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# محدوده نور کند با پاشندگی پایین در موجبر های بلور فوتونی با ساختار حفره از طریق پر کردن حفره های هوا با سیلیکون نایتراید

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**چکیده – در این مقاله با استفاده از قرار دادن استوانه هایی از جنس سیلیکون نایتراید ($Si_3N_4$) در داخل حفره های هوا، در موجبر تیغه ای W09با ساختار بلور فوتونی، به رژیم نور کند ( $n_g$=24.89، $n_g\times\Delta\omega/\omega_c$=0.219) با پاشندگی پایین ($\beta_2$<250)، به صورت تئوری، دست یافته ایم. حفره های هوا به صورت مثلثی در بستری از جنس سیلیکون با ثابت شبکه *a* و شعاع r=0.3a ایجاد شده اند. استوانه های $Si_3N_4$ در دو ردیف مجاور موجبر، در هر دو طرف، رشد داده شده اند. از روش 3D-FDTD برای به دست آوردن نتایج استفاده شده است.**

کلید واژه- بلور فوتونی، پاشندگی، نور کند

# Low dispersion slow light regime in hole-type photonic crystal waveguides by means of filling of air holes with Silicon Nitride

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Abstract- In this paper, we have achieved low dispersion ($\beta_2$<250) slow light regime ($n_g$=24.89, $n_g\times\Delta\omega/\omega_c$=0.219) in a W09 photonic crystal slab waveguide by means of filling of the air holes with Silicon Nitride ($Si_3N_4$), theoretically. Photonic crystal waveguide with the lattice constant ɑ, consists of air holes of radii r=0.3ɑ with hexagonal arrangement in a background of Silicon. $Si_3N_4$ rods are grown inside the air holes of 2 rows adjacent to the waveguide on both sides. 3D-FDTD method is employed to calculate the results.

Keywords: dispersion, Photonic crystal, slow light

# Low dispersion slow light regime in hole-type photonic crystal waveguides by means of filling of air holes with Silicon Nitride

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**Abstract:** *In this paper, we have achieved low dispersion ($\beta_2$<250) slow light regime ($n_g$=24.89, $n_g \times \Delta\omega/\omega_c$=0.219) in a W09 photonic crystal slab waveguide by means of filling of the air holes with Silicon Nitride ($Si_3N_4$), theoretically. Photonic crystal waveguide with the lattice constant a, consists of air holes of radii r=0.3a with hexagonal arrangement in a background of Silicon. $Si_3N_4$ rods are grown inside the air holes of 2 rows adjacent to the waveguide on both sides. 3D-FDTD method is employed to calculate the results.*

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## 1 Introduction

In recent years, slow light in photonic crystal (PhC) waveguides has been attracting wide attention because of their potential application in both nonlinear photonics and compact optical devices [1-8]. In particular, slow light planar photonic crystal waveguides have received much attention for their groundwork of optical delay lines and nonlinear optics. Light matter interaction augments due to the presence of slow light in the photonic crystal structures that results in longer time interval that light travels through the structure. Furthermore, typically the operating point of slow light in PhC is near the edge of Brillouin zone, which is a near-parabolic dispersion curve. Therefore, high group velocity dispersion (GVD) eliminates most advantages of slow light in PhC and severely limits the useful bandwidth [8]. This compromising issue that was quite a challenge for slow light in photonic crystal was compensated to some extend by dispersion engineering techniques by which the GVD can be optimized and yet the optical pulse shape is maintained intact [9-20].

In this paper we propose a dispersion engineering technique that leads to very low group velocity dispersion (GVD) values.

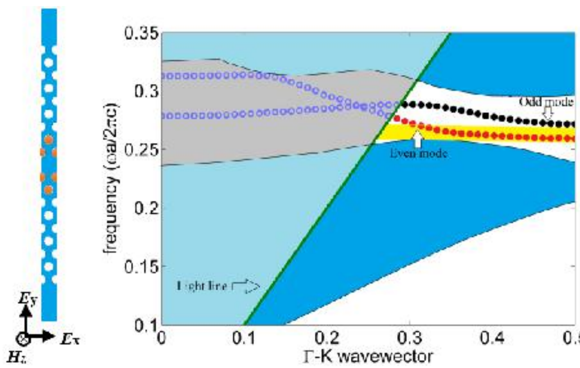
In the next section designing method and structure is introduced. In section two numerical results of the proposed structure are shown and we have finished the paper with the conclusion section.

## 2 Design and Structure

The photonic crystal (PhC) slab structure (with lattice constant *a*) consists of hexagonal arrangement of air holes of radii *r*=0.3*a* in a background of standard silicon (n=3.52 [9]). The silicon slab thickness is set to be t=0.524*a*.The W09 waveguide is formed by omitting one row of air holes in *Γ-K* direction and also narrowing the waveguide width to $0.9\times3^{0.5}$ *a*. The top view of the super cell of the waveguide and the calculated band structure for $TE(H_z, E_x, E_y)$ polarization in *Γ-K* direction are depicted in Fig. 1 a and b. 3D-FDTD method [21] is employed in calculating the band structure of the mentioned PhC waveguide. PBC and PML boundary conditions are used in x and y,z directions respectively in calculating the band structure.

Green solid line in Fig. 1b shows the light line. Red and black dots under the light line represent the even and odd modes respectively. Yellow dashed region is the spectral range used in simulations to search for low dispersion slow light regime.

As we can see in Fig. 1b, the simulated W09 waveguide has an optical gap in the range of 0.2544 to 0.2981 (ω*a*/2πc).




(a) (b)

Figure1: a) Top view of the super cell, b) *TE* polarized ($H_z$, $E_x$, $E_y$) band structure for W09 waveguide in *Γ-K* direction ($r$=0.3$a$).

$Si_3N_4$ material inside the air holes is shown with the brown colour in Fig. 1a.

In the next section we will show the simulation results after growth of $Si_3N_4$ rods in two rows adjacent to the waveguide.

## 3 Results and Discussion

To have flat band slow light regime, we have simulated the W09 waveguide, assuming that the air holes of two adjacent rows to the waveguide are filled with $Si_3N_4$. Refractive index of $Si_3N_4$ material assumed to be 1.98 [22]. Growth of $Si_3N_4$ can be done using a PECVD or Photo-CVD machine as a real fabrication process. Fundamental even band of the simulated W09 waveguide filled with $Si_3N_4$, is shown in Fig. 2. To investigate the slow light properties of the waveguide, we have calculated the group index ($n_g$) and group velocity dispersion ($\beta_2$) of the even fundamental mode using equations 1 and 2 [2].

$$n_g = \frac{c}{v_g} = \frac{c}{d\omega / dk} = \frac{1}{d\omega_N / dk_N} \qquad (1)$$

$$\beta_2 = \frac{d^2k}{d\omega^2} = \frac{1}{c}\frac{dn_g}{d\omega} = \frac{a}{2\pi c^2}\frac{dn_g}{d\omega_N} \qquad (2)$$

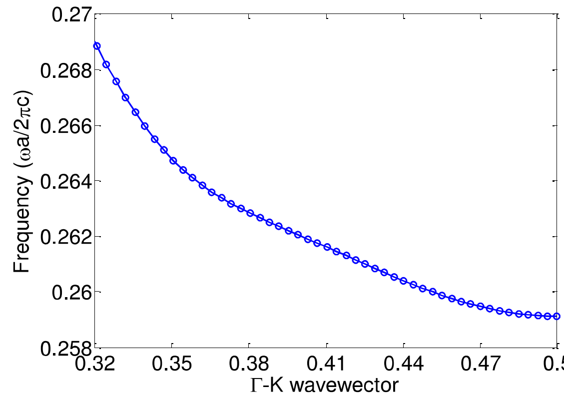



Figure 2: Fundamental even band of the W09 waveguide filled with $Si_3N_4$.

Where $\omega_N=\omega a/2\pi c$ and $k_N=ka/2\pi$ are normalized frequency and wave vector with *a* as lattice constant and c the velocity of light in vacuum. Calculated results are plotted in Fig. 3.

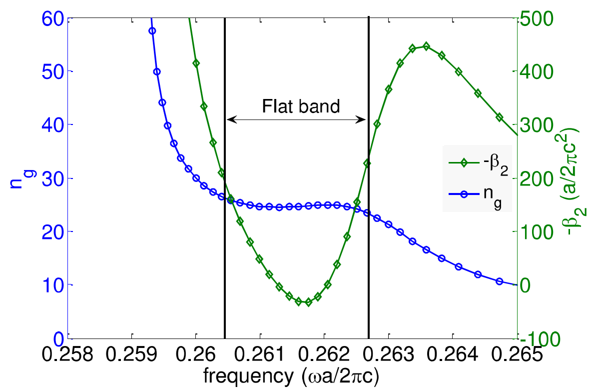



Figure3: Calculated group index ($n_g$) and group velocity dispersion ($\beta_2$) values of even fundamental mode depicted in Fig. 2.

Assuming the constant group index criterion as ±5%, we have calculated the normalized band width ($\Delta\omega/\omega_c$) and group index-Band Width product ($n_g \times \Delta\omega/\omega_c$) as shown in table 1.

Table1: Average group index, normalized band width and normalized group index -bandwidth product.

| $n_g$ | $\Delta\omega/\omega_c$ (%) | $n_g \times \Delta\omega/\omega_c$ |
|---|---|---|
| 24.89 | 0.88 | 0.219 |

The flat band region, considering the constant group index criterion, is shown with double arrows in Fig. 3. As it is clear in Fig. 3, the GVD values are very low in flat band slow light region. This low values lead to a low third order dispersion that can distort the pulse shape like second order dispersion.

## 4 Conclusion

We wanted to design flat band slow light regime to operate in a W09 hole-type slab photonic crystal waveguide. To achieve this aim, we have assumed that the air holes of the two rows adjacent to the waveguide are filled with $Si_3N_4$. This filling can take place using a standard PECVD machine as a real fabrication process. The result of this design is a flat band in the calculated group index values of the fundamental even modes of the W09 photonic crystal waveguide. Very low group velocity dispersion values in the flat band region and high normalized band width and group index-band width product are achieved. 3D-FDTD method is employed to calculate the results. We believe that our proposed W09 waveguide can be used in optical devices such as couplers, switches, gates and modulators.

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