

Fabrication and Characterization of InAs Ballistic Rectifiers

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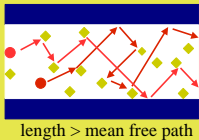
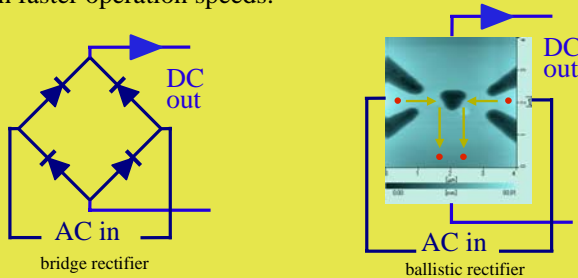
Rectifying devices change AC current into DC current. Ballistic is a term describing microscopic lengths that are shorter than the mean free path of a given material, meaning that, on average, electrons travel ballistic distances without colliding with any impurities in the material. This ballistic transport allows for very fast, scatter-free and predictable movement of electrons through the medium, which makes it possible for nanostructures to be used to control the path of the electrons. These properties are the basis of ballistic rectifiers; using nanoscale geometry to rectify electrical current. Because of the very fast, unimpeded movement of the electrons, ballistic rectifiers also have the advantage of being able to operate at much higher frequencies than today's microscopic semiconductors. The ballistic rectifiers investigated in this project were created on substrate with a complex series of layers which provide a buffer zone between the irregularities in the lattice structure of the channel layer (InAs) and the lattice structure of the substrate (GaAs). To develop the device, several patterns are exposed, developed and etched onto the wafer using e-beam lithography, photo lithography, e-beam evaporation and vacuum deposition machinery. The effectiveness of a ballistic rectifier is evaluated by applying a series of voltages at the inlet terminals of the device and measuring the resulting voltage at the outlet terminals. Ballistic rectification occurs when there is a voltage difference between the outlet terminals of the device, even if the voltage difference between the inlet terminals is very small. The current goal of this research is to develop ballistic rectifiers that demonstrate ballistic rectification characteristics at both low temperatures (77K) and room temperature (300K).

Characterization and Fabrication of InAs Ballistic Rectifiers

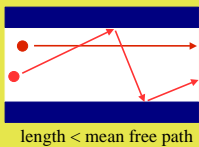
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Background

A rectifier is a device that takes AC current and changes it to DC current. Ballistic rectifiers are different than traditional bridge rectifiers because they operate by ballistic electron transport. This allows for the use of nanostructures to rectify current as opposed to pn junction diodes, resulting in much faster operation speeds.

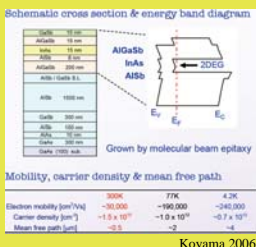


In diffusive electron transport, electrons collide with impurities in the material, scattering them and slowing them down. Traditional bridge rectifiers use diffusive transport, so they cannot operate at high frequencies.



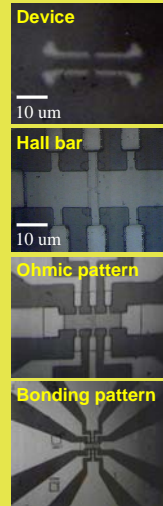
In ballistic electron transport, electrons do not collide with any impurities. Ballistic distances are only nanometers in length. Because of this, ballistic rectifiers can operate at very high frequencies.

The Substrate



An InAs/AIGaSb heterostructure is used for fabrication as it has a very long mean free path, further increased by cooling. Buffer layers between the bottom layer (GaAs) and the channel layer (InAs) are needed to accommodate differences in lattice constants.

Fabrication



1. The ballistic rectifier device structure is exposed with electron-beam (e-beam) lithography onto the substrate and defined with wet chemical etching. The central part of the device cannot be seen in the photograph because it is too small.

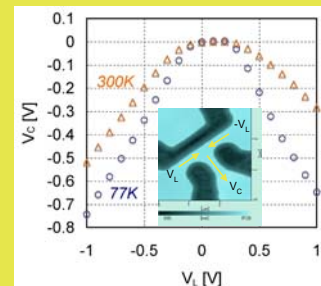
2. The Hall-bar houses the device structure and isolates it from the rest of the wafer. It is exposed above the device with photolithography and, after etching, ~220 nm of SiO₂ is added with e-beam deposition as an insulator.

3. In order to take measurements we must expose the Ohmic contact pattern and bonding pattern. After development, indium and gold are added with vacuum deposition as conductors. Under a microscope, adhesive carbon paste is used to bond gold wire to the bonding pattern.

Measurements

The graphs below show the rectification characteristics of two ballistic rectifiers (“T”-branch and “Y”-branch devices) at 300K (room temperature) and 77K (achieved with liquid nitrogen cooling). Bias was applied such that the voltage at the left and right terminals was equal but of opposite sign. Then the voltage at the central branch was measured. Ballistic rectification effects are observed in the sections of the graphs with non-linear trends. As can be seen, both devices achieved ballistic rectification at room temperature!

3 Terminal “T” Branch device



3 Terminal “Y” Branch device

