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Quantum Ratchets and Room Temperature Nano-Devices

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Ratchets are non-equilibrium systems in which directed particle motion is generated using spatial or temporal asymmetry, in the absence of time-averaged macroscopic forces or gradients. After introducing basic concepts, an overview will be given on recent experiments on quantum ratchets. The devices are based on GaAs/AlGaAs heterostructures containing a two-dimensional electron gas. The non-linear response of a spatially asymmetric nanostructure (a triangular quantum dot) to an applied voltage is used to partially rectify a symmetric AC voltage. The required non-linear behavior is generated using quantum effects such as electron interference or tunneling through an asymmetric energy barrier[1].

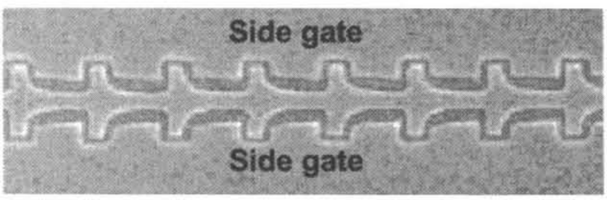

Fig. 1 A scanning electron microscope image of a ratchet structure, consisting of etched trenches and side gates.

We also show that ballistic rectification[2,3] can be realized in high-mobility InGaAs/InP quantum well materials. Using electron-beam lithography, wet chemical etching and epitaxial overgrowth with InP, we obtain heterostructurally defined symmetry-breaking electron scatterers as well as electron wave-guides. Smaller, single device ballistic rectifiers than previously reported are realized, which give higher efficiency and even functionality at room temperature[4].

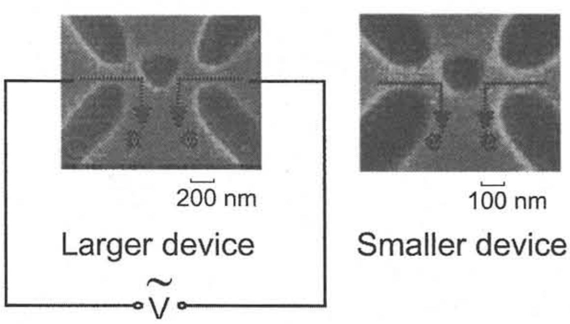

Fig. 2 Scanning electron microscope images of ballistic rectifiers of difference sizes, fabricated from high-mobility InGaAs/InP quantum well materials.

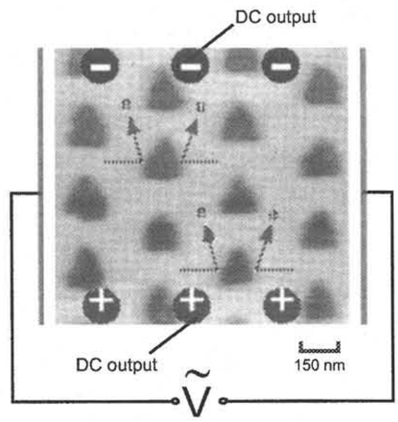

Fig. 3 Atomic force microscope image of the artificial electronic nanomaterial, fabricated from a high-mobility InGaAs/InP quantum well materials.

Furthermore, by arrangement of the nanometer-sized symmetry-breaking elements into a two-dimensional lattice, a new class of artificial functional material is constructed[5]. Fig. 3 shows an atomic force microscope image of the material. We use a modulation doped InGaAs/InP QW structure in which electrons are confined in a 2DEG. The triangular areas are either etched away or, after etching, filled with higher band-gap InP material in an overgrowth process. The overgrowth makes the structured material truly "heterostructure-defined" in all three dimensions. This increases the sharpness of the structures, minimizes the electrical depletion around the triangles and planarizes the final wafer. Even at room temperature such nanomaterial exhibits nonlinear electronic functionality. We show that individual devices can be made by, simply, cutting pieces from the material, and that these devices operate at least up to 50 GHz.

References

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