Electronically tunable external-cavity laser diode

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We present a new concept for an electronically tunable diode laser. It is based on an external-cavity configuration with simultaneous feedback and intracavity spatial separation of the laser's spectral components. The electronical tunability is achieved by insertion of a liquid-crystal array as an electronically controlled aperture into the region of spatial separation of the spectral components. Wavelength tunability without mechanical movement over a range of 10 nm and two-color operation are demonstrated with a 670-nm laser diode.

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Wavelength-tunable laser diodes have numerous applications in metrology and spectroscopy. Many attempts have been made to fabricate realize monolithic devices with spectral tunability; the C^3 laser,[1] tunable twin guide lasers,[2] Y lasers,[3] and tunable distributed feedback lasers[4] have been produced. However, none of them can compete with external-cavity arrangements in terms of tuning range and narrow linewidths, both of which are crucial for spectroscopy. Therefore external-cavity configurations are usually used for those applications. The most successful realizations of external-cavity laser diodes are the Littman[5] and the Littrow[6] configurations. In both cases the external cavity contains a diffraction grating that provides wavelength-selective feedback. Wavelength tuning is achieved by mechanical tilting of either the diffraction grating or a tuning mirror.

Littman and Littrow lasers are commercially available and widely used but suffer from important problems and limitations: First, wavelength tuning implies mechanical movement, which leads to wear and fundamentally restricts the tuning rate to the subkilohertz range. Second, feedback is given only for one wavelength, so multicolor synchronous operation is intrinsically impossible. Recently, a different external-cavity concept was used by Shi *et al*. that allows for synchronous multiwavelength operation of a picosecond diode laser for wavelength-division-multiplexing applications.[7] In this Letter we describe a purely electronically tunable laser diode based on a cavity configuration similar to that used by Shi *et al*.

The configuration of our electronically tunable external-cavity laser diode (ETECAL) is shown in Fig. 1. The external cavity consists of an antireflection-coated (AR) commercial 670-nm laser diode (LD), a collimator, a diffraction grating (2000 grooves/mm), an $f = 17.5$ cm lens, a liquid-crystal array (LCA), and a high-reflection end mirror. The output beam of the laser diode is collimated and sent onto the diffraction grating. The grating is placed such that its first diffraction order is directed toward the lens and that the distance between grating and lens equals the focal length of the lens. The high-reflection mirror is placed in the other focal plane of the lens, and the LCA is located directly in front of the mirror. The basic advantage of this cavity geometry is that without the LCA it provides simultaneous feedback for all spectral components of the laser diode while the spectral components are spatially separated in the cavity. This spatial separation enables us to introduce the LCA as an electronically controllable aperture to select feedback for the various spectral components, which can be independently switched on and off. This configuration permits both tuning of the emission wavelength and operation of the laser at various wavelengths simultaneously.

First we study the wavelength tunability. We achieve wavelength tuning by making successive areas of the LCA transparent. Figure 2 shows a set of emission spectra with emission wavelengths between 665 and 676 nm. Our total tuning range is slightly less than that of commercial mechanically tuned systems because our cavity contains more optical components and thus suffers slightly higher losses. The tuning rate in our case is limited by the speed of the LCA in the kilohertz range. But we stress that this is no intrinsic limit. Switching rates in the megahertz range can be obtained when faster electronically controlled

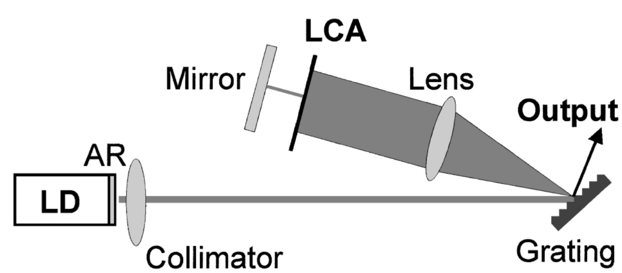

Fig. 1. Schematic depiction of the ETECAL setup.

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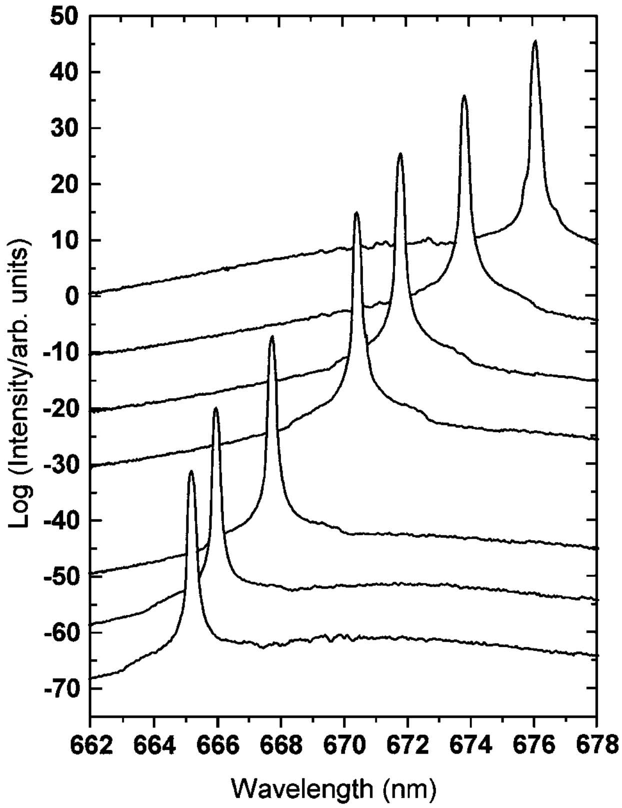

Fig. 2. Spectra of ETECAL emission for several settings of the LCA. The traces have been vertically offset.

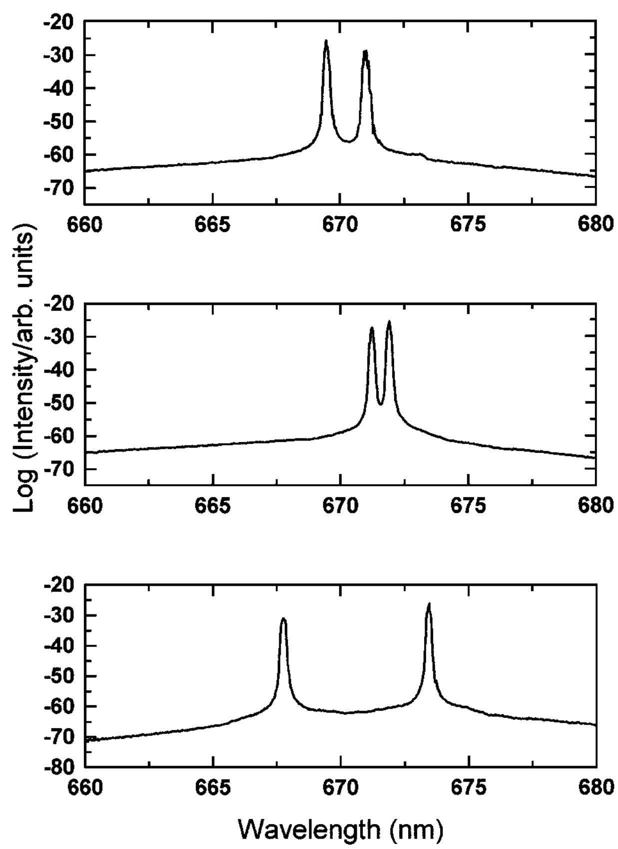

Fig. 3. Three emission spectra of the ETECAL with dual-color operation.

apertures such as semiconductor electroabsorption modulators[8] are used. The linewidth of our laser was measured with a Fabry–Perot interferometer to be smaller than 30 MHz (i.e., the resolution of the interferometer) with a side-mode suppression of better than 10 dB.

Second, the possibility of multicolor synchronous operation is one of the great advantages of the ETECAL. Figure 3 shows three emission spectra with the LCA set to be transparent for two wavelengths. Dual emission is obtained at various spectral positions and with variable spacing between the emission modes. We confirmed that the laser operates at both wavelengths simultaneously by a combination of linewidth and time-resolved emission measurements: A broadening of the linewidth above 30 MHz would be expected if the laser were switching between the two modes on a time scale faster than approximately $(30\ \mathrm{MHz})^{-1} \approx 30$ ns. This broadening was not observed during dual-mode emission. In addition, our time-resolved emission measurements showed no indication of switching between the modes on a time scale slower than 10 ns. We thus conclude that we have achieved real (simultaneous) dual-mode emission, which is attractive for many applications, such as pump–probe spectroscopy and difference-frequency generation in the terahertz regime.

Finally, we point out that the LCA also allows us to vary the losses at each position so there is no principal restriction for two-color and even multicolor operation.

In conclusion, we have suggested and realized a new concept for a purely electrically tunable external-cavity laser-diode. The configuration contains no mechanically movable parts. We have demonstrated with a 670-nm laser diode a spectral tunability of 11 nm and dual-color emission with variable spacing between the emission wavelengths. The linewidth of the ETECAL is below 30 MHz. Our concept for electro-optical wavelength tuning can easily be adapted to other laser systems such as Ti:sapphire lasers.

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