RCE photodiodes at wavelength band of 1.06 μm

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Resonant cavity enhancement (RCE) typed optical detector and modulator which operating at wavelength band of 1.06 μm is reported. The peak quantum efficiency of detector is reasonably high as 50% without bias, and the photocurrent contrast ratio of modulator is 3.6 times at -3.5 V as compared to 0 V. The incident angle dependence of RCE device's photoelectric response is investigated carefully.

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The study on 1.06 μm photonic devices has been paid attention for being applied widely in the field such as radar guide and space laser communications. It also allows low-loss penetration through Si optical mounts or circuitry for free-space multiple-chip module interconnects[1]. Compact semiconductor lasers with high beam quality emission have potential applications currently dominated by Nd:YAG lasers[2]. There is ample motivation to the needs of optical detector and modulator operating at wavelength band of 1.06 μm. By placing MQW inside a Fabry-Perot cavity, the resonant-cavity enhanced (RCE) devices function largely as before[3]. The RCE photodetectors have the properties such as wavelength-selectivity, high quantum efficiency, and high-speed response[4]. The RCE optical modulators require fewer quantum wells, so they are capable of reduced voltage operation[5]. The RCE devices are also highly suitable for integrated emitters and detectors with logic application and in communication networks. The study on 1.06 μm RCE photodiodes needs to settle such question on how to ensure high quality active region.

In this paper, we have grown $In_{0.3}Ga_{0.7}As/GaAs$ strained QW by molecular beam epitaxy (MBE) as an absorption layer which is sandwiched between two high-reflectivity mirrors. Using the structure wafer, RCE photodetector and modulator operating at wavelength band of 1.06 μm were fabricated. Their photoelectric performances depending on electric field and incident angle were investigated theoretically and experimentally.

	P^+	GaAs	$\lambda/4$
	P	AlAs	$\lambda/4$
14×	P	GaAs	$\lambda/4$
	P	AlAs	$\lambda/4$
	I	GaAs	
3×	I	$In_{0.3}Ga_{0.7}As$	
	I	GaAs	
	N	AlAs	$\lambda/4$
22×	N	GaAs	$\lambda/4$
	N	AlAs	$\lambda/4$
		GaAs buffer	
	N^+	GaAs substrate	

Fig. 1. The epitaxial structure.

As shown in Fig. 1, the epitaxial structure mainly contains: 14 periods of P-doped GaAs/AlAs DBR, 22 periods of N-doped GaAs/AlAs DBR, and a λ_0 optical cavity consisting of three undoped 6.5-nm $In_{0.3}Ga_{0.7}As$ QW with 18-nm GaAs barriers and GaAs confined layers. The resonant mode of structure was designed at 1064 nm.

Using micro-spot spectrum analyzing system, the wafer's reflectivity and transmissivity were measured carefully, as shown in Fig. 2. The variation of resonant mode is caused mainly by deviation of layer thickness while growing structure. Though the deviation does not affect active region so much as it affects resonant cavity, the mode absorption is varied with deviation. According to conservation law of the sum of reflectance, transmittance and absorption, for the structure having small transmissivity and high reflectivity at $\lambda_{\rm mode}$, there must be strong mode absorption; for the structure having clear transmission at $\lambda_{\rm mode}$, there must be weak mode absorption. We chose the former structure material to make RCE photodetector, and chose the latter to make RCE modulator.

As shown in Fig. 3, with the amplitude of bias on RCE detector being increased, the resonant photocurrent had a slightly variation and the reflectivity had no variation nearly. Because MQW is placed inside resonant cavity with high reflectivity, incident light is sent passing through absorption region back and forth many times to make the total absorption increase greatly. The photoelectric response of RCE detector can be reasonably high even without bias. The peak quantum efficiency $\eta_{\rm p}$ and optical bandwidth $\Delta\lambda_{1/2}$ are given by[3]

$$\eta_{\rm p}=\frac{(1-R_{\rm in})(1+R_{\rm back}{\rm e}^{-\Gamma_{\rm enh}\alpha d})(1-{\rm e}^{-\Gamma_{\rm enh}\alpha d})}{(1-\sqrt{R_{\rm in}R_{\rm back}}{\rm e}^{-\Gamma_{\rm enh}\alpha d})^2}, \quad (1)$$

$${\rm FWHM}=\Delta\lambda_{1/2}=\frac{\lambda\cdot\lambda_0(1-\sqrt{R_{\rm in}R_{\rm back}}{\rm e}^{-\Gamma_{\rm enh}\alpha d})}{2\pi L_{\rm eff}(R_{\rm in}R_{\rm back})^{1/4}{\rm e}^{-\Gamma_{\rm enh}\alpha d/2}}. \quad (2)$$

As shown in Fig. 4, there exists optimizing relationship between quantum efficiency and structure parameters. By precisely chemical etching, we altered the period of top DBR of structure to optimize input mirror's reflectivity[6]. The $\eta_{\rm p}$ of RCE detector high as 50% was achieved.

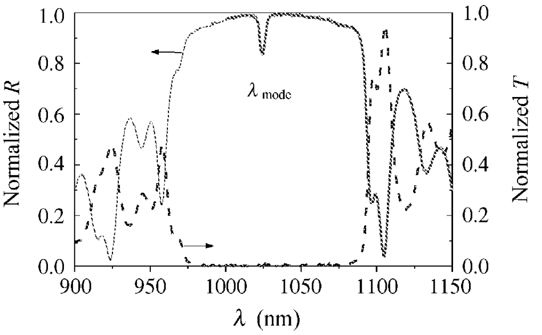

Fig. 2. Measured reflectivity R and transmissivity T.

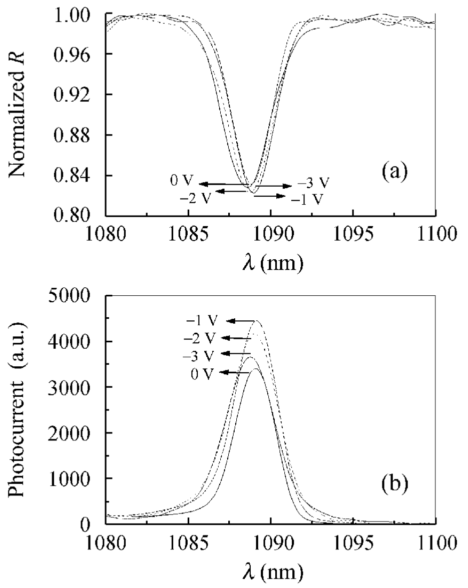

Fig. 3. Measured reflectivity R (a) and photocurrent (b) of RCE detector at biases.

For the case of RCE modulator shown in Fig. 5, with the amplitude of negative voltage being increased steply, the resonant photocurrent was largely increased and the reflectivity had variation simultaneously. While MQW being placed in reverse electric field, its exciton peak of absorption spectrum red shifts and absorption decreases in magnitude. It is called quantum confined stark effect (QCSE). Because the resonant mode was situated in wavelength region slightly broader than exciton peak at 0 V, the mode absorption would be increased for QCSE, and reflectivity and photocurrent were changed greatly. In Fig. 5, the reflectivity at $\lambda_{\rm mode}$ fell from 86% at 0 V to 81% at −3.5 V, meanwhile the peak photocurrent increased over 3.6 times. The resonant wavelength had a slightly blue shift, due to the slight variation of refraction index caused by electric field. The contrast ratio of device was mainly confined by high reflectivity of input mirror[7].

RCE photodiodes not only have great wavelength selectivity, but also have interesting space selectivity subjected to the resonance effect. Experimental results for the RCE photodiode with $\lambda_{\rm mode}$ at 1084 nm to normal incidence are shown in Fig. 6. While the incidence angle being changed from 0° to 60°, the resonant wavelength blue shifts about 40 nm totally. The variation patterns

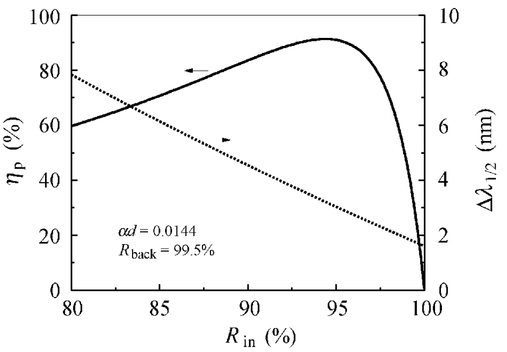

Fig. 4. Calculated $\eta_{\rm p}$ and $\Delta\lambda_{1/2}$ varying with $R_{\rm in}$.

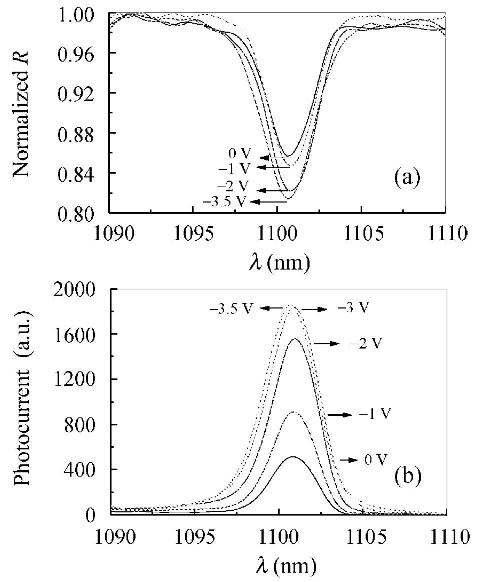

Fig. 5. Measured reflectivity R (a) and photocurrent (b) of RCE modulator at biases.

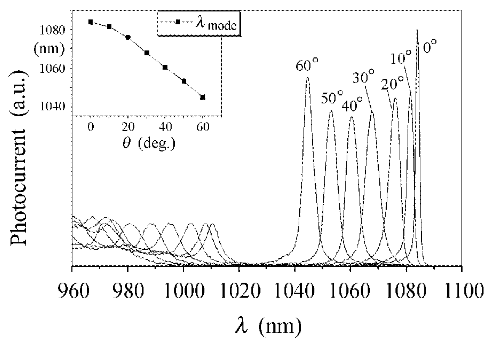

Fig. 6. Measured photocurrent of RCE photodiode with different angle incidence.

of peak quantum efficiency and linewidth were relevant closely to the variation of absorption at different mode. The convenient tuning of peak quantum efficiency wavelength in a certain range will be helpful to relax the strict constraint of RCE photodiodes to light source with narrow emitting spectrum, particularly in the application of space communications and interconnects.

In summary, we grew the structure that using $In_{0.3}Ga_{0.7}As/GaAs$ strained MQW as active region and measured the wafer's micro-spot optical characteristics. We fabricated RCE typed photodetector and modulator operating at wavelength band of 1.06 μm. By optimizing top DBR's reflectivity using precisely etching technique, the RCE photodetector had η_p as high as 50%. The photocurrent of RCE modulator increased 3.6 times at −3.5 V as compared to the value at 0 V. The wavelength transition of RCE photodiode depending on angle incidence was analyzed. The property can be used in spectrum meter and wavelength demultiplexing, etc.

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References

1. R. P. Moeller and W. K. Burns, Opt. Lett. **16,** 1902 (1991).
2. H. Q. Hou, K. D. Choquette, K. M. Geib, and B. E. Hammons, IEEE Photon. Technol. Lett. **9,** 1057 (1997)
3. M. S. Ünlü and S. Strite, J. Appl. Phys. **78,** 607 (1995).
4. A. G. Dentai, R. Kuchibhotla, and J. C. Campbell, Electron. Lett. **27,** 2125 (1991).
5. R. J. Simes, R. H. Yan, and R. S. Geels, Appl. Phys. Lett. **53,** 637 (1988).
6. K. Liang, H. D. Chen, and H. Deng, Chin. J. Semiconductors **22,** 409 (2001).
7. Z. B. Chen, W. Z. Gao, and H. D. Chen, Chin. J. Semiconductors **17,** 891 (1996).