Vol 10 No 2, February 2001
1009-1963/2001/10(02)/0121-03

Chinese Physics

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STUDY OF THE FOUR-WAVE MIXING DIFFRACTION EFFICIENCY OF LONGITUDINAL-FIELD MULTIPLE-QUANTUM-WELL PHOTOREFRACTIVE DEVICE GROWN AT LOW TEMPERATURE*

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(Received 2 June 2000; revised manuscript received 23 August 2000)

We investigate the relationship between the beam intensity and the four-wave mixing diffraction efficiency of the longitudinal-field multiple-quantum-well (LMQW) photorefractive device grown at low temperature. A optimum beam intensity is found. We also explain the different mechanisms of the beam intensity effect on the diffraction efficiency of the LMQW device and the transverse-field MQW device. Some advice on how to improve the diffraction efficiency is given.

Keywords: multiple-quantum-well photorefractive device
PACC: 4265, 4280K, 7220H, 7360F

Multiple-quantum-well (MQW) photorefractive devices have wide applications in the field of high-speed optical holography because of their advantages, such as rapid response time, high sensitivity, high resolution, low saturation intensity and operation at diode-laser wavelength.[1−4] The longitudinal-field multiple-quantum-well (LMQW) device has attracted more attention than the transverse-field MQW device due to its higher diffraction efficiency and lower applied voltage. Since the diffraction efficiency is the most important characteristic of the MQW photorefractive device from the practical viewpoint, it is important to study the effect of the beam intensity on the diffraction efficiency of the LMQW device. In this paper, we investigate the relationship between beam intensity and four-wave mixing diffraction efficiency. The optimum beam intensity has been found. We could explain the different mechanisms of the effect of beam intensity on the LMQW device and the transverse-field MQW device. Finally, we give some advice on how to improve the diffraction efficiency.

The sample used in our experiments was grown on the semi-insulating miscut [4° off (001) towards (111) A] GaAs substrate by molecular beam epitaxy (MBE) in a V80H system at 380°C. The as-grown sample had a resistivity of $10^7\Omega\cdot$cm. The structure of the sample was as follows: 500 nm GaAs buffer layer, 50 nm AlAs, and an electro-optic layer consisting of 100 period MQWs of 4 nm $Al_{0.3}Ga_{0.7}As$/8 nm GaAs which was sandwiched between two 150 nm $Al_{0.3}Ga_{0.7}As$ trap layers. After the substrate was removed using the selective lift-off technique, the epitaxial layer 5×5 mm was put on a piece of glass on which an electrode and an insulating layer had been deposited with ITO and SiN_xO_y. The final step was bonding another electrode on the surface with transparent epoxy.

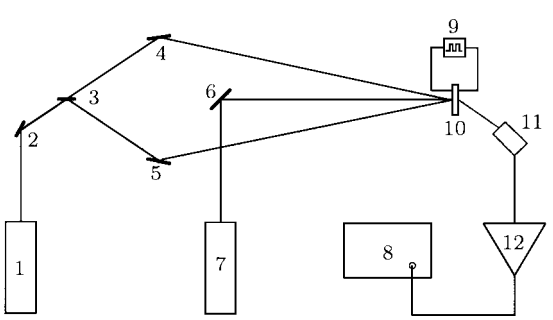


Fig.1. A schematic diagram of the experimental set-up: 1, He–Ne laser; 2, 4, 5 and 6, mirror; 3, beamsplitter; 7, diode-laser; 8, oscilloscope; 9, square-wave generator; 10, LMQW; 11, photodiode detector; 12, amplifier.

*Project supported by the National Natural Science Foundation of China (Grant No. 69896260).

The experimental set-up is shown schematically in Fig.1. The output light of the He–Ne laser, which is used as the write beam, is split into two beams by a mirror and then focused on the LMQW. There is an angle of 0.7° between each beam and the normal of the sample. Due to the interference between these two beams, a space distribution of carrier concentration exists in the LMQW. Consequently, absorption and index of refraction gratings are formed as a result of the process of carrier migration and material electro-optical effect. We used a laser diode (LD) with a wavelength of 840 nm to read the gratings. The first-order diffraction light is detected by an Si photodiode detector, which has a response time less than 10 ns. A digital real-time oscilloscope (TDS340) is employed to record the diffraction signal.

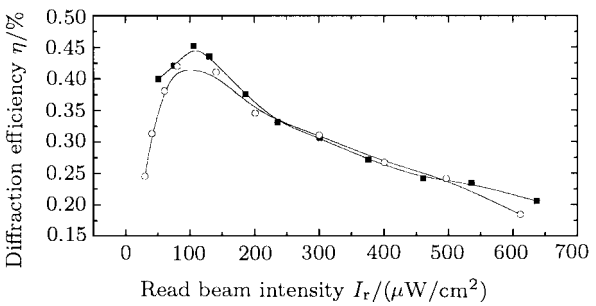


Fig.2. The curves of diffraction efficiency η versus the read beam intensity I_r with the write beam intensity I_w of $250\mu W/cm^2$ (full squares) and $400\mu W/cm^2$ (open circles).

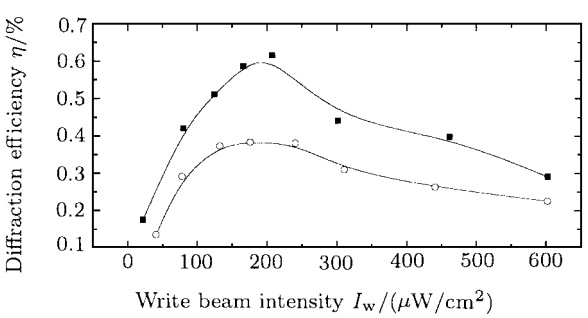


Fig.3. The curves of diffraction efficiency η versus the write beam intensity I_w with the read beam intensity I_r of $100\mu W/cm^2$ (full squares) and $310\mu W/cm^2$ (open circles).

With a different write beam intensity, the curve of diffraction efficiency versus the read beam intensity I_r is shown in Fig.2. It indicates that the diffraction efficiency decreases when I_r increases to a certain value. The optimum value of I_r is about $100\mu W/cm^2$. Fig.3 presents the diffraction efficiency versus the write beam intensity I_w for different write beam intensities. The diffraction efficiency increases first, then decreases as I_w increases. The optimum value of I_w is about $200\mu W/cm^2$.

Our experimental results indicate that different LMQW devices have different optimum values of I_w and I_r. However, the optimum values of I_w and I_r are relatively independent of each other; that is, when $I_w(I_r)$ changes, the optimum value of I_r (I_w) is almost kept constant.

The diffraction of the LMQW device originates from the electro-absorption and electro-refraction. Therefore, a larger electro-absorption leads to a larger diffraction efficiency. The curve of the electro-absorption signal versus the He–Ne beam intensity is shown in Fig.4. It indicates that increasing the He–Ne beam intensity results in a smaller maximum of the electro-absorption signal amplitude. This can be explained by the effect of partial voltage. The existence of resistance and capacitance in the trap layers should be considered and the effective voltage across the MQW layer is only part of the whole voltage across the device. The beam intensity is assumed to be proportional to the carrier concentration which is proportional to the conductivity. Therefore, the beam intensity is inversely proportional to the resistance of the MQW layer. Hence, the effective voltage across the MQW layer decreases with the increase of the He–Ne beam intensity and this results in the decrease of the electro-absorption signal. The experiment also shows that the diffraction efficiency reduces when the intensity of the LD beam increases to a certain value. The LD intensity I_r at the maximum diffraction efficiency is just the intensity of the maximum electro-absorption effective, as shown in Fig 5. (The data is of another LMQW device, so the optimum value of I_r, which is about $150\mu W/cm^2$, is different from the above.)

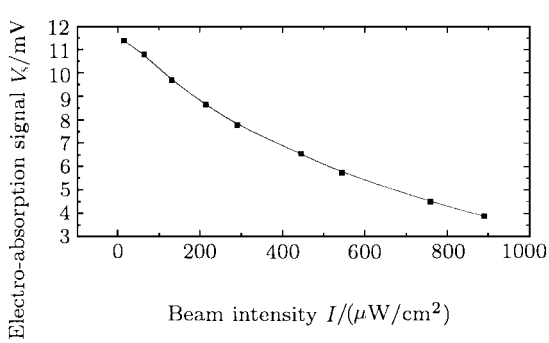


Fig.4. The curve of the electro-absorption signal V_s versus the He–Ne beam intensity I.

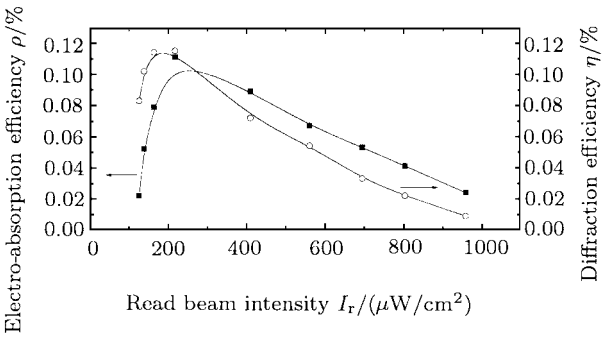


Fig.5. The curves of the electro-absorption efficiency ρ versus the read beam intensity I_r (full squares) and the diffraction efficiency η versus the read beam intensity I_r (open circles).

For the transverse-field photorefractive device, the diffraction efficiency decreases when the read beam intensity reaches a certain value. Physically, the number of the excited carriers increases as the read beam intensity increases. This leads to the erasing of the space modulation of the carrier concentration formed by the write beam. When the write beam intensity reaches a certain value, the diffraction efficiency of the transverse-field device also decreases, because the diffusion of the carriers from the light fringes to the dark fringes will increase, and this results in the reduction of the grating modulation.

Our experimental results indicate that the optimum write beam intensity and the optimum read beam intensity of the LMQW device are relatively independent of each other. If the LMQW device has the same erasion mechanism as the transverse-field device, then the optimum read beam intensity will depend on the write beam intensity. Although the diffraction efficiency of both the LMQW and transverse-field devices decreases when the read or write beam intensity reaches a certain value, the underlying mechanisms are different.

From the above analysis, the principal factor for the diffraction efficiency of the transverse-field device is the grating modulation. In contrast, the diffraction efficiency of the longitudinal-field device depends on both the grating modulation and the partial voltage across the electro-optical layer (the MQW layer). Since the latter factor is more important for the LMQW, the most efficient method to increase the diffraction efficiency is to increase the thickness or the periods of the electro-optical layers properly.

In conclusion, this paper investigates the mechanism of beam intensity on the four-wave mixing diffraction efficiency of the LMQW photorefractive device. The optimum beam intensity is found. We also explain the different mechanisms of the effect of beam intensity on the diffraction efficiency of the LMQW device and the transverse-field MQW device. Some advice on how to improve the diffraction efficiency is given.

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