# Operation of a single mode external-cavity laser diode array near 780 nm

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We have narrowed the spectral bandwidth of a commercial 2 W laser diode array to be less than 120 MHz near 780 nm. The external-cavity laser diode array system is a standard double-pass Littman–Metcalf configuration operating on a dominant single longitudinal mode. © *2002 American Institute of Physics.* [DOI: 10.1063/1.1516848]

## I. INTRODUCTION

Laser diodes[1,2] and laser diode arrays[3,4] (LDAs) find a wide range of applications in atomic physics due to their relative ease of operation, low cost, and compact size. High-powered LDAs, characterized by linewidths of approximately 2 nm, have been important in the production of samples of laser polarized $^{3}He$[4] and $^{129}Xe$[3], and we have shown the importance of narrowing LDA spectral output in an earlier paper.[3] The use of external cavities has been shown to significantly narrow the spectral profile for free running LDAs[3,5,6] and enhance the nuclear magnetization of $^{129}Xe$ samples for NMR, magnetic resonance imaging, and precision measurement symmetry studies. In these applications, narrowed spectral output does not require single mode operation, however a broad range of additional applications is possible with the spectral characteristics of a single mode laser. In this article we report improvements that have led to the operation of external cavity LDAs in a single dominant longitudinal mode with linewidth less than 120 MHz and power of 1 W or more. This development enables applications such as spectroscopy, laser cooling, and trapping, and production of Bose condensates with relatively inexpensive, high-powered, LDAs.

## II. TECHNIQUES

The external-cavity laser diode array (ECLDA), constructed in a standard double-pass Littman-Metcalf configuration,[7] is shown in Fig. 1. This is comparable to Ref. 3 with the following changes: (1) As shown in Fig. 2, light emitted from LDA is incident on the grating at a more grazing angle so that $\theta \approx 90°$ in order to increase the total number of grating lines, is required for narrow-band, used for feedback; (2) an antireflection (AR)-coated λ/2 plate isolates the laser polarization to be perpendicular to the grating grooves; (3) AR coating on the laser's front facet reduces the gain of the intrinsic LDA and increases stability by mitigating mode competition between the intrinsic laser and external cavity; (4) laser light is well collimated by the combined spherical and cylindrical lenses to approximately $7^0$ divergence over 3-m distance; and (5) the effective length of the double pass external cavity is about 44 cm, corresponding to a mode spacing of 341 MHz.

We used Coherent Semiconductor Group Model Number S-79-2000C lasers mounted in a C-block. Single emitter devices with $150\times2$ $\mu$m and $200\times2$ $\mu$m dimensions and 2-nm bandwidth at nominal power of 2 W were used. Since the angular spread of the intensity emitted from the rectangular region of the LDA is larger in the lateral dimension (parallel to the junction plane) than in the transverse dimension (perpendicular to the junction plane), a combined two-lens system is used to collimate the beam in both dimensions. The beam is first passed through an antireflection-coated aspheric lens, of focal length 2.7 mm, and then passed through a cylindrical lens with focal length of 10 cm. The collimated beam of about 3-mm diameter passes through a λ/2 plate and is coupled to the external cavity with a holographic diffraction grating, which serves as a frequency selective output coupler. A feedback mirror serves as a frequency-tuning element. The holographic grating has 2400 grooves/mm. The polarization of light was made perpendicular to the grooves of the grating by using a half wave plate. Nearly all of the grooves were illuminated to reach optimum diffraction efficiency of the output beam. The first order from the grating is reflected toward the feedback mirror, which in turn directs the desired wavelength back to the grating. The frequency of the external cavity is changed by tilting the feedback mirror with respect to the grating using a high-precision micrometer and piezoelectric element. The output beam is the zeroth-order specular reflection from the holographic grating and contained 60% of the free running power. Since the external cavity is very sensitive to back reflections of the output beam, an optical isolator is used for the output beam. The

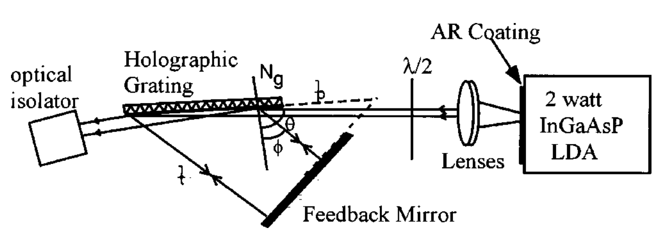


FIG. 1. Schematic diagram of the Littman–Metcalf configuration. In the laser tuning geometry; $\ell_t = 2.5$ cm, $\ell_p = 3.5$ cm, $L = 22$ cm ($L$ is the cavity length for single-pass) and $N_g$ is the normal to the grating.

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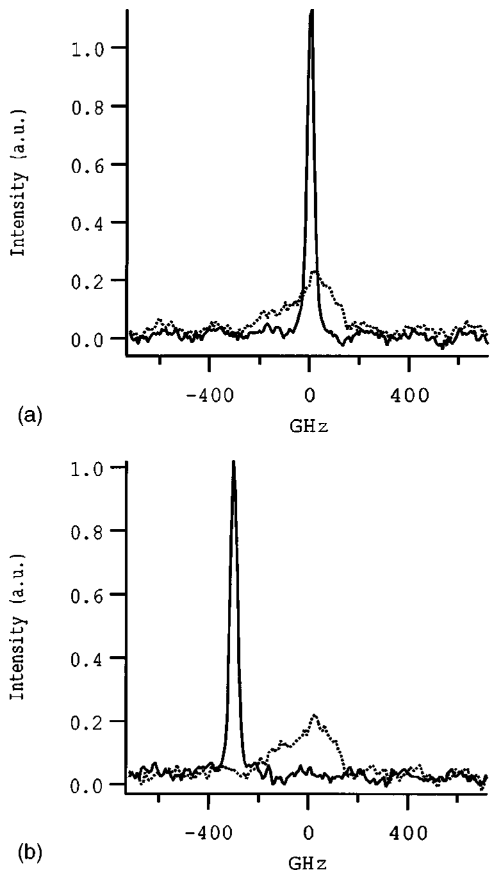


FIG. 2. ECLDA optical spectrum at $I=2$ A at room temperature with the free-running (dotted line) and with the optical feedback applied (solid line). (a) Shows the narrowed laser is on the center of the free-running frequency (top) and (b) shows the narrowed laser detuned by about 180 GHz from the center of the free-running frequency (bottom). The data are limited by the instrumental width of the spectrum analyzer.

LDA temperatures are thermoelectrically stabilized and held at approximately 25 °C at all times during the measurements.

The LDA's are antireflection coated to decouple the intrinsic laser from the external cavity.[8] We coated the front facet of our two high-power InGaAsP LDA with a single-layer silicon–oxide film (refractive index of 1.9) in order to reduce the gain of the intrinsic laser. We used a standard diffusion-pumped evaporator system at pressures of $1\times10^{-7}$ Torr. The threshold current was monitored, increasing from 0.47 A to a maximum of 0.7 A.

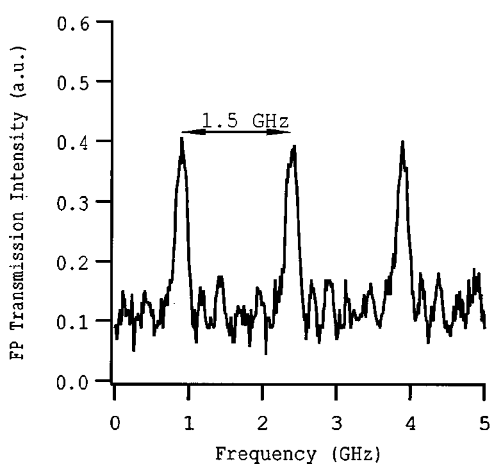


FIG. 3. Transmission intensity from scanning Fabry–Perot Interferometer with FSR 1.5 GHz and resolution 30 MHz. With optical feedback applied the FWHM = 120 MHz as shown.

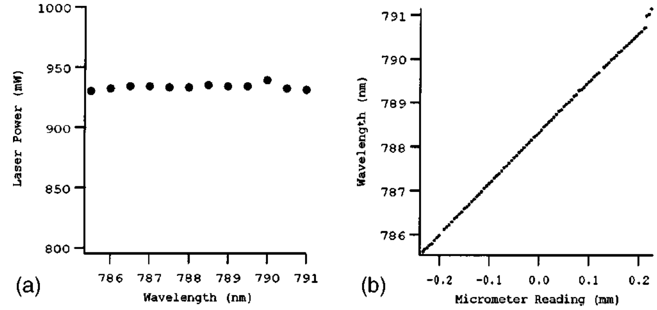


FIG. 4. The tuning curve of the external-cavity LDA after the coating: (a) Laser power with respect to the wavelength of the narrowed laser (left); (b) lasers accessible wavelengths with respect to micrometer reading (right).

## III. RESULTS

The spectra obtained from a 0.25-m spectrometer and a Fabry–Perot interferometer are shown in Figs. 2 and 3, respectively. A typical spectrum of the ECLDA for the narrowed and free-running lasers is shown in Fig. 2. The spectrum was obtained through the spectrometer with a linear (change-coupled device) array for real-time recording. Figure 2(a) shows the frequency of the external cavity laser tuned to the center frequency of the free-running laser, and Fig. 2(b) shows the frequency of the external cavity laser detuned from the center frequency of the free-running laser.

A precise calibration of the quality and the bandwidth of the laser was performed using a scanning Fabry–Perot etalon with 1.5 GHz FSR and 30 MHz resolution. The typical narrowed frequency spectrum is shown in Fig. 3. The spectral width of the ECLDA laser is about 120 MHz. The ECLDA is stable and tunable to wavelengths satisfying the Fabry–Perot condition $(2L=N\lambda)$ over a 5-nm range. For continuous broad tunability,[9] we would also require $Nd\lambda/d\phi=2dL/d\phi$, where $N$ is the longitudinal mode number and $L$ is the cavity length as shown in Fig. 1. The current configuration does not satisfy this condition; thus the laser does not smoothly tune in a single mode. In Figs. 4(a) and 4(b), we demonstrate the tuning curves of the narrowed portion of the 1 W ECLDA with dependence of wavelength and a micrometer reading, respectively. The wavelength measurements were done using a Burleigh wavemeter with precision of 0.001 nm. The ECLDA is extremely sensitive to acoustic and mechanical vibrations and may be improved with active stabilization and improved vibration isolation.

Coated lasers could be worked into the single mode operation with moderate effort. We were able to achieve single mode operation with an uncoated LDA, but did not observe similar stability or a broad tunability. We concluded that even though LDA operates at lower power after the coating, antireflection coating appears essential for stability and the broad range of accessible wavelengths shown in Fig. 4.

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