Characterization and Fabrication of InAs Ballistic Rectifiers

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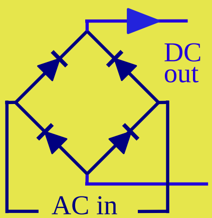
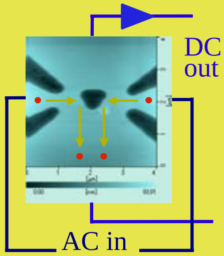
---------------------------Background---------------------------

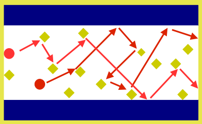
A rectifier is a device that takes AC current and changes it to DC current. Ballistic rectifiers are different than traditional bridge rectifiers because they operate by ballistic electron transport. This allows for the use of nanostructures to rectify current as opposed to pn junction diodes, resulting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



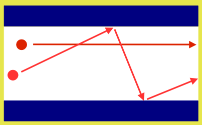
bridge rectifier



ballistic rectifier

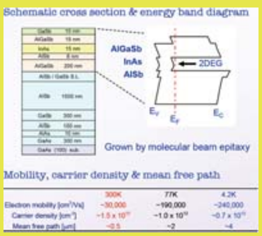

length > mean free path

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.


length < mean free path

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.

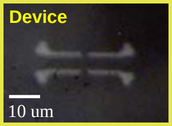
--------------------------- The Substrate ---------------------------

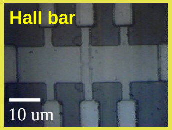


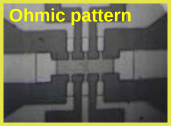
Koyama 2006

An InAs/AlGaSb 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.

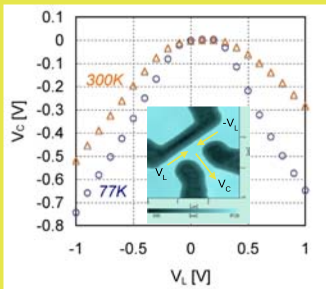
2. The Hall-bar houses the device structure and isolates it from the rest of the wafer. It is exposed above the device with photolithography and, after etching, ~220 nm of SiO_2 is added with e-beam deposition as an insulator.

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.

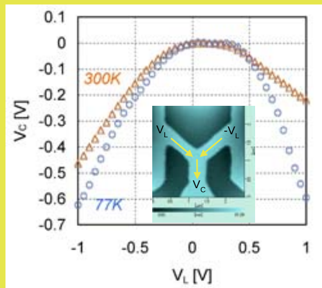
------------------------------- Measurements -------------------------------

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



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Research conducted at Osaka Institute of Technology as a participant in the Rice University and NSF-PIRE sponsored NanoJapan 2007 program.

National Science Foundation

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