Ratchet transport of carriers in graphene

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Free carriers driven by an alternating electric field can exhibit a directed motion facilitated by thermal or quantum fluctuations. Here, we report on theoretical and experimental study of such ratchet effects of Dirac fermions in graphene demonstrating that the ratchets can be downscaled to one-atom thick crystals. We show that the single-layer graphene samples subjected to an in-plane magnetic field rectify ac electric current converting it into a dc electric signal. The ac electric field, in our experiments provided by terahertz (THz) radiation, pushes electrons back and forth in the graphene plane while the static magnetic field acts as a valve letting the electrons move in one direction and suppressing the oppositely directed motion.

The ratchet current is proportional to the square of the amplitude of the ac electric field, scales linearly with the static magnetic field magnitude, and reverses its direction by switching the magnetic field polarity [1]. We show that it is generated for both linearly polarized as well as rotating ac electric field. For linear polarization, the current depends on the angle between the electric field polarization and the static magnetic field. For the rotating field, the current reveals a helicity-sensitive component reversing its sign by switching the rotation direction of the electric field.

Ratchets effects are only possible in systems with broken space inversion symmetry. Therefore, the observation of electronic ratchet demonstrates that the spatial symmetry of graphene layers, nominally centrosymmetric two-dimensional crystals with the honeycomb lattice, is broken due to substrate or chemisorbed adatoms on the graphene surface. We present a microscopic theory of the quantum ratchet effect and show that the dc current stems from the asymmetry of scattering of Dirac fermions in graphene, which is caused by the mixing of π- and σ-band states in the in-plane magnetic field. The developed theory is in a good agreement with the experiment describing the observed dependence of the ratchet current on the static magnetic field, ac electric field amplitude and polarization. The results suggest that the ratchet current can be calibrated to nondestructively measure the strength of the structure inversion asymmetry.

The experiments were carried out on single-layer graphene samples grown on the Si-terminated face of a 4H-SiC(0001) semi-insulating substrate or synthesized by chemical vapor deposition (CVD) on Si/SiO2. The samples (5 x 5 mm^2 with ohmic contacts) were placed into an optical cryostat with crystal quartz windows and split-coil superconducting magnet providing magnetic fields up to 7 Tesla. The THz radiation is generated by an optically pumped ammonia laser. The dc current generated in the unbiased graphene sample was measured via the voltage drop across a load resistor.

[1] C. Drexler, S.A. Tarasenko, P. Olbrich et al., Nat. Nanotechnol. **8**, 104 (2013).