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Pulse selection by on-the-fly wavelength conversion in 2D photonic crystals

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1. Introduction

Ultrafast wavelength conversion of a light pulse is one of the key technologies in photonics. Previously we have proposed and demonstrated ultrafast on-the-fly wavelength conversion, where the wavelength of an input pulse is altered by temporally changing the refractive index of the material in which the pulse is propagating [1,2]. Distinct from the method based on nanocavities so far proposed [3,4], this conversion method is highly flexible and can be integrated in a straightforward manner with photonic nano-devices because the only requirement to include this functionality is the propagation component of a waveguide. The integration of a wavelength conversion functionality greatly broadens the versatility of photonic nano-devices.

In this paper we propose and demonstrate an example of such an integrated device. More concretely, by combining the wavelength conversion system with frequency sensitive photonic crystal components, we selectively deflect an input pulse from a waveguide.

2. Principle of on-the-fly wavelength conversion

Figure 1 illustrates the principle of the on-the-fly wavelength (actually, frequency) conversion process. In Fig. 1 (a), a light pulse, represented by the several lines of wavefronts, propagates through spatially and temporally uniform region, where no conversion occurs. In Fig. 1 (b), the refractive index experiences a sudden, uniform decrease, then remains constant at this new value. At the instance of refractive index change, the frequency of the light pulse changes according to the modification of the phase velocity while the wavenumber is conserved due to the continuity condition at the interface between different refractive index regions in the spacetime. In this connection, the on-the-fly wavelength conversion is the time-space-exchanged version of the wavenumber change due to the spatial propagation into a different refractive index region (Fig. 1 (c)).

As can be understood from the above principle, this method can accept a broad wavelength range of light pulses. Also, the portion of the converted component over the original pulse can be very large because, in principle, a whole pulse can be converted into a new wavelength.

3. Pulse selection device proposal and demonstration

A schematic of the pulse selection device is shown in Fig. 2(a), consisting of a two-dimensional photonic crystal (PC) waveguide and a nanocavity. A signal pulse of which center wavelength is slightly longer than that of the cavity resonance is injected into the waveguide, so that the signal pulse cannot be coupled into the cavity. When the refractive index of the waveguide is temporally reduced while the signal pulse is propagating, the wavelength of the signal pulse becomes shorter, enabling coupling to the nanocavity, and light emission to free space.

In order to experimentally demonstrate this operation, we fabricated an air-suspended PC slab of Si with triangular lattice of air holes. The lattice constant of the PC is 420 nm with an air hole radius of 120 nm. The waveguide consists of a filled row of air holes with a length of 250 μm, which has a propagation mode around 1550 nm. The cavity consists of three-missing air holes of which resonant wavelength and Q factor are 1555.2 nm and $Q \sim 4500$, respectively.

The source of optical pulses is a fiber-based, tunable, passively mode-locked laser (operating wavelength 1535-1555 nm, pulse width ~4 ps). A signal pulse from this source is injected to the waveguide, where the center wavelength is set to 1556.0 nm. In order to induce a refractive index change, a control pulse, which is a frequency doubled pulse (~4 ps duration, center wavelength ~778 nm), is shone on to the waveguide. The control pulse's wavelength allows for partial absorption by the silicon, immediately generating free carriers within the waveguide. These free carriers immediately lower the refractive index according to the carrier plasma effect. Because the carrier lifetime in Si is on the order of ~ ns, a step-like refractive index change occurs with a transition time of the order of the control pulse width (~4ps). The control pulse spot has a Gaussian distribution with a full width half maximum of ~10 μm along the waveguide. A variable optical delay line is used to change the timing between the two pulses and optical fiber amplification permits control pulses doing up to ~8.3 pJ of work on the waveguide, producing a decrease of refractive index with a ratio on the order of 10^{-3}. Light coupled out from the cavity is collected to observe the response of the device.

Figure 2 (b)-(e) shows the results. Initially, the injected signal pulse (1556 nm) is too long to couple to the cavity (1555.2 nm), and no emission is observed (b). However, if sufficient index change is induced while the signal travels through that region, a clear peak of light is emitted from the cavity (c). If the irradiation timing of the control pulse is later than the signal pulse by 6.6ps (d), no wavelength shift occurs and the dominant part of the input pulse's spectra can no longer couple to the cavity. Also, if the irradiation timing of the control pulse is earlier than the signal pulse by 6.6ps (e), no wavelength shift occurs and the vertical emission is not observed. This is because the signal pulse enters the region where the index has already changed (see Fig. 1 (c)). Again it is important to note that if the control pulse timing is off by as little as a few picoseconds, the signal pulse witnesses none of the temporal index change. Because of the high temporal selectivity, this form of wavelength conversion system could conceivably be used to target and divert individual pulses.

Acknowledgements

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References

[1] J. Upham, Y. Tanaka, T. Asano and S. Noda: *Abstracts of LEOS Annual Meeting*, p. 349, (2007).

[2] J. Upham, Y. Tanaka, T. Asano and S. Noda: *Ext. Abstr. of 68th Autumn Meet. of JSAP* , 8p-ZS-6, (2007).

[3] S. Preble, Q. Xu and M. Lipson: *Nature Photonics* **1** (2007) 293.

[4] T. Tanabe, M. Notomi, H. Taniyama and E. Kuramochi: *Phys. Rev. Let.* **102** (2009) 043907.

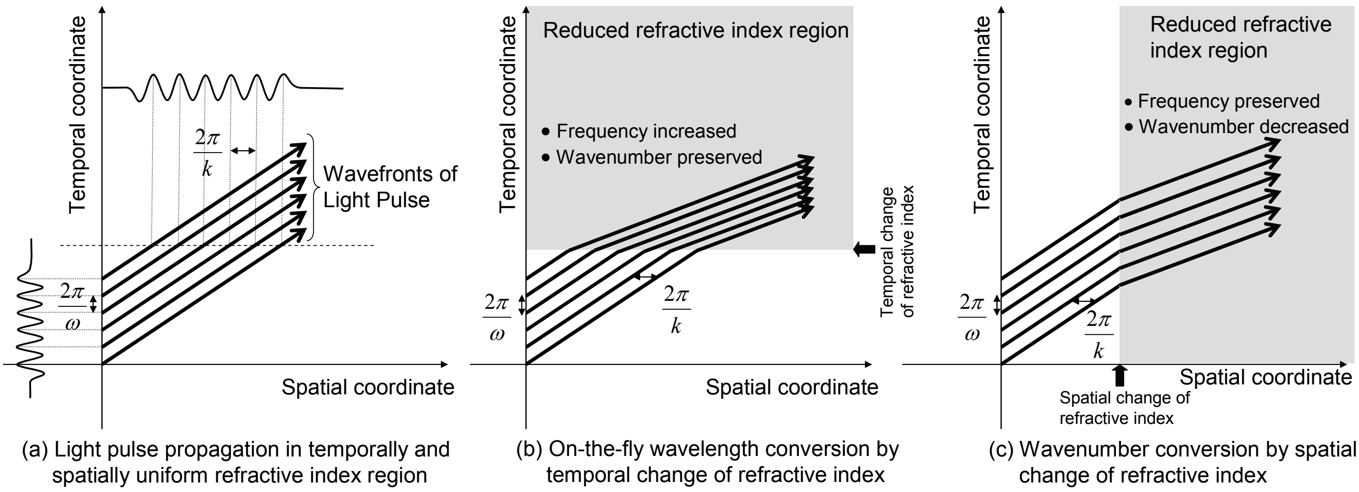

Fig. 1 Time-space diagram of light pulse propagation for three cases: (a) Refractive index is unchanged spatially and temporally. The solid lines with arrows schematically represent the wavefronts of the light. The light pulse is unchanged in frequency (ω) and wavenumber (k). (b) Refractive index changes temporally while remains uniform in space. ω changes while k is preserved due to the continuity condition. (c) Refractive index changes spatially but is unchanged in time. k changes but ω is preserved due to the continuity condition.

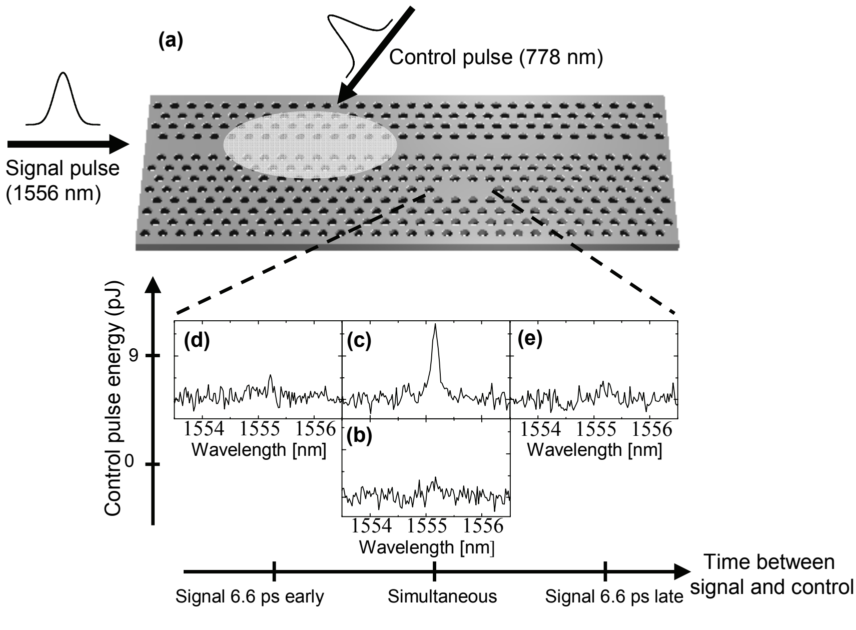

Fig. 2 Dynamic wavelength conversion in a waveguide observed via an adjoining cavity (a) Schematic of PC device with dynamically altered region of waveguide shaded. (b-e) The cavity vertical emission spectra for different control pulse energies and time delays.