Modeling of charge transport and high frequency response in gated 2D diamond conduction channels.

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The physical characteristics of diamond, such as high thermal conductivity of 23 W/cmK and high breakdown field of 13 MV/cm suggest that diamond is a promising semiconductor material for high power operation. A high carrier concentration of up to 10^{14} cm^{-2} in two dimensional hole gas formed at a hydrogenated diamond surface by the mechanism of transfer doping is achievable [1], and high performance diamond transistors based on the hydrogenated diamond channel were demonstrated in the past [2]. Additionally, an optical phonon energy in diamond results in suppression of optical phonon scattering and, consequently, in a very large momentum relaxation time limited by optical phonon scattering, opening a possibility of high quality plasma resonance [3]. The goal of this work is to explore the transport properties of diamond based quasi-two-dimensional conduction channels formed at the hydrogenated diamond surfaces and at the interfaces of diamond / boron nitride heterostructures, in order to enable modeling and characterization of diamond transistors.

In higher mobility channels subject to moderate electric fields a hydrodynamic model allows a convenient scheme for analysis of charge transport under both constant and high frequency electric fields. In case of high electric fields and strongly non-equilibrium carrier distribution we apply the Monte-Carlo (MC) simulation of the Boltzmann transport equation. In order to apply hydrodynamic model, we evaluated relevant carrier relaxation times and obtained the temperature and density dependent transport parameters, such as carrier mobility, 2D Fermi gas viscosity, and thermal conductivity. The results for carrier mobility is illustrated in the figure. The effect of Coulomb scattering of mobile holes by fixed negative charges on hole mobility μ was evaluated using dielectric FET model of p-diamond/BN interface. We find weak dependence on channel-to-gate distance d, but strong dependence on channel-to-fixed charges distance di. Left panel shows μ(d) for two values of di: 0.3 nm and 0.21 nm. Right panel shows μ(di) for two values of d: 3 nm and 2 nm. We also evaluated the effect of the carrier scattering by the polar BN phonons at the diamond/BN interface on mobility. In high carrier density channels, we find that the scattering by the interface phonons is weak due primarily to the Pauli blocking in the final states available for the scattered mobile charge carriers. At the carrier density of 10^{14} $1/cm^2$ the Fermi en0rgy is 443 meV, and the mobile carriers at room temperature are to be treated as a strongly degenerate Fermi gas. We have also obtained an analytical approximations for the viscosity and heat conductivity that can be conveniently used in the numerical solutions of hydrodynamic model equations to study the current and voltage response of the gated diamond channel to the high frequency electric field. In the modeling of transport in the strongly non-equilibrium case by MC simulation the relevant scattering processes and band structure effects were included.

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