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# New Wavelength Generation in the Semiconductor Circular Ring Laser Diode by Four Waves Mixing

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## Abstract

Here we demonstrate the generation of new wavelength by four waves mixing in a semiconductor circular ring laser diode. By investigation the output spectrum of the laser diode, it showed that instead of the laser emission from circular ring resonator, new wavelengths can be generated by four waves mixing excited by strong emission from the circular ring resonator. New generated wavelengths were calculated and confirmed with four waves mixing condition.


**Key words:** four waves mixing, optical nonlinearity, semiconductor circular ring laser

## Introduction

Semiconductor circular ring laser diode (SCRLD) has been attracted research interest for its strong side modes suppression characteristics and the potential of integration with others passive components to achieve advance function of controlling light propagation in the same chip.[1-2] We had demonstrated the generation of spatial solitons wave could be excited in the SCRLD due to strong nonlinearity effect which can provide light wave guiding without forming a physical waveguide structure.[3]

In general, the optical nonlinearity constant of most materials is relatively small such that a power density on the order of $MW/cm^2$ is necessary to excited significant nonlinearity effect. It was reported that strong third order optical nonlinearity can be excited in a medium of GaAs quantum wells structure thus third order nonlinearity effects could be excited by moderate intensity of light.[4-8] Here we present the observation of new wavelength generation in the SCRLD by four wave mixing, and the analysis of its output characteristics.

## Device Fabrication

The SCRL was fabricated on a metal organic chemical vapor deposition (MOCVD)-grown InGaAlP multiple-quantum-well structure. Fig. 1 shows the material structure and dimensions of the SCRLD device which consisting of a ridge waveguide circular ring resonator coupled with a directional Y-junction coupler to couple out the clockwise(CW) emission modes in the SCRLD. The diameters of the fabricate SCRLD was 1000 um, and the ridge waveguide was 25 um in width.

For the device processing, at the beginning, an etching resisted layer of $SiO_2$ about 300 nm was grown by plasma enhanced chemical vapor deposition (PECVD). Then, the SCRL device pattern was transferred to the laser substrate by photolithography followed by reactive ion etching (RIE). stripping off the photoresist, an inductively coupled plasma (ICP) etching was used to form the ridge waveguide structure

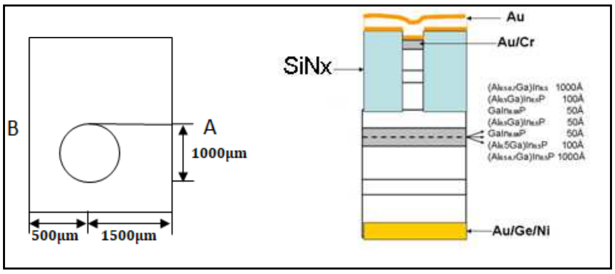


Fig. 1. Material structure and dimensions of the fabricated SCRL device.

of the SCRLD device with a depth of about 1 um where is near to the quantum wells layers. Then, buffer oxide etcher (BOE) was used to remove the $SiO_2$ layer and followed by the Lift-off process to deposit $SiN_x$ as the insulation layer. At the end, a layer of Au (200 nm)/Cr (10 nm) was deposited and then annealed at 650 $^0$C for good ohmic contact. The substrate was grinded to 150 um of thickness to minimize the resistance, deposited a layer of AuGe/Ni for n-type metal contact. The fabricated device was scribed and cleaved by a diamond to form mirror like die edges.

## Output Characterizations

The fabricated device was probe-tested on a micro stage for light-current (L-I) and spectral measurements. As we had reported that emission of the SCRLD can be clearly seen not only from the output terminal of the Y–junction coupler but also from the opposite side of the non-waveguide region due to the formation of spatial soliton. Fig. 2 shows the L-I characteristics of a fabricated SCRLD with a circular resonator of 1000 um in diameter measured at terminal A; the Y-junction coupler terminal and at terminal B; the soliton wave guiding terminal. The L-I characteristics of both terminals clearly show two threshold of the emission that revealing two different lasing resonators, the lower threshold at 0.6 A corresponding to the circular ring resonator and the higher threshold at 0.85 A corresponding to another resonator mode to be identified.

Fig. 3 shows the spectrum from terminal A at various current injection. It shows that the laser emission starts at 657.8 nm with current of 0.8A which is related to the laser emission of the circular ring resonator mode. When increasing the current above 0.87A, spectrums at 656.6 nm, 656.8 nm, and 657.1 nm taking off rapidly. At higher injection at 0.95A, the 656.6 nm peak shifts to lower wavelength at 656.0 nm and the 657.1 nm peak shifts to 657.6 nm.
Basically, Fig. 4 shows the same spectrum as from port A

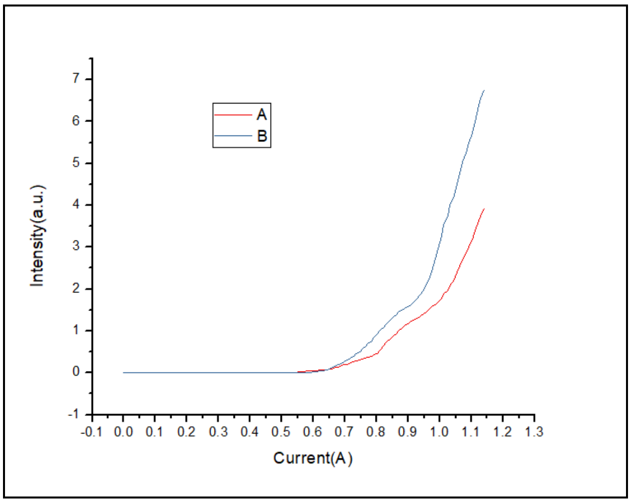


Fig. 2. L-I characteristics from terminal A; the Y-junction coupling terminal and from port B; the soliton wave guiding terminal of a SCRLD with a circular ring resonator of 1000 um in diameters.

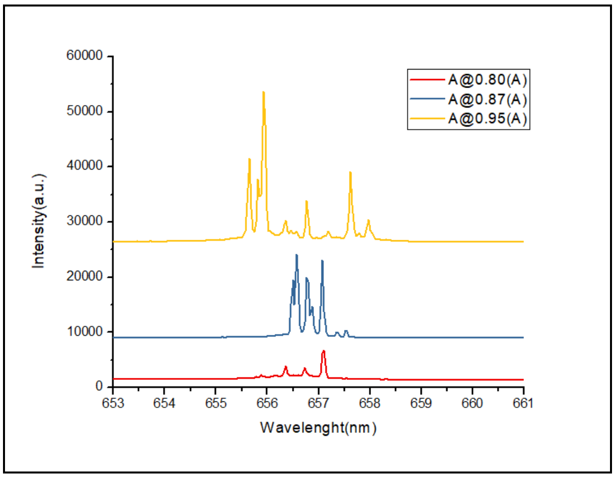


Fig. 3. Spectrum from terminal A at various current injection. It shows that the laser emission starts at 657.1 nm with current of 0.8A which is related to the laser emission of the circular ring resonator mode.

## Discussion and Conclusions

Since we had observed strong confined emission from terminal B at non-waveguide region of the SCRLD that can be reasonably explained by the formation of spatial solitons excited in a medium with strong third order nonlinearity coefficient. Therefore, we would expect that four waves mixing can also be generated in this system.

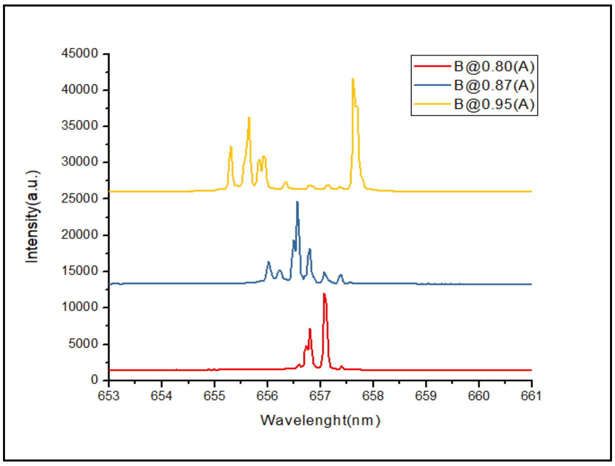


Fig. 3. Spectrum from terminal B at various current injection. It shows similar spectrum as from terminal A.

When carefully analysis the peaks position in Fig. 3, they fit the four waves mixing relation as below.

$$\frac{c}{656.6} + \frac{c}{657.1} \cong \frac{c}{656.8} + \frac{c}{656.8}$$

As injected current increasing to 0.95A, the peak of 656.6 nm and 657.1 nm equally move away from the center peak at 656.8 nm. These new peaks wavelengths also fit to the four wave mixing condition.

We have demonstrated the generation of new wavelengths in the SCRLD due to four waves mixing. There is other related issues of conjugated reflection which can form conjugated resonator and further investigation results will be presented in the conference.


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