Generation of spectrally-isolated violet to blue wavelengths by cascaded degenerate four-wave mixing

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Abstract: The spectrally-isolated violet to blue wavelengths within the spectral range of 430 to 472 nm are experimentally generated by cascaded degenerate four-wave mixing in a tailor-made photonic crystal fiber with two adjacent zero dispersion wavelengths.

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1. Introduction

The generation of discrete new wavelengths in the violet to blue spectral region has important applications in the basic physics and applied science. In order to directly generate discrete violet to blue wavelengths by the phase-matched four-wave mixing (FWM) [1], the pump wavelengths should be located in the normal dispersion region close to the zero dispersion wavelengths (ZDWs) which are shorter than 700 nm in the fundamental mode of the photonic crystal fibers (PCFs). The relative air-hole sizes should be greater than 0.8 and core diameters are less than 1.5 µm. However, not only are the laser sources to achieve the phase-matched condition not available currently, but such PCFs are difficult to fabricate and suffer from high propagation loss and low damage threshold. We note that cascaded FWM occur easily in general PCFs, and can be utilized to generate discrete new wavelengths in the violet to blue regime. Recently, broadband cascaded FWM centered at wavelengths of 1, 1.55, and 2 µm in PCFs have been demonstrated when continuous waves and short pulses are used as the pump sources [2-4].

Here, the spectrally-isolated second anti-Stokes waves are generated by cascaded degenerate FWM within the violet to blue spectral range of 430 to 472 nm when femtosecond pump pulses are launched into the normal dispersion region close to the second ZDW in the fundamental mode of a tailor-made PCF.

2. PCF properties and experiment

The inset of Fig. 1 shows the cross section of the silica PCF with a core diameter of 1.63 µm and average relative air-hole diameter of 0.65. Fig.1 shows the calculated group-velocity dispersion curve of the fundamental mode of the PCF. The two ZDWs are located at 696 and 852 nm, respectively. The anomalous dispersion region between the two ZDWs covers a wavelength range of 156 nm with a dispersion value less than 12 ps/nm/km. The nonlinear coefficient around 850 nm is estimated to be 0.117 $W^{-1}m^{-1}$.

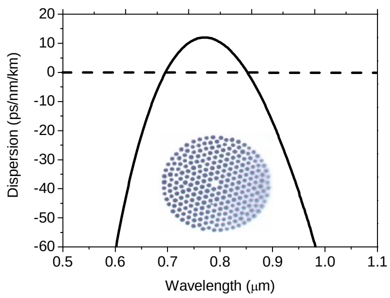
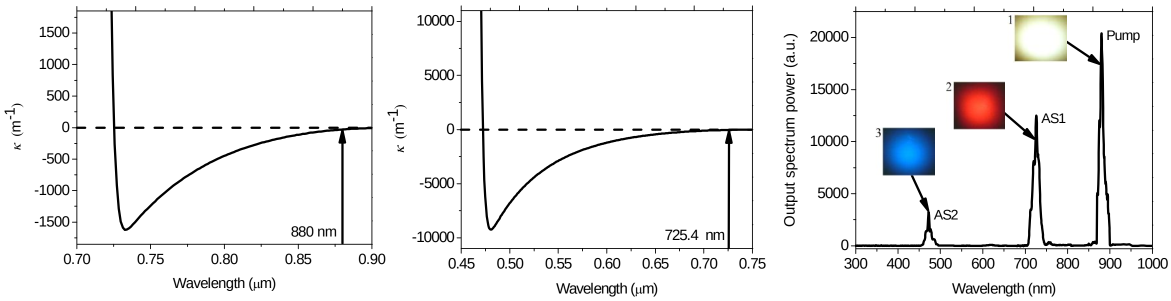


Fig. 1. The calculated group-velocity dispersion curve of the fundamental mode of the PCF. The inset shows the cross-section of the PCF used.

In the experiment, the pump pulses are provided by a mode-locked Ti:sapphire laser, which operates at the tunable wavelength range from 780 to 900 nm and emits 120 fs pulse trains at a repetition rate of 76 MHz. The incident pump light is coupled by a 40× microscope objective into the fundamental mode of a 36 cm-long PCF. The free-space coupling efficiency is about 58%.

3. Results and discussion

Fig. 2(a) shows the calculated phase-mismatched parameter κ when the initial pump pulses at wavelength λ_p 880 nm and input average power P_{av} = 500 mW (peak power = 60 kW) are launched into the normal dispersion region close to the second ZDW (852 nm) in the fundamental mode. The phase-mismatched parameter κ = 0 at wavelength of 725.4 nm. Moreover, because the anti-Stokes wave generated at 725.4 nm is located near the first ZDW (696 nm), it would serve as a secondary pump for the next FWM process such that the second anti-Stokes wave is generated at the shorter wavelength. From Fig. 2(b), κ which is calculated without considering the nonlinear contribution reaches zero at the blue wavelength of 472.3 nm for the secondary pump wavelength of 725.4 nm. Neglecting the nonlinear contribution in the calculation of κ is reasonable because the peak power of the first anti-Stokes wave used as the secondary pump is greatly reduced by the dispersive and nonlinear effects. Fig. 2(c) shows the observed output spectra. The self-phase modulation and Raman effects lead to the asymmetrical broadening of the incident optical spectrum. The spectrally-isolated first and second anti-Stokes waves are generated at 726 and 472 nm by cascaded FWM, which agrees well with the theoretical predictions. Insets 1, 2, and 3 of Fig. 2(c) show the Gaussian-like far field mode patterns at the pump, first, and second anti-Stokes wavelengths observed from the output end of the PCF.



(a) (b) (c)

Fig. 2. The phase-mismatched parameters κ calculated for the fundamental mode of the PCF in the (a) first FWM process with the nonlinear contribution and (b) second FWM process without the nonlinear contribution. Initial pump pulses at wavelength λ_p = 880 nm and input average power P_{av} = 500 mW (peak power = 60 kW) are used. (c) The output spectra from the PCF. Insets 1, 2, and 3 show the output far fields at the pump and anti-Stokes wavelengths of 880 (white), 726 (red), and 472 nm (blue), respectively.

Fig. 3 shows that the second anti-Stokes waves are generated at 472, 456, and 430 nm when pump pulses at P_{av} =500 mW and λ_p=880, 870, and 860 nm, respectively, are propagated inside the PCF. We observe that λ_{as2} is tunable from 472 to 430 nm as λ_p is shifted toward the second ZDW from 880 to 860 nm. In the experiment, the single-mode propagation is maintained. Effective spatial overlaps between the pump, first, and second anti-Stokes waves are controlled in order to achieve efficient energy conversion. The measured conversion efficiency of the second anti-Stokes wave at 430 nm can be up to 9.66%.

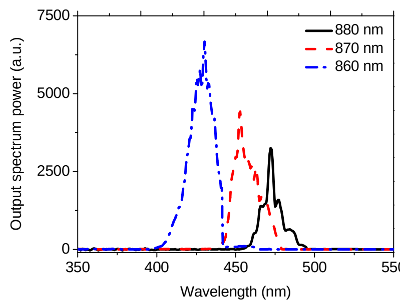


Fig. 3. The observed output spectra when pump pulses at input average power P_{av}= 500 mW (peak power = 60 kW) and wavelength λ_p=880, 870, and 860 nm, respectively, are used.

4. Conclusion

In summary, we generate the spectrally-isolated violet to blue wavelengths within the spectral range of 430 to 472 nm by cascaded degenerate FWM process in a PCF with two adjacent ZDWs.

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5. References

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