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Physics

BANDWIDTH AND DURATION OF NONLINEAR-DISPERSIVE SIMILARITON

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Studying the spectral peculiarities of nonlinear-dispersive similariton, generated in single-mode optical fiber without gain (passive fiber), we reveal that the bandwidth of such a similariton is conditioned only by the initial pulse power. This property of nonlinear-dispersive similariton can be used for the pulse duration measurements at the femtosecond time scale, alternatively to the autocorrelation technique.

Keywords: fiber, femtosecond pulses, chirp, similariton.

Introduction. Similaritons, the pulses that maintain their temporal profiles during the propagation in fibers, is a modern topic in ultrafast optics. Initially the shaping of pulses with parabolic temporal, spectral and phase profiles for high-intensity pulses was predicted by Anderson et al [1]. Later on, parabolic pulses were generated in fibers with gain or distributed dispersion [2–4]. The parabolic pulses generated in both kinds of fibers with either gain or distributed dispersion maintain their temporal profiles during further propagation beginning from a certain distance. The majority of studies in this field is related to the parabolic similaritons of fibers with gain or distributed dispersion. Recently, a new type of similariton was generated in a passive fiber under the combined impacts of Kerr nonlinearity and dispersion [5]. This nonlinear-dispersive (NL-D) similariton has a parabolic phase (linear chirp) independently of the input pulse characteristics, and bell-shaped spectral and temporal profiles. The chirp factor practically matches with the one for the pure dispersive propagation. To describe the similariton completely the features of its bandwidth and duration are also necessary.

In this work we experimentally study the peculiarities of bandwidth of such similaritons formed in passive optical fibers under the combined impacts of nonlinearity and dispersion. Together with our previous research [5], this study gives the comprehensive description of NL-D similaritons.

Experiment and Results. The objective of our study is the revealing of the spectral broadening regulation for NL-D similariton. In our experiment we shape similaritons from transform-limited and chirped input pulses. We use Coherent Verdi V10–Mira 900F femtosecond laser system with $\tau_0 = 100\,fs$ pulse duration at

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a 76 *MHz* repetition rate, $\Delta\lambda_{in} = 10$ *nm* bandwidth, and central wavelength at $\lambda_0 = 800$ *nm*. The schematic of our experiment is shown in Fig. 1.

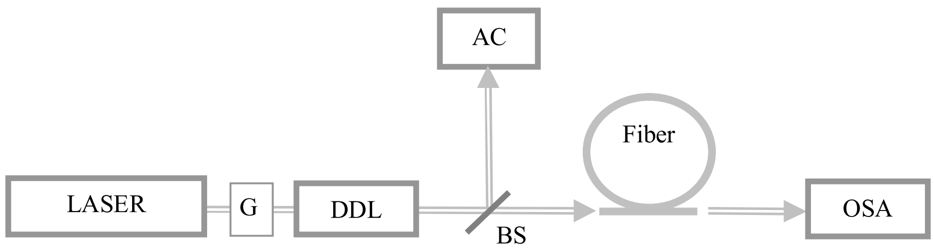

Fig. 1. Schematic of experimental setup.

We stretch the laser pulse, chirping it positively and negatively in SF11 glasses (G) with different thickness and dispersive delay line (DDL) consisting of two dispersion prisms. The beam splitter (BS) splits the laser radiation into the low- and high-power parts. We direct the low-power part to the autocorrelator APE PulseCheck (AC) to measure the input pulse autocorrelation duration, and the high-power part we inject into the fiber, where the similariton is shaped. Afterwards, we measure the bandwidth of similariton and the average power of radiation by means of optical spectrum analyzer (OSA Ando 6315). We also carry out the numerical modeling of the process under study, based on the solution of nonlinear Schrödinger equation with the terms of Kerr nonlinearity and group velocity dispersion (adequate to pulse durations of ≥ 50 *fs* [6]), using the split-step Fourier method.

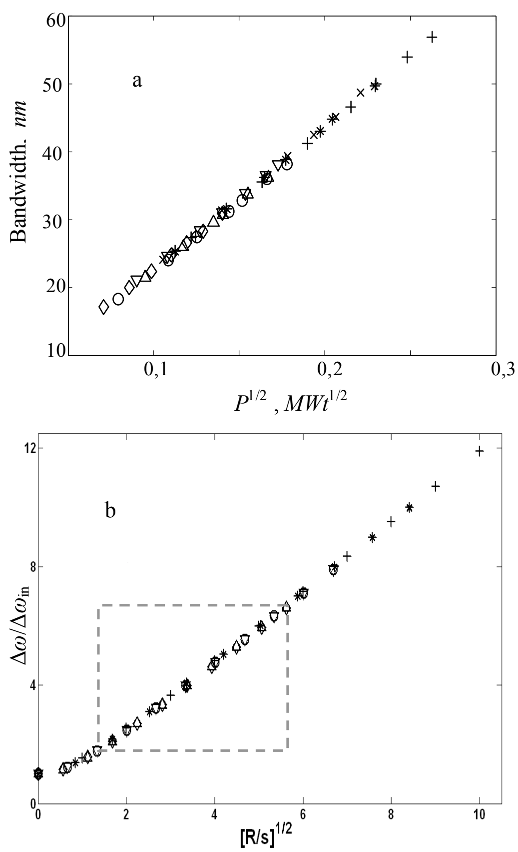

Fig. 2. Similariton's bandwidth versus the square root of its power: (a) – experiment; (b) – numerical simulation for an input Gaussian pulse (the bandwidth $\Delta\omega$ is normalized to the input pulse bandwidth $\Delta\omega_{in}$). + corresponds to the transform-limited pulse with the pulse stretching ratio $s = 1$, $\times - s = \sqrt{2}$, $\nabla - s = \sqrt{5}$, $\Diamond - s = \sqrt{10}$ (positive chirp coefficients); $* - s = \sqrt{2}$, $\circ - s = \sqrt{5}$, and $\Delta - s = \sqrt{10}$ (negative chirp coefficients); $\Delta\lambda_0 = 10$ *nm*. The selected section of (b) corresponds to the experimental range of (a).

Fig. 2 shows the experimental (a) and numerical (b) results in comparison with each other. Fig. 2 (a) shows the similariton's bandwidth $\Delta\lambda$ versus the square root of the pulse power $P = W / \tau_{in}$ (W is the pulse energy). Fig. 2 (b) shows an analogue numerical curve for an input Gaussian pulse. In numerical simulations the bandwidth $\Delta\omega$ is normalized to the input pulse bandwidth $\Delta\omega_{in}$. The experimental and numerical results are in good accordance with each other.

Discussion. NL-D similariton origins from the rectangular pulse shaped due to the pulse NL-D self-interaction in passive fiber [5, 6]. The pulse optimal compression ratio in the regime of rectangular pulses is $\tau_{in} / \tau_c \approx \sqrt{R} / 1{,}8$ [6], where $R = WC^2 / (\tau_{in}\Delta\omega_{in}^2)$, τ_{in} and τ_c are the input and compressed pulse durations, $\Delta\omega_{in}$ is the input pulse bandwidth, and $C = \sqrt{\frac{n_2 k_0}{k_2 S}}$ is a constant (n_2 is the fiber nonlinearity coefficient, S is the fiber mode area, $k_0 = 2\pi / \lambda_0$ is the wave number, and $k_2 \equiv \partial^2 k / \partial\omega^2\big|_{\omega_0}$). For a transform-limited input pulse $2\tau_{in} / \tau_c = \Delta\omega / \Delta\omega_{in}$, and thus, $\Delta\omega / \Delta\omega_{in} \approx \sqrt{R}$, where $\Delta\omega$ is the bandwidth of the rectangular pulse in fiber. Numerical studies show that NL-D similariton practically keeps the bandwidth of rectangular pulse, thus, the expression above can be used for it. Thus, for the bandwidth of NL-D similariton we have

$$\Delta\omega_{sim} = C\sqrt{P}, \qquad (1)$$

where $P = W / \tau_{in}$ is the pulse power. Expression (1) motivates the obtained experimental and numerical results. Note for comparison that the bandwidth of parabolic similariton is $\Delta\omega(z) = [(gk_0 n_2 PW) / (2k_2^2 S)]^{1/3} \exp(gz/3)$, where g is the gain coefficient and z is the fiber length [3].

This peculiarity of NL-D similatiton's bandwidth can be used for pulse duration measurement at the femtosecond time scale. Since the value of C is given, we can have the pulse duration by measuring its bandwidth and energy.

Since the chirp of NL-D similariton is given by the fiber dispersion $\gamma \equiv \Delta\omega_{sim} / \Delta t = (k_2 z)^{-1}$ [5], for its duration we have

$$\Delta t = z\sqrt{k_0 k_2 n_2 P / S}. \qquad (2)$$

Similariton's duration increases linearly during the propagation. Thus, we can control similariton's duration and bandwidth by changing the initial pulse power.

Conclusion. Our numerical and experimental studies show that the bandwidth $\Delta\omega$ of NL-D similariton generated in passive fiber depends linearly on $\sqrt{P}$ with the coefficient, given by the fiber parameters only.

The revealed property of NL-D similariton can be used for pulse duration measurements at the femtosecond time scale, alternatively to the autocorrelation technique.

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Ա. Ս. Զեյթունյան

Ոչ գծային-դիսպերսիոն սիմիլարիտոնի սպեկտրային լայնությունը և տևողությունը

Առանց ուժեղացման (պասիվ) միամոդ օպտիկական մանրաթելային լուսատարում ձևավորված ոչ գծային-դիսպերսիոն սիմիլարիտոնի սպեկտրային առանձնահատկությունների ուսումնասիրության արդյունքում ցույց է տրվել, որ այդպիսի սիմիլարիտոնի սպեկտրային լայնությունը կախված է բացառապես իմպուլսի հզորությունից: Ոչ գծային-դիսպերսիոն սիմիլարիտոնի այս հատկությունը կարող է օգտագործվել ֆեմտովայրկյանային սանդղակում իմպուլսների տևողությունների չափման նպատակով՝ որպես այլընտրանք ավտոկոռելյացիոն մեթոդին:

А. С. Зейтунян.

Спектральная ширина и длительность нелинейно-дисперсионного симиляритона

На основе исследований спектральных особенностей нелинейно-дисперсионного симиляритона, сформированного в одномодовом оптическом волоконном световоде без усиления (в пассивном волоконном световоде), показано, что спектральная ширина такого симиляритона обусловлена исключительно исходной мощностью импульса. Эта особенность нелинейно-дисперсионного симиляритона может быть использована для измерения длительностей импульсов в фемтосекундном временном масштабе в качестве альтернативы автокорреляционному методу