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Optical bistability in ZnSe–ZnS superlattices with a Fabry–Pérot cavity

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A Fabry–Pérot (FP) cavity is prepared by the vacuum deposition method on ZnSe–ZnS superlattices grown on CaF_2. Optical bistability (OB) of excitonic origin is observed at a wavelength of 440 nm in ZnSe–ZnS superlattices on CaF_2 with FP cavity for the first time.

1. Introduction

Optical bistable elements were studied extensively in the last few years because of the possible applications for optical switching and modulation. These elements are based on nonlinear absorption and dispersion. A FP resonator is needed in the case of dispersive bistability. In the study of optical bistable devices, Gibbs et al. [1] have reported the bistable action of nonlinear refraction with a FP etalon due to excitonic saturation in GaAs/AlGaAs multiple quantum wells (MQWs). Thermal dispersive OB and absorptive bistability have been observed in bulk ZnSe with parallel polished planes, forming a natural-reflectivity, low-fineness FP etalon [2]. Recently, we have reported the transmission OB in ZnSe–ZnS MQWs grown by MOCVD on GaAs substrates at 77 K [3]. It should be noted that the FP cavity consisted of the two natural faces of ZnSe–ZnS MQWs as the GaAs substrate was removed. This paper describes the first observation of the transmission OB at 77 K in ZnSe–ZnS superlattices on CaF_2 substrates with a FP cavity prepared by the vacuum deposition method and the origin of the OB is found to be attributable to the excitonic OB.

2. Experimental procedure

2.1. Preparation of FP cavity

ZnSe–ZnS superlattices are grown by MOCVD on 300 μm thick CaF_2 substrates, which are cleaved along the $\langle 111 \rangle$ direction, commencing with a 0.3 μm ZnS buffer layer, followed by the 0.8–1.6 μm thick ZnSe–ZnS superlattices, which consist of 8 nm wells and 8 nm barries repeated for 50–100 periods.

The FP cavity used in our research is made by vacuum deposition with a thermal source under a background pressure of 10^{-6} Torr. The reflective layer is made according to the prescription: $(HL)^p(H')\ (LH)^p$, where $p = 5$. The notation $(HL)^p$ implies a quarter-wave of high-index material, H, followed by a quarter-wave of low-index material, L, p times. The region H' is the ZnSe–ZnS superlattice; here $H' = 1.1$ μm. The high-index material is ZnS with refractive index n_{h} of 2.35. The low-index material used is cryolite (Na_3AlF_6) with refractive index n_{l} of 1.35. The quarter-wave layers, having ZnS and Na_3AlF_6 alternatively, are deposited on the up-side of the superlattice layer and the down-side of the CaF_2 respectively. Care is taken to achieve a nearly

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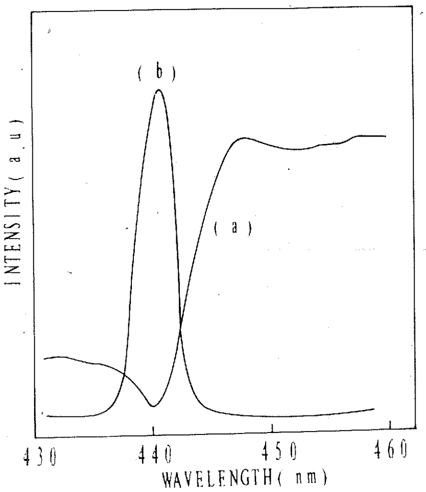

Fig. 1. Absorption (a) and emission (b) spectra in ZnSe–ZnS superlattices on CaF_2 substrate at 77 K.

perfect match in reflectance of the two dielectric mirrors, $(HL)^5$ and $(LH)^5$ respectively.

2.2. *Selection of peak transmission wavelength of FP cavity*

Our early work [4] was focused on the luminescence properties of ZnSe–ZnS superlattices. It was found that a intense emission band E_s could be obtained in the photoluminescence spectra of the ZnSe–ZnS superlattices. This band, E_s, was attributed to the free exciton recombination following scattering from free electrons. In order to obtain excitonic OB in ZnSe–ZnS superlattices, it is necessary that the transmission wavelength (λ_0) of FP cavity in the ZnSe–ZnS superlattices is selected to be at the excitonic emission and absorption regions of the samples. In our case, the emission and absorption bands of the superlattice samples with 50 periods of ZnSe (8 nm)–ZnS (8 nm) are at 440 nm, as shown in fig. 1. So the transmission wavelength λ_0 of FP cavity should be controlled at 440 nm.

2.3. *Optical properties of FP cavity*

The reflective layer is deposited on the surface of the CaF_2 substrate, on which ZnSe–ZnS superlattices are not grown. Its reflective spectrum is measured by a Model U-V 3000 spectrophotometer. The reflectivity is 70% over wavelength range 420 to 540 nm, as shown in fig. 2. Then an entire FP cavity consisting of two reflective faces on the top of the superlattice layer and bottom of the CaF_2 substrate is made. The peak transmission wavelength λ_0 of samples with FP cavity is measured and shown in fig. 3. From fig. 3, λ_0 is at 445 nm and has a full width at half-maximum (FWHM) of 23 nm. The transmission is 50%.

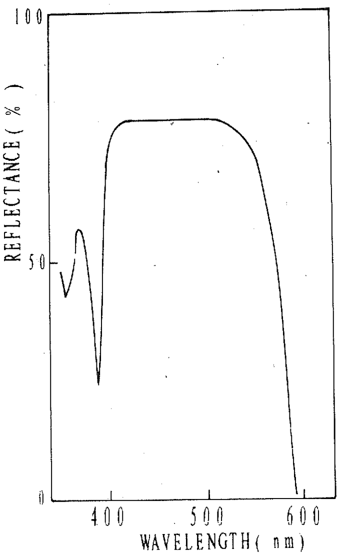

Fig. 2. Reflectivity spectrum for structure with 5 periods of ZnS and Na_3AlF_6 alternate layers on CaF_2 substrates.

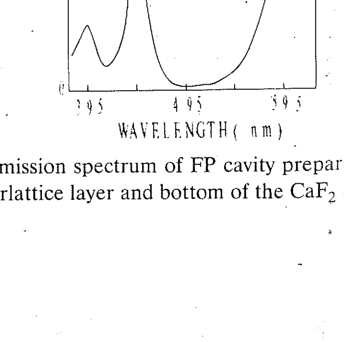

Fig. 3. Transmission spectrum of FP cavity prepared between top of superlattice layer and bottom of the CaF_2 substrate.

Here $\lambda_0 = 445$ nm deviates slightly from the selected wavelength 440 nm and its FWHM is wider.

3. Optical bistability properties

The excitation source was generated by a dye laser, using Coumarin-440, pumped by a Model UV-24 N_2 laser. The dye laser pulse has a FWHM of 4 nm with a central wavelength of 440 nm and a duration FWHM of 10 ns. The time dependence of the incident I_0 and transmitted I_t pulses was measured using a Model 4400 Boxcar [3].

In order to clearly assertain the influence of the FP cavity, a number of ZnSe–ZnS superlattice samples are selected. When the samples have no FP cavity, the I_0 and I_t shapes are the same. However, when the samples have a FP cavity, the I_t has an apparent change. The changes of I_0 and I_t are shown in fig. 4. It is clear that when the FWHM of the time duration of the incident I_0 is 10 ns, that of the transmitted I_t is reduced to 5 ns. There is an apparent effect of transmission light pulse compression near 440 nm with a switching intensity of 70 mW/μm^2. According to the changes in I_0 and I_t, the OB loop is obtained and is shown in fig. 5. The curves 5a and 5b indicate the change of I_0 and I_t when the samples have no FP cavity and when they have FP cavity, respectively.

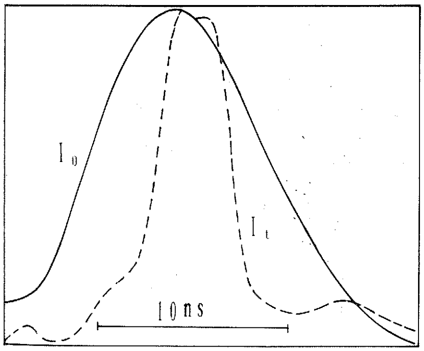

Fig. 4. Time dependence of averaged normalized incident I_0 (solid curve) and transmitted I_t (broken curve) in ZnSe–ZnS on CaF_2 with FP cavity at 77 K.

4. Discussion

According to the result of fig. 2 and the theory of FP etalon, we can calculate the transmission of the FP etalon. In the presence of loss, the nonlinear FP etalon transmission T is written as [5]

$$T = A/(1 + F\sin^2\Delta), \tag{1}$$

where

$$A = \exp(-\alpha L)\,(1 - R_F)(1 - R_B)/(1 - R_e)^2, \tag{1a}$$

$$F = 4R_e/(1 - R_e)^2, \tag{1b}$$

$$\Delta = (2\pi/\lambda)nL, \tag{1c}$$

$$R_e = (R_F R_B)^{1/2}\exp(-\alpha L). \tag{1d}$$

Here, the etalon front and rear reflectivities are R_F and R_B, the thickness is L, the refractive index is n, the transmission wavelength is λ, the absorption coefficient is α, the effective reflectivity is R_e and the coefficient of fineness is F. In our cases, α is about 10^3 cm^{-1} and L is 1.1 μm. n should be taken to be the average value as H' consists of both ZnSe and ZnS layers. In addition, it is possible that R_F, the reflectivity of the medium film prepared on the ZnSe–ZnS superlattices, is lower than R_B because of the difference in quality between the superlattice surface and the cleaved face of CaF_2. We suppose that this R_F is higher than the reflectivity R' of the ZnSe–ZnS superlattice natural face which has no FP cavity. Here, R_F is taken to be 0.45 [3]. Calculating the transmission T in ZnSe–ZnS superlattices with a FP cavity gives a value of 55% using the above parameters. This value is in agreement with the measured one in fig. 3. Olbright et al. [6] have reported the OB of thermal origin in ZnS and ZnSe interference filters that have a transmission $T = 60\%$ at room temperature. This result indicates that above OB, the result obtained in the ZnSe–ZnS superlattices with FP cavity is reasonable.

In fig. 3 the peak transmission wavelength λ_0 is 445 nm. It slightly deviates from the selected wavelength (440 nm) by about 5 nm. From eq. (1c) [5], we see that the λ in the FP etalon

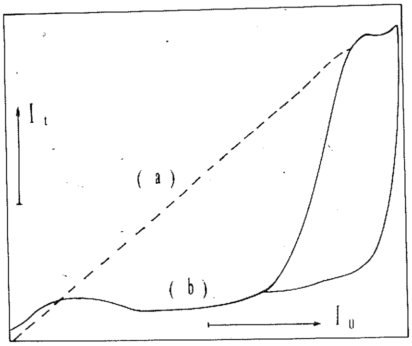

Fig. 5. Hysteresis loops $I_t = f(I_0)$ of ZnSe–ZnS superlattices on CaF_2 (a) without FP cavity and (b) with FP cavity, corresponding to results shown in fig. 4.

changes with the optical thickness nL. In our case, nL is the superlattice thickness H'. It may be that the deviation between λ_0 (445 nm) in fig. 3 and the selected wavelength (440 nm) results from the error in H'. It is necessary to control the optical thickness in order to obtain the desired value of λ_0 in the FP etalon. This will have the great advantage of reducing the switching intensity of the OB.

On the basis of our work [4,5], the origin of the OB in the ZnSe–ZnS superlattices on CaF_2 substrates with a FP cavity should be attributed to excitonic OB because the exciting wavelength is located in the excitonic resonance region.

In conclusion, a FP cavity for a ZnSe–ZnS superlattice on CaF_2 has been prepared and optical bistability of excitonic origin has been observed for the first time.

Acknowledgements

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References

[1] H. Gibbs, S. Tang, J. Jewell, D. Weinberger, K. Tai, A. Gossard, S. McCall, A. Passner and W. Weigman, Appl. Phys. Letters 41 (1982) 221.
[2] A. Kar and B. Wherrent, J. Opt. Soc. Am. B 3 (1985) 345.
[3] D.Z. Shen, X.W. Fan, G.H. Fan and J.Y. Zhang, J. Luminescence 48&49 (1991) 299.
[4] X.W. Fan, G.H. Fan, D.Z. Shen, Z.P. Guan, F.Y. Jiang and J.Y. Zhang, presented at C-MRS-90 Intern. Conf., Beijing, 1990.
[5] E. Garmire, IEEE J. Quantum Electron. QE-25 (1989) 289.
[6] G. Olbright, N. Peyghambarian, H. Gibbs, H. Macleod and F. Milligen, Appl. Phys. Letters 45 (1984) 103.