Dark dissipative soliton of nonlinear wave interaction

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Abstract: The spacial distribution of the amplitude of the dynamical grating has a pattern of a dark dissipative soliton in the case of reflection two-beam coupling in a medium with nonlocal response. The manipulation of the pattern depends on the input intensity ratio. The effect of alteration of the shape of input pulse by means of two-wave mixing is considered.

I. INTRODUCTION

The process of nonlinear interaction of waves is quite efficient to study many phenomena, among others: propagation of pulses with different frequency components in optical fibers, optical parametric amplification and oscillators in fibers, wavelength division multiplexing in fiber communications, phase conjugation, holographic imaging, and optical image processing. Together with the generation of new frequency or wavelength components, amplifications and oscillations, in the last years the wave-mixing has been found to lead to the formation of coherent states localized either in time or in space [1-3]. The two key ingredients for the creation of localized states during the wave mixing are: some time delay between the excitation intensity pattern and the response, a nonlocal response of the medium. This temporal or spatial delay between the intensity pattern and the refractive index modulation leads to a phase shift between the interacting waves, and this is precisely the process responsible for the formation of localized states.

There exist two main geometries to operate this process of wave interaction: the transmission geometry and the refection geometry. The spatio-temporal pattern in the transmission geometry resembles the bright dissipative soliton [2-3]. The pattern possesses properties of the dark dissipative soliton in the reflection geometry [1]. We derive the complex Ginzburg-Landau equation to describe the spatio-temporal dynamics of the dissipative soliton in the transmission geometry [2]. Both the position of the dissipative soliton and its localization degree can be altered by changing the input intensity ratio [1-3]. Output intensities are determined by a pattern recorded in the medium. It was shown that output intensities can be significantly changed in dependence on the input intensity ratio [3-4] as the result of changes of the spatio-temporal pattern. One expects many of these features to find applications in the wave interaction process itself as well.

II. STEADY STATE DARK DISSIPATIVE SOLITON

We consider the reflection two-wave mixing (TWM) scheme in nonlinear media with nonlocal response (Fig.1). The input waves I_{10} and I_{2d} form the interference pattern I_m, which modulates the refractive index. The dynamical refractive index grating is created in the medium volume. But the grating maximum amplitude E is shifted relative to the maximums of the intensity pattern I_m in the case of the nonlocal response. The interacted waves lead to formation of the dynamical grating at the same time they diffract on this grating. The output intensities (I_1^{out}, I_2^{out}) are the result of the interference between propagated and diffracted waves. In the case of the direction of the grating shift relative to the interference pattern pictured in the Fig.1, the intensity of the beam 1 is amplified because the interference between propagated and diffracted waves are constructive. Contrariwise the beam 2 is reduced because of unconstructive interference between propagated and diffracted waves in that direction.

The intensity value of the interference pattern defines the grating amplitude E and depends on the intensity ratio of the interacting waves. As the mutual intensities are changed due to energy transfer between the interacting waves, the distribution of the intensity in the interference pattern is not uniform in the medium volume. We will describe this distribution by the profile $I_m(z)$ for the intensity pattern and by the profile $\mathrm{E}(z)$ for the grating amplitude. We will show, that the grating amplitude profile is a step-like one between maximum and minimum values, namely it is the $\tanh-$function. The position of this "step" inside the medium volume depends on the input intensity ratio.

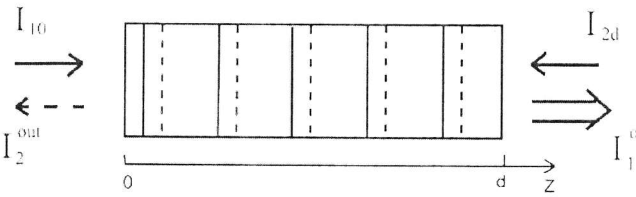


Fig. 1. Two-wave mixing scheme in the reflection geometry in a medium with nonlocal response. Straight lines show the maximums of the interference pattern, dashed lines show the maximums of the refractive index grating. d is the thickness of the medium.

The dynamical process of the self-diffraction in the reflection geometry can be described by the following set of equations:

$$\partial A_1 / \partial z = -i\mathrm{E}A_2 / I_0\,;\ \partial A_2^* / \partial z = -i\mathrm{E}A_1^* / I_0 \quad (1)$$

$$\partial \mathrm{E} / \partial t = \gamma A_1 A_2^* / I_0 - \mathrm{E} / \tau \quad (2)$$

where $A_1(t,z)$, $A_2(t,z)$ are the amplitudes of the waves 1 and 2 correspondently, "star" means the complex conjugation, $\mathrm{E}(t,z)$ is the grating amplitude, $I_0(t,z)=|A_1|^2+|A_2|^2$ is the total intensity, $I_m(t,z)=A_1A_2^*$ is the distribution of the intensity pattern, $\gamma=\gamma_L+i\gamma_N$ in the amplification gain in the nonlinearl medium, γ_L describes the local response, γ_N corresponds to the nonlocal response, τ is the time relaxation constant of the reflective index grating in the medium. The system has the first integral $I_d=|A_1|^2-|A_2|^2=const$.

We consider here the case of pure nonlocal response, when the shift between the interference pattern and the dynamical grating is equal to quarter of the grating period, i.e. $\gamma=i\gamma_N$. In this case the system is significantly simplified, it becomes a real one. The solutions of such system in the steady state are the following:

The profiles of the intensity and the grating amplitudes:

$$I_m = \exp(\gamma\tau \cdot z - p) \quad (3)$$

$$\mathrm{E} = \gamma\tau \cdot I_m / I_0 = \sqrt{[1+\tanh\left(\gamma\tau \cdot z - p + \ln(4/I_d^2)\right)]/2} \quad (4)$$

where p is the integration constant, which can be found from the boundary conditions.

The amplitudes of the waves:

$$\begin{cases} A_1 = C_1 e^{U} + C_2 e^{-U} \\ A_2 = C_1 e^{U} - C_2 e^{-U} \end{cases} \quad (5)$$

where the constants are:

$$\begin{cases} C_1 = \left(A_{2d}e^{-U_0} + A_{10}e^{-U_d}\right)/(2\cosh(U_d - U_0)) \\ C_2 = \left(A_{10}e^{U_d} - A_{2d}e^{U_0}\right)/(2\cosh(U_d - U_0)) \end{cases}$$

The variable U is the area under the grating amplitude profile

$$U(z) = \int_0^z \mathrm{E}(z)dz \quad (6)$$

and $U_0 = U(z=0)$, $U_d = U(z=d)$, d is the thickness of the medium.

In Fig.2 we calculate the grating amplitude profiles for different values of the nonlinear gain. However the amplification of the input signal depends not only on the medium gain, but also on the intensity ratio, in the medium with nonlocal response, like it is shown in the Fig.3. The smaller is the input intensity of the wave 1 the higher is its coefficient of the amplification. The reason of this effect is different distributions of the amplitude of the steady state grating (see Fig.4). The "step" of the $\mathrm{E}(z)$ function is located out of the medium volume shen I_{10} is small. Then the grating amplitude is uniform distributed in the medium volume. With increasing of I_{10} (to compare with I_{2d}) the grating amplitude profile "is shifted" inside the medium volume. So that non uniform distribution of the $\mathrm{E}(z)$ takes place in the medium.

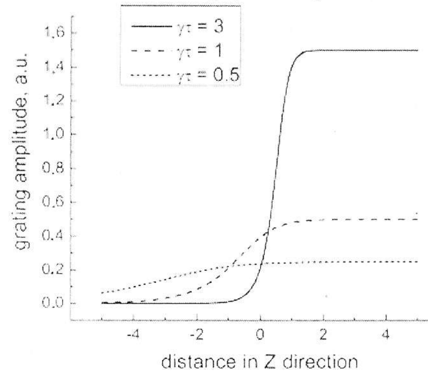


Fig. 2. Profile of the grating amplitude E along the medium volume Z for different nonlinear gains. $I_{10}=I_{2d}=0.5$.

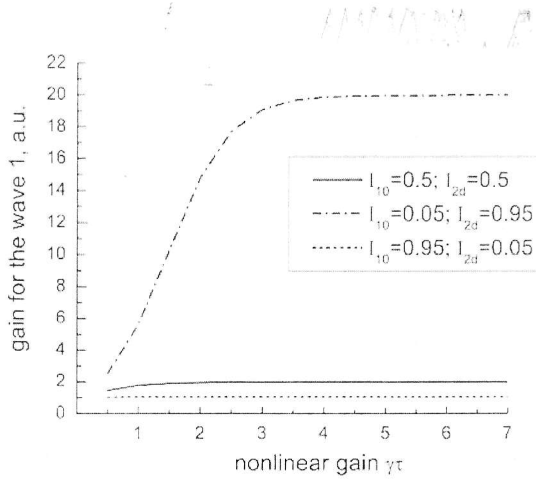


Fig. 3. The gain of the wave 1 (I_1^{out}/I_{10}) for different input intensity ratios (I_{10}/I_{2d}).

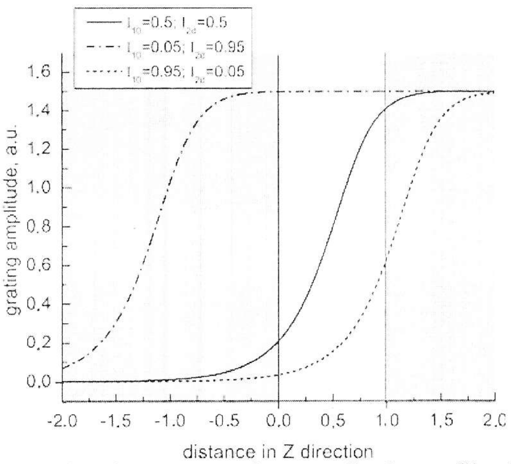
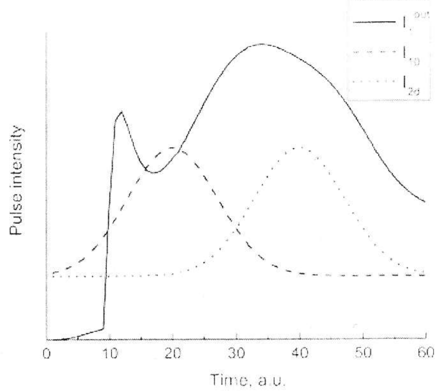


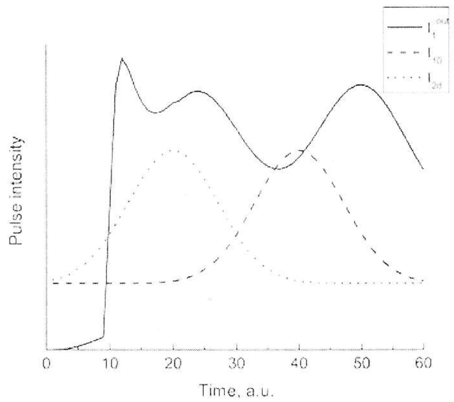
Fig. 4. Steady state grating amplitude profile for the intensity ratio given in Fig.3. The nonlinear gain is $\gamma\tau = 3$. $Z = 0...1$ is the volume of the medium ($d = 1$).

III. Manipulation of Laser Pulses

We apply the idea to alert the grating amplitude profile to look for effects that can take place in the case of interaction of input pulses. We consider the dynamical system (1)-(2) for the case of pure nonlocal response. Here we present the results of interaction of two input pulses, which have a delay relative to each other, in TWM in the reflection geometry. I_{10} and I_{2d} are two input Gaussion beams of the equal intensity. The halfwidth of the pulses is much higher to compare with the time relaxation constant of the grating ($\tau_{imp} : \tau = 10:1$). In Fig.5. it is shown changes of the Gaussian shape of the impulse 1 on the output of the medium. The input pulses are overlapped in the medium, so that the intensity distribution is changed as well. Different intensities distributions will create different profiles of the dynamical diffracted grating. As the result, the output pulse will change its shape. The effect depends, which input pulse is the first on the time, and which is the second one. When the first pulse is I_{10}, the output pulse is spread, has a delay of the maximum and has one minimum (Fig. 1a). When the first pulse is I_{2d}, the output pulse has two minimums.



(a)



(b)

Fig. 5. Pulse delay and changes of the pulse profile (I_1^{out}) due to interaction of two input pulses I_{10} and I_{2d}
(a) when the pulse I_{2d} inputs later than the pulse I_{10};
(b) when the pulse I_{2d} inputs earlier than the pulse I_{10}.

IV. Conclusions

We consider the effect of formation of non uniform distribution of the grating amplitude $E(z)$ that takes place in the reflection two-wave mixing in nonlocal media. The steady state solutions are obtained. $E(z)$ profile resembles the properties of the dark soliton. Its steady state location in the medium volume depends on the input intensity ratio.

This feature to change the grating amplitude profile in dependence of mutual intensities of interacting wave is used to consider new effects of manipulation of laser pulses. That may be very perspective for applications in signal information processing, laser spectroscopy, optical fiber communication systems.

Akcnowlegments

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