# Demonstration of Two-Wavelength Lasing in a GaAsP Ring/Fabry-Perot Composite Cavity Semiconductor Laser

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## Abstract

We demonstrate two-wavelength lasing in a circular ring / FP composite cavity GaAsP laser with two separate p-electrodes. Lasing of 1.0~4.3 nm wavelength separation and almost equal powers (total ~7.5 mW) under CW operation was accomplished by controlling the currents injection to the FP and ring sections independently.

## 1. Introduction

Laser diodes that emit light of multiple wavelengths simultaneously are useful for many applications, such as dual-wavelength interferometry [1], optical switching [2] and terahertz (THz) wave generation [3]. Several techniques have been developed to achieve two-wavelength operation of a diode laser system. The two DBR lasers with integrated Y-junction combiner [3] and multi-section distributed feedback (DFB) lasers [4] used grating structures to achieve dual-wavelength operation; however, the grating fabrication was rather complicated. Hence, the low cost devices with simple fabrication process are still required. Semiconductor ring laser [5-7] requires relatively simple fabrication process as compared to the grating incorporated lasers. We recently reported the stable single mode operation of a circular ring / FP (RFP) composite cavity laser [7]. In this work, we demonstrate two-wavelength lasing of an RFP composite cavity semiconductor laser with two-electrodes.

# 2. Device Concept

Figure 1 shows the schematic of the RFP laser geometry consisting of an active circular ring resonator coupled to an active straight channel waveguide by a tangential cou-



Fig. 1 Schematic of the ring / Fabry-Perot composite cavity laser.

pler [7]. Ridge type waveguides with same width are used for both of the ring and straight waveguides. Two separate p-electrodes are used to control the injection currents to the ring  $(I_R)$  and straight  $(I_F)$  sections independently. The mode frequencies (spacings) of the ring and FP cavities can be written as  $f_{Rm} = mc/2\pi R n_{Re}$  ( $\Delta f_R = c/2\pi R n_{Reg}$ ) and  $f_{Fm'} =$  $m'c/2Ln_{Fe}$  ( $\Delta f_F = c/2Ln_{Feg}$ ), respectively, where  $n_{Re}$  ( $n_{Reg}$ ) and  $n_{Fe}$  ( $n_{Fee}$ ) are the effective (effective group) refractive indices of the ring and straight waveguides, and m and m'are the mode numbers of the ring and FP cavities. The FP and ring cavity mode frequencies of an RFP laser of  $2R < L < \pi R$  ( $\Delta f_F > \Delta f_R$  for  $n_{Reg} \approx n_{Feg}$ ) are shown schematically in Fig. 2(a) and (b). It can be easily shown that the ring/FP mode pairs of minimum separation are arranged nearly periodically with an approximate period of  $\Delta f_{CC}$  $\approx \Delta f_F \Delta f_R / (\Delta f_F - \Delta f_R) = c/2(\pi R n_{Reg} - L n_{Feg})$  [7]. The FP cavity with the cleaved facets and the ring cavity coupled to each other form a composite resonator. At first we assume that  $f_{Rm}$  coincides with  $f_{Fm'}$  ( $f_{Rm} = f_{Fm}$ ), then the position of the adjacent ring/FP mode pair of minimum separation is around  $f_{Rm} + \Delta f_{CC}$ . We also assume that the separation between the ring and FP modes around  $f_{Rm} + \Delta f_{CC}$  is positive  $(f_{Rm+k} > f_{Fm'+k-1})$  as shown by the blue solid vertical lines in Fig. 2(b). When  $I_R$  is increased with keeping  $I_F$  at a fixed value,  $n_{Re}$  increases due to the temperature rise in the active region, and  $f_{Rm}$  shifts to lower frequency with slight shrinkage of  $\Delta f_R$  as shown by the red dashed lines in Fig. 2(b). The separation  $|f_{Fm'}-f_{Rm}|$  increases and  $|f_{Rm+k}-f_{Fm'+k-1}|$ decreases continuously, and these separations can be made equal. Further increase of  $I_R$  causes the coincidence between the ring and FP modes at  $f_{Rm} + \Delta f_{CC}$  ( $f_{Rm+k} = f_{Fm'+k-1}$ ) and the separation  $f_{Fm'}$ - $f_{Rm}$  increases more as shown by the



Fig. 2 Schematic diagram illustrating the relationships between the cavity mode frequencies. (a) FP cavity modes. (b) Ring cavity modes. (c) Expected lasing spectra of the RFP laser for three different values of  $I_R$ .



Fig. 3 P-I characteristics of the RFP laser measured at various fixed injection currents to the (a) ring section and (b) straight section.

green dotted lines in Fig. 2(b).

Analysis of lasing condition, given by complex round trip gain between facet mirrors of the RFP laser equated to unity, shows that the close ring/FP mode pairs give rise to the composite cavity modes of low threshold gain arranged with a period  $\Delta f_{CC}$ . Simultaneous lasing of two composite modes (two wavelengths) with nearly equal output powers can be accomplished by fine controlling the injection currents  $I_R$  and  $I_F$  so that the frequency separation between a pair of ring and FP modes close to each other becomes approximately equal to the separation between another pair. This expected two wavelength lasing is shown by the red dashed lines in Fig. 2(c). In order to confirm this possibility, we actually fabricated the RFP laser (R=395 µm and  $L=1090 \ \mu\text{m}$ ) using a GaAs<sub>0.86</sub>P<sub>0.14</sub> tensile strained singlequantum-well separate confinement heterostructure (SQW-SCH) and examined the performances by experimental measurements.

### 3. Experimental Results

Figure 3 (a) shows the dependence of the output power P on  $I_F$ , obtained for  $I_R$  kept at several fixed values. Threshold current was  $I_{Fth}$ =82 mA, and output power of 13 mW was obtained at  $I_F$ =200 mA. Figure 3 (b) shows the dependence of the power P on  $I_R$ , for  $I_F$  at several fixed values. When  $I_F$  was increased from 0 to 75 mA, the threshold current  $I_{Rth}$  decreased from 200 to 140 mA and the maximum output power increased from 1.4 to 4.4 mW. The reduction of  $I_{Rth}$  was due to the reduction of the absorption loss in the part of the ring section close to the coupler region. The increase of the output power was the result of the amplification of the light in the straight waveguide.

Keeping  $I_F$  at 100 mA higher than the threshold  $I_{Fth}$ =82mA,  $I_R$  was increased from 0 mA slowly and carefully observing the lasing spectrum. Initially, multiple peaks of unequal power were observed. With increasing  $I_R$ , another peak appeared and grew. Then  $I_R$  was fine adjusted so as to have equal intensity for the two lasing wavelengths. Two-wavelength lasing of 4.3 nm separation was obtained at  $I_F$ =100 mA and  $I_R$ =163 mA as shown in Fig. 4 (a). When  $I_F$  was increased to 110 mA with keeping  $I_R$ =163 mA, two wavelength lasing of 1.8 nm separation was obtained as shown in Fig. 4(b). Further increase of  $I_F$  to 120 mA with  $I_R$ =163 mA resulted in disappearance of two-wavelength lasing. When  $I_R$  was reduced to 100 mA, two-wavelength



Fig. 4 Lasing spectra of the RFP laser at different injection currents to the straight section without injection to the ring section.

lasing with 1.0 nm separation was obtained as shown in Fig. 4(c). When  $I_F$  was increased to 150 mA with  $I_R=100$  mA, two wavelength lasing disappeared but readjustment of  $I_R$  to 84 mA gave two-wavelength lasing again with 3.7 nm separation as shown in Fig. 4(d).

#### 4. Conclusions

We demonstrated two-wavelength lasing in a simple ring / FP composite cavity GaAsP laser having two separate p-electrodes. Lasing of almost equal powers with total  $3.3\sim7.5$  mW under CW operation was accomplished by keeping the current injection to FP section at a constant value and fine controlling the current injection to the ring section. Discrete sets of wavelength separations in  $1.0\sim4.3$ nm in the 800 nm band were obtained. The corresponding beat frequencies in  $0.5\sim2.0$  THz are suitable for photomixing generation of THz waves.

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