NONLINEAR OPTICAL PHENOMENA

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Nonlinear dispersive similariton: spectral interferometric study

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***Abstract*. A similariton formed in a passive optical fibre is experimentally found and investigated by spectral interferometry completely characterising the complex radiation field. A nonlinear dispersive character of similariton formation leads to chirp linearisation and spectrotemporal similarity of this similariton.**

Keywords: *optical fibre, femtosecond pulse, spectral interferometry, similariton, spectrotemporal imaging.*

Recent interest in optical similaritons has been stimulated by their prospects for signal analysis and synthesis in ultrafast optics [1]. The main object of study is the generation of parabolic similaritons in single-mode fibres (SMFs) with amplification [2, 3] or with decreasing dispersion [4]. It was shown in [5, 6] that a similariton can also be generated (formed) in a passive (i.e., without amplification) SMF due to the combined effect of Kerr nonlinearity and group velocity dispersion. The nonlinear dispersive similariton, as well as the parabolic one, is of interest for ultrafast-optics applications, such as spectral interferometry [7], spectrotemporal imaging in a time lens [8], etc.

We experimentally investigated the nonlinear dispersive similariton generated in a passive SMF in order to reveal its characteristic features. The analysis was performed using spectral interferometry, which completely characterises ultrashort pulses (USPs) by reconstructing the complex radiation field [9]. A schematic of the experiment is shown in Fig. 1. $\sim$ 100-fs laser pulses with a pulse repetition rate of 76 MHz were split by a Mach – Zehnder interferometer into two beams. The lower intensity beam served as a reference. In the second interferometer arm the radiation passed through a standard USP synthesis system [10], where the initial 11-nm-wide spectrum was cut to 2 nm, and USPs of different shapes were formed. Then, these USPs were coupled into the SMF to generate similaritons. We used standard polarisation-maintaining SMFs (Newport F-SPF@820 nm, ThorLabs HP@780 nm), whose lengths z were 1, 9, and 36 m. The interference spectra were recorded at the interferometer output using an OSA Ando 6315 optical spectral analyser, and the spectral phases $\phi(\omega)$ of the similaritons were reconstructed using the technique reported in [11].

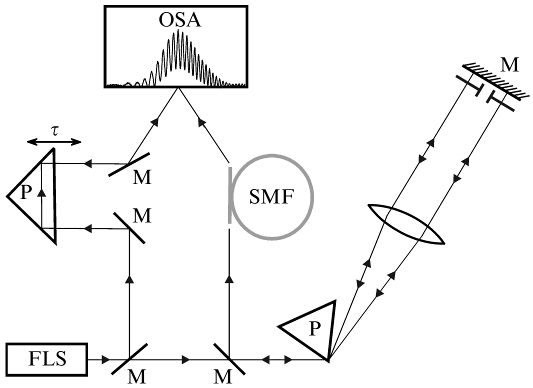

Figure 1. Schematic of the experimental setup: (FLS) Coherent Verdi V10-Mira 900F femtosecond laser system, (M) mirrors, (P) prisms, (OSA) optical spectral analyser, and (SMF) single-mode optical fibre.

The reconstructed spectral phases of the similaritons formed in a 9-m-long SMF from different input USPs are shown in Fig. 2. The phases are parabolic, independent of the initial-USP shape: $\phi(\omega) = -\alpha\omega^2/2$. It is important that the coefficients $\alpha \equiv -\phi''(\omega)$, independent of the initial USP parameters, almost coincide with the corresponding value for purely dispersive USP propagation: $\alpha \approx k_2 z = 0.32$ ps^2 (k_2 is the group-velocity dispersion coefficient for SMF). Rectangular USPs, whose spectral phases are parabolic only in the central energy-carrying part of the spectrum, are formed in shorter SMFs ($z \sim 1$ m); in this case, according to the SMF length, $\alpha = 0.0465$ ps^2.

The experimental study, in agreement with the numerical analysis [6], showed that the induced similariton parabolic phase in the SMF is almost independent of the initial USP parameters and is given only by the SMF dispersion. Having the similariton spectrum $S(\omega)$ and spectral phase $\phi(\omega)$ and using the Fourier transform $\hat{F}$, one can reconstruct the complex temporal amplitude of the similariton:

$$A(t,z) = \hat{F}\left\{\sqrt{S(\omega,z)}\exp[\mathrm{i}\phi(\omega,z)]\right\}$$

$$\approx \frac{1}{\sqrt{\mathrm{i}\alpha}}\exp\left(-\frac{\mathrm{i}\alpha\omega^2}{2}\right)\sqrt{S(\omega,z)}\Big|_{\omega=t/\alpha}. \quad (1)$$

Approximate relation (1) [which is based on the parabolicity of $\phi(\omega)$], by analogy with the Fraunhofer

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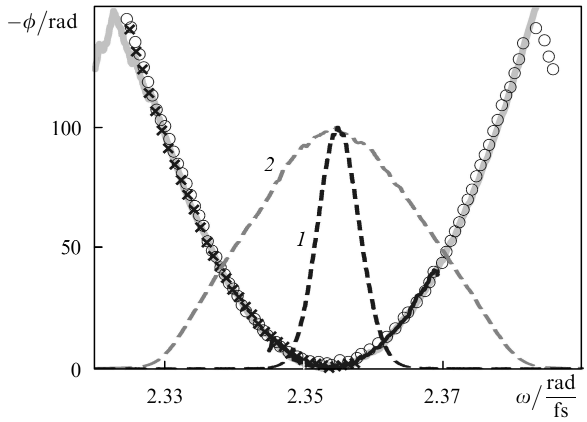

Figure 2. Spectral phases of nonlinear dispersive similaritons formed from different input USPs and the USP spectral phase at dispersive propagation (black curve, $\alpha \equiv -\phi''(\omega) = 0.32\ \mathrm{ps}^2$). The gray curve corresponds to the input single-peak 525-fs USP ($\alpha = 0.33\ \mathrm{ps}^2$); circles ($\alpha = 0.328\ \mathrm{ps}^2$) and crosses ($\alpha = 0.35\ \mathrm{ps}^2$) are for double-peak pulses with peak separations $\Delta t = 628$ and 743 fs, respectively. The dashed curves show the normalised spectra of (*1*) a single USP at the SMF input and (*2*) the corresponding similariton at the output of the 9-m-long SMF.

diffraction, is satisfied more rigorously at large α values; i.e., at large USP self-action lengths z in the SMF. Thus, the parabolicity of the similariton phase (chirp linearity) leads to spectrotemporal similarity: the temporal profile of similariton intensity coincides with the similariton spectrum, $I(t) = |A(t)|^2 \propto S(\omega = t/\alpha)$. Figure 3 shows the spectrotemporal intensity profiles of the similaritons formed from a two-peak USP, at different radiation intensities and an SMF length of 36 m.

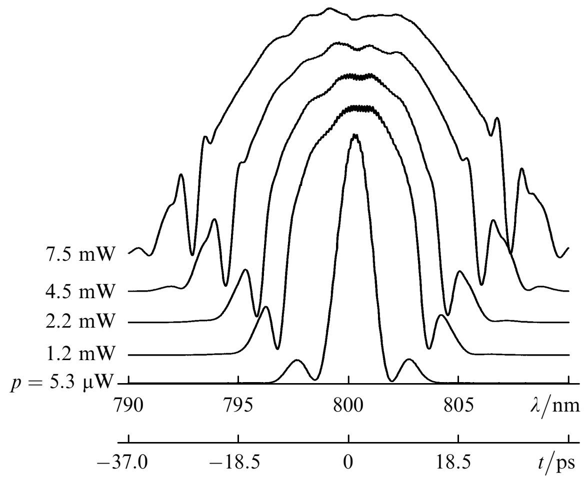

Figure 3. Spectrotemporal intensity profiles of the similaritons formed from a two-peak USP at intermediate radiation powers p (indicated in the figure) and SMF length $z = 36$ m. The curve with $p = 5.3\ \mu\mathrm{W}$ corresponds to dispersive propagation (and the input spectrum).

Thus, the spectral interferometric characterisation of the similariton formed in a passive SMF revealed its inherent features, ensuring its adequate description by relation (1). The nonlinear dispersive process of self-action and formation leads to the spectrotemporal similarity of the similariton due to the linearisation of its chirp, whose slope is given by the optical fibre dispersion; according to the numerical analysis [6], the intensity profile in the central energy-carrying part tends to a parabolic shape, independent of the initial USP parameters. The revealed properties of nonlinear dispersive similariton are important for the problems of signal analysis and synthesis in ultrafast optics and, in particular, for spectral interferometry [7] and spectrotemporal imaging in a parabolic time lens [8].

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