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Broad-Band Wavelength Tunable Picosecond Pulses from CW Passively Mode-Locked Two-Section Multiple Quantum-Well Lasers

Thomas Schrans, Steve Sanders, and Amnon Yariv

Abstract—**Wavelength tunable CW passive mode-locking of a two-section quantum-well laser coupled to an external cavity is demonstrated. A tuning range of 26 nm is achieved with typical autocorrelation full widths at half maximum of 4.5 ps.**

WAVELENGTH tunable picosecond pulses have recently been demonstrated in semiconductor lasers, using external cavity active mode-locking [1]-[6]. Tuning ranges of 33 nm [3], 60 nm [4], [5], and 40 nm [6] were obtained at wavelengths of 0.82, 1.3, and 1.55 μm, respectively, and typical minimum emitted pulse widths were 10-20 ps reduced to as short as 3.7 ps by pulse compression [4]. Passive mode-locking of a semiconductor laser, using an external multiple-quantum-well (MQW) saturable absorber has resulted in subpicosecond deconvolved pulse widths after compression [7], [8], but the laser had to be tuned to a wavelength slightly longer than the excitonic absorption peak, thereby preventing broadly tunable passive mode-locking. More recently external cavity passive mode-locking of two-section MQW semiconductor lasers, incorporating a monolithically integrated saturable absorber and gain medium was demonstrated [9], [10]. Wavelength temperature tuning of a monolithic passively mode-locked CPM laser resulted in pulses shorter than 1.6 ps, tunable over 8.8 nm at 1.5 μm [11]. In this letter we report on broad wavelength tuning of a passively mode-locked two-section quantum well laser coupled to an external grating, resulting in a tuning range of 26 nm at 0.84 μm with a minimum autocorrelation full width at half maximum (FWHM) of 3.5 ps.

The laser used in this experiment is a two-section quadruple quantum well laser similar to the lasers used in previous passive mode-locking experiments [9], [10], with a high-reflectivity (HR) coating (90%) on the absorber section side, and an anti-reflection (AR) coating (< 5%) on the gain section side. The AR-coated facet of the laser is coupled to an external cavity terminated by a 600 lines/mm blazed grating mounted in Littrow configuration, as shown in Fig. 1. The beam is focused by a 40 × (0.65 NA) microscope objective on the grating, which can be rotated for tuning purposes. A 9% reflection pellicle beamsplitter (BS) placed at a 45° angle is used to couple the light out to an optical

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The authors are with the Department of Applied Physics 128-95, California Institute of Technology, Pasadena, CA 91125.

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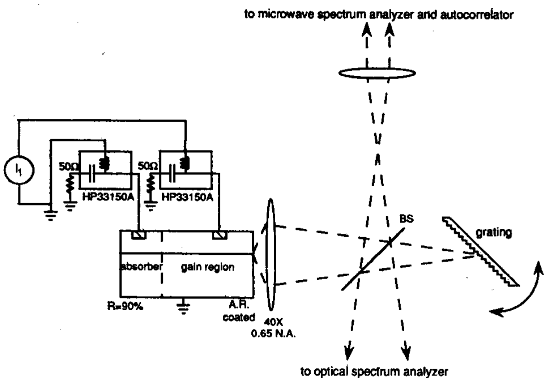

Fig. 1. Two-section laser passively mode-locked in external cavity with grating.

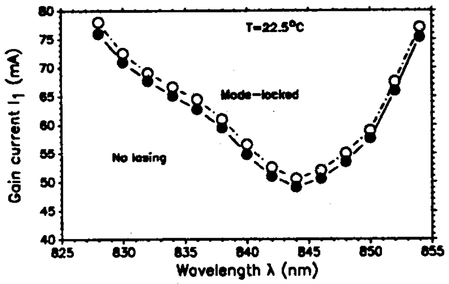

Fig. 2. Mode-locking range (solid line) as a function of gain current, I_1, and wavelength, λ. Autocorrelations and intensity spectrum measurements were performed at current and wavelength values indicated by dashed line.

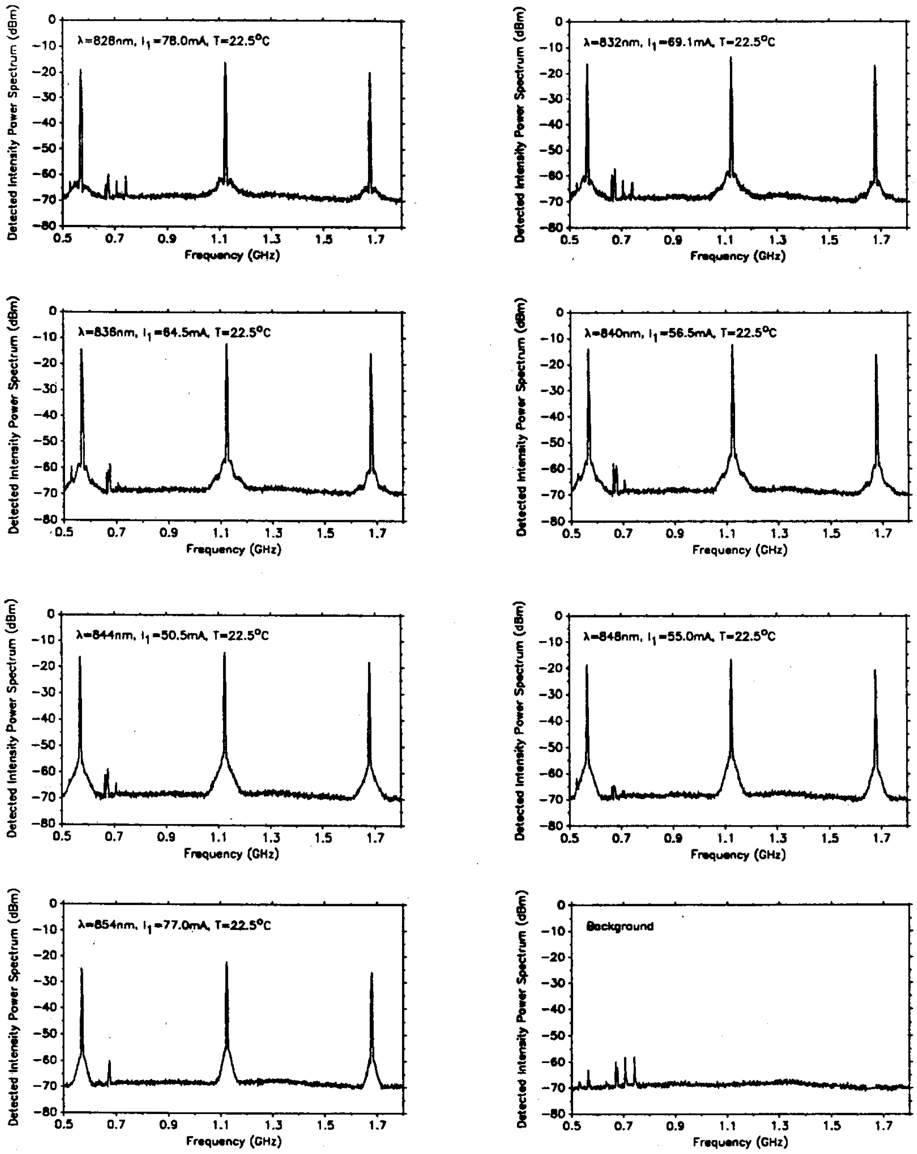

Fig. 3. Detected optical intensity power spectra at different gain currents and wavelengths as indicated.

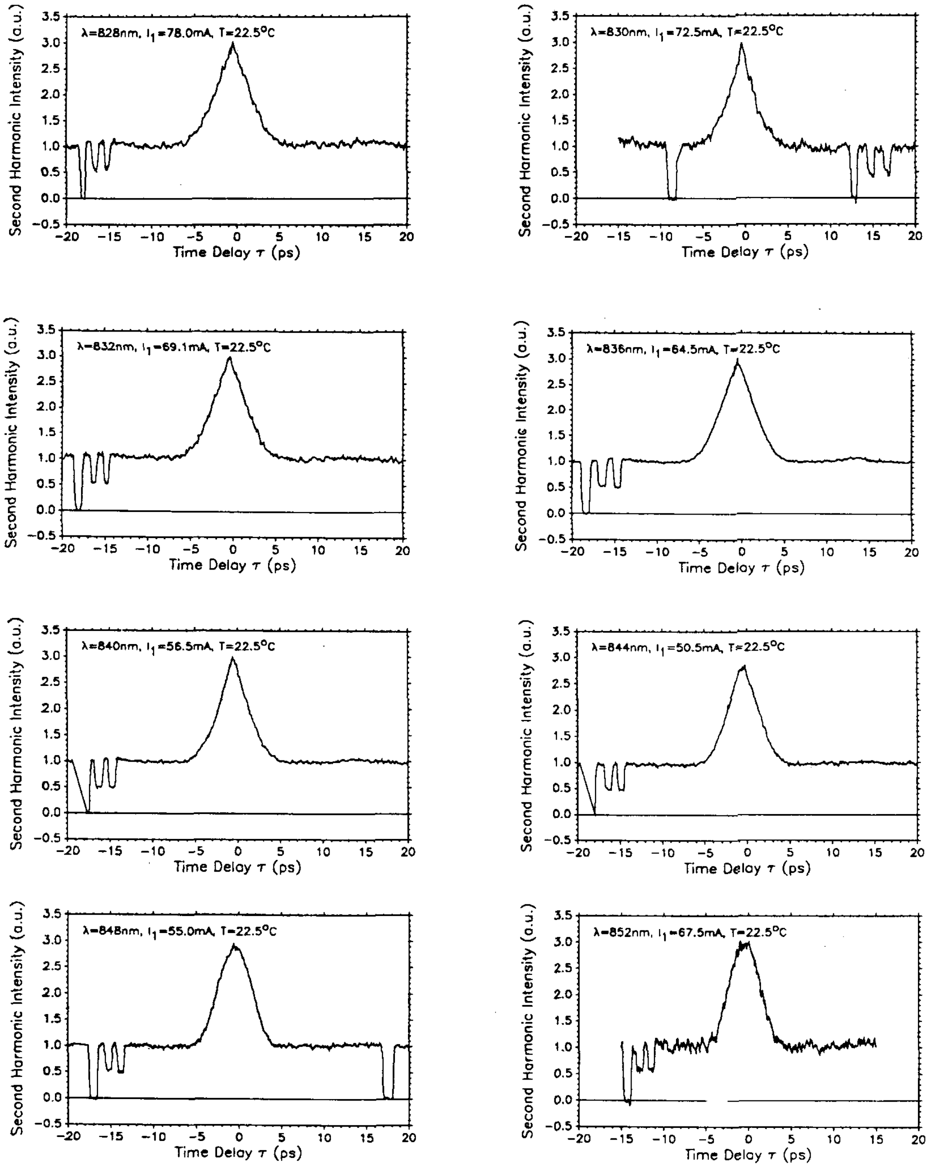

Fig. 4. Optical intensity autocorrelations at different gain currents and wavelengths as indicated.

grating spectrometer on one side, and to a second harmonic (SH) collinear intensity autocorrelator and a microwave spectrum analyzer on the other side. The laser package is mounted to an aluminum block, which remained at a temperature of 22.5°C ± 0.5°C during the experiment, and the gain section is pumped by a dc current source as shown in Fig. 1. The threshold current of the laser without external feedback and with the absorber floating is 42 mA.

Due to hysteresis in the L-I curve [9], and to avoid exposing the laser to high gain section currents, the laser is turned on with a floating absorber. After setting the gain current, I_1, to an appropriate value, the absorber is grounded, and the laser switches to mode-locked operation. By adjusting the current I_1, mode-locked operation at the first harmonic of the round-trip frequency is achieved [9]. The minimum current level for mode-locking as a function of the lasing wavelength is shown in Fig. 2. A tuning range of 26 nm is obtained.

The dashed line in Fig. 2 represents the current and wavelength values at which intensity autocorrelations and intensity power spectra were measured. The optical intensity power spectrum is measured from the photocurrent of an ~ 12 GHz bandwidth photodiode followed by a 0.5-4.5 GHz bandwidth amplifier. Intensity power spectra are shown in Fig. 3 for different wavelengths, together with a background measurement. The laser is mode-locked at 561 MHz,

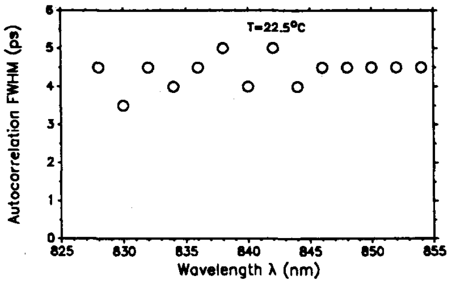

Fig. 5. Autocorrelation FWHM versus wavelength.

corresponding to the first harmonic of the round-trip frequency, and the signals at about 530 MHz and between 600 and 800 MHz are part of the background. At the longer wavelength edge of the tuning range the laser was less stable, resulting in larger noise spectra and turn off of the laser under external perturbation.

Fig. 4 shows SH optical intensity autocorrelations at different wavelengths, including background and single-beam SH intensity measurements. Due to the weak output coupling (9% from the beamsplitter), the energy per pulse was very low, resulting in a noisy autocorrelation measurement. The autocorrelation FWHM was therefore measured with an estimated error of 0.5 ps, and is shown in Fig. 5 as a function of wavelength. A minimum autocorrelation FWHM of 3.5 ps ± 0.5 ps is measured for a wavelength of 830 nm. The pulses are not transform limited and have a typical time-bandwidth product of 2.5, which is about eight times the transform limit for a hyperbolic secant pulse. Pulse compression may therefore be possible. It was observed that the pulse width and the spectral bandwidth tend to increase with increasing gain current, indicating a possible larger frequency chirp at higher pumping levels. At some wavelengths weak satellite pulses were observed, centered at a time delay τ of about 13 ps, corresponding to the round-trip time between the semiconductor facets. These satellite pulses are attributed to a residual reflection from the AR coated facet, but may be partially suppressed by the presence of the monolithically integrated saturable absorber.

In conclusion, we have demonstrated broad-band wavelength tuning of a passively mode-locked semiconductor laser, with a tuning range of 26 nm and typical autocorrelation FWHM of 4.5 ps. The pulses are not transform limited, having a typical time-bandwidth product of 2.5.

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