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Coupled Optical and Electronic Simulation of Integrated Photonics based Hot-Electron Graphene Photoemitters using a 2-D Ensemble Monte Carlo Boltzmann Transport Equation Solver and a Finite-Difference Time-Domain Maxwell's Equation Solver

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Recently, we have shown that a waveguide integrated graphene photocathode excited with sub-workfunction energy photons can emit electrons at optical power densities significantly lower than traditional multi-photon or strong-field emission cathodes using metallic tips. Initial modeling efforts indicated that the behavior was due to non-equilibrium heating of electrons in graphene beyond the lattice temperature, and direct field-emission of excited electrons before scattering. Here, we develop a rigorous optical and electronic simulation to study the behavior by considering the fundamental generation, scattering, and emission rates. This is enabled via a 2-D ensemble Monte Carlo Boltzmann Transport Equation solver coupled to an optical simulation. Using this simulation, we have studied the ultrafast relaxation of the electrons considering both K and K' valleys close to the Dirac point. The uniqueness of our model lies in the dynamic calculation of the scattering rates rather than using a precalculated net scattering rate. The dynamic scattering rates are particularly important due to Pauli blocking, which modifies the scattering phenomena as the system evolves. We have considered the major scattering mechanisms: coulomb scattering including auger processes, optical phonons, and supercollision acoustic phonons. Using the dynamically calculated electron lifetimes, we have determined the tunneling rates of electrons into the vacuum following Bardeen's tunneling Hamiltonian approach within WKB approximation. To calibrate our scattering models, we have reproduced published pump-probe spectroscopic data on graphene. The calibrated tool is then used to model our own experimental devices, showing good fits to our experimental results. The tool is then used to predict the potential performance of the integrated photonics based hot electron emitters.

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