بیست و سومین کنفرانس اپتیک و فوتونیک و نهمین کنفرانس مهندسی و فناوری فوتونیک ایران
دانشگاه تربیت مدرس
۱۲-۱۴ بهمن ۱۳۹۵
23rd Iranian Conference on Optics and Photonics and 9th Conference on Photonics Engineering and Technology
Tarbiat Modares University, Tehran, Iran
January 31- February 2, 2017

بهبود مشخصات فنی ادوات نیمه‌هادی نور آهسته چند چاه کوانتومی مبتنی بر روش نوسانات جمعی همدوس

سعید عبدالحسینی، حسن کاتوزیان، بهرام چوپان زاده و رضا کهندانی

ایران، تهران، دانشگاه صنعتی امیرکبیر، دانشکده مهندسی برق، آزمایشگاه تحقیقاتی فتونیک

چکیده - این مقاله اثرات تغییر ابعاد فیزیکی بر روی پارامترهای نوری یک سیستم نور آهسته با ساختار چاه‌های کوانتومی چندگانه از جنس گالیم آرسناید و آلومینیوم گالیم آرسناید بر اساس روش نوسانات جمعی همدوس را نشان می‌دهد. این ابعاد فیزیکی شامل طول و تعداد چاه کوانتومی می‌باشد. به منظور تحلیل و شبیه‌سازی پارامترهای مختلف دستگاه نور آهسته از معادلات بلوخ استفاده شده است. این مقاله چندین روش به منظور تنظیم فرکانس مرکزی و پارامتر کاهش سرعت نور در دستگاه نور آهسته ارائه می‌دهد. براساس روش‌های پیشنهادی، ما قادر به بهبود پارامترهای نوری یک سیستم نور آهسته با ساختار چاه‌های کوانتومی چندگانه هستیم. براساس نتایج شبیه‌سازی‌ها، ماکزیمم مقدار پارامتر کاهش سرعت نور می‌تواند با تغییر در پارامترهای فیزیکی در محدوده $۳×۱۰^{۵}$ به دست آید.

کلید واژه- تعداد چاه‌های کوانتومی، طول چاه‌های کوانتومی، چاه‌های کوانتومی چندگانه، سیستم نورآهسته، نوسانات جمعی همدوس.

Technical Characteristics Improvement of Multiple Quantum Well Semiconductor Slow Light Devices Based on Excitonic Population Oscillations

Saeed Abdolhosseini, Hassan Kaatuzian, Bahram Choupanzadeh, and Reza Kohandani

Photonics Research Laboratory (PRL), Department of Electrical Engineering,
Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran

Abstract- This article indicates the effects of physical dimensions variations on optical properties of GaAs/AlGaAs multiple quantum well (MQW) slow light devices based on coherent population oscillations (CPO) method. These physical parameters include, quantum well size and number. Bloch equations have been used to analyze and simulate the device with different parameters. This paper offers several methods for tuning the central frequency and slow down factor (SDF) of the slow light device. Based on these proposed approaches, we could improve optical properties of MQW slow light devices. According to simulation results, the maximum value of SDF can be achieved in a range of $3×10^5$ with variations of physical parameters.

Keywords: quantum wells number, quantum wells size, multiple quantum well, slow light device, coherent population oscillations.

Technical Characteristics Improvement of Multiple Quantum Well Semiconductor Slow Light Devices Based on Excitonic Population Oscillations

Saeed Abdolhosseini **Hassan Kaatuzian** **Bahram Choupanzadeh** **Reza Kohandani**

s.abdolhosseini@aut.ac.ir hsnkato@aut.ac.ir choupanzadeh@aut.ac.ir rezakohandani.a@aut.ac.ir

1 Introduction

There are a lot of reports about the reduction of speed of light in various media and it is because of slow light benefits in optical systems. Thus, experts have invented different ways to reach best values of optical parameters for slow light devices [1]. The structure parameters and type of materials play an important role in each of methods [2].

CPO and EIT are important techniques in order to reduce the speed of light because they use semiconductor materials [2], [3]. Slow light devices with semiconductor materials have many benefits. One of the advantages of using semiconductors in slow light devices is compatibility with other optical systems and integrated circuits [4]. In contrast to EIT method, CPO technique requires a long relaxation time [5]. Slow light devices have useful applications in optical systems [6].

Quantum dots (QDs) and QWs structures are used for slow light purpose based on exciton population oscillations method [5]. Effects of physical parameters variations have already been investigated on QWs and QDs structures [7], [8] but we look into impacts of QWs size and number simultaneous alterations in optical properties of slow light device based on CPO method. In other words, physical parameters play an important role in optical outputs of the slow light system. Therefore, these changes are caused to obtain suitable values of optical parameters of the device.

In this article, firstly, we simulate GaAs/AlGaAs MQW slow light device based on exciton population oscillation method. Next, we show the effects changes in number of QWs on SDF and real part of the refractive index. Then, we illustrate refractive index and SDF for central frequency and QWs size simultaneous variations. Moreover, we display maximum value of SDF and central frequency shifts for different values of QWs size and numbers at the same time. Finally, we can adjust values of physical parameters including QWs numbers and size concurrently due to reach an appropriate profit of slow light appliance.

2 Theory

2.1 GaAs/AlGaAs MQW Slow Light Device According to CPO

Figure 1 displays experimental structure of GaAs/AlGaAs MQW slow light system. Slow light systems need sharp alterations of refractive index in order to reduce group velocity. In CPO method, if the difference between signal and pump frequency is near the reverse of exciton lifetime, a population oscillation will be created. This population oscillation will cause a hole in the absorption curve and consequently a sharp variation in refractive index.

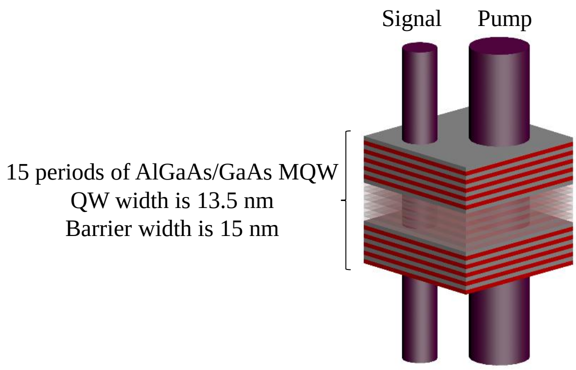

Figure 1: Experimental structure of MQW slow light device including pump and signal.

Semiconductor Bloch equations are worked out to provide refractive index and dispersion of slow light device[7]. Refractive index, absorption and slow down factor (SDF) specified, respectively, as follows:

$$n_S\left(\omega_S\right) = \sqrt{\varepsilon_S\left(\omega_S\right)} \quad (1)$$

$$A_S\left(\omega_S\right) = 2\,\frac{\omega_S}{c}\,Im\left[n_S\left(\omega_S\right)\right] \quad (2)$$

$$R_S\left(\omega_S\right) = Re\left[n_S\left(\omega_S\right)\right] + \omega_S\,\frac{\partial Re\left[n_S\left(\omega_S\right)\right]}{\partial \omega_S} \quad (3)$$

where $\varepsilon_S(\omega_S)$ linear relative permittivity tensor that obtains based on relevant optical equations in semiconductors in the steady state area [7]. Where pump frequency is near signal frequency, we obtain gradient in absorption scheme because of induced population beating. These variations of absorbance in zero pump-signal frequency are led to provide positive modifications of refractive index in short range of zero detuning frequency[7].

2.2 Impacts of Quantum Well Thickness Alteration

In this section, we look into effects of well width variations on characteristics of slow light device. Based on reference [9], changes of well thickness make different amounts of binding energy. By increasing well thickness the binding energy will be reduced. Hence, changes of QWs thickness should be considered in the simulation of slow light device, whereas exciton energy is a function of binding energy. Changes of exciton energy are opposite of variations of binding energy. Thus, we expect that increment of QWs thickness will be led to increasing the exciton energy. Alterations of QWs width are also caused to change the effective length of MQW slow light device.

Figure 2 illustrates impacts of well width changes on real part of refractive index and SDF. As it can be seen in this curve, an increase in QW thickness, makes smooth slope in refractive index and consequently it will decrease the amount of SDF for large value of QWs width. The main reason of SDF alterations is the effect of well width variations on MQW effective length.

Another optical property that we should pay attention to Figure 2 is the central frequency of the slow light system. Increment and reduction of QW thickness change the central frequency and lead to shift of central frequency. The reason of focal frequency shift is alterations of binding energy due to well width changes.

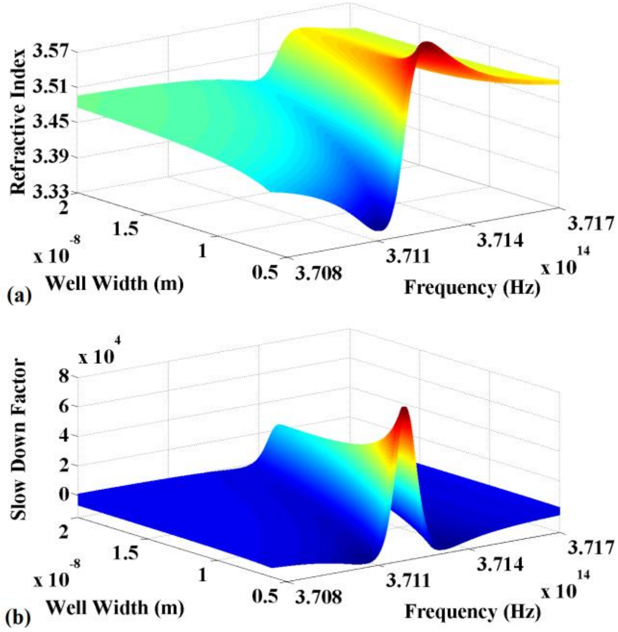

Figure 2: Variations of (a) refractive index and (b) slow down factor as a function of frequency and QW widths.

2.3 Impacts of Quantum Wells Number Variation

Effects of change in number of quantum wells are investigated in this part. Effective length is related to QWs size and number. We consider constant value for QWs width in this part. Therefore, the increment of QWs number is caused to increase the effective length of the device. Effective length has direct impact on linear relative permittivity tensor and could change it.

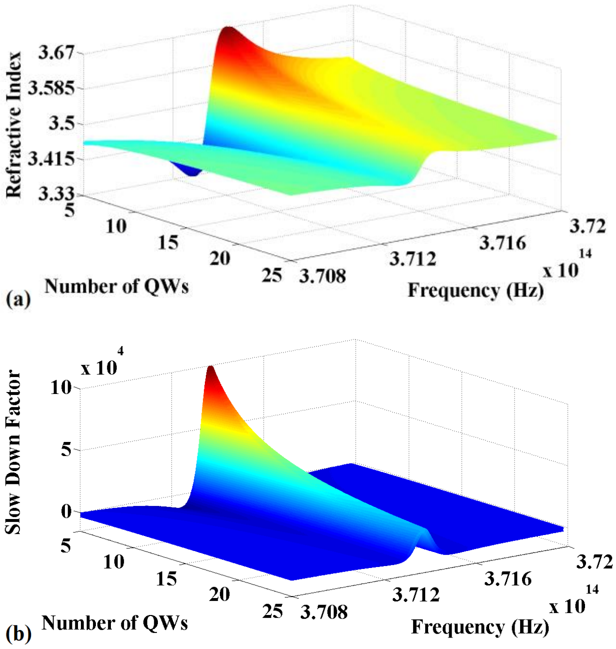

Figure 3: (a) real part of refractive index (b) the SDF as a function of frequency and number of QWs.

Figure 3 displays SDF and real part of refractive index as a function of QWs number and frequency. According to simulation results, QWs number reduction makes a sharp dip in refractive index scheme due to decrease of effective length.

3 Results and Discussion

Based on mentioned theory in previous parts, alterations of QWs size are caused to change binding energy and the effective length of MQW slow light device and variations of these parameters are led to reach different values of SDF and central frequency shift. The maximum value of SDF is also related to QWs number.

Figure 4 demonstrates variations of SDF maximum value and central frequency shift as a function of QWs size and number at the same time. According to these simulation results, the central frequency shift is not related to QWs numbers and just has a relation with QWs size. When QWs width increases, focal frequency shift goes up. Both of QWs size and number have relation with maximum value of SDF. Reduction of QWs number is led to decrease the effective length of the slow light device and it is caused to increase the maximum value of SDF. QWs thickness increment is occasioned exciton energy increase and enhancement of effective length. These variations are led to decrease of SDF maximum value.

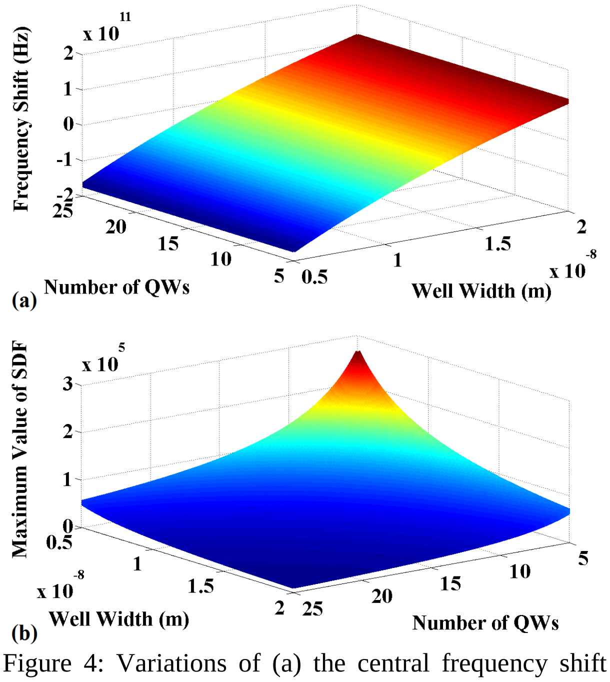

Figure 4: Variations of (a) the central frequency shift and (b) the slow down factor due to alterations of QW width and QWs number simultaneously.

4 Conclusions

This article looked into impacts of simultaneous alterations of QWs width and number in MQW slow light device based on CPO method. The impacts of variations in QWs width and number on optical parameters of slow light devices, such as maximum amount of SDF and the focal frequency has been completely investigated. Based on the best results, the simultaneous reduction of number and size of QWs is led to reach maximum value of SDF about 3×10^5 that it is 10 times greater than the experimental result in reference [5].

References

[1] D. J. Gauthier, A. L. Gaeta, and R. W. Boyd, “Slow light: from basics to future prospects,” *Photon. Spec.*, Vol. 40, No. 3, pp. 44-50, 2006.

[2] J. B. Khurgin, and R. S. Tucker, *Slow light Science and Applications*, CRC, 2009.

[3] H. Kaatuzian, *Photonics*, 2nd ed, Vol. 2, in Persian, AKU press, 2009.

[4] C. J. Chang-Hasnain, P. C. Ku, J. Kim, and S. L. Chuang, “Variable optical buffer using slow light in semiconductor nanostructures,” *Proc. IEEE*, Vol. 91, No. 11, pp. 1884–1896, 2003.

[5] S. W. Chang, S. L. Chuang, P. C. Ku, C. J. Chang-Hasnian, P. Palinginis, and H. Wang, “Slow light using excitonic population oscillation,” *Phys. Rev. B*, Vol. 70, No. 23, pp. 235-333, 2004.

[6] W. Yan, T. Wang, X. M. Li, and Y. J. Jin, “Electromagnetically induced transparency and theoretical slow light in semiconductor multiple quantum wells,” *Appl. Phys. B*, Vol. 108, No. 3, pp. 515–519, 2012.

[7] R. Kohandani, A. Zandi, and H. Kaatuzian, “Analysis of the effects of applying external fields and device dimensions alterations on GaAs/AlGaAs multiple quantum well slow light devices based on excitonic population oscillation,” *Appl. Opt.*, Vol. 53, No. 6, pp. 1228–1236, 2014.

[8] B. Choupanzadeh, H. Kaatuzian, R. Kohandani, and S. Abdolhosseini, “Simulation and characteristics improvement of quantum dot slow light devices by geometrical dimension alteration,” *Opt. Photonics J.*, Vol. 6, No. 8, pp. 114-119, 2016.

[9] H. Mathieu, P. Lefebvre, and P. Christol, “Simple analytical method for calculating exciton binding energies in semiconductor quantum wells,” *Phys. Rev. B*, Vol. 46, No. 7, pp. 4092-4101, 1992.