Wavelength switching using multicavity semiconductor laser diodes

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Abstract

We demonstrate wavelength switching in a novel multicavity distributed Bragg reflector semiconductor laser diode. This new device, which uses an integrated saturable absorber and single-mode fiber Bragg gratings, digitally switches wavelength as a function of drive current between all possible binary combinations.

Studies of photon cavity formation in external cavity Fabry-Perot laser diodes [1-3] inspired us to consider the possibility of creating new laser devices which exhibit greater levels of functionality than presently available. In this letter, we report results of initial experimental work which demonstrate digital wavelength switching and mode-locked repetition rate switching using a laser diode with integrated saturable absorber and external optical feedback from Bragg gratings embedded in a single-mode fiber. In contrast to previous work (for example Ref. 4-7) wavelength selection is digital in nature and the use of Bragg grating defined wavelengths is intrinsically temperature insensitive.

The laser diode used for these experiments is a 500 μm long InGaAs/InP buried heterostructure four quantum well device with an integrated saturable absorber (Ref. 8 gives details of diode structure and fabrication). The series resistance between the 12 μm long saturable absorber and the laser gain section is 500 Ω. The as-cleaved device lases at $\lambda = 1548$ nm wavelength with a threshold current of $I_{gain}(th) = 19$ mA. The threshold current of the laser after anti-reflection (AR) coating one mirror facet is greater than 100 mA. As illustrated in Fig. 1(a), optical feedback is provided by coupling emission from the AR coated facet into a single-mode fiber in which is embedded two discrete Bragg gratings [9]. The 2 mm long Bragg gratings have a peak reflectivity of 95% and are centered at wavelengths $\lambda_1 = 1524.6$ nm and $\lambda_2 = 1529.9$ nm with a -3 dB full-width optical bandwidth of 0.190 nm and 0.242 nm respectively. The coupling efficiency between emission from the laser and the single-mode lensed fiber is 0.42.

Fig. 1(a) shows results of measuring the light versus gain-section current (L-I_{gain}) characteristic of the laser in an external cavity for different saturable absorber voltage levels. Note the region of negative slope (dL/dI_{gain}). Fig. 1(b) shows the measured optical spectrum of the laser at different bias points of the L-I_{gain} with the saturable absorber biased at V_{sat} = 0.80 V. It is evident from the optical spectra that wavelength switching, between all four binary combinations, with a discrimination of at least -30 dB is possible using this arrangement.

When biased to the peak of the L-I_{gain} characteristic, laser light intensity pulsates at frequencies corresponding to photon cavity round-trip times defined by the two gratings. The cavity round-trip time for photons of wavelength λ_1 is τ_1 = 1.7 ns corresponding to a frequency of f_1 = 580 MHz. The cavity round-trip time for photons of wavelength λ_2 is τ_2 = 1.5 ns corresponding to a frequency of f_2 = 670 MHz. Fig. 2(a) shows the measured radio frequency (RF) spectrum of the light output at different bias points on the L-I_{gain} curve shown in Fig. 1(a). Wavelength λ_1 = 1524.6 nm has RF spectral content at frequency f_1 = 580 MHz and its higher harmonics. Similarly, wavelength λ_2= 1529.9 nm has RF spectral content at frequency f_2 = 670 MHz and its higher harmonics. Lasing light output pulsates at the cavity round-trip time because the effective loss seen by the photons decreases if the photons travel through the saturable absorber in pulses [10]. As shown in Fig. 2(b), the measured time-domain emission intensity at wavelengths λ_1 and λ_2 exhibit peaks corresponding to the photon cavity round-trip times for the two wavelengths.

A possible explanation for the L-I_{gain} characteristic is the dynamic coupling between the pulses at the two wavelengths. As the cavity round trip times are in the ns range optically generated carriers do not fully relax to their equilibrium distribution in the absence of the optical pulses. Consequently, the time average saturable absorber carrier density, n_{sat}, changes with light intensity. Adjusting the L-I_{gain} bias points from position 1 to 2 in Fig. 1(a) causes n_{sat} to increase due to light induced generation of carriers in the saturable absorber as well as leakage current from the gain section to the saturable absorber. With increase in n_{sat} the net absorption of photons at wavelengths λ_1 and λ_2 in the saturable absorber changes. Net absorption at wavelength λ_2 decreases more rapidly than at λ_1 so that light intensity at λ_2 increases with I_{gain}. Light emission at the two Bragg grating defined wavelengths pulsate through the gain section at their respective Bragg grating defined cavity round-trip times. The light pulses deplete the gain medium as they pass through it. Pulses at one wavelength decrease the effective gain seen by pulses at the other wavelength. Increasing I_{gain} from bias point 2, the intensity of pulses at wavelength λ_1 starts to decrease due to this competition for dynamic gain between the two wavelengths. Further work is needed to obtain a more complete explanation for the observed L-I_{gain} characteristic.

In this letter we reported results of a novel scheme to digitally switch lasing optical wavelength. The new device uses a hybrid multicavity distributed fiber Bragg grating and a semiconductor laser diode with integrated saturable absorber. The device has potential application in wavelength division multiplexing and optically controlled phase array radar which require fast wavelength switching between precisely defined optical wavelengths. Our experimental arrangement is also a convenient means to study of the physics of mode competition and transient photon cavity response in semiconductor lasers.

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Figure Captions:

Figure 1. (a) Measured L-I_{gain} characteristics of the laser with saturable absorber biased at V_{sat} = 1 V, 0.8 V, and 0.78 V. Inset shows a schematic of the laser in an external cavity. Optical feedback is provided by two discrete Bragg gratings embedded in a single-mode fiber. The 2 mm long Bragg gratings have a peak reflectivity of 95% and are centered at wavelengths λ_1 = 1524.6 nm and λ_2 = 1529.9 nm with an -3dB optical bandwidth of 0.190 nm and 0.242 nm respectively. (b) Measured optical emission spectra at indicated bias points on the L-I_{gain} curve with V_{sat} = 0.8 V. Spectrometer resolution is 0.1 nm.

Figure 2. (a) Measured RF spectra of light output at various points on the laser's L-I_{gain} (V_{sat} = 0.8V) indicated in Fig. 1(a). There is a one-to-one correspondence between the wavelengths present in the light output and the peaks in the RF spectra. (b) Measured self-pulsation emission at wavelengths λ_1 and λ_2. The laser gain section is biased at the indicated values and the saturable absorber is biased at V_{sat} = 0.95 V.

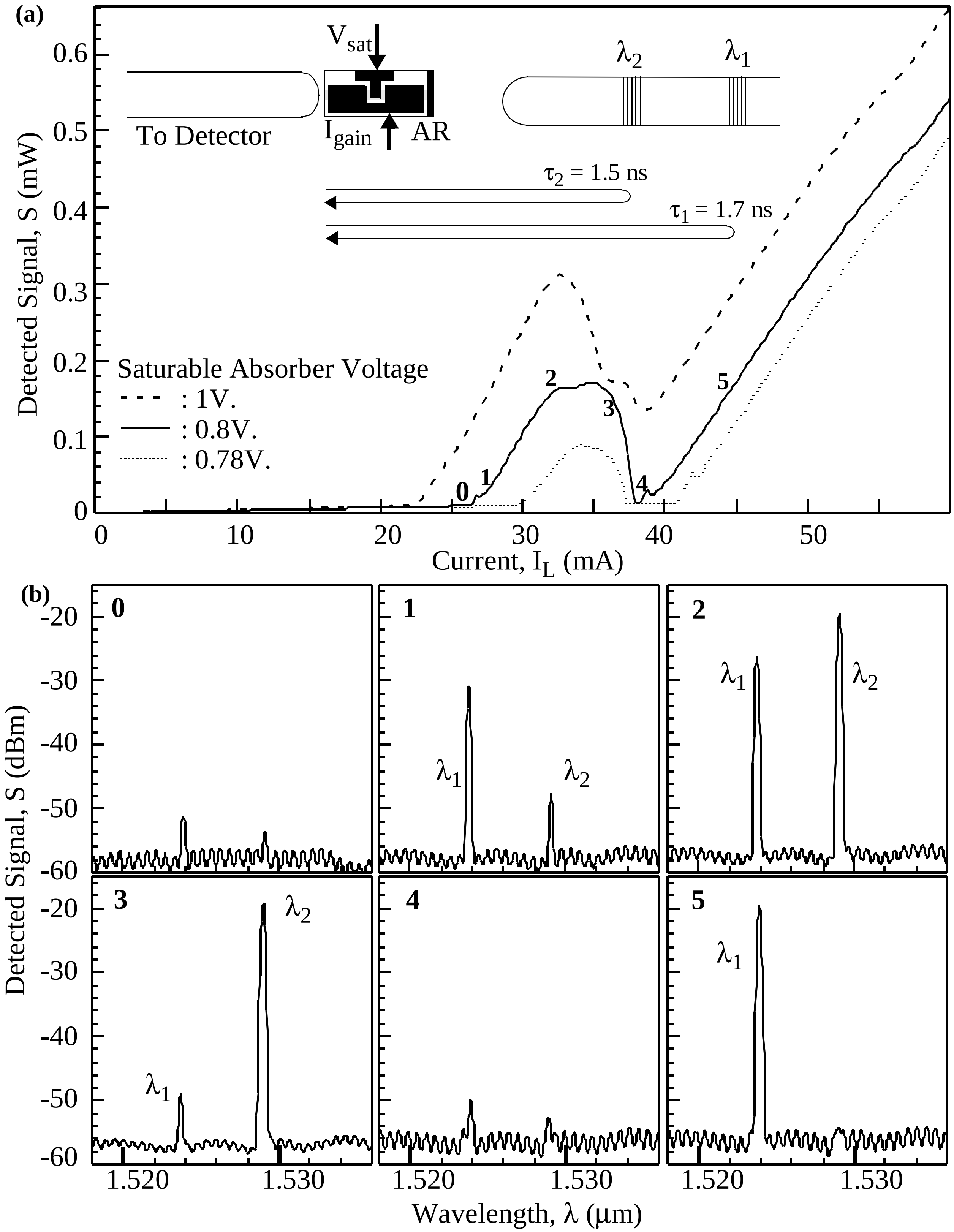
(a)
V sat
I gain
AR
To Detector
λ2
λ1
τ2 = 1.5 ns
τ1 = 1.7 ns
Saturable Absorber Voltage
: 1V.
: 0.8V.
: 0.78V.
Detected Signal, S (mW)
Current, I L (mA)
0
1
2
3
4
5
(b)
λ1
λ2
Detected Signal, S (dBm)
Wavelength, λ (μm)
1.520
1.530

Fig.1.

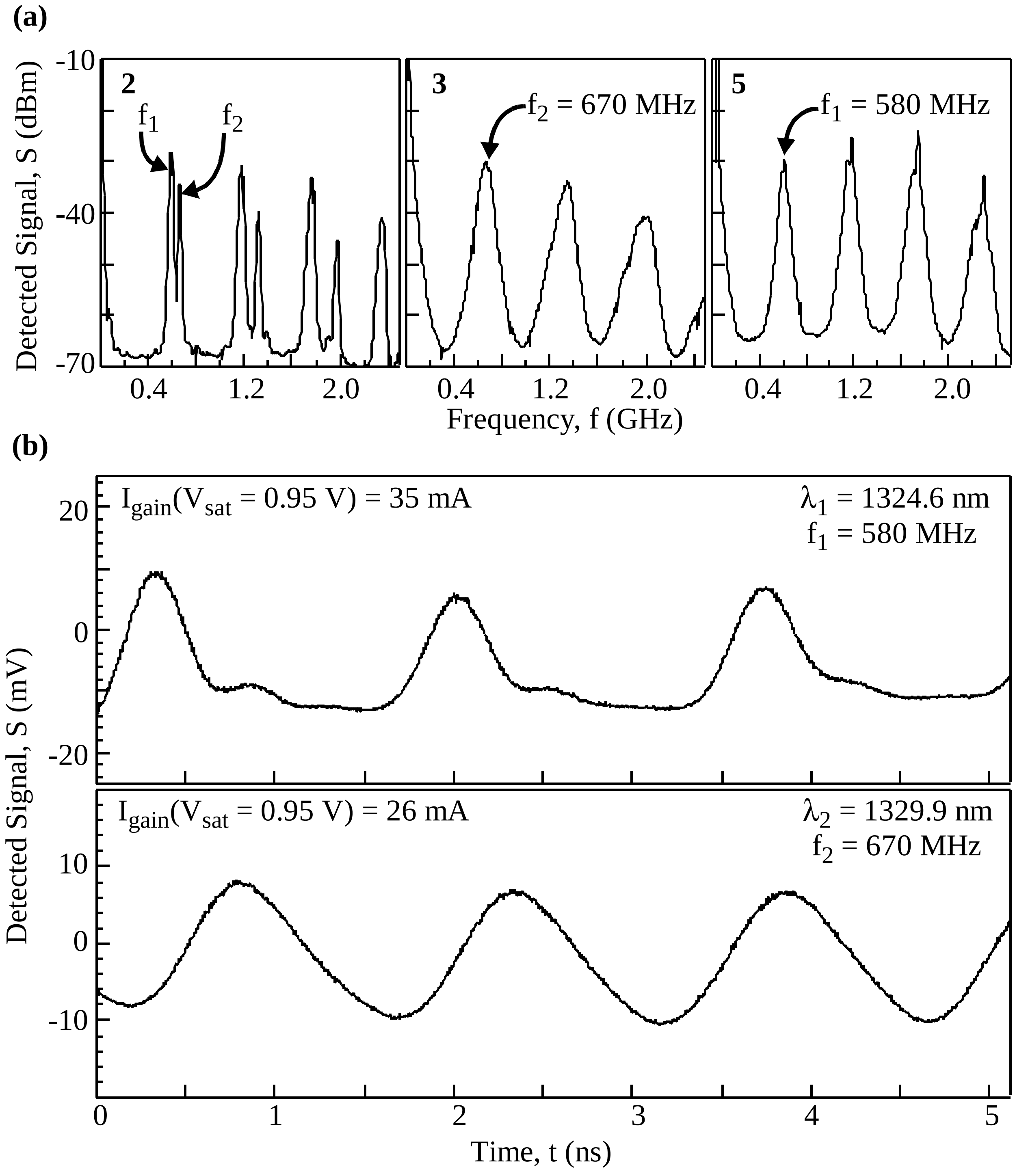
(a)
-10
-40
-70
Detected Signal, S (dBm)
2
f1
f2
3
f2 = 670 MHz
5
f1 = 580 MHz
0.4
1.2
2.0
Frequency, f (GHz)
(b)
Igain(Vsat = 0.95 V) = 35 mA
λ1 = 1324.6 nm
f1 = 580 MHz
20
0
-20
Igain(Vsat = 0.95 V) = 26 mA
λ2 = 1329.9 nm
f2 = 670 MHz
10
0
-10
Detected Signal, S (mV)
0
1
2
3
4
5
Time, t (ns)

Fig.2.