Opt
https://doi.org/10.1007/s12596-021-00776-x

RESEARCH ARTICLE

# Nonlinear interaction of quadruple Gaussian laser beams with narrow band gap semiconductors

Naveen Gupta[1] · Sandeep Kumar[1] · Gnaneshwaran A[1] · S. B. Bhardwaj[2] · Sanjeev Kumar[1,3] · Suman Choudhry[1,3]

Received: 1 June 2021 / Accepted: 4 September 2021


**Abstract** This paper presents an investigation on nonlinear propagation of quadruple Gaussian (Q.G) laser beam in narrowband semiconductor (e.g., n-type InSb) plasmas. In the presence of laser beam, the electron fluid in the conduction band becomes relativistic that makes the medium highly nonlinear. As a result the laser beam gets self-focused. Following variational theory approach in W.K.B approximation the numerical solution of the nonlinear Schrodinger wave equation (NSWE) for the field of incident laser beam has been obtained. Particular emphasis is put on dynamical variations of beam spot size and longitudinal phase (Gouy phase). Self-trapping of the laser beam resulting from the dynamical balance between diffraction broadening and nonlinear refraction also has been investigated.

## Introduction

The advent of laser [1] in the early 1960s set in motion a train of events that led to a renaissance in the field of light–matter interactions. The past few years have seen two important advances. One was the proposal of initiating fusion reactions [2] for viable energy production that would quench humanity's endless thirst for energy without worsening the global climate change. Another noteworthy advance was the laser-driven particle accelerators [3]. Particle acceleration by laser-driven plasma wave is an extremely interesting and far-reaching idea that can bring huge particle accelerators to bench top. The efforts to translate these concepts into reality, however, have to surmount two serious problems: (1) The creation of relativistic plasmas requires ultrahigh laser intensities in the excess of $10^{18}$-$10^{20}$ $W/cm^2$, and (2) the plasmas have to be extremely homogeneous. These rather daunting requirements have made it difficult even to carry out exploratory experiments to test the proposed ideas.

Therefore, there have been ongoing efforts to find alternatives to standard plasma experiments, where these severe constraints could be mitigated. One could then validate the theoretical frameworks and shed light on the eventual feasibility of these ideas. Fortunately, such an alternative exists; it is provided by certain special plasmas found in the narrow-band semiconductors [4, 5] (Fig. 1). Plasmas contain negative and positive carriers under conditions in which they do not combine. In Fig. 1 a red dot is an electron, or negative charge, a blue dot containing a plus sign is a positive charge, and neutral atoms are shown green. In a gas there are two kinds of charge carrier: electrons and positive ions (atoms lacking electrons). In a simple metal the only mobile carriers are electrons; positive ions are locked in the crystal lattice. A semiconductor has two kinds of mobile carrier: electrons and positive "holes" or missing electrons. All three plasmas can transmit waves.

Interaction of intense laser beams with semiconductor plasmas is rich in copious nonlinear effects. This spans a gamut from parametric instabilities to several self-action effects like self-focusing, self-trapping self-phase modulation, etc. All these nonlinear effects are extremely complex but rich in physics to provide a necessary test bed for

✉ Naveen Gupta
naveens222@rediffmail.com

1 Lovely Professional University, Phagwara, India

2 SUS Govt College, Matak-Majri, Indri, Karnal, India

3 Government College for Women, Karnal, India

Published online: 07 October 2021