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Conservative Finite-Difference Scheme and Two-Stage Iteration Process of its Realization for the 2D Problem of Semiconductor Plasma Generation by Femtosecond Pulse

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Abstract. In this paper we develop conservative finite-difference schemes (FDS) for the process of femtosecond pulse interaction with semiconductor. This process is described by the set of 2D dimensionless differential equations concerning concentrations of both free electrons and ionized donors, and potential of electric field, induced by laser pulse and laser beam intensity changing. The electron mobility, electron diffusion, nonlinear dependence of absorption coefficient on semiconductor characteristics are taken into account also.

For the problem under consideration we have constructed and compared two conservative FDS. One of them is based on the well known split-step method, the second one is based on the original two-stage iteration process. We paid the special attention to the 2D Poisson equation solution. This equation is solved by using an additional iteration process. Thus, to solve the problem under consideration it is necessary to achieve a convergence of two iteration processes.

As follows from computer simulation provided by us, the criterion choice for the iteration process convergence can significantly affect on the equations solution accuracy. We used the criterion based on assessment of an absolute and relative error of the solution obtained on iterations. This criterion is also used for Poisson equation solving. However, the iteration convergence criterion, based on discrepancy estimating, is more effective for using in this case.

Computer simulation results showed that the developed conservative FDS on the base of two-stage iteration process is an effective tool for investigation of complicated modes of semiconductor characteristics changing.

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1 Introduction

Investigation of a laser radiation interaction with semiconductor is very modern problem because semiconductors are widely used in many applications such as optoelectronics devices (see, for example [1-22]). Among them we would stress an optically bistable element, based on using various nonlinear responses of semiconductor, exposed by a laser radiation. As it is well-known, the optical bistability (OB) is very promising phenomenon for the creation and developing of all-optical data processing. This phenomenon characterizes by existence of a hysteresis loop for semiconductor characteristics. This results in two stable states appearing: upper and low states for the same value of the incident optical pulse intensity. Realization of one of them depends on initial conditions for the problem. Thus, the problem has not the unique steady state solution if an OB occurs. Moreover, under certain conditions, the problem solution can become unstable and complicated oscillating regimes of semiconductor characteristics changing develop.

OB phenomenon accompanies also by many various nonlinear effects occurring in semiconductor. So, we face to necessity of computing very complicated regimes. For example, developing of the helical wave for electron-hole plasma was demonstrated in [23-24] if a semiconductor is placed in the external electric field. For computer simulation of these complicated nonlinear non-stationary processes it is necessary to use especially developed finite-difference schemes (FDS) which possessing such properties as conservatism, stability to initial condition perturbation and stability to round-off errors. Of course, at developing the FDS, the main question is the difference solution proximity to the solution of the differential problem. However, if we provide a computer simulation during long-time interval in comparison with characteristic times of processes under investigation, we have to take into account accumulation of rounding errors at computer simulation. If the FDS possesses property of stability to rounding errors accumulation, then this FDS possesses the property of asymptotic stability [25]. Construction of such FDS is an urgent problem. For example, in [26] there is at least one sample of using FDS which doesn't provide asymptotic stability property. To avoid this influence one has to use extraordinary small grid steps.

One of the well-known approaches for computer simulation of multi-dimensional equations is the split-step method using [27-32]. However, in [33] we had shown that this method possesses some disadvantages for the problem under consideration and it is stimulated us to develop a new FDS for computer simulation of this problem. In the present paper we continue our research in this direction. Below we paid our main attention to solving the Poisson equation with respect to the electric field potential. The aim is a choice of an iteration process termination criterion for high computation accuracy achievement at long time interval (about 1000 dimensionless units). For this purpose we have to develop a FDS, which possess the asymptotic stability property.