Modeling Semiconductor Gain Medium Using a Multi-Level Multi-Electron Finite-Difference Time-Domain Algorithm

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The Finite-Difference Time-Domain (FDTD) method is a conceptually simple, yet powerful, numerical solver capable of achieving arbitrary accuracy limited only by the spatial and temporal stepping increments. One of its specific applications is to efficiently simulate the electromagnetic (EM) interactions with various optical materials, for example, very importantly, the semiconductor gain media widely used in products and devices affecting our daily activities, such as the laser diode and solar cell.

In this talk, we report and discuss our recently developed FDTD computational model for simulation of EM interactions with a direct band-gap semiconductor medium, a problem often encountered in photonics and RF studies. In this algorithm, the auxiliary differential equation (ADE) FDTD method is employed to semi-classically incorporate the EM wave characterized by the classical Maxwell's equations into a multi-level multi-electron atom system with the material's macroscopic polarization quantum-mechanically derived. The carrier transitions between quantized energy levels are governed by coupled differential rate equations incorporated with the state filling effect and the Pauli Exclusion Principle, which thus naturally takes into account the Fermi-Dirac statistics of carriers in simulations.

This model is capable of simulating various gain and absorption effects under optical pumping and current injection over a large range of signal intensities, thus permits in principle a much more robust treatment of the overall electron dynamics in the semiconductor materials integrated into virtually arbitrary EM confinement geometries, and therefore seeks broad applications in the area of computational photonics. The technical details as well as some numerical results are to be covered and discussed during the presentation.