 0.1 and 10 mrad, respectively in spectral region from 400 to 2700 nm [6, 7]. High diffraction efficiency (better than 95%) of PTR-glass Bragg-grating, low intrinsic losses (below 2%) and high optical damage threshold (more than 100 kW/cm<sup>2</sup>) create opportunity for replacement the space and wavelength selective elements and mirrors in the laser cavity by a single volume Bragg grating.

Spectral stabilization and narrowing is a particular case of using of PTR-glass VOBLA concept. Angle selectivity of volume Bragg grating does not play a significant role for this task; and experimental situation is similar to spectral stabilization of LD by fiber Bragg grating. In Ref. [8], spectral stabilization with positioning within 0.2 nm in 35 K temperature range was obtained for a single mode LD. High-selective transmitting volume Bragg grating used in this work allowed producing optimization of LD efficiency and wavelength tuning in the region of 6 to 7 nm simultaneously. Reflecting Bragg grating in inorganic glass was used for thermo stabilization of laser bar in the range from 20 to 55°C [9]. Origin and laser stability of a photosensitive material used in Ref. [9] is not clear.

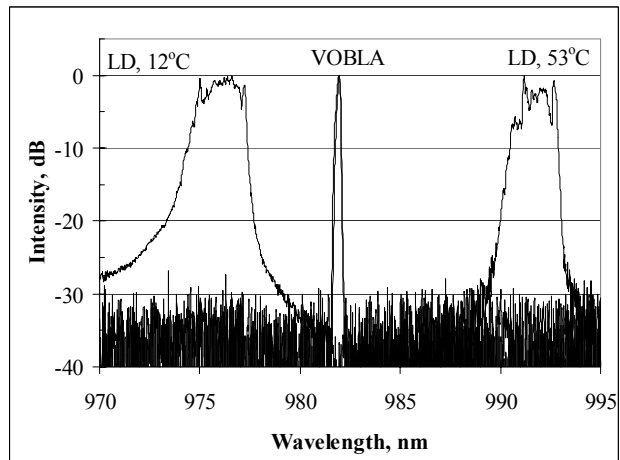


Fig. 1 Normalized spectra of 2W 100- $\mu\text{m}$  stripe Al-free free running LD and volume Bragg laser at different temperatures.

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In this work, 0.5 nm spectral width and 10 dB spectral side mode suppression were demonstrated for an optical design with Bragg grating, located in a beam collimated along the fast axis only.

To provide proper selection of transverse and longitudinal modes, we produced adjustment of angular and spectral parameters of emitters and volume Bragg gratings by means of different types of collimating optics. Collimation of radiation with divergence significantly narrower compare to angular selectivity of Bragg mirror was used for spectral stabilization. Projection of front facet with variable magnification was used to obtain both narrow-line and diffraction limited LD emission.

For demonstration of spectral narrowing and stabilization, we used aluminum-free 2W laser diodes, produced by Alfalight Inc, having 100  $\mu\text{m}$  stripe and 5% AR-coating of output mirror. In Fig. 1 normalized spectra for these lasers are presented with and without grating feedback for two temperatures. One can see that volume Bragg-grating feedback eliminates resonance frequency of LD and suppresses other wavelength with efficiency better than 33 dB. Emission spectrum of LD in external Bragg cavity was narrowed down to 45 pm and stabilized in 0.1 nm spectral region for temperature variation from 12 to 53 C. Efficiency of stabilized VOBLA was 83% in comparison with free running LD measured in the same geometry. This relatively low efficiency resulted from high reflection coefficient of the front facet which had to be replaced by external feedback.

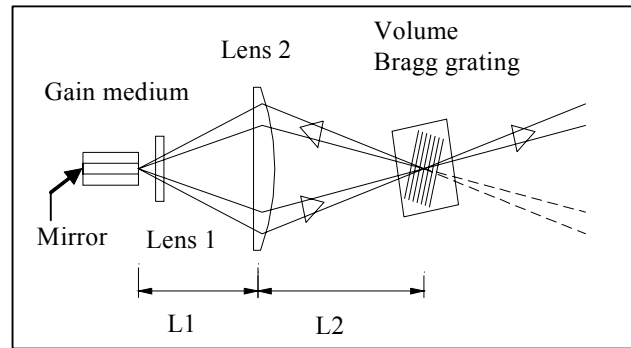


Fig. 2. Volume Bragg laser with total reflecting gratins as a resonant output coupler. Magnification by cylindrical lenses provides adjustment between angular selectivity of the Bragg mirror and angular divergence of the selected mode.

For demonstration narrow spectral line near-diffraction limited LD emission we have chosen external LD cavity laser geometry similar geometry proposed in 1987 [1,2]. This technique is one of the most successful approaches, as it allows separating modes that is preferable naturally for broad-area LD. Due to high angle selectivity Bragg-grating can replace very efficiently thin stripe mirror used in this off-axis resonator schema. Optical design of VOBLA used for obtaining near-diffraction limited LD emission is shown in Fig. 2. A 35- $\mu\text{m}$ -stripe LD had AR-coating at the front facet with reflection less than 0.5%. Its radiation is collimated along the fast axis and focused with magnification along the slow axis. As for wide-stripe LD dominant modes manifest off-axis emission with two main lobes, a reflecting Bragg mirror was placed in the plane of image and aligned for back reflection of one of the main lobes of a most intensive mode. This Bragg mirror had central wavelength of 960.9 nm, spectral width FWHM=380 pm and angular selectivity FWHM=3.1°. Effective selection of the single mode was provided by angular selectivity of the Bragg mirror and appropriate magnification of the optical system.

In the considered configuration, spectral behavior of LD is the same as for LD with volume Bragg grating feedback, located in collimated beam. Emission spectrum of VOBLA with 0.5% reflection from the LD front facet had width of 65 pm and was similar to than shown in Fig. 3. Maximum spectral brightness of VOBLA was about 40 times higher than that of the free running LD. One more advantage of an efficient AR-coating is extension of the range of thermal stabilization within 0.1 nm up to 75°C at least (Fig. 3).

It is important that angular selectivity of the feedback provided by the Bragg grating in optical setup with magnification of 1.4 resulted in narrowing of the angular divergence to the diffraction limit with

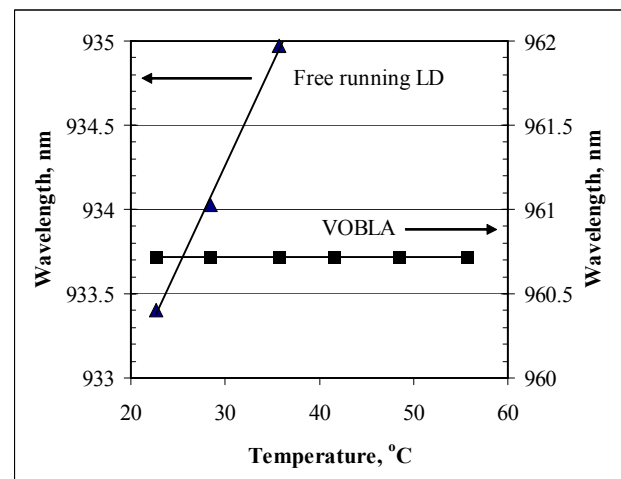


Fig. 3. Dependence of central wavelength on temperature for the free running laser diode and the semiconductor volume Bragg laser.

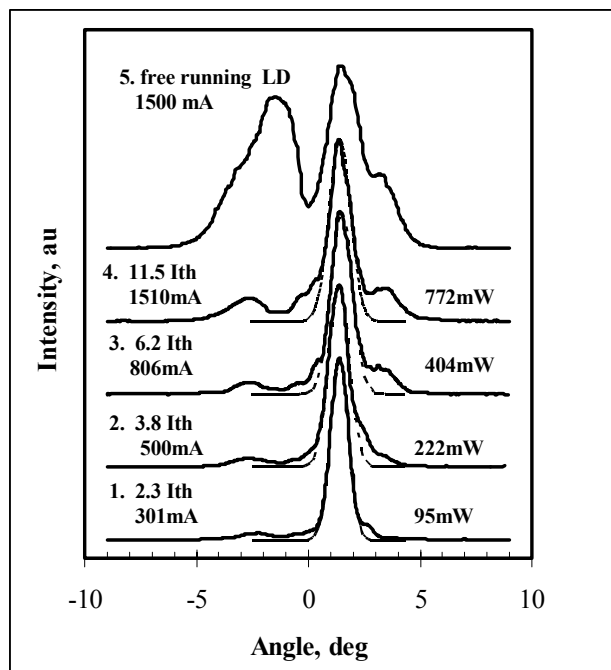


Fig. 4. Far field pattern for VOBLa with the reflective grating (curves 1-4), and for free running LD. Thin lines show diffraction limited divergence.

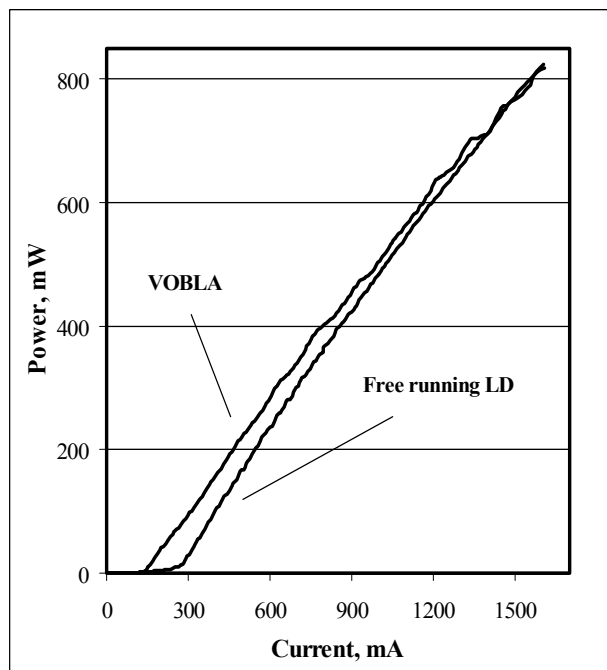


Fig. 5. CW light-current characteristic for the free running laser diode and the semiconductor volume Bragg laser.

FWHM=1.14° (Fig. 4). Increasing of pumping up to 12 thresholds results in increasing of the background radiation but the single mode regime is controlled by PTR volume Bragg grating in the whole region. This means that LD with volume Bragg grating as an external resonator provides narrow-band diffraction limited radiation at high levels of pumping.

Output power versus pumping current is shown in Fig. 5 for VOBLa and free running LD in the same arrangement with detuned Bragg grating (Fig. 1). The grating feedback reduced threshold current by 1.9 times to 131 mA. Slope efficiency for VOBLa (0.62 W/A) is 94% of that for the free running LD. Absolute reduction of slope efficiency for about 25% compare to that in an original LD (0.90 W/A) is caused by losses in the 0.5 NA fast axis collimator and by Fresnel reflection of the used PTR grating that had no AR coating.

Wide-stripe semiconductor laser diodes with reflective PTR volume Bragg gratings as a coupling element in an external resonator provide narrowing of emission spectral down to tens of picometers, thermal stabilization of emission line within 100 pm for temperature increment up to 75 K, and narrowing of angular divergence down to diffraction limit.

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