Fabrication and Characterization of InAs based Ballistic Rectification Devices

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Rectifiers allow the transition from AC current to DC and currently are mostly solid state P-N junctions. Ballistic rectification is a semi-new branch of research based mainly around semiconductor devices which don't require PN junctions, only a layer of InAs, therefore they have increased speed. This effect illustrates a clear potential negative deviation in the structure, even at 300K. This negative variation can't be explained by Ohm's law. These effects can occur in nanostructures fabricated on high-mobility heterostructures such as GaAs/AlGaAs. An important feature of ballistic rectifiers is the electron scattering length also known as the mean-free path. This is the average distance between scattering events such as impurities and lies in submicron range. By designing device geometry in a specific orientation, the electrons will follow abnormal behavior in a prearranged, controlled path. The primary purpose behind this experiment is the fabrication of several structures on InAs/AlGaSb heterostructures to obtain differing measurements and increased rectification effects at room temperature. Fabrication of the devices is accomplished through the use of; E-beam lithography, wet-chemical, atomic force microscopy, thermal evaporation, and finally photolithography. Characterization of the ballistic semiconductor devices consists of recording various measurements including: etch depth by profilometer, temperature variable resistance using two-terminal and four-terminal junctions, and observation of rectification effect. Currently fabrication and characterization are ongoing, but preliminary findings show ballistic rectification at temperatures varying from 4.2K to 300K for all currently measured samples, though there is a definite increase of effects at lower temperatures.

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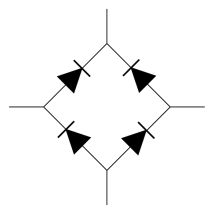
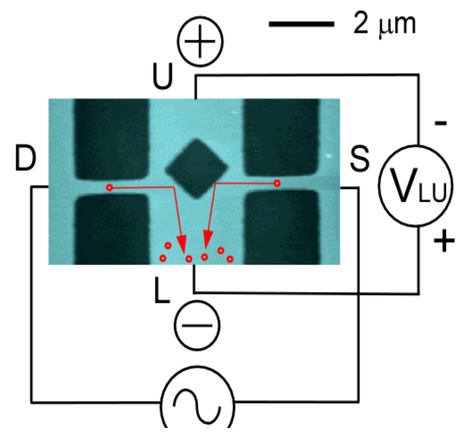
Introduction:

Standard Rectifiers:

- •Convert AC to DC current.
- •Mostly solid state P-N junctions.
- •Voltage and current are the same.



Bridge Rectifier



Ballistic Rectifier

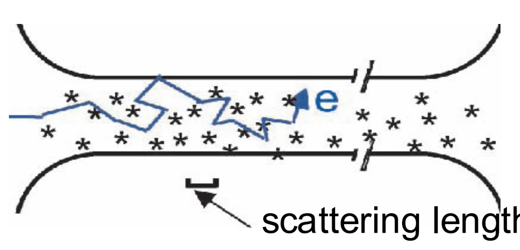
Ballistic Rectifiers:

- •Don't require PN junctions, only a layer of InAs for ballistic electron transport.
- • Among various III-V compound semiconductors, InAs has one of the longest mean free path(~ 3 um @ 77K, 500 nm @ 300K).
- •Voltage and current are not symmetrical.

Mean Free Path = electron scattering length

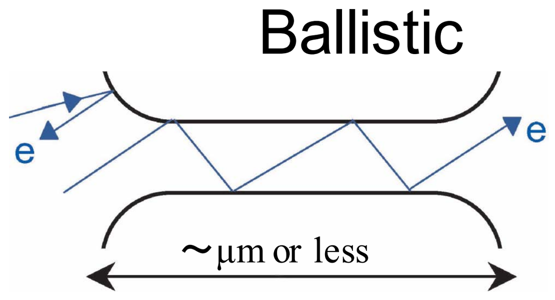
- •Average distance between scattering events.
- •Lies in the submicron range in InAs/AlGaSb heterostructures
- •Follows a straight path which is defined by device geometry.

Diffusive



Length > Mean Free Path

Ballistic



Length < Mean Free Path

Purpose:

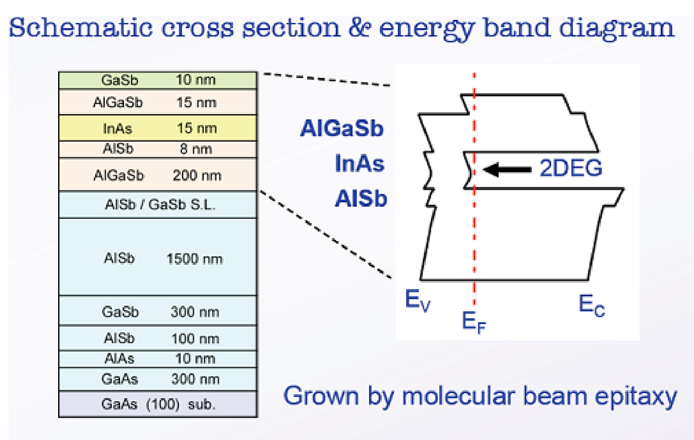
Higher mean free paths and shorter electron transport lengths means electrons do not encounter many scattering effects.

•Allows ballistic rectifiers to operate at very high frequencies,

- •Currently as much as 50GHz (reported with InGaAs related heterostructures[1])
- •Theoretically upwards of 1THz. [2]

This is a significant improvement over standard diffusive electron transport, where electrons collide with impurities in the material, scattering them and slowing down rectification.

Approach:

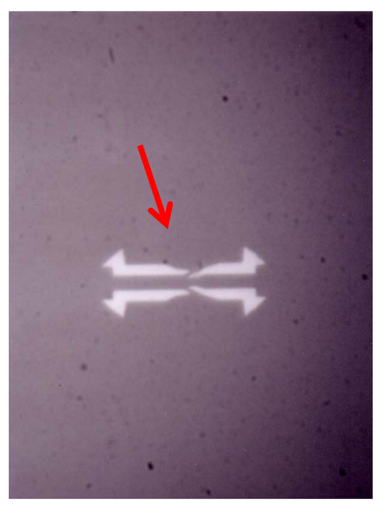


Mobility, carrier density & mean free path

	300K	77K	4.2K
Electron mobility [cm^2/Vs]	~30,000	~190,000	~240,000
Carrier density [cm^{-2}]	~1.5×10^{12}	~1.0×10^{12}	~0.7×10^{12}
Mean free path [μm]	~0.5	~2	~4

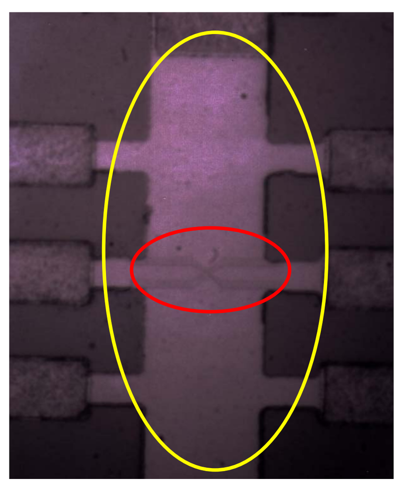
An image depicting the band alignment of this Type-II staggered and broken gap system.

There are various buffer layers that lie between the bottom layer of GaAs and the channel layer of InAs. These layers accommodate large lattice mismatch between the InAs channel layer and the GaAs substrate.



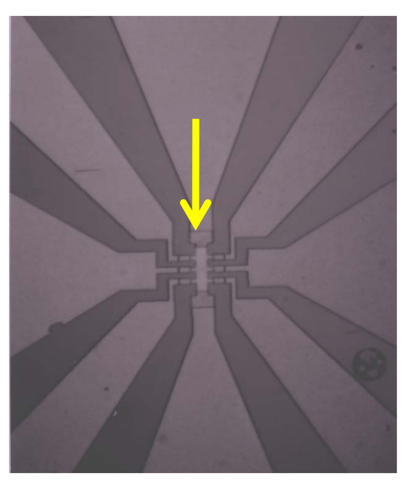
Device –

- • structure is exposed with electron-beam (e-beam) lithography onto substrate
- •defined with wet chemical etching
- •Central part of the device is too small to be visible with optical microscope.
- •Image is at 10X100 magnification (taken with optical microscope).



Hall Bar –

- •The Hall bar pattern was formed with standard photolithography and wet chemical etching.
- •About 220 nm of SiO_2 were deposited on the etched part with an E-Beam evaporator, as an insulating layer.
- •Image is at 10x100 Mag.



Electrode pattern –

- •Ohmic contact pattern and large electrode bonding pattern.
- •In and Au metals were deposited with vacuum deposition
- •After the metal formation processes, a layer of photoresist is applied as a protection layer of the surface.
- •Using a microscope, small amounts of In are used to bond Au wire to the electrode pattern.
- •Image is at 10x20 Mag.

Results:

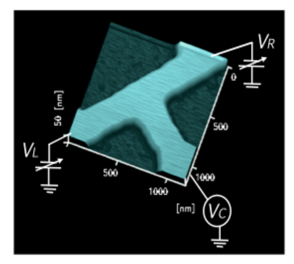
The graphs below show the rectification characteristics of two 3-Terminal Ballistic Rectifiers, a T-branch and Y-branch device respectively. The T-branch device shows varying rectification effects from 77K, achieved with the use of liquid N_2, to 300K (room temperature). Bias was then applied to the left and right terminals in equal but opposite amounts and the voltage was measured at the central branch.

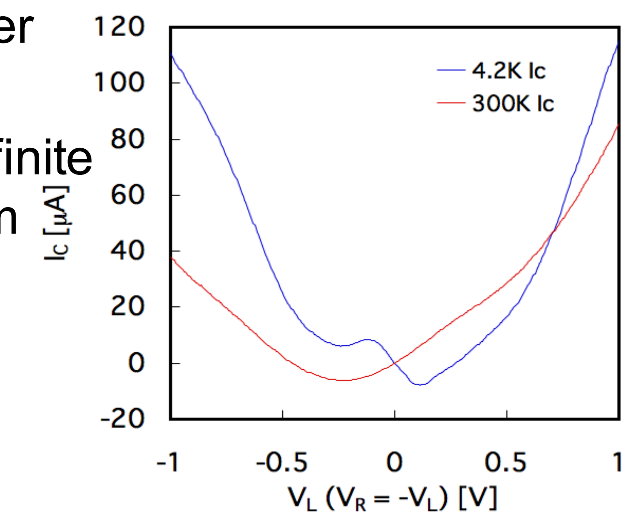
Temperature Dependence

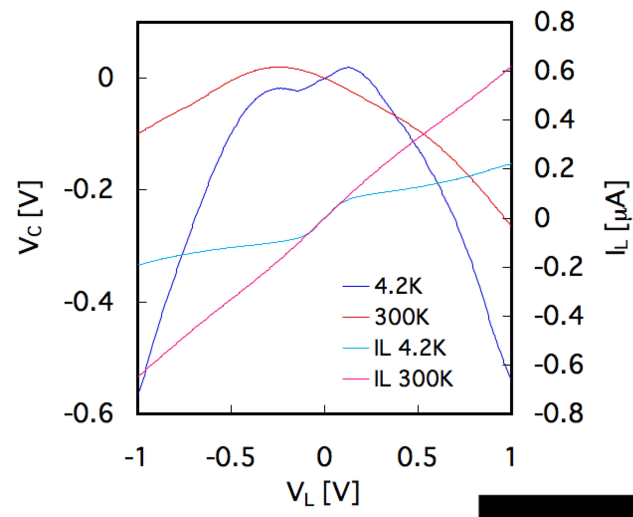
Lower Temperatures = Higher Mean Free Path

Weaker Rectification at higher temperatures

Results are reasonable - Definite ballistic effects at room temperature

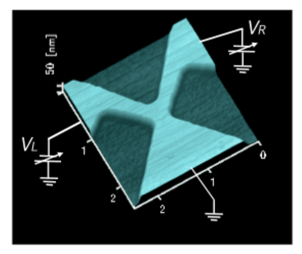






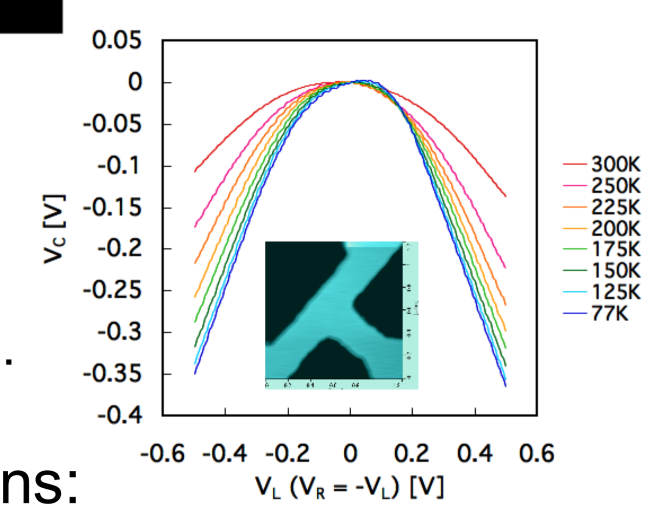
Voltage Rectification Effect

The actual voltage flow of the device in a non linear fashion.



Current Rectification Effect

Shows non-linearity, non-symmetry, and a downward curvature.



Summary and Conclusions:

Studied fabrication, measurement, and design of InAs ballistic rectifier devices.

- •Observed rectification in all devices at 300K.
- • The T-branch device shows greater temperature dependence.
- •The Y-branch device is an original design, and demonstrated acceptable rectification.

References and Acknowledgements;

1] A. M. Song et al., JJAP 40, L909 (2001).
[2] B. G. Vasallo et al., Nanotechnology 15, S250 (2004).

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