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بهینه‌سازی عملکرد لیزر فانو با بهبود ساختار نانوکاواک

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چکیده- در این مقاله ساختار یک لیزر فانو بلورفوتونی بررسی شده است. تاثیر شعاع حفره‌های هوا اطراف نانوکاواک بر عملکرد لیزر فانو بررسی شده است. در این شبیه سازی از روش المان محدود سه بعدی برای حل معادلات حاکم استفاده شده است. بر اساس نتایج تجربی موجود عملکرد لیزر فانو برای شعاع حفره‌ها ۱۰۹ بررسی شده است. جهت دستیابی به یک پالس استاندارد گوسین با کمترین مقدار پهنا و بیشترین مقدار انتقال، شعاع حفره‌های اطراف نانوکاواک از ۵۰ نانومتر تا ۱۳۰ نانومتر تغییر داده شده است. با توجه به شبیه سازی انجام شده بهترین عملکرد لیزر برای حفره‌های اطراف نانوکاواک با شعاع ۸۰ نانومتر مشاهده شده است. برای این شعاع پهنای پالس ۲۲/۸۷۸ گیگاهرتز، بیشینه انتقال ۰/۹۵۷۸ و میزان مشابهت با پالس گوسین استاندارد ۰/۹۹۷۱ محاسبه شده است.

کلید واژه- لیزر فانو، حفره هوا، انتقال، انعکاس، نانوکاواک

The performance Optimization of Fano laser by modifying the structure of the nanocavity

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Abstract- In this paper, we analyze the performance of the photonic crystal Fano laser. Our aim is to investigate the effects of modifying the nanocavity structure by changing the air holes radius around nanocavity on the Fano laser performance. 3-D Finite Element Method is used to solve the governing equations of the Fano laser. The Fano laser performance the air holes radius of 109 nm was experimentally reported recently. To achieve optimized output pulse, the air holes radius around nanocavity is changed from 50 nm to 130 nm. This optimized pulse should have standard Gaussian pulse shape, with minimum achievable full width at half maximum (FWHM) and maximum transmission. Based on our simulation the optimized Fano laser performance for the air holes radius around nanocavity of 80 nm is observed. For this radius, the FWHM, maximum transmission and correlation with standard Gaussian pulse, 22.878GHz, 0.9578 and 0.9971 are respectively computed.

Keywords: Fano laser, air hole, transmission, reflectivity, nanocavity

1. Introduction

Nowdays, due to the trends of technology, the need for expanding the bandwidth and data processing speeds in telecommunication links is increasing rapidly. In optical networks, due to the use of photons instead of electrons as an information carrier, the speed of information processing and the capacity of communication networks increases significantly.

Recently, with the introduction of defects in photonic crystal, high-quality cavities and ultra-compact lasers have been reported. Two types of photonic crystal lasers are point defect laser and linear defect laser [1]. These lasers have many advantages, such as very low power consumption, very high speed [2], and self-pulsing operation [3]. In conventional photonic crystal lasers, terminated waveguide, act as reflection mirror [4].

A new type of photonic crystal laser so-called the Fano laser. For the first time, the Fano laser structure was introduced by Mork et.al [2]. The two mirrors of this laser are: a broadband mirror that made by termination of the waveguide and a narrow-band mirror, that called Fano mirror [5]. Then, in 2016, it was shown that this type of a laser can generate pulses at gigahertz frequencies [5]. In 2017, laser performance was extensively investigated and its two regimes of operation (continuous wave and self-pulsing regimes) are investigated [3]. In 2018, the large and small signal response of this type of lasers was analyzed [1]. Finally, in 2019, a small-signal equivalent circuit model of photonic crystal Fano laser was developed [6]. Also in the same year, the effect of optical confinement factor on photonic crystal Fano laser performance was investigated [7].

In this paper, we first discuss about the structure of the Fano laser. Then the reflection and transmission spectra of the Fano structure are analyzed by using 3D finite element method in COMSOL software. Finally, the effect of variation of the air holes radius around the nanocavity on the Fano laser performance is investigated.

2. Fano Laser Structure

In [7] the Fano laser structure is shown. This structure is composed of a line defect waveguide and two mirrors in a InP membrane. The left mirror is a conventional mirror. The right mirror is based on the Fano resonance, also called the Fano mirror [7]. In this structure, the lattice constant, the radius of the holes and the thickness of the air holes are 464 nm, 109 nm and 300 nm, respectively. The governing equation for modelling the presented structure are mentioned in [7].

3. Simulation Results

The results of these simulations are as follows. First, we investigate the laser performance for air holes with radius (r_n) of 109 nm. This structure experimentally was investigated in [8]. We assume this structure as reference structure in this paper. Then in order to optimize Fano laser operation, we vary the r_n. The FWHM, maximum transmission and similarity with a standard Gaussian pulse for every r_n are computed. As depicted in inset figure of Fig. 3, for the radius of the air holes beyond $r_n \geq 114$ nm the output pulse is split. the vertical red dashed line in following Figs. 3,4 and 5, represent the radius in which after that double peak phenomena take place in cross port (CP) spectra of Fano structure.

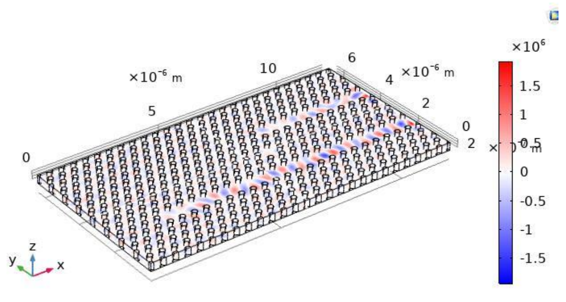

Fig.1: Distribution of magnetic field (H_z) in the Fano Laser Structure

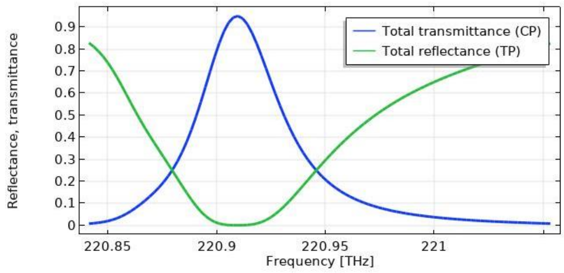

Fig.2: Transmission and reflection characteristics of the Fano laser structure shown in Fig. 1

3.1. Investigation of Laser Performance for the r_n of 109 nm

In this structure, an external continues wave optical field is launched to the waveguide. Due to the Fano interference between the waveguide modes and the discrete resonance of the nanocavity, the optical field is reflected in the laser waveguide and resonance condition is satisfied for specified frequencies. Fig. 1, depicts the optical field propagating in the photonic crystal waveguide, nanocavity and the laser CP. The nanocavity couples the optical field to the CP.

Fig. 2 shows the spectra of the transmission and reflection coefficient. The transmission coefficient is calculated by the ratio of the power emerging from the CP to the input power. Also the reflection coefficient is calculated by the ratio of the reflected power from the nanocavity to the input power. As demonstrated in this figure, at resonance frequency of the nanocvaity the reflection coefficient has a peak and the corresponding transmission spectrum has dip which shows that most of the power in the resonance condition couples to the CP.

3.2. The Effect the r_n Variation

To find minimum achievable FWHM of CP output pulse r_n is changed. As shown in Fig. 3 the variation of FWHM curve is non-uniform. The maximum and minimum FWHM occur in r_n of 125 nm and 80 nm respectively. Based on our calculations, the reference structure FWHM is 39.226 GHz. As shown in Fig. 3 r_n of 80 nm has the best FWHM which is 22.878 GHz. Moreover, as discussed before the output pulse is split from r_n=114 nm (inset figure in Fig. 3).

In optical communication networks, desirable pulse shapes are hyperbolic-secant or Gaussian. To find out the similarity of the output CP pulse of the Fano laser and the sample Gaussian pulse, the correlation coefficient between these two pulses is calculated. When this correlation coefficient become closer to 1, the similarity between these the two pulses becomes greater. To make fair comparison between these two pulses, the FWHM of sample Gaussian pulse is selected to be the same as the FWHM of output CP pulse. The Gaussian pulse (P_G) defined as [9]:

$$P_G = \exp\left(-T^2/2T_0^2\right) \quad (9)$$

$$T_{FWHM} = 2(\ln 2)^{1/2} T_0 \approx 1.665\, T_0 \quad (10)$$

As shown in Fig. 4, the r_n of 80 nm has the maximum correlation coefficient (0.9971).

Another important parameter in the Fano laser is power of the output CP pulse. As shown in Fig. 5, the maximum output CP power occur at r_n of the 90 nm. However, at r_n of the 80 nm and 109 nm (reference radius), the normalized CP power become 0.9578 and 0.9502, respectively. Finally, it can be concluded by changing the r_n, one can find optimum performance of Fano laser. Since the 80 nm radius has the lowest FWHM, the highest correlation coefficient and the peak power of the output is higher than the reference structure, it can be concluded that in this radius, the Fano laser has the best performance.

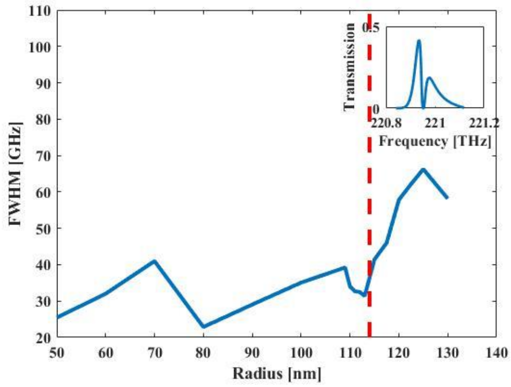

Fig. 3: FWHM dependency to r_n. The inset figure is the double peak pulse which occur in transmission spectra of CP for r_n =114 nm. The vertical red dashed line represents the radius in which after that the double peak phenomena in CP spectra take place.

4. Conclusion

In this paper, the Fano laser performance was optimized. 3D finite element method was employed to simulate the laser operation. The effects the r_n variation were investigated on performance of Fano laser. It was shown that the best performance of the Fano laser occurs in the r_n of 80 nm. For this r_n, the FWHM, maximum normalized CP power and correlation of CP pulse with standard Gaussian pulse, were 22.878 GHz, 0.9578 and 0.9971 respectively.

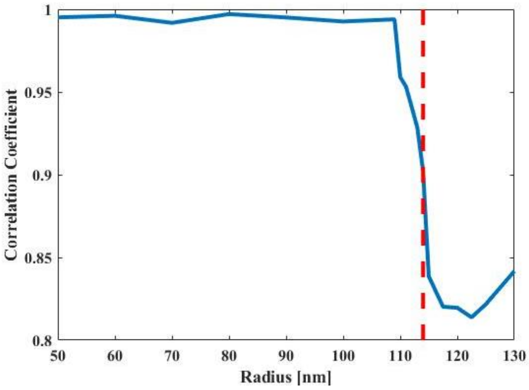

Fig. 4: Correlation coefficient dependency to r_n. The vertical red dashed line represents the radius in which after that the double peak phenomena in CP spectra take place.

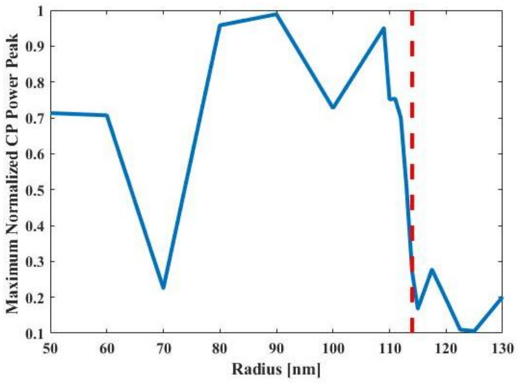

Fig. 5: maximum transmission peak versus r_n. The vertical red dashed line represents the radius in which after that the double peak phenomena in CP spectra take place.

References

[1] A. R. Zali, M. K. Moravvej-Farshi, Y. Yu, and J. Mork, "Small and Large Signal Analysis of Photonic Crystal Fano Laser," *Journal of Lightwave Technology*, 2018.

[2] J. Mork, Y. Chen, and M. Heuck, "Photonic crystal Fano laser: terahertz modulation and ultrashort pulse generation," *Physical review letters*, vol. 113, p. 163901, 2014.

[3] T. S. Rasmussen, Y. Yu, and J. Mork, "Theory of Self-pulsing in Photonic Crystal Fano Lasers," *Laser & Photonics Reviews*, vol. 11, p. 1700089, 2017.

[4] J. O'Brien, O. Painter, R. Lee, C.-C. Cheng, A. Yariv, and A. Scherer, "Lasers incorporating 2D photonic bandgap mirrors," *Electronics Letters*, vol. 32, pp. 2243-2244, 1996.

[5] Y. Yu, W. Xue, E. Semenova, K. Yvind, and J. Mork, "Demonstration of a self-pulsing photonic crystal Fano laser," *Nature Photonics*, vol. 11, p. 81, 12/12/online 2016.

[6] A. R. Zali, M. K. Moravvej-Farshi, and M. H. Yavari, "Small-Signal Equivalent Circuit Model of Photonic Crystal Fano Laser," *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 25, pp. 1-8, 2019.

[7] G. Hamzeh, M. Razaghi and A. R. Zali, " Investigation of optical confinement factor effect on photonic crystal Fano laser performance," in The 25th Iranian Conference on Optics and Photonics, pp. 1129-1132, Iran, 2019.

[8] J. Mork, Y. Yu, T. S. Rasmussen, E. Semenova, and K. Yvind, "Semiconductor Fano Lasers," *IEEE Journal of Selected Topics in Quantum Electronics*, 2019.

[9] GP. Agrawal, *Nonlinear Fiber Optics*, Academic Press, pp. 57-85, 2013.