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Coupled Resonator Vertical Cavity Laser Diodes

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For many applications, the device performance of edge emitting semiconductor lasers can be significantly improved through the use of multiple section devices. For example, cleaved coupled cavity (C^3) lasers have been shown to provide single mode operation, wavelength tuning, high speed switching, as well as the generation of short pulses via mode-locking and Q-switching [1]. Using composite resonators within a vertical cavity laser opens up new possibilities due to the unique ability to tailor the coupling between the monolithic cavities, incorporate passive or active resonators which are spectrally degenerate or detuned, and to fabricate these devices in 2-dimensional arrays. Composite resonator vertical cavity lasers (CRVCL) have been examined using optical pumping and electrical injection [2-5]. We report on CRVCL diodes and show that efficient modulation of the laser emission can be achieved by either forward or reverse biasing the passive cavity within a CRVCL.

Fig. 1 shows a schematic of the CRVCL structure, which consists of a lower 1-wavelength thick active resonator containing three 8 nm InGaAs quantum wells and a passive upper resonator composed of 1-wavelength thick GaAs layer. The structure

was grown by metalorganic vapor phase epitaxy (MOVPE) with a bottom p-type distributed Bragg reflector (DBR), a middle n-type DBR, and a top p-type DBR with periods of 33.5, 11.5 and 21, respectively. The coupling between the two cavities can be accurately controlled by changing the number of periods of the middle n-DBR. In the bottom active cavity we employ selective oxidation of AlGaAs to form buried oxide layers for efficient electrical and optical confinement. Separate electrical contacts to each DBR provide independent current injection into the two resonators, thus producing a three terminal optoelectronic source.

Fig. 2 (a) shows output intensity with varying forward biased active and passive cavity current into a CRVCL device with a 20x20 μm oxide aperture. The maximum laser intensity decreases with increasing forward bias current applied to the passive cavity. As carriers are injected into the passive cavity, the index of refraction of the bulk GaAs layer is depressed causing a change in the optical path length of the passive cavity. The amount of coupling between the two cavities is changed so that a smaller fraction of the lasing mode remains in the passive cavity, which leads to a reduced output intensity in agreement with our coupled cavity simulations.

It is well known that heating in a VCSEL causes the lasing wavelength to red shift with increasing applied current until the emission is finally extinguished due to the spectral misalignment of the laser gain and the cavity resonance. In order to determine if the modulation observed in Fig. 2 (a) is due to a depression of the refractive index, the fundamental lasing mode was tracked as a function of active cavity current for various passive cavity currents. When no current is applied to the passive cavity and the laser is operated near its maximum output value, the wavelength of the fundamental mode is 998.7 nm. If the VCSEL is operated at a higher active current to suppress lasing, the device emission shifts 2.9 nm. Alternatively, we can operate the CRVCL at its maximum output point and inject current into the passive cavity to shut off lasing, which produces a wavelength shift of only 1.1 nm. The reduced spectral shift as compared to the thermally induced misalignment shows that the device is not merely driven into thermal shutdown by the heat generated from the passive cavity. Furthermore, since changes in the coupling between resonators may also lead to a change of the emission wavelength, it is difficult to separate what fraction of the modulation is due to thermal effects and what fraction is due to coupled cavity effects. Although heat produced in the passive cavity will reduce the output emission, heating alone cannot explain the modulation observed in Fig. 2 (a).

The output intensity of the CRVCL device can also be modulated by reverse biasing the passive cavity. Fig. 2 (b) shows the output intensity as a function of active cavity current for several different reverse bias voltages. For a given active cavity current, the output intensity decreases with increasing reverse bias voltage. Since the reverse breakdown voltage of the passive cavity diode is about –10.5 V, considerable modulation occurs before an appreciable amount of current flows. The reverse bias modulation mechanism is therefore not related to carrier induced changes in the device but rather to the large field present in the active region. Thus, electroabsorption caused by the Franz-Keldysh effect is the most likely cause of the modulation under reverse bias conditions. Although the active area of the passive cavity is bulk GaAs, there will still be a small amount of absorption at the lasing wavelength (990 nm) induced by the applied voltage which can be sufficient to drive the device below lasing threshold. We also measured the shift in the lasing wavelength under reverse bias operation of the passive cavity. The small shift of only 0.2 nm again indicates that heating does not play a significant role in the modulation under reverse bias operation.

In summary, we have discussed two different modulation mechanisms by which the emission from a coupled resonator vertical cavity laser can be varied for an active-passive structure. The first mechanism occurs under forward bias of the passive cavity and is due to a carrier depression of the index of refraction which changes the optical path length and hence the coupling between the two resonators. The modulation scheme agrees with our composite mode theory used to model the output of the coupled structure under forward bias operation. The second mechanism occurs under reverse bias of the passive cavity and is due to electroabsorption loss in the cavity. We are currently investigating other unique characteristics of CRVCL devices, such as frequency tuning, gain switching, and high speed modulation.

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Figure Captions:

Fig. 1 : Schematic of a coupled resonator vertical cavity laser (CRVCL).

Fig. 2 : (a) Light output from the CRVCL for various forward bias passive cavity currents. (b) Light output from the CRVCL under reverse bias operation of the passive cavity.

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Figure 1

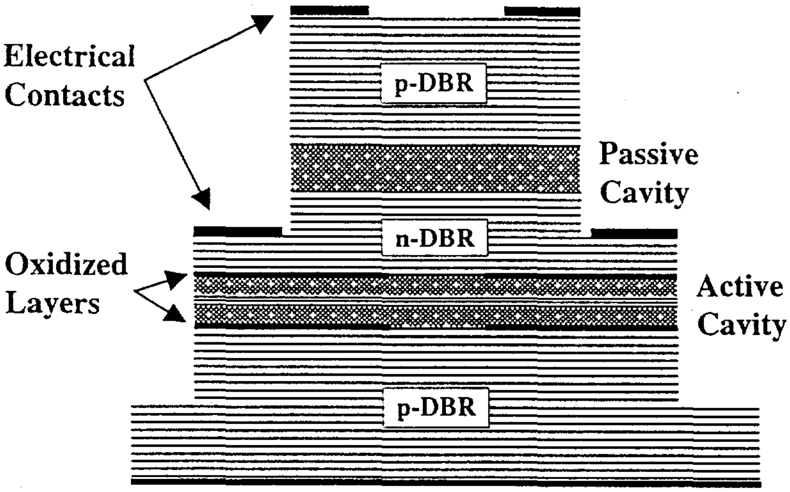
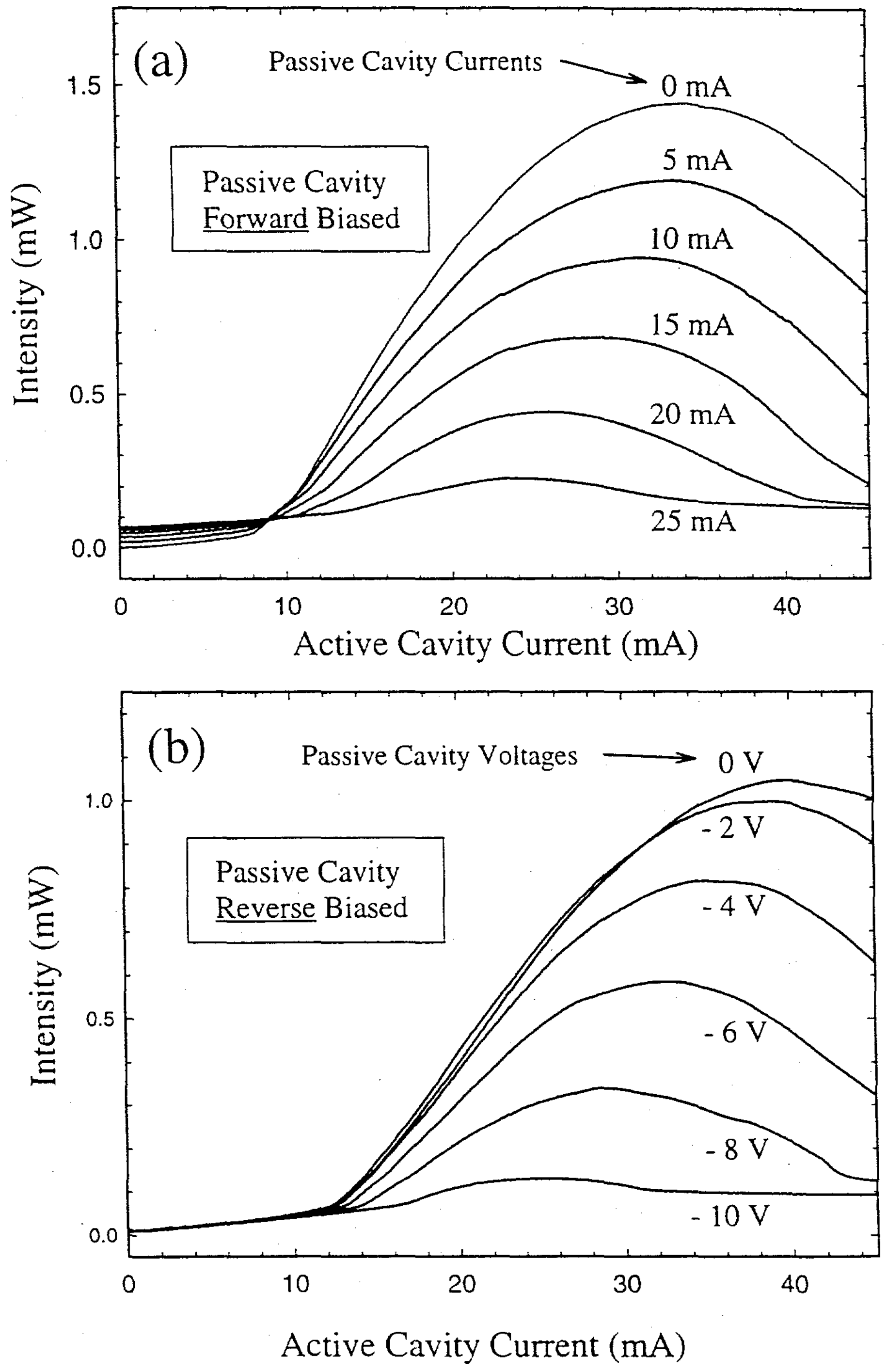

Electrical Contacts
p-DBR
Passive Cavity
n-DBR
Oxidized Layers
Active Cavity
p-DBR

Figure 2:


(a)
Passive Cavity Currents
0 mA
5 mA
10 mA
15 mA
20 mA
25 mA
Passive Cavity
Forward Biased
Intensity (mW)
1.5
1.0
0.5
0.0
0
10
20
30
40
Active Cavity Current (mA)
(b)
Passive Cavity Voltages
0 V
- 2 V
- 4 V
- 6 V
- 8 V
- 10 V
Passive Cavity
Reverse Biased
Intensity (mW)
1.0
0.5
0.0
0
10
20
30
40
Active Cavity Current (mA)