Photonic crystal fiber tunes a femtosecond laser

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A fiber-based femtosecond laser takes advantage of photonic-crystal fiber technology to extend the tuning range to more than 200nm, making it a potential source for biomedical imaging.

Most animal and human tissues are considered to be nearly transparent in the spectral range of 700-1100nm.1 Tunable laser sources capable of emitting pulses less than a nanosecond long in this wavelength range will be an ideal source for biomedical imaging applications such as multiphoton microscopy, time-resolved photoluminescence, and nonlinear spectroscopy. Titanium-doped sapphire lasers have been the dominant source because of their broad bandwidth and high average power. However, many biological applications need only a few milliwatts of average power. For such applications, fiber-based lasers have the potential of being more compact, robust, and less expensive than conventional solid-state lasers.

A diode-pumped, fiber-based, femtosecond tunable source operating around 1μm would be useful for some applications. Ytterbium-doped fiber is an ideal gain medium for such sources. However, its gain bandwidth of less than 50nm is considerably narrower than that of Ti:sapphire lasers. By incorporating a photonic crystal fiber (PCF) into a fiber-optic parametric oscillator (FOPO) and combining it with a newly developed mode-locked Yb-fiber laser, we recently extended the tuning range to 200nm.2

Figure 1. Experimental configuration for a broadly tunable femtosecond laser source. PCF: photonic-crystal fiber. PBS: polarizing beam splitter. P1, P2, and P3: achromatic waveplates.

The gain in FOPOs relies on the nonlinear process of four-wave mixing inside optical fibers, in which light at pump and signal wavelengths create light at another ‘idler’ wavelength. Conventional fibers are not suitable for this because of the phase matching required for efficient four-wave mixing. The efficiency of the nonlinear process is usually highest near the fiber’s zero-dispersion wavelength, and in PCFs this wavelength can be designed to be near 1μm. Furthermore, the enhanced nonlinearity of PCFs leads to significantly-higher four-wave-mixing efficiencies. Recently, it has been shown that four-wave mixing with large frequency shifts can be realized by pumping a PCF in the normal-dispersion regime.3 This approach can provide parametric generation in the spectral regions that cannot be reached by other techniques.

The experimental setup is shown in Figure 1. The ring cavity consists of 65cm of PCF with the zero-disperssion wavelength at 1038nm. The FOPO is pumped through a dichroic filter using a recently-developed mode-locked Yb-doped fiber laser.4 This source is attractive because it is also based on fiber and it provides the power, tunability, and short pulses necessary for a FOPO pump. The pump laser produces 1.3ps pulses at 36.6MHz with 260mW of average power, and its center wavelength is tunable from 1020 to 1038nm. Figure 2(a) shows the phase-matching condition as a function of pump wavelength for the PCF used. With such a steep phase-matching curve, the parametric gain varies widely with a small change in the pump wavelength. When pumping in the normal-dispersion region of the PCF, a wavelength range of 800 to 1400nm can be covered by tuning the pump over 20nm. A short piece of PCF is used as the gain medium to minimize the walk-off between the pump and signal pulses. Figure 2(b) shows the walk-off delay for the 65-cm-long PCF and a typical output spectrum from the FOPO.

As shown in Figure 3, by turning the intracavity grating, the output wavelength can be tuned over 140nm on the long-
Figure 2. (a) The phase-matching curve over the tuning range of the pump laser shows how the wavelengths of the Stokes and anti-Stokes lines vary greatly with small changes in the pump wavelength. ZDWL: zero-dispersion wavelength. (b) Walk-off delay for the PCF and a typical output spectrum from the fiber-optic parametric oscillator.

In conclusion, we demonstrated the first femtosecond FOPO using four-wave mixing in the normal-dispersion region of a PCF. This novel system displayed a tuning range of 200nm around 1\(\mu\)m for pulses as short as 460fs. By combining the tunability of the fiber laser and the FOPO, this scheme has the potential of becoming a practical fiber-based broadly-tunable femtosecond pulse source. We are considering options for scaling to higher average powers.

Figure 3. (a) The signal wavelength can be tuned through wavelengths longer than the pump. (b) The idler wavelength can be tuned through wavelengths shorter than the pump.

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References