On a van Roosbroeck-Helmholtz model for a semiconductor laser diode

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Abstract

We consider a coupled light-matter model for semiconductor lasers consisting of the transient van Roosbroeck system for charge transport and a Helmholtz eigenvalue problem for the transversal optical field. The coupling is realized through a stimulated recombination operator in the carrier continuity equations and a carrier-dependent dielectric function in the Helmholtz problem. In this paper, we establish, under physically relevant assumptions, local-in-time well-posedness of the coupled van Roosbroeck-Helmholtz system. The proof relies on the abstract framework of quasi-linear parabolic equations in Banach spaces developed by Kaiser, Neidhardt, and Rehberg which requires in particular a local Lipschitz continuity property of the nonlinear recombination operators. By deriving precise local Lipschitz bounds for the stimulated recombination operator, we verify the conditions needed to apply the abstract existence theorem. As a consequence, we obtain the existence and uniqueness of weak solutions to a drift-diffusion-Helmholtz model of semiconductor lasers that incorporates stimulated emission in a mathematically consistent way. To the best of our knowledge, this is the first rigorous existence and uniqueness result for the nonlinear coupling of the van Roosbroeck system with a Helmholtz eigenvalue problem under physically motivated assumptions.