직류 전압 인가를 이용한 파장 가변형 광 결정 스위치

Wavelength tunable photonic crystal switch utilizing electric field bias control

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PC based all-optical switching devices have been a topic of recent research efforts with its inherent, distinguished features; low power consumption, and size of the order of the wavelength. One of the notable art demonstrated so far includes a PC based optical bi-stable switch structure with a high Q cavity at the intersection of two dimensional waveguide(1). Using the same structure, the control of signal light with a control signal also has been proposed, and numerically demonstrated. To extend the scope of application for such a device – with the inclusion of wavelength tunability(2-3) –, in this study within our knowledge for the first time we study about the resonance wavelength tuning of a cross-waveguide switch utilizing the Kerr effect. Results show that the wavelength shift can be controlled with the intensity of static electric field, in a very deterministic manner, with sufficient tuning range well exceeding several nanometers.

For the analysis, we assumed a PC with high-index rods, including instant Kerr nonlinearities. Utilizing 2-dimensional FDTD method(4), numerical analysis was carried out following the device structures and parameter sets used in Yanik *et al.*(1). With Kerr coefficient of $n_2 = 1.5 \times 10^{-17}\mathrm{W/m^2}$ and the device geometry shown in Fig. 1, resonance frequency of $\omega_X = 0.3704\times2\pi c/a$ and Q factor of 1190 was obtained at low input signal powers, consistent with the previous publication.

After verifying the operation at fixed electrical DC bias (E=0), investigation on the wavelength tuning of the device as a function of electric field has been carried out. DC electric field bias up to 1,200 V/㎚ was applied on the resonance cavity, in parallel direction to the rod. Figure 2 shows the obtained peak wavelength shift in the transmission spectrum at different bias filed intensities. Wavelength shift of 16 ㎚ at 600 V/㎛ bias was achieved, sufficient for most applications. With higher bias of 1200 V/㎛, it was possible to obtain up to 65.1 ㎚ wavelength shift, but at the expense of reduced Q factor.

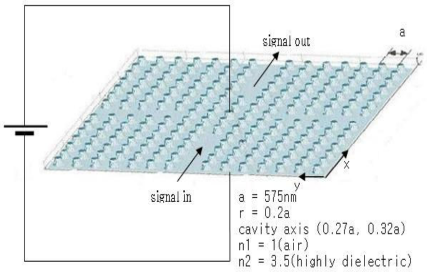

Fig. 1. Device geometry used in the study

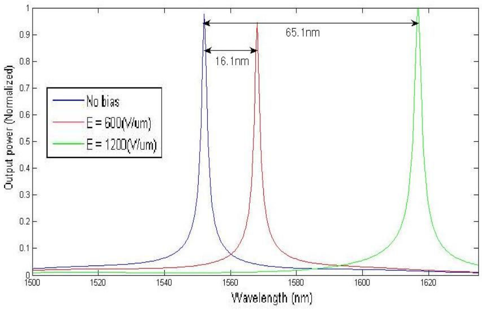

Fig. 2. Resonance frequency shift as a function of electric field bias

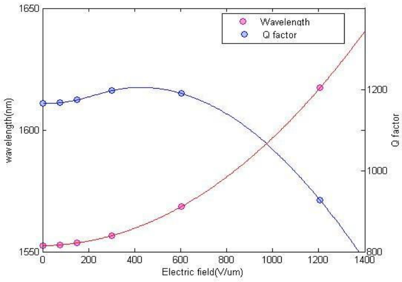

Fig. 3. Resonance wavelength and Q factor variation.

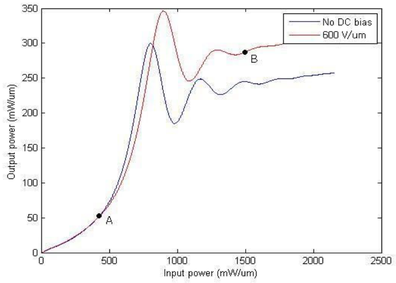

Fig. 4. Input versus output power of the signal in waveguide.

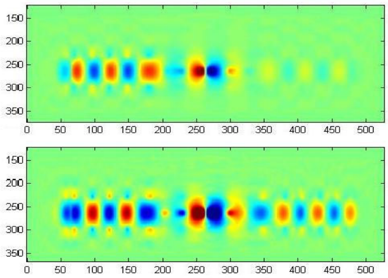

Fig. 5. Signal transmission of point A and B indicated in Fig.4.

Figure 3 shows the resonance frequency ω_X and cavity Q factor obtained as a function of applied DC bias. The observed wavelength shift was proportional to the square of the static electric field, consistent with the fact that Δn is proportional to electric field intensity. It is worth to note that the Q factor values plotted in Figure 3 was used to determine the input signal wavelength ω_{inX} for the switching operation. To observe the switching operation, an input ramp signal with carrier frequency (detuned by an amount of $\delta_X = (\omega_X - \omega_{inX})/\gamma_X = 2\sqrt{3}$, away from the resonance of the cavity mode where $\gamma_X = 1/2Q_X$) was applied to the input of the device. Switching was observed from the shift of the guiding mode resonance frequency, well agreeing with the simple fit of $\delta_\omega = \kappa \Delta n/n$ (κ being the ratio between; energy in the guided mode with frequency shift and the total energy of the mode) with $\Delta n = n_2|E(z,t)|^2$. Fig. 4 shows the switching hysteresis curves thus obtained at the bias settings at 0 V/㎛ and 600 V/㎛. It is interesting to note that the red curve (600 V/㎛) exhibited higher on-state transmission power than the blue curve (0 V/㎛). We attribute this behavior to the slight increase in Q factor at the presence of bias fields. Fig. 5 shows the signal transmission along the PC at different input power values (point A and B in Fig. 4).

To conclude, we showed that it is possible to change the operation wavelength of the nonlinear PC optical switch, with the application of reasonable electric field bias. This study also suggests a possible usage of a high Q cavity PC optical switch as a frequency selective filtering device with the application of external electric field bias. Acknowledging that the amount of wavelength tuning to be dependent on the Kerr nonlinearity, with the usage of highly nonlinear material, the performance of the device would improve by many orders.

Reference

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