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Wavelength, power and pulse duration influence on spatial soliton formation in AlGaAs

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Abstract

This work presents the dependence of spatial soliton formation in AlGaAs slab waveguide versus significant parameters such as wavelength, light power, and pulse duration. Comparison between theory and experiments reveals the importance of multiphoton absorption to understand the soliton behavior. Experimental measurements establish some limits of soliton formation such as usable wavelengths and pulse durations.

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1. Introduction

In materials that exhibit optical Kerr effect, for which the nonlinear index change is proportional to the light irradiance, optical fields localized in space or time can self-trap due to an optically induced positive index change [1]. If the nonlinear effect exactly balances diffraction or dispersion, respectively, spatial or temporal optical solitons exist, resulting in propagation without change of profile [2]. Solitons have received a great deal of attention due to their unique physical properties and a number of possible novel applications, such as long haul data transmission in optical fibers or light-induced reconfigurable waveguide structures [3]. One of the main reasons for the interest in solitons is their remarkable stability, which leads to a particle-like behavior [4,5].

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Since the early nineties, much attention has focused on the use of semiconductors for realizing nonlinear integrated optical devices [6,7]. In particular, AlGaAs operated below the half-band gap spectral region has an almost ideal Kerr nonlinearity [8]. Its nonlinear refractive coefficient, n_2 is two order of magnitude greater than in silica and the absorption is low. In addition, the mature semiconductor fabrication technology available allows low-loss integrated optical component fabrication. Many publications deal with spatial solitons in AlGaAs [9–11]. Other works present this material's two- and three-photon absorption (2PA and 3PA) coefficients and show the implications for all optical switching and spatial solitons [8,12]. However, to the best of our knowledge, no direct implications of the multiple photon absorption (MPA) on solitons have been experimentally characterized in AlGaAs. In addition no studies of soliton behavior as a function of wavelength has been published.

In this paper we show the importance of nonlinear absorption on the soliton behavior as a function of light power. The influence of dispersion of MPA and Kerr effect versus wavelength is also explored. In addition we study the limits on soliton formation as a function of wavelength. Finally, we also discuss the influence of pulse duration on soliton propagation.

The paper is organized as follows. In Section 2 we introduce the basic equation and explicit the physical meaning of the different constituting terms. We present the experimental setup used in Section 3, along with typical results showing the remarkable stability of solitons in AlGaAs, in Section 4. We indeed propagate a soliton on 17 diffraction lengths. The soliton behavior versus wavelength is presented and discussed in Section 5 and the influence of MPA on soliton behavior versus power is analyzed in Section 6. The last section, deals with the influence of pulse duration on such solitons.

2. Theoretical background

The spatial soliton studied in this paper propagates in a planar waveguide. This guided configuration is necessary to obtain stable soliton in a Kerr medium. The beam propagates in the z-direction and is confined in the y-dimension by the fixed waveguide, diffraction can occur only in the third x-dimension. Model for the propagation of pulsed beam is based on the standard nonlinear Schrödinger equation which includes absorption

$$\frac{\partial E}{\partial z} - \frac{\mathrm{i}}{2k}\frac{\partial^2 E}{\partial x^2} + \frac{\alpha}{2}E - \mathrm{i}\frac{2\pi}{\lambda}n_2 I E = 0, \tag{1}$$

where E is the optical field related to the intensity through the relation: $I = 1/2c\epsilon_0 n|E|^2$. n_2 is the Kerr nonlinear coefficient, λ is the wavelength in free space, k is the propagation constant in the medium whose average refraction index is n. The total absorption α is given by

$$\alpha = \alpha_0 + \alpha_2 I + \alpha_3 I^2, \tag{2}$$

where α_0 is the linear absorption, α_2 is the 2PA coefficient and α_3 is the 3PA coefficient. Eq. (1) is numerically solved using the Split Step Fourier method, where the temporal shape of the beam is included. Absorption coefficient and n_2 values are extracted from reference [8].

3. Experimental setup

The semiconductor waveguides used in the experiments were grown by molecular beam epitaxy. Two different structures have been used. The structure of the first waveguide (WG1) consists of a 1-μm-thick guiding layer of $Al_{0.21}Ga_{0.79}As$, a 3-μm-thick lower cladding region and a 1-μm-thick upper cladding region of $Al_{0.3}Ga_{0.7}As$ deposited on a GaAs wafer. It was cleaved to give a 12-mm-long waveguide. The structure of the second waveguide (WG2) consists of a 1.5-μm-thick guiding layer of $Al_{0.24}Ga_{0.76}As$, sandwiched between two claddings similar than the first waveguide. This waveguide is 14-mm long.

Three different laser sources have been used: two optical parametric systems continuously tunable in the near-infrared region, delivering either femtosecond or picosecond pulses, and a 1.53-μm laser providing nanosecond pulses. The femtosecond system is an optical parametric amplifier (OPA) pumped by a CW-titanium:sapphire. The