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Control of visible harmonic generation using polarization in photonic crystal fibers

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Abstract: The polarization state of the input pulses to a segment of microstructured fiber controls the harmonic generation yielding specific frequencies depending on of the input state.

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Photonic crystal fibers (PCF) continue to attract considerable interest for their unique structure and optical properties [1,2]. In a previous paper [3] we have reported about the observation of power-dependent generation of visible radiation in PCFs. We present here the dependence of the generated visible radiation on the polarization state of the input pulse coupled into the photonic crystal fiber. We experimentally observe that the propagation of a pulse of fixed energy, yet polarized along different directions, yields different visible components at the output, suggesting polartization-dependent selectivity for phase-matching according to the input polarization state.
For the experiments we use a microstructured fiber with a solid silica core of 2.5 microns in diameter, suspended in

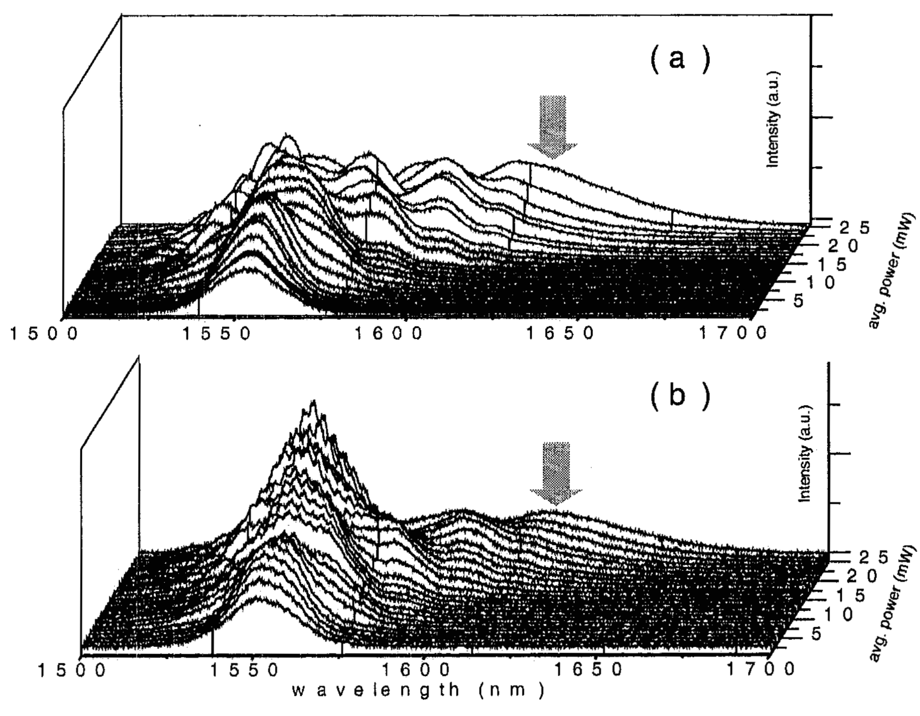

Fig. 1 Detected spectra of the fundamental radiation for polarization states (a) α and (b) β at the output of the photonic crystal fiber as a function of power. The shift at P=25 mW (indicated by the arrow) is the same for both polarization states

air by a web of sub-micron silica strands with a cladding diameter of 90 microns and that exhibits six-fold symmetry in its structure. The light coupled into the fiber is generated by an optical parametric oscillator (OPO) that produces ~170 fs pulses (repetition rate of 80 MHz) with average powers up to 100 mW (energies of 1 nJ) at a wavelength of 1550 nm at the input face of the fiber.

The present analysis is performed for low average power values (i.e. up to 25 mW). In this range, the fundamental wavelength λ_{FUND}=1550 nm appears to propagate in the fundamental mode through the PCF. An intensity transmission analysis as a function of input polarization reveals two principal polarization states α and β orthogonal to one another. When the input pulses are polarized along one of these two directions, one of two visible modes of different colors is detected at the output. These generated visible frequencies are higher-order modes exhibiting an eight-lobed structure and centered at λ_1=514 nm and λ_2=533 nm . It has been previously noted [3] that the observed components λ_1 and λ_2 bear a relation to the fundamental such that $\lambda_{FUND}\sim 3\lambda_1$ and $\lambda_{F,Shift}\sim 3\lambda_2$, (or $3\omega_{FUND}\sim \omega_1$ and $3\omega_{F,Shift}\sim \omega_2$ and where is the $\omega_{F,Shift}$ Raman self-frequency shifted portion of the fundamental).

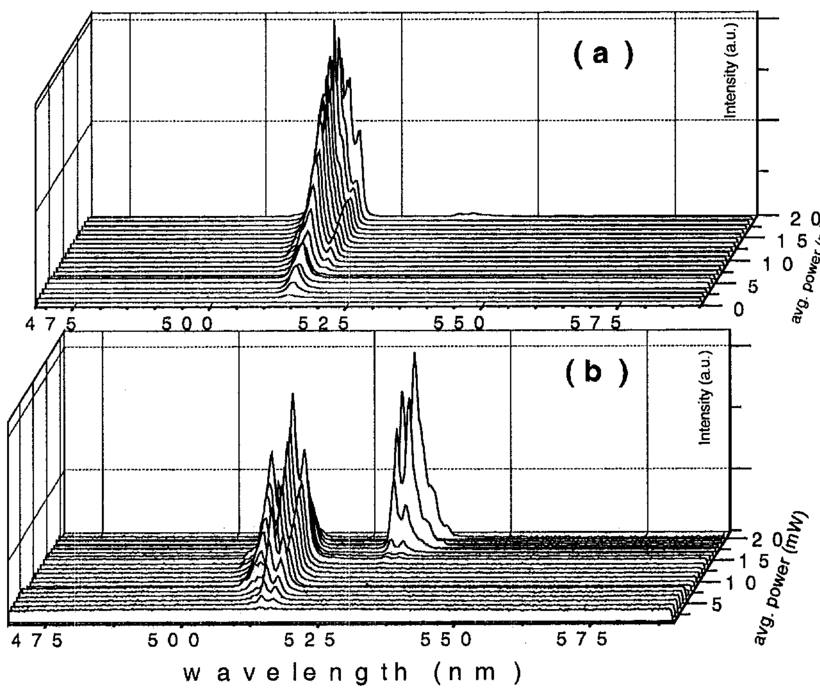

Fig. 2 Detected spectra of the visible radiation at the output of the photonic crystal fiber as a function of power for both polarization states (a) α and (b) β. The component at 533 nm appears only in one polarization state.

A power dependent spectral analysis is carried out on the fundamental and on the visible harmonics for the two different polarizations. The detected spectra for the fundamental pulse are illustrated in figure 1(a,b), whereas the results for the generated visible harmonics are shown in figure 2(a,b).

A comparison between the spectral features of the fundamental pulse polarized along the direction α (fig 1a) and the direction β (fig 1b) shows different spectral dynamics as a function of power but a fundamentally similar behavior: in both cases the spectrum shifts as expected toward longer wavelengths and the magnitude of the shift (~50 nm at P=25 mW) appears to be the same for both input polarization orientations (independent of the initial polarization). Analysis of the generated visible frequencies reveals, in contrast, a polarization-dependent pattern. In the direction α (fig 2a) a spectral feature centered around λ=514 nm is detected for pulses of average power of 4 mW at 1550 nm. As the power of the fundamental is increased, more light is converted to the visible (with an

estimated conversion efficiency of 0.2 % for a 25 mW pump) but only a feature at λ_1=514 nm is observed. The relationship of this component to the fundamental wavelength is consistent with the generation of third harmonic of the fundamental yet no third harmonic from the self-shifted component is observed. When the input pulse polarization is rotated along the direction β (fig 2b), however, a sharp feature centered at λ_2=534 nm appears for pulses of average powers of 16 mW in addition to the λ_1 component that subsequently vanishes as the power if the fundamental is further increased. Whereas for both polarizations the fundamental shifts to 1600 only for the β polarization case the shifted fundamental is converted to third harmonic radiation. A combination of the two states (i.e. an input pulse polarized at 45 degrees with respect to the axes α, β) generates the two visible components simultaneously. No frequency components that could be attributed to mixing processes are detected for the wavelength interval covered by the fundamental and its shifted components.
These results provide evidence of the existence of a new control parameter for the nonlinear processes which occur in a photonic crystal fiber using femtosecond pulses at a wavelength of 1.55 microns. Polarization selectivity combined with Raman self-frequency shifting and third harmonic generation, provides an avenue to control the generation of specific harmonics. This approach can provide an avenue for all-fiber signal control and ultrafast optical switching based on nonlinear phenomena in microstructured fibers.

References

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