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Generation and application of wavelength tunable ultrashort soliton pulse in optical fiber

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Abstract: 0.78-1.0 um wavelength tunable femtosecond soliton pulse generation using photonic crystal fibers and fiber laser is demonstrated. Novel pulse trapping phenomena by soliton pulse are discovered and 1 THz ultrafast all optical switching is demonstrated.

1. Introduction

Optical fiber is one of the most effective nonlinear optical devices. So far, we have been doing the investigation and application of ultrafast nonlinear optical phenomena using ultrashort pulse fiber laser and optical fibers. We have succeeded in the generation of widely wavelength tunable ultrashort soliton pulse[1]. The wavelength of the soliton pulse can be shifted continuously by merely varying the fiber input power. In connection with this soliton pulse, novel phenomena of pulse trapping in optical fibers have been discovered. In this paper, the recent progress of generation and application of wavelength tunable ultrashort soliton pulse is mentioned. The wavelength tunable soliton pulse generation using photonic crystal fibers and investigation about pulse trapping are described.

2. Wavelength tunable ultrashort soliton pulse generation using photonic crystal fibers

Using the anomalous dispersive fibers and ultrashort pulse, we can generate the wavelength tunable ultrashort soliton pulse. So far, 1.55 to 2.03 um widely wavelength tunable soliton pulse generation has been demonstrated using diameter reduced type polarization maintaining fibers and ultrashort pulse fiber laser [1].

Using the photonic crystal fibers, we can obtain anomalous dispersion below 1 um wavelength region. Recently, we have demonstrated 0.8 to 1.0 um wavelength tunable soliton pulse generation using Er-doped fiber laser, periodically polled $LiNbO_3$ crystal, and 2 m of photonic crystal fibers [2]. Figure 1 shows the optical spectra of wavelength tunable soliton pulses. As the fiber input power is increased, the center wavelength of the soliton pulse is shifted toward the longer wavelength side continuously and monotonously by merely varying the fiber input power. The temporal widths of the generated pulses are about 94 fs. The generated pulses are pedestal free clear pulses and the corresponding time bandwidth products are about 0.38. This system is very compact and useful for practical applications.

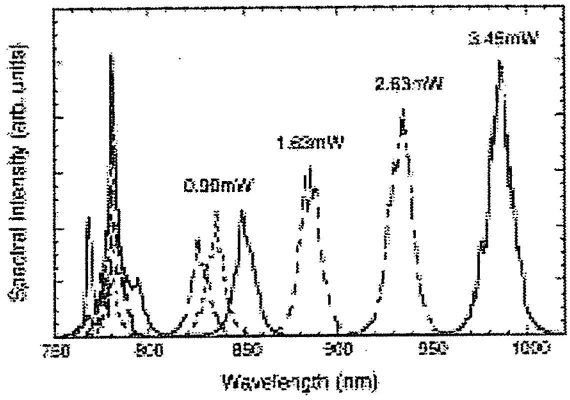

Fig.1 Optical spectra of wavelength tunable soliton pulse

3. Pulse trapping by ultrashort soliton pulse

Recently, we have discovered the novel two phenomena of pulse trapping by ultrashort soliton pulse. One of them is the pulse trapping across the zero dispersion wavelength[3]. The optical pulse in the normal dispersion region is trapped by the soliton pulse in anomalous dispersion region. The center wavelength of the trapped pulse is blue shifted to satisfy the group velocity matching condition and they copropagate along the fiber. Since the center wavelength of the soliton pulse can be controlled by varying the fiber input power, the magnitude of the wavelength shift of the trapped pulse can be changed by the power control. This trapping phenomenon is the physical mechanism of the wavelength shift of anti-stokes pulse which we can see using ultrashort pulse and nearly zero dispersive fibers. We have confirmed the temporal overlapping between the soliton pulse and trapped pulse by use of X-FROG technique. Numerical results are well in agreement with the experimental ones.

The other trapping phenomena is trapped pulse generation in birefringent fiber[4]. When the polarization direction of the soliton pulse is along the slow axis, the fast axis components at longer wavelength side which satisfies the group velocity matching condition are trapped by the soliton pulse and they copropagate along the fiber. Then the soliton pulse is red-shifted by the SSFS and the trapped pulse is also red-shifted to satisfy the group velocity matching. The trapped pulse is also amplified by the Raman gain of the soliton pulse. Thus, in the propagation along the fiber, the energy of the soliton pulse is transferred into the trapped pulse and at some condition, orthogonally polarized and temporally overlapped two colored ultrashort soliton pulse pair is generated. If the fiber length is enough long, almost all of the energy of the soliton pulse is transferred into the traped pulse. These interesting phenomena of pulse trapping are attractive for the control of ultrashort pulse.

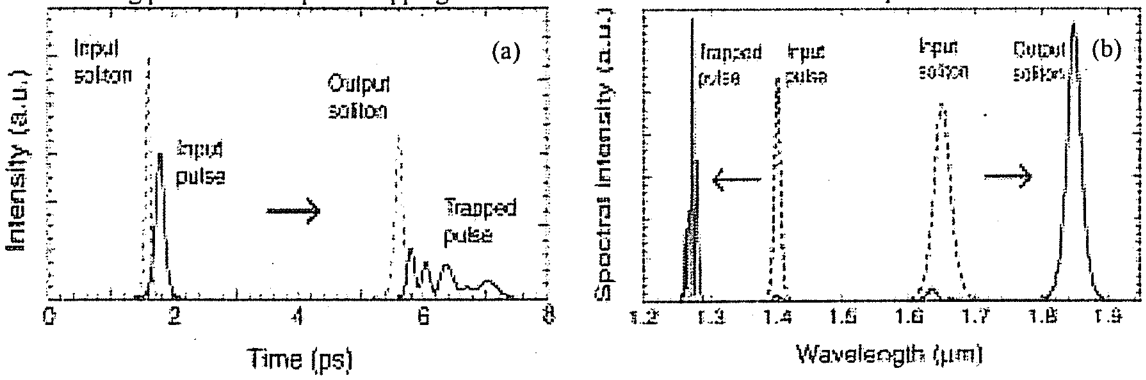

Fig.2 Numerical results of (a) temporal and (b) spectral variation for pulse trapping across zero dispersion wavelength

4. Ultrafast all optical switching using pulse trapping

Using the pulse trapping, we can control the optical pulse selectively by ultrashort soliton pulse. We have demonstrated the ultrafast all optical switching using pulse trapping across zero dispersion wavelength[5]. The sequential four pulse train is generated by use of birefringence and nonlinearity of cascadely spliced polarization maintaining dispersion shifted fiber. The generated pulse train is overlapped with the soliton pulse and they are coupled into polarization maintaining highly nonlinear dispersion shifted fiber. Figure 3 shows the spectrogram of all optical switching observed with the cross correlation frequency resolved optical gating (X-FROG) technique. In Fig.3, only the second pulse is trapped by the soliton pulse and they copropagate along the fiber. The trapped pulse is easily picked off using wavelength filter. Although the third and fourth pulses overlapp with the soliton pulse, since the group velocity matching condition is not satisfied, they are not trapped by the soliton pulse. We have demonstrated 1THz ultrafast all optical switching using pulse trapping.

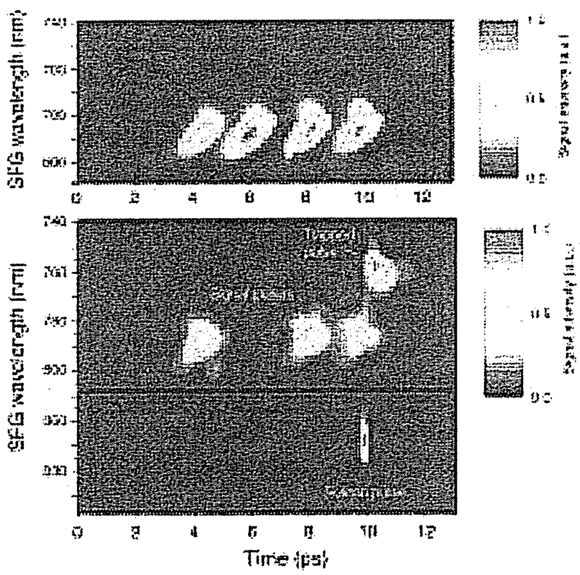

Fig.3: Observed spectrogram of ultrafast all optical switching using pulse trapping

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