ND*nano* Undergraduate Research Fellowship (NURF)
2012 Project Summary

1) Student name: Christopher Newman
2) Faculty mentor name: Gyorgy Csaba and Wolfgang Porod
3) Project title: On-Chip Spin Waves for Computation

4) Briefly describe any new skills you acquired during your summer research:
I learned how to use the Objected Oriented MicroMagnetic Framework simulation to test my designs. I also gained more experience using MATLAB and Tcl scripting language. I gained a significant understanding of the physics behind nanoscopic magnetic interactions and magnetic spin waves. Lastly, I developed my creative and analytical thinking skills as they pertain to research work and acquired a practical understanding of the processes and methodologies by which engineering research is undertaken.

5) Please briefly share a practical application/end use of your research:
My research involved studying the properties of spin waves generated by Spin Torque Oscillators (STOs) and exploring the means by which these spin waves can be manipulated. More research is required, but an ultimate application would be to control the waves enough so that they could transmit information. My research shows that spin waves behave similar to optical waves and can be controlled to a certain degree by the application of an AC current to the STO. Therefore, spin waves might be used to implement optical computing algorithms (an already extensive field), allowing more compact devices that are compatible with microelectronic circuits.

Begin two-paragraph project summary here:

Over the past four decades, the trend in transistor integration density has remained relatively steady, doubling roughly every 2 years as described by Moore's Law. Recent technological advances, however, are approaching the physical limitations of transistor scaling. Therefore, non-Boolean computing paradigms may be the key to increased computing power. Optical computing is an example of a non-Boolean computing paradigm that has already developed into an extensively researched field, but has yet to achieve widespread application. My summer research centered on studying the properties of a relatively newly discovered phenomenon: spin waves. Spin waves are propagating disturbances in the orientation of magnetic moments along a ferromagnetic film. Spin waves have the potential to form a new physical implementation for optical computing algorithms, but only if they are proven to behave like light waves and can be manipulated to carry information. The use of spin waves to implement optical computing algorithms could allow more compact devices that are also compatible with microelectronic circuits. Therefore, my summer goal was to use the Object Oriented MicroMagnetic Framework (OOMMF) simulation to study the properties of spin waves and attempt to manipulate their oscillations. The aim is to evaluate spin waves' usefulness for implementing optical computing algorithms.

My first task was to examine whether spin waves behave similar to optical waves. Using the OOMMF simulation, I generated spin waves with a 30x30 nm Spin Torque Oscillator (STO), sourced by an 8.5 mA DC current. An STO is a current source running perpendicular to the ferromagnetic film that generates spin waves in the presence of an external magnetic field. The waves were found to propagate at a frequency of 22.6 GHz with a wavelength of 110 nm, and their intensity (a time-average of the magnetization in the y-direction) decayed as:

$$M_y = \frac{3.1146}{r} * e^{-r/746}$$

where M_y is the normalized magnetization in the y-direction and r is the distance from the STO in nm. The equation shows that a point source STO generates spin waves that decay according to the same governing equation as optical waves generated by a point source. The 1/r term dominates the decay while the exponential only becomes significant after 746nm from the STO. In order for the waves to transmit information, the propagation distance needs to be much greater, which can be achieved by removing the 1/r term. This can be done by using a line source or multiple STOs aligned in parallel instead of a stand-alone point source. However, it was discovered that magnetic interactions cause different regions of the STO to oscillate out of phase when larger STO geometries are used, for example 200x30 nm. Similarly, when multiple STOs are aligned on the same film, the demagnetizing force causes them to oscillate 180° out of phase if magnetically coupled, or exhibit an unpredictable phase relationship when isolated. The proposed solution was to apply an AC component on top of the 8.5 mA DC current to force the oscillations in phase. The STO frequency was first measured without the AC component using Fourier transform analysis. This frequency was then used as the control frequency for the applied AC current. Since the STO frequency is highly dependent on the value of current applied, the AC component must have a small amplitude relative to the DC value. As the figures indicate, the application of the AC component succeeded in forcing the STOs to oscillate in phase, generating more coherent spin waves with longer propagation distances that are more suitable for use in computing. More research is needed to find the optimal frequency and amplitude for the AC current, but my research shows that it is possible to force in-phase oscillations, a significant step towards demonstrating spin waves' application for optical computing algorithms.

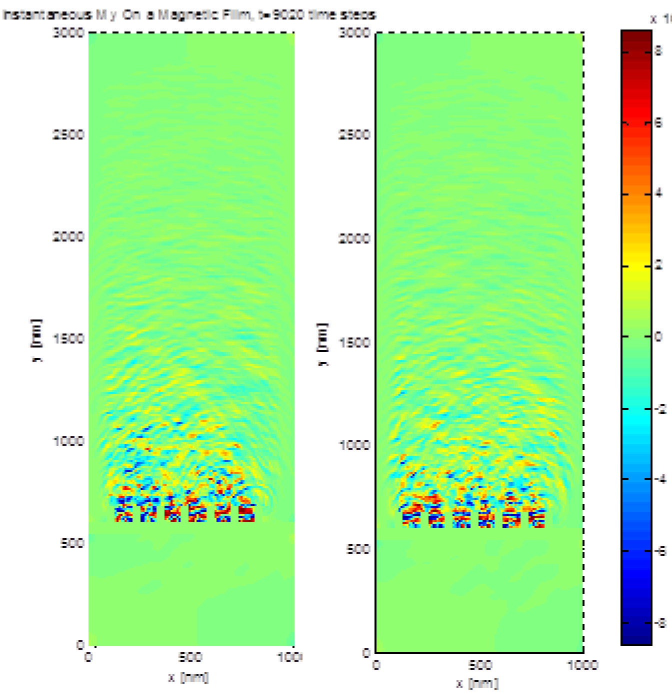

Fig 1. Comparison of spin waves with and without AC current: Spin waves generated without an AC current component applied to the STO (left) are not coherent and exhibit unpredictable phase relationships. When an AC component with amplitude 0.05 mA and frequency 22.594 GHz is applied in addition to the 8.5 mA DC (right) the spin waves oscillate in phase and a distinguishable wave front begins to appear. The propagation distance is also greatly improved.

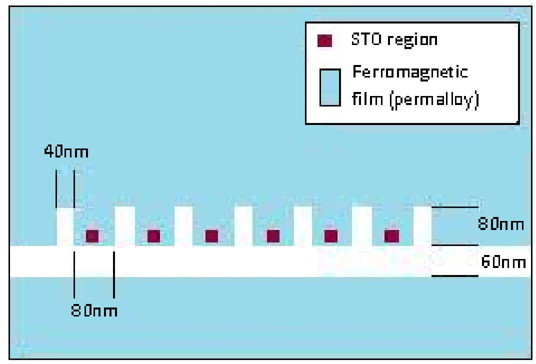

Fig 2. Geometry of magnetic film used in Figure 1: The 40nm cuts isolate the individual 30x30 nm STOs and prevent magnetic coupling that would otherwise result in out of phase oscillations. The cuts also focus the spin waves in the direction of propagation, generating stronger signals. This geometry may also be applicable to parallel optical computing; by turning on and off the various STOs, unique wave fronts may be created that can transmit information.

Publications (papers/posters/presentations):
Presenting a poster at the NURF summer symposium
Continuing with this topic for my senior research thesis (to be completed April 2013)