Measurement and simulation of I-V properties of triple barrier resonant tunnelling diodes

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Abstract

One of the most important issues in spintronics research is the production of spin polarized currents. In the past, magnetic materials such as ferromagnets have been used to produce spin polarized currents. However, the magnetic fields associated with these materials can lead to unwanted effects such as stray magnetic fields. Hence, we propose to make a spin filter utilizing only non-metallic materials. By combining the triple barrier resonance tunnelling structure (TB-RTS) and the Rashba spin-orbit coupling effect, we can realize a usable spin polarized current source, where we match the spin-dependent resonance levels to lift the spin degeneracy. As a preparation for performing the experimental proof of the principle for this proposal, I have been studying the *I-V* properties of "non-doped" TB-RTS's that were made with InAs layers as quantum wells and AlSb layers as barriers. I also have been performing theoretical simulations of these devices to understand the experimental *I-V* curves we obtained at 300K, 77K and 4.2K.

Introduction/Motivation

What is a triple barrier resonance tunnelling diode (TB-RTD)?

- It consists of three barriers, forming two quantum wells.
- After tuning the gate voltage, the energy levels in the two wells will match up allowing electrons to tunnel through and current to flow.

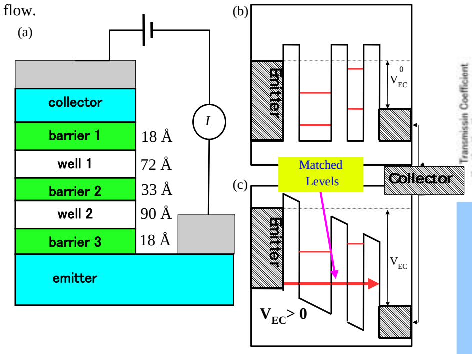


Fig. 1 TB-RTD, **(a)** basic design of a TB-RTD, our specific design has two wells of different thicknesses, **(b)** simplified potential profile of an asymmetric TB-RTD under zero bias, red lines indicate energy levels, hatched regions indicate the Fermi energies of the collector and emitter, **(c)** at certain gate voltages, the energy levels in the two wells match, allowing a current to flow.

Device and Experiment

•Our TB-RTD samples utilize AlSb for barriers and InAs for the quantum wells. Prof. Keita Ohtani carried out the growth and fabrication of our samples at Tohoku University.

•Expected results?

-We expect a single peak in the negative and positive regions of the *I-V* profiles of the samples, however, we expect the *I-V* profiles to not be symmetric with respect to zero biasing due to the asymmetry in the quantum wells.

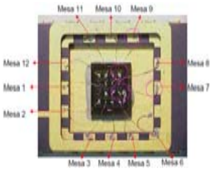


Fig. 2 sample received from Dr. Ohtani, it consisted of 11 different TB-RTD's mounted on a chip carrier. Each sample had a diameter of 20μm.

•To determine the *I-V* profiles, we swept the gate voltage between -4.0V and 1.5V at temperatures ranging from 300K to 4.2K.

Results

•Obtained *I-V* curves for samples at 300K, 77K and 4.2K.

•Single peak was observed in the positive bias region, an additional peak was found in the negative bias region of the *I-V* curve. Apparent two peaks at 77K are probably due to some artificial effects in the measurement circuit, most likely not due to spin splitting.

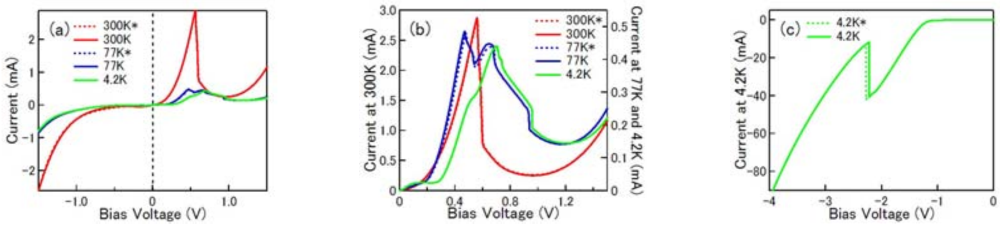
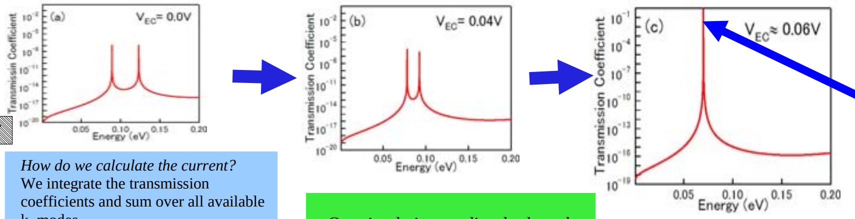


Fig. 3 **(a)** experimental *I-V* profile of an actual device (Mesa 1) measured at 300K, 77K, and 4.2K **(b)** magnified image of peaks occurring under positive bias. *Dotted lines denote voltage sweeps from 1.5V to -1.5V while solid lines denote voltage sweeps from -1.5V to 1.5V. **(c)** peak in negative bias region at 4.2K. We were not able to obtain measurements of this second peak at 300K and 77K since the current was too high at these temperatures and risked damaging the samples. *Dotted line denotes sweep from 0V to -4V, solid line denotes sweep from -4V to 0V.

Simulation

•Used Transfer Matrix Method to calculate the transmission coefficients as a function of energy for a given bias voltage, which revealed details of the level matching.



By varying the bias voltage, we can find where level matching occurs.

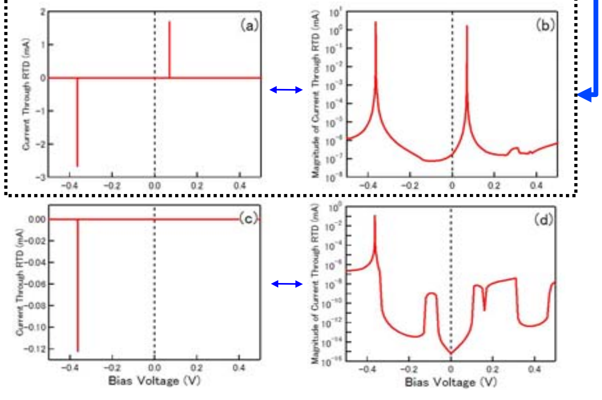
Levels match, the transmission coefficient goes to unity.

Fig. 4 **(a)**, **(b)**, and **(c)** RTD transmission coefficients as a function of the electron energy and the applied bias voltage.

How do we calculate the current?
We integrate the transmission coefficients and sum over all available $k_{\|}$ modes.

Using this method, we can obtain the theoretical *I-V* curves.

Our simulation predicts both peaks just as we observed in the experimental results.



Due to absence of two peaks in the bottom graphs our results suggest the real situation is closer to this simulation.

Fig. 5 **(a)** Theoretical *I-V* profile of experimental device assuming a Fermi energy of 0.2eV (Ns = 1.4x10^{18}cm^{-3}) in the emitter (collector) for the positive (negative) bias region, **(b)** semi-log plot of the magnitude of the current in (a), **(c)** *I-V* profile of device assuming a Fermi energy of 0.045eV(Ns= 1.5x10^{18}cm^{-3}) in the emitter (collector) for the positive (negative) bias region. Note the absence of a peak in the positive bias region in (c) and (d), **(d)** semi-log plot of the magnitude of the current in (c).

Conclusions

Simulation accounts for both peaks observed in experiment. Simulations in Fig.5 (a) and (b) agree with the experimental results better than those in Fig. (c) and (d).

Acknowledgement

We thank Prof. Ohtani for growing and fabricating the TB-RTD sample.

Support

Research conducted at Hokkaido University as a participant in the Rice University and NSF-PIRE sponsored NanoJapan 2007 program. Funding was also provided by the CEED program of Hokkaido University.