# Wavelength Conversion Using Kerr Nonlinearity in a GaInP Photonic Crystal Fabry-Perot Resonator


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***Abstract*—We report GaInP photonic crystal Fabry-Perot resonators containing integrated reflectors. Efficient wavelength conversion of 30 ps pulses was demonstrated where the Kerr effect dominates and the device speed is limited by the resonator structure.**



***Photonic crystals; Kerr effect; Optical switching devices***


## I. INTRODUCTION

Photonic crystals (PhC) hold the promise of complex functional photonic components for future photonic devices and circuits. Nonlinear PhC resonators are key components for ultrafast, ultra-compact and low energy consuming all-optical switches and logic devices [1-2]. Most reported PhC resonators are small volume cavities with high Q values in which the switching speed is limited by the long cavity life time. A different type of resonator based on a 1.3 mm long PhC waveguide with cleaved end facets serving as reflectors was introduced in [3]. Wavelength conversion of a 10Gbit/s signal was demonstrated in that device.

In this paper we describe all-optical switching based on the instantaneous Kerr effect in a new type of nonlinear GaInP PhC Fabry-Perot (FP) resonator. GaInP is particulary advantageous for this and other nonlinear applications since its large bandgap (1.9 eV) prevents losses due to two photon absorption in the 1550 nm wavelength range. Any fast nonlinearity exhibited by the device is therefore exclusively due to the Kerr effect. The FP resonator we report is a low loss PhC waveguide containing integrated reflectors which have a complex wavelength dependent transfer function. This results in a series of transmission resonances with various spectral widths and offers some degree of freedom when choosing the control (pump) and signal (probe) wavelengths, in switching and wavelength conversion experiments. Efficient wavelength conversion of 30 ps wide pulses as well as an extremely large static and low frequency (below 500 kHz) response due to thermal effect were demonstrated. At high frequencies, the switching process is strictly due to the instantaneous Kerr effect and the device speed is determined by the resonator life time.

## II. RESULTS

The device consists of a W1 type PhC waveguide that contains mode converters which enhance the coupling efficiency and eliminate the end facet reflectivities. The 250 µm long FP resonator is created by placing identical reflectors, composed of two holes, within the waveguide [4]. The resonator is shown schematically in the inset of Fig. 1(a). The finesse spectrum was extracted from linear transmission spectroscopy and is presented is Fig. 1(a). Due to the reflector complex transfer function, the finesse shows a periodic modulation which is superimposed on a general increase for long wavelength. This wavelength dependent finesse induces a series of transmission resonances with various spectral widths, ranging from 4 GHz to 37 GHz.

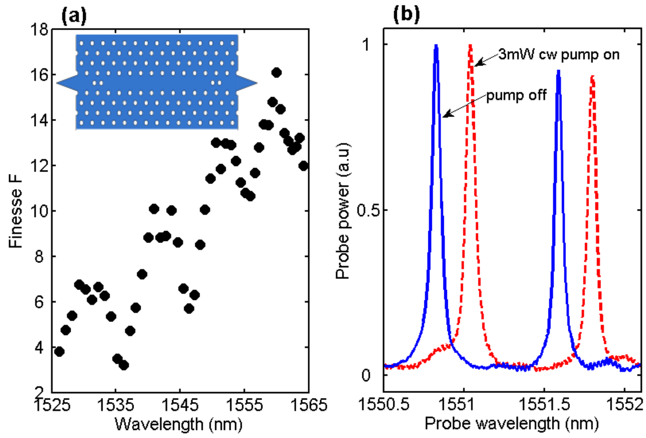


Figure 1. (a) Finesse spectrum of the resonator. Inset: Structure of the resonator. (b) Static transmission spectrum: pump off (blue) and on (red).

The static nonlinear response was measured first and is presented is Fig. 1(b). The blue line corresponds to the linear transmission of FP fringes over a 2 nm range obtained with a weak broad band source (ASE of an EDFA). The influence of a CW pump on the fringes was measured by combining a signal to the EDFA source. The obtained transmission is described by the red line, which clearly shows a red shift of the FP fringes. In this probe wavelength range the 3 mW CW pump induced a phase shift $\delta\varphi$ of $\pi/3$. The static nonlinearity was quantified by the phenomenological parameter $\gamma$ according to $\gamma=\delta\varphi/4PL$ with P and L being the circulating pump power and the resonator length, respectively. $\gamma$ takes on the large value of $\gamma=2.2 \times 10^5$ $m^{-1}W^{-1}$ for the mode at $\lambda$=1551 nm. The $\gamma$ values were extracted for each fringe shift across the transmission spectrum and have a linear dependence on the group index at the probe wavelength. These values are about two orders of magnitude larger that the corresponding values obtained from self-phase modulation (SPM) [5] and four wave mixing (FWM) [6] experiments in similar waveguides.

The dynamic nonlinear response of the device was tested by modulating a CW tunable laser and using a low power (≈1 mW) tunable CW probe. The response of the resonator depends on two factors, the fundamental response of the nonlinearity and the structural limitations imposed by the life time of the cavity. All-optical switching was performed with the control and signal optical signals aligned to two distinct FP resonances. Fig. 2(a) shows the dependence on resonance width of small-signal modulation responses for frequency range of 50 MHz to 20 GHz. The modulated pump was aligned with a fringe having a large spectral width of 35 GHz while the probe was tuned to fringe peaks of different widths (labeled in the legend). The modulation bandwidths correspond to the resonance spectral widths, indicating that the wavelength conversion is induced by an instantaneous process and is structurally limited. Since the pump causes an increase in the modal index (confirmed by the large signal modulation results), we conclude that the nonlinearity is due to the Kerr effect. The response a very low frequencies, 50 kHz to 500 kHz, was more than two orders of magnitude larger than that in the low frequency range of Fig. 2(a) but dropped off fast beyond 500 kHz. This indicates that the very large static response shown is Fig. 1(b) is due to a thermal effect. Wavelength converted results for large signal are illustrated in Fig. 2(b) and (c) for 92 ps and 30 ps wide pump pulse, respectively. Fig. 2(b) shows the 200 mW peak power input pump (black) and converted probe waveforms for a probe aligned to a fringe with spectral width of 20 GHz (blue) and 5.5 GHz (red). The probe wavelengths with no pump were tuned to the valley on the long wavelength side of the fringe. The converted probes follow the sense of the pump modulation, consistent with an index increase induced by the pump. The converted probe aligned with the narrower resonance shows a higher contrast. The converted pulse is obtained from the shifting fringe crossing the CW probe; therefore a narrower fringe causes a larger change in probe transmission yielding a pulse with higher contrast. Fig. 2(c) shows the probe transmission dynamics for 30 ps wide pump pulses and a probe which was tuned to the peak of a fringe with a spectral width of 5.5 GHz. The converted signal exhibits the complementary modulation of the pump. The converted probe outputs are shown for different coupled pump pulse energies. For contrasts of 20% to 60% the required switching energies are in the range of 5 pJ to 18 pJ.

## III. CONCLUSION

To conclude, we have demonstrated efficient and fast all-optical switching in a GaInP PhC FP resonator based on the instantaneous Kerr effect. Structural parameters determine the speed at which the device can be operated in wavelength conversion experiments. 30 ps wide pulses were converted using pulse energies of a few pJ.

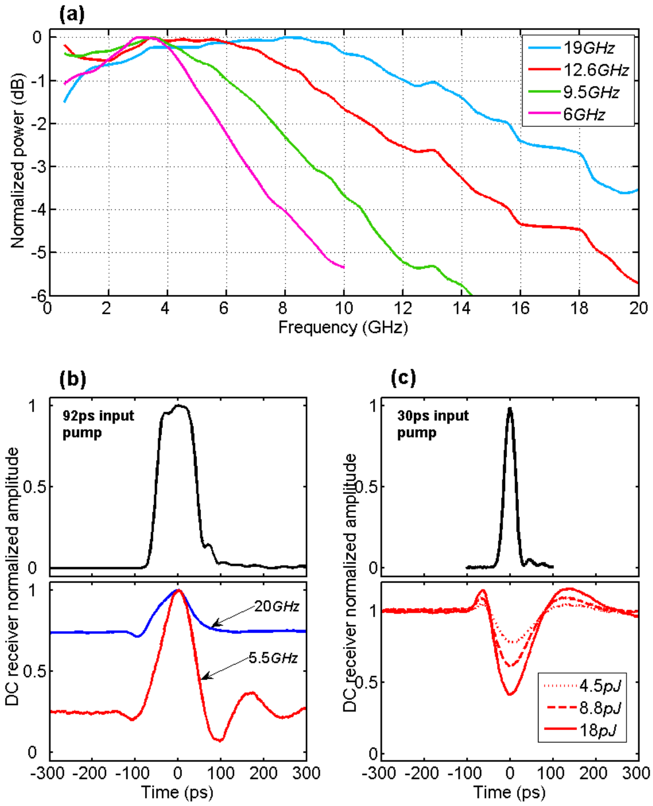


Figure 2. (a) Small-signal modulation response of converted probe for various probe fringes. (b) and (c) Pump and probes transmission dynamics of a single 92 ps and 30 ps wide pulse, respectively.


## ACKNOWLEDGMENT

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