WDD3 (Contributed Oral)
4:15 PM – 4:30 PM

Optically Tunable Ring External-Cavity Laser

J. Zheng[1], C. Ge[1], C. J. Wagner[1], L. Meng[2], B. T. Cunningham[1], and J. G. Eden[1]
[1]Department of Electrical and Computer Engineering
University of Illinois at Urbana-Champaign
Urbana, IL 61801
[2]SRU Biosystems, Inc.
Woburn, MA 01801

***Abstract*—We have demonstrated a tunable external cavity ring laser, in which the lasing wavelength can be controlled by external illumination that excites a nonlinear dye within a photonic crystal resonant reflector.**

I. INTRODUCTION

Tunable external cavity diode lasers have generated considerable interest in optical communications, atomic laser spectroscopy, and environmental monitoring, since the introduction of the first external cavity diode laser (ECL) in 1964 [1] and the first tunable systems shortly thereafter [2]. While conventional tunable lasers usually involve a mechanical stage either for rotating the diffraction grating, stretching a Fiber Bragg Grating (FBG), or adjusting the cavity length of an etalon, they are often complex, difficult to assemble, and sensitive to vibration. Recently, surface photonic crystals (SPC) with efficient narrow-band reflection, wide tunability range, and inherently compact structure, have been investigated and have found application as biosensors and optical resonant filters. Surface photonic crystals are especially attractive as the wavelength selective element of ECLs, because the resonant modes can be tuned by electrical or optical means.

In 2003, Chang et al. reported an electrically tunable ECL in the telecommunication wavelength range (1550 nm) with a liquid-crystal, subwavelength resonant grating filter as the wavelength selective element [3]. Here, we report the design, fabrication, and characterization of the first, optically-tunable external cavity laser employing a surface photonic crystal resonant reflectance filter that incorporates an optically active polymer (azobenzene N-ethyl-N-(2-hydroxyethyl)-4-(4-nitrophenylazo) aniline - also known as DR1). This arrangement combines the selectivity of the photonic crystal passive resonator with the resolution afforded by an external cavity.

Our SPC-ECL employs a fiber ring configuration with the SPC as the only wavelength selective element. A semiconductor optical amplifier (SOA) with an AR coating ($R=10^{-3}$) on both facets is used as the gain medium. The combination of the SOA and the ring cavity configuration improves the side mode suppression, and singularizes the wavelength selection effect of the SPC by reducing nonresonant reflections. Working in normal incidence mode, the SPC reflects by 180° the resonant light back into the gain medium. Control of the SPC resonant wavelength is realized by adjusting the refractive index of the nonlinear azobenzene molecules through optical excitation. As a result of absorbing a photon, the azobenzene molecule is excited from the lower energy trans state to the excited cis state. Since the cis state is bent and is compacted relative to ground, the transition from trans to cis state results in a decrease in the optical density of the molecule.

II. DEVICE FABRICATION AND EXPERIMENTAL SETUP

A cross-sectional diagram of the surface photonic crystal resonant reflectance filter incorporating a superstate layer of azobenzene-doped isopropyl alchohol (IPA) is shown in Figure 1. The substrate is a flexible and transparent polyethylene terephthalate (PET) film. The PC grating is formed in a layer of low refractive index (n=1.46), ultraviolet (UV) curable polymer by a replica molding technique. Following grating replication, a layer of titanium dixoide (TiO_2) (n=2.35) is evaporated over the grating. The active layer (5% DR1 in IPA) was subsequently spun on, covered by a microscope slide and sealed around the edges of the slide. The resonant wavelength is determined by the period of the PC grating (Λ=550 nm), the step height of the grating (h_{PC}=170 nm), the TiO_2 thickness (h_{TiO_2}=120 nm), and the refractive index of the DR1 doped IPA.

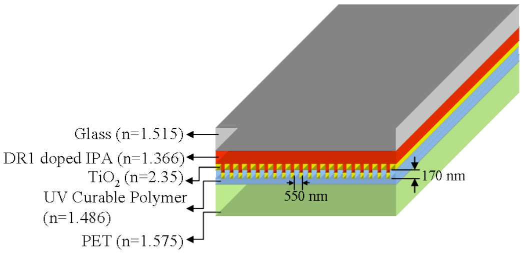

Fig. 1. Schematic diagram of the cross section of the surface photonic crystal resonant reflectance filter incorporating a superstate layer of DR1-doped isopropyl alcohol.

Figure 2 is a diagram of the layout of the optically tunable ring external-cavity laser. A 850 nm band SOA is employed to provide the optical gain, with a center wavelength of 843 nm and a full-width-half-maximum (FWHM) of ∼10 nm. The amplified spontaneous emission (ASE) from the SOA enters the isolator, and then travels to port 1 of a 50:50 coupler. Half of the power exits port 3, passes through a polarizer, and impinges onto the surface of the photonic crystal grating incorporating the DR1 molecule. A continuous wave pump

978-1-4244-8939-8/11/$26.00 ©2011 IEEE

beam from a frequency doubled Nd:YVO$_4$ laser (532 nm) illuminates the device at an angle of 30°, which excites the DR1-IPA layer and modulates the peak reflection resonance of the PC, thus controlling the lasing wavelength. The reflected signal re-enters port 3 and half exits port 2, passes through the SOA and gets amplified, while the other half of the reflected signal enters port 1 and is blocked by the isolator. The light emission is picked up at port 4 by a single mode fiber with a core diameter of 11 μm connected to a high resolution (50 pm) spectrometer (Ando).

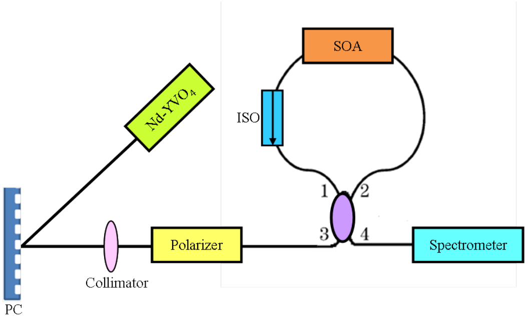

Fig. 2. Configuration of the optically tunable ring external-cavity laser.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The amplified spontaneous emission spectrum of the SOA, the reflection spectrum of the SPC filter, and the emission spectrum of the SPC-ECL laser at a driven current of 90 mA are shown together in Figure 3. The SPC filter exhibits a resonance peak with a 3-dB bandwidth of 1.84 nm, while the SPC-ECL laser emission was measured to be as narrow as 0.05 nm, which is limited by the resolution of the spectrometer. It should be pointed out that the 1 nm spaced ripples in the PC reflection spectrum are a product of the Fabro-Perot cavity formed by the PET substrate of the PC having a thickness of 0.25 mm.

The ECL generates single mode, continuous laser emission, and is tunable over a range of at least 6 nm under laser illumination, as illustrated in Figure 4. The tuning is achieved by optical excitation of the DR1 molecule from the trans state to cis state. It is clear from Figure 4 that, by varying the operating power of the pump beam up to 260 mW, the radiation peak shifts from 848.6 nm to 842.5 nm, and the corresponding FWHM of each peak was measured to be from 0.3 nm to 0.06 nm. All spectra in Figure 4 were obtained with a bias current of 190 mA, and similar tunability was achieved at other bias currents.

IV. CONCLUSION

In conclusion, an optically tunable ring external-cavity laser has been demonstrated for the first time, in which the lasing wavelength can be controlled with laser illumination through the incorporation of a nonlinear azobenzene dye-DR1. Photon excitation of the DR1 molecule from the trans state to cis state results a net decrease in the refractive index of the dye-doped region of the device, thus providing controlled tuning of the lasing wavelength. A tuning range of ∼6 nm was achieved with the pump beam of 260 mW, and the shift was totally reversible after the termination of the laser illumination. This system demonstrates an easy approach to obtain a tunable narrow linewidth output, and could have great potential in spectroscopy, biochemical assay, and optical communication.

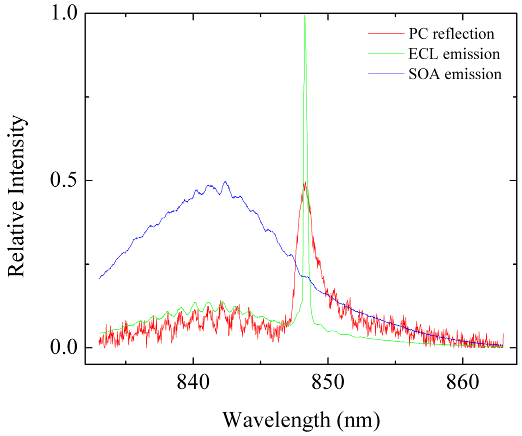

Fig. 3. Overlaid PC resonant reflection spectrum, ECL laser single mode emission spectrum, and the SOA gain spectrum at a driven current of 90 mA.

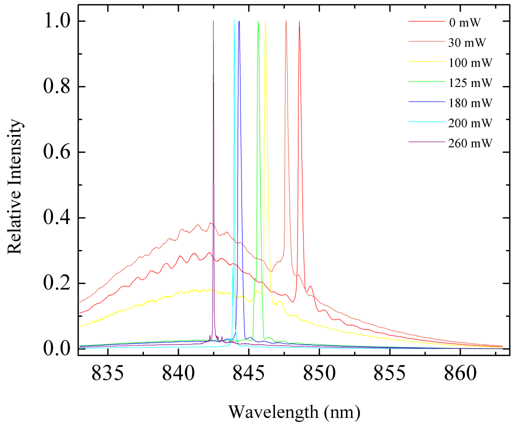

Fig. 4. Measured lasing spectrum of the mechanical-free optically tunable external cavity laser under different optical excitation.

REFERENCES

[1] J. W. Crowe and R. M. Craig, “GaAs laser linewidth measurements by heterodyne detection,” *Applied Physics Letters*, vol. 5, no. 4, pp. 72–74, 1964.

[2] R. Ludeke and E. P. HarriS, “Tunable GaAs laser in an external dispersive cavity,” *Applied Physics Letters*, vol. 20, no. 12, pp. 499–500, 1972.

[3] A. S. P. Chang, H. Tan, S. Bai, W. Wu, Z. Yu, and S. Y. Chou, “Tunable external cavity laser with a liquid-crystal subwavelength resonant grating filter as wavelength-selective mirror,” *IEEE Photonics Technology Letters*, vol. 19, no. 13-16, pp. 1099–1101, 2007.