ELSEVIER

Journal of Crystal Growth 138 (1994) 625–628

JOURNAL OF CRYSTAL GROWTH

Light interference effect in optical bistability of multiple quantum well etalons

D.Z. Shen *, X.W. Fan, B.J. Yang

Changchun Institute of Physics, Academia Sinica, Changchun 130021, People's Republic of China

Abstract

The light interference effect in optical bistability of multiple quantum well (MQW) etalons has been studied by a simplified formula according to the light propagating theories in multiple layers medium. On the basis of the formula, the analyzed results show that the light interference effect in the MQW can directly affect the threshold of the optical bistability of the MQW etalons, particularly in the case of large periodic number and large reflectivity in interfaces between the well and barrier layers of the MQW etalons. The optical bistabilities in the CdZnSe–ZnSe and ZnSe–ZnTe MQW etalons have been measured and compared with the analyzed results; the experimental results further indicate that the large reflectivity in the interface between the well and barrier layers of the MQW will cause the threshold of the optical bistability in the MQW etalons to increase due to the light interference effect in the MQW etalons.

1. Introduction

Recently, optical bistability in MQW etalons has become an interesting research topic because of the possible application of the switching property in optical computer. Many studies on optical bistability in MQW etalons have been reported, in which the major interests are to reduce the threshold of optical bistability in MQW etalons by using optimal structure of the MQW and Fabry–Pérot (FP) cavity [1,2], but the light interference effect in the MQW is not considered. In this paper, we report the study of the light interference effect in MQW etalons, in which the light interference effect in the MQW has been analyzed by a simplified formula. The research results indicate that the light interference effect in the MQW can directly affect the threshold of the analyzed bistability of the MQW etalons. On the basis of the analyzed results obtained here and the experimental results of optical bistabilities in the CdZnSe–ZnSe and ZnSe–ZnTe MQW etalons measured here, the influence of the light interference effect on the threshold of optical bistability in the CdZnSe–ZnSe MQW etalons is smaller than that in the ZnSe–ZnTe MQW etalons. The major reason for the difference is due to the smaller reflectivity in the interface between the well and barrier layers in the CdZnSe–ZnSe MQW etalons than that in the ZnSe–ZnTe MQW etalons.

---

* Corresponding author.

0022-0248/94/$07.00
SSDI 0022-0248(93)E0626-I

2. Analysis

For an optical bistable device of a MQW etalon, when the direction of light propagation is perpendicular to the multilayers of the MQW etalon, the light wave is reflected on the interface between the well and barrier layers, and also on the front and back surfaces of the MQW etalons. In the general case, the difference of refractive indices of well and barrier layers is very small. Because of the very small reflectivity on the interface between the well and barrier layers in the MQW etalons, we only consider the first reflection of light on the interface and assume that the reflectivity of the front surface is equal to the reflectivity of back surface in the FP cavity. In this case, the transmission can be written in the form [3]:

$$T'_{\mathrm{FP}} = \frac{F'(1-R)^2/4R}{1+F'\sin^2\delta/2}\left(1+2\sqrt{RR_0}\,f_t\right), \tag{1}$$

where the finesse is

$$F' = 4R'_e/(1-R'_e)^2, \tag{1a}$$

with

$$R'_e = R(1-R_0)^{2n}\,\mathrm{e}^{-\alpha L}, \tag{1b}$$

$$\delta = (4\pi/\lambda)(n_1 a_1 + n_2 a_2)n, \tag{1c}$$

$$R_0 = \left[(n_1-n_2)/(n_1+n_2)\right]^2. \tag{1d}$$

Here, n_1 and n_2 are the refractive indices of well and barrier layers, respectively, a_1 and a_2 are the widths of well and barrier layers, respectively, n and α are the periodic number and average absorption coefficient of the MQW, respectively, λ, L and R are the incident light wavelength, cavity length and reflectivity of the FP cavity, respectively, and f_t is the function of the parameters of the materials and structures in the MQW etalons [3]. In the general case, f_t is much smaller than one unless $(4\pi/\lambda)(a_1 n_1 + a_2 n_2)$ is close to 2π. Therefore, T'_{FP} becomes:

$$T'_{\mathrm{FP}} = \frac{F'(1-R)^2/4R}{1+F'\sin^2\delta/2} \tag{2}$$

Obviously, the form of Eq. (2) is the same as the expressive formula in the case of a uniform medium; particularly in the case of $R_0 = 0$, Eq. (2) is identical with that in the case of uniform medium.

On the basis of the FP cavity's nonlinear theories, from Eq. (2), the finesse of the MQW etalons and the threshold of the optical bistability in the MQW etalons is not the same as that in a uniform medium; the threshold required for the optical bistability in a MQW etalons can be written as [3]:

$$I'_{\mathrm{th}} = 2C'I_s, \tag{3}$$

where

$$C' = \frac{\alpha L(1-R'_e)^2}{(1-R)(1+R'_e)(1-T_0^{2n}\,\mathrm{e}^{-\alpha L})}, \tag{3a}$$

with

$$R'_e = RT_0^{2n}\,\mathrm{e}^{-\alpha L}, \tag{3b}$$

$$T_0 = 1 - R_0. \tag{3c}$$

Here I_s is the saturating absorption intensity of the MQW within a FP cavity. According to Eq. (3), the threshold I'_{th} increases with decreasing T_0^{2n} for any light absorption loss αL and reflectivity R in the MQW etalons. Therefore, in order to get the lowest possible I'_{th}, we must increase the value of T_0^{2n}, i.e., use the smallest possible periodic number of MQW and smallest difference values of refractive indices between the well and barrier layers medium. Based on the above analysis, we can get results as follows: light interference effect in MQW etalons can directly affect the quality of FP cavity and the threshold of the optical bistability in the MQW etalons, and the effect depends on the periodic number and the reflectivity in the interface between the well and barrier layers in the MQW etalons.

3. Experimental results and discussion

ZnSe-based MQW is a kind of important material system; it has been used as the active layer in p–n junction blue-green lasers. Many studies on the ZnSe-based MQW have been reported, and the research results indicate that the ZnSe-based MQW has a strong room-temperature excitonic effect, low nonlinear threshold and good waveguide character. In the MQW lasers, the FP cavity is parallel to the multilayers of the MQW, in which the emitting light needs to be limited in the multilayers so that the emission can propagate along the direction of the FP cavity. As an FP optical bistable device, the FP cavity is perpendicular to the multilayers of the MQW, in which the low threshold for the optical bistable device needs a small light interference effect in the MQW besides the strong room-temperature nonlinear effect according to the above-analyzed results. Because the CdZnSe–ZnSe MQW has smaller light reflectivity in the interface between the well and barrier layers than that in the ZnSe–ZnTe MQW, the influence on the threshold of the optical bistable device in the CdZnSe–ZnSe MQW etalons should be smaller than that in the ZnSe–ZnTe MQW etalons. Therefore, in order to study the influence of light interference effect on the MQW etalons for the threshold, CdZnSe–ZnSe and ZnSe–ZnTe MQW etalons are prepared and measured.

The two material systems within the FP cavities studied here are a $Cd_{0.24}Zn_{0.76}Se$–ZnSe MQW and a ZnSe–ZnTe MQW of total thicknesses of 0.75 μm grown by metalorganic chemical vapor deposition on n-GaAs substrates, which consist of 50 periods of 5 nm $Cd_{0.24}Zn_{0.76}Se$ (or ZnTe) wells and 10 nm ZnSe barriers. The GaAs substrates were removed by etching to allow making FP cavities; the FP cavities are prepared according to the method described in our earlier work [4].

In both optical bistable devices, the reflectivities of the interface between the well and barrier layers in the CdZnSe–ZnSe MQW and the ZnSe–ZnTe MQW are about 1.6×10^{-4} and 8×10^{-2}, respectively [5,6], and the reflectivities of the front and back surfaces in the both FP cavities are about 0.35 and 0.9, respectively.

On the basis of the measuring setup describe in our earlier work [7], the room-temperature optical bistabilities in CdZnSe–ZnSe and ZnSe–ZnTe MQW etalons are measured. Figs. 1a and 1b show the accumulated and normalized temporal shapes of incident and transmitted pulses in the CdZnSe–ZnSe and ZnSe–ZnTe MQW etalons, respectively. On the basis of the change of transmitted intensities as a function of incident intensities, the optical bistabilities in the CdZnSe–ZnSe and ZnSe–ZnTe MQW etalons are obtained as shown in Figs. 2a and 2b.

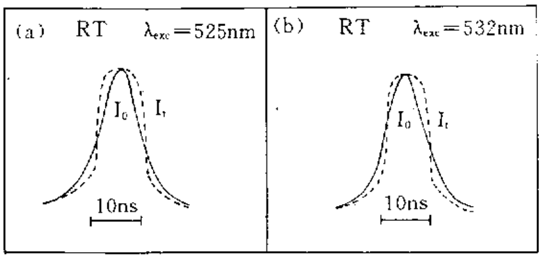

Fig. 1. Time dependence of averaged normalized incident (solid curve) I_0 and transimitted (dashed curve) I_t pulses (a) in the CdZnSe–ZnSe MQW etalon and (b) in the ZnSe–ZnTe MQW etalon.

From Figs. 2a and 2b, we can see that the thresholds I'_{th} in the CdZnSe–ZnSe and ZnSe–ZnTe MQW etalons are about 80 and 750 kW/cm^2, respectively. The threshold of the optical bistability in the CdZnSe–ZnSe MQW etalons is about one order lower than that in the ZnSe–ZnTe MQW etalons. Because the nonlinear threshold in the CdZnSe–ZnSe found in experiments (not shown here) is close to that in ZnSe–ZnTe and the structure parameters of the FP cavities are the same in both optical bistable devices, the different thresholds in both optical bistable devices should be due to the different light reflectivities in the CdZnSe–ZnSe and ZnSe–ZnTe MQW etalons. This indicates that the experimental results agree with the analyzed

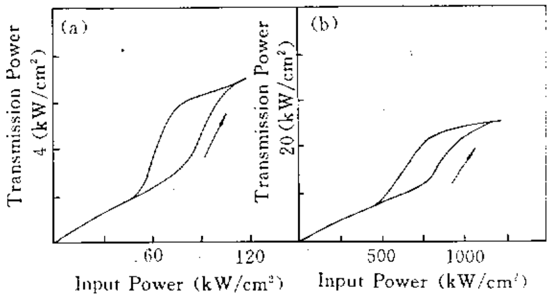

Fig. 2. The optical bistabilities (a) in the CdZnSe–ZnSe MQW etalon and (b) in the ZnSe–ZnTe MQW etalon.

results, i.e., the light interference effect in the MQW etalons can directly affect the threshold of the optical bistability in the MQW etalons. Therefore, in order to reduce the threshold of the optical bistability in the MQW etalons, it is necessary to consider the light interference effect in the MQW and use the material systems with smallest possible periodic number and reflectivity in the interface between the well and barrier layers in the MQW etalons.

4. Conclusions

We have studied the light interference effect in the optical bistability of MQW etalons, in which the light interference effect can be described by a simplified formula. The research results indicate that the light interference effect in the MQW etalons can affect the quality of the FP cavity and the threshold of the optical bistability in the MQW etalons. Particularly in the case of large periodic number and large reflectivity on the interface between the well and barrier layers in the MQW etalons, the effect cannot be neglected. In order to get the lowest possible threshold of optical bistability in the MQW etalons, it is necessary to reduce the values of the periodic number and the reflectivity of the interface between the well and barrier layers in the MQW etalons. The experimental results of the optical bistabilities in the CdZnSe–ZnSe and ZnSe–ZnTe MQW etalons measured here further support the above analyzed results and indicate that the optical bistable device in the CdZnSe–ZnSe MQW etalons is a better FP type optical bistable device because of the smaller light interference effect in the CdZnSe–ZnSe MQW etalons than that in the ZnSe–ZnTe MQW etalons.

5. Acknowledgements

This work is supported by the “863” High Technology Research Program in China, the National Fundamental and Applied Research Project of China, the National Natural Science Foundation of China and the Project of the Laboratory of Excited State Processes of Changchun Institute of Physics of China.

6. References

[1] Z. Garmire, IEEE J. Quantum Electron. QE-25 (1989) 289.

[2] H. Yokyama, IEEE J. Quantum Electron. QE-25 (1989) 1190.

[3] D.Z. Shen, Optical nonlinearities and optical bistability in ZnSe–ZnS MQW, Chinese Doctor Thesis, Changchun Institute of Physics, Academia Sinica, Jilin, Changchun (1993).

[4] D.Z. Shen, X.W. Fan, B.J. Yang and J.M. Sun, presented at Int. Conf. on Solid State Devices and Materials, Japan, 1993.

[5] W.J. Walecki, A.V. Nurmikko, N. Samarth, H. Luo and J.K. Furdyna, J. Opt. Soc. Am. B 8 (1991) 1799.

[6] D.T.F. Marple, J. Appl. Phys. 35 (1964) 539.

[7] D.Z. Shen, X.W. Fan and G.H. Fan, Nonlinear Opt. 1 (1992) 319.