Spin Injection into GaAs Quantum Wells with Light

J. Holden, H. Munekata, Y. Hashimoto, T. Schallenberg, H. Nose
Imaging Science and Engineering Laboratory, Tokyo Institute of Technology, Yokohama, Japan

In order to study the spin injection, pump and probe spectroscopy was utilized. This is due to its high time resolution (on the order of picoseconds) as this is a very quick process. Two pulses are used called the pump pulse, which injects the spin, and the probe pulse, which analyzes this injection.

We have employed a GaAs quantum well sample, which is grown by using molecular beam epitaxy. This quantum well effectively makes the Heavy Hole and Light Hole valence bands more favorable than the other bands. With these samples it is possible to excite electrons from one of these two specific valence bands into the conduction band. By injecting either right handed or left handed circularly polarized light into the sample the electrons from either the Heavy Hole or Light Hole valence bands are excited into the conduction band. This process is due to the conservation of the angular momentum of the polarized light.

The pump and probe laser pulses pass thought the top layer of AlGaAs because its wavelength is such that its energy is less than the band gap of AlGaAs. After the pump pulse, which is right or left handed circularly polarized light, only one of these valence band's electrons are excited. The imbalance creates an imbalance in the indexes of refraction n+ and n- for the sample. This in turn causes the probe pulse, which is linearly polarized, to undergo the rotation of its polarization plane, so-called Kerr rotation.

This rotation is what is measured to indirectly monitor this process at room temperature, and at temperatures at and below 77k. The main purpose of this research is to study the ability to manipulate spin polarization of electrons with light for use in spintronics. We are looking at how long the relaxation time takes, how this is affected by magnetic fields, and other properties of this process.

Spin Injection into GaAs Quantum Wells with Light

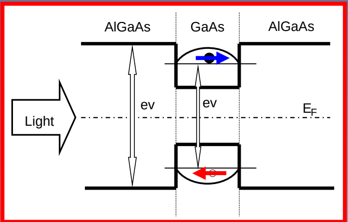
RICE

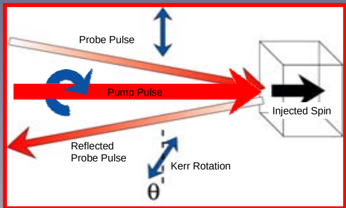
Jason Holden, Yusuke Hashimoto, Hiro Munekata, Imaging Science and Engineering Laboratory, Tokyo Institute of Technology, Yokohama, Japan

Tokyo Institute of Technology

Over the course of the summer, I stumbled over the little Japanese that I know, and worked with Pump and Probe Spectroscopy. By injecting either right or left handed circularly polarized light into a GaAs Quantum Well we are able to cause electrons to be excited with spin polarization. Employing Pump and Probe Spectroscopy we are then able to see this electron spin polarization. This spin manipulation technique is much faster than manipulation using magnetic fields (a few orders of magnitude faster) so it may have uses in creating faster computers and other technologies. This study program has allowed me to learn a wealth of theoretical, cultural, and research knowledge.

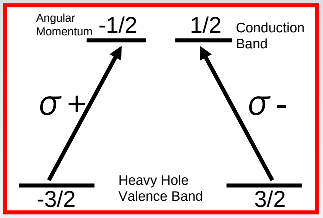
Theory





- GaAs is sandwiched between two layers of AlGaAs as shown above
- Molecular Beam Epitaxy (MBE) is used to deposit the very thin layers on to a substrate. I assisted with a few of these growth sessions
- The quantum well allows this process to be viewed at room temperature
- The laser will pass through the top layer because its wavelength corresponds to less energy than the band gap of AlGaAs

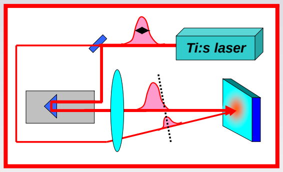
- The fact that many of the electrons with a certain angular momentum are already excited, causes an imbalance in $\sigma+$ and $\sigma-$ (the indices of refraction for right and left handed circularly polarized light respectively)
- This makes an incident linearly polarized beam (which is a combination of right and left handed circularly polarized light) rotate its polarization plane angle in what is called Kerr rotation



- When circularly polarized light hits the sample it promotes only one band's electrons to the conduction band (due to conservation of angular momentum)
- These electron's spins are all polarized along the axis of the pump laser pulse propagation

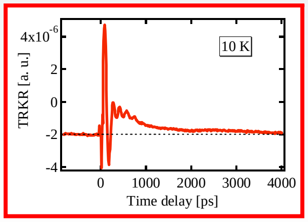
Experimental Setup

- I set up experiments and helped reduce noise in the measurements
- Titanium-sapphire laser with wavelengths between 720nm and 870nm
- Time Resolution ~ 100 femtoseconds
- Kerr Rotation Sensitivity ~ 1 millidegree
- Laser is chopped into pulses
- Pump Pulse is circularly polarized to inject spin



Future Research

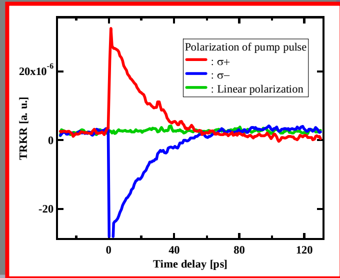
- The next step is to be able to depolarize, or amplify in the middle of the process. Allowing us to switch polarization on and off
- We are now doing Pump and Probe Spectroscopy, with a linear pump pulse, on (In,Mn)As and (Ga,Mn)As
- We are also looking at the effects of a magnetic field on these processes
- With liquid He we can cool the sample down to 4 degrees above absolute zero



Data From GaMnAs

Sample in cryostat with magnets on either side

Results



- This graph shows the Magnitude of this Polarization via Kerr rotation
- The decay of the kerr rotation is a result of spin relaxation and recombination relaxation
- Notice that you must have circular polarized light to get an effect

Conclusion

- At the nanoscale, changing the size of the crystal affects its physical properties, and allows us to see the spin polarization
- We are manipulating spin with light instead of magnetic fields
- My research time has opened my eyes to the vast amount of knowledge and work that makes up the foundation of new technology
- And I made some Japanese friends in the process

SUMMER NANOTECHNOLOGY STUDY PROGRAM IN JAPAN

NSF

Rice University NanoJapan Program
Generously Supported by a Grant from the
National Science Foundation