**Fabrication and Characterization of InAs/AlGaSb Ballistic Rectifiers**

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Ballistic electron transport is when electrons move in a small device without scattering. One application utilizing this property is the ballistic rectifier. In a ballistic rectifier, the electrons are directed by the device boundaries and so their only limitation is the size of the device and electron transport time. Because of this, ballistic rectifiers are very attractive for high frequency applications and operations. For this type of device to function at room temperature, InAs/AlGaSb heterostructure is used. The InAs/AlGaSb heterostructure is grown such that there is a two dimensional electron gas layer at the InAs level. InAs is one of the most attractive materials for this because of its properties at room temperature, such as a relatively long mean free path.

These ballistic rectifiers are created using electron beam lithography, photo lithography, and evaporation techniques on MBE grown InAs/AlGaSb heterostructures. The ballistic rectifiers that have been fabricated so far in this research involve two narrow horizontal inlets leading to a scattering anti-dot and two vertical openings. The vertical openings are output electrodes to measure the voltage difference, $V_{LU}$, between the upper and lower regions. Electrons enter through the horizontal inlets and are scattered downward by the triangle or diamond shaped anti-dot in the center, creating the voltage difference $V_{LU}$. The device's properties are measured at temperatures between 77K and 300K. Based on these results, it can be shown that nonlinear ballistic transport was observed in the device.

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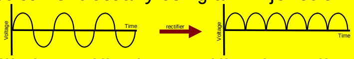
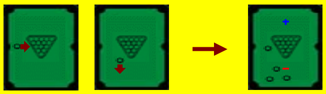
# Ballistic Rectifiers FOR DUMMIES

## What is a ballistic rectifier?

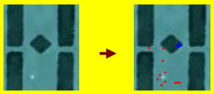
Firstly, a normal diode rectifier is an electrical component used to convert alternating current to direct current usually using a P-N junction.




A ballistic rectifier is a rectifier that relies on ballistic electron transport to operate. Ballistic electrons can be thought of as billiard balls, confined by the boundaries of the pool table.



Instead of a pool table, we have a 2DEG (two dimensional electron gas) confining the electrons to two dimensional motion and also confining them to the device boundaries we created.

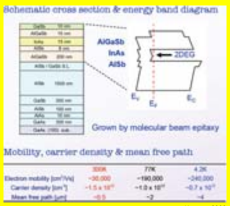


## Why ballistic rectifiers?

Current P-N junction rectifiers aren't capable of high frequency operations. The only limiting factor in a ballistic rectifier is the distance the electron must travel, which is very small, making them ideal for high speed operations (in the terahertz range).

## The substrate

The substrate consists of many layers. It starts as a GaAs substrate which then has other materials deposited by MBE (molecular beam epitaxy) creating the final InAs/AlGaSb heterostructure.



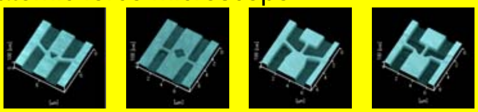

-Koyama 2006

## Fabrication

The fabrication process begins on the MBE grown InAs/AlGaSb heterostructure substrate. Then the device is outlined using electron-beam lithography, and then formed with wet chemical etching.

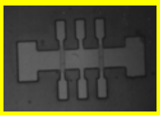
2 Samples: 1000x magnification

The device is then measured using an atomic force microscope.

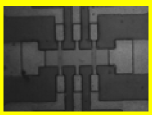


AFM images of four different designs of ballistic rectifiers
The darker area was etched by E-beam Lithography

Next the isolation pattern, ohmic pattern, and big electrodes are created using photo lithography. These are used to access the device electrically.



Isolation pattern

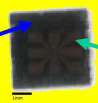


ohmic pattern

big electrodes

About 240 nm of $SiO_2$ is deposited as an insulator, and In and Au (40 nm and 250 nm) are deposited for conductivity.

Outer area insulated with $SiO_2$

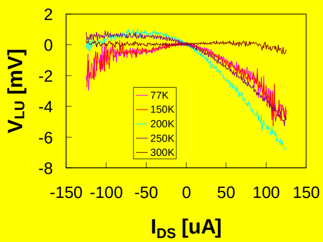


Big electrodes (leading to ohmic and isolation area) coated with gold and indium for conductivity

## Results

Samples were measured at temperatures between 77K and 300K with varying current in the micro-ampere range.

Color coded system used to measure the devices




The graph to the left shows the results from testing the above design

Non-linear electron transport properties were observed using several different designs of ballistic rectifiers. In the data shown above, rectification effects were observed - especially at 150K and 77K.

## Future Work

- Create the most efficient design(s)
- Utilize the properties of InAs to obtain room temperature (300K) rectification effects in future devices

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