Exploring Rh and Fe Doped RuGe for a New Ferromagnetic Semiconductor

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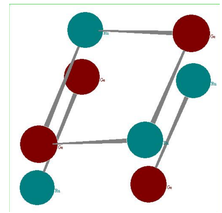
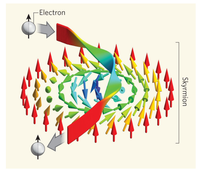
Abstract

Spin electronics, or spintronics, is thought to be an important future technology that will combine the logic and memory functions of processors into one nanoscale device. Spintronics will use magnetic semiconductors such as FeSi and RuGe that work as both a ferromagnetic material and a semiconductor. Spintronics has the potential to reduce heating, increase computing speed, reduce energy cost, and to reduce the size of logic elements. The idea in this project was to discover new magnetic semiconducting materials by doping small gap insulator RuGe with Fe and Rh. The samples were made by melting in an arc-furnace and/or the RF furnace followed by annealing at 1100 °C for 1 week. The magnetic susceptibility of our samples was measured at a field of 1 kOe at temperatures between 2 and 400 K. The magnetization was measured up to fields of 7 T at 2 and 300 K. Our data show a systematic increase in magnetic moment without signs of magnetic ordering for x<0.2. Resistivity and Magnetoresistance measurements are underway. Attempts to grow $Ru_{1-x}Fe_xGe$ have been unsuccessful in producing single phase materials thus far.

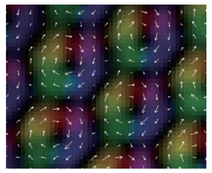
Background

Magnetic semiconductors such as FeSi and RuGe form in the B20 crystal structure, which is a non-centrosymmetric, simple cubic structure.
Some of these materials order helimagnetically at lower temperatures such as MnSi and FeGe. Applications of small magnetic fields has been discovered to create Skyrmion lattices. Skyrmions are topological structures theoretically predicted by Tony Skyrme.
Carriers are asymmetrically scattered by a skrymion lattice creating a distinct Hall effect.
Skyrmions are being considered as future memory elements in nano-electronics.

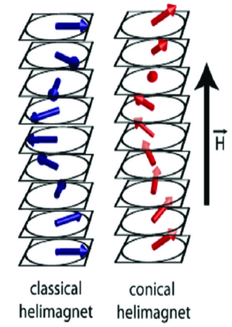




[5] Skyrmion



[6] Skyrmion Lattice



[3] Helimagnetism

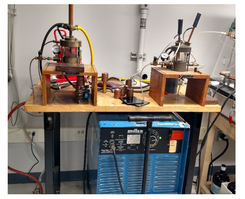
Methods for Synthesis

- $Ru_{1-x}Rh_xGe$ and $Ru_{1-x}Fe_xGe$ samples were prepared with the arc-furnace and the RF furnace
- All samples were annealed in a tube furnace at 1100 C for a week under vacuum
- SQUID measurements include magnetization, susceptibility, resistivity, and magnetoresistance

RF Furnace

SQUID Magnetometer

Tube Furnace



Arc-Furnace

Conclusions

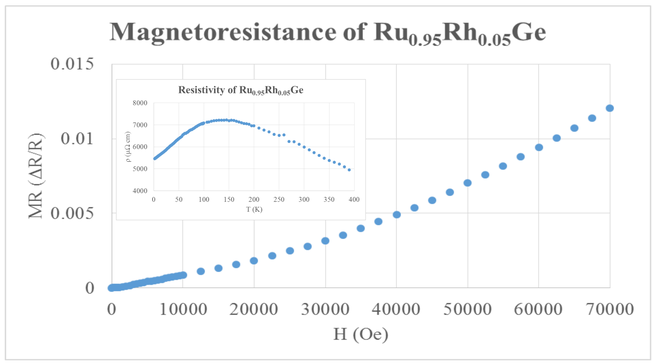
$Ru_{1-x}Rh_xGe$ remains paramagnetic for x < 0.2. Higher dopant amounts needed. Even though both types of chemical substitutions, $Ru_{1-x}Rh_xGe$ and $Ru_{1-x}Co_xGe$, demonstrate metallic charge transport, only Co substitution appears to nucleate a ferromagnetic phase.

Present and Future Work

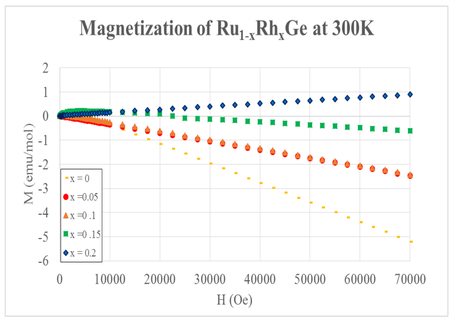
Continue efforts produce/grow single phase $Ru_{1-x}Fe_xGe$ polycrystalline sample for exploration. Increased substitution of Rh and Fe into RuGe. Continue resistivity and Hall Effect measurements to determine carrier transport properties.

Acknowledgements

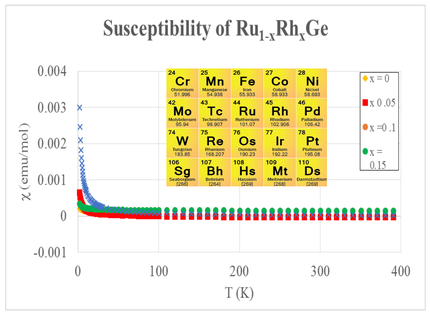
We thank Emily Kramer for assistance with XRD characterization of our samples and Dr. Browne and Jordan Ball for Electronic structures calculations. This work was supported by the National Science Foundation under the NSF EPSCoR Cooperative Agreement No. EPS-1003897 with additional support from the Louisiana Board of Regents

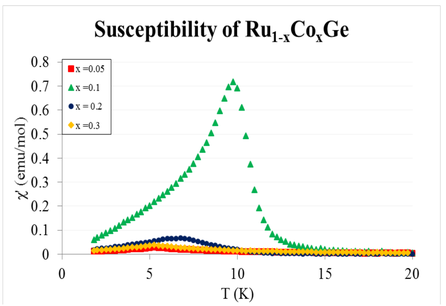


A small positive magnetoresistance was measured at 10 K. The inset displays the resistivity from 2-400 K at zero field demonstrating weakly metallic behavior.

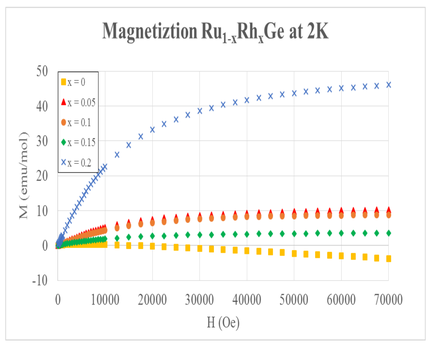


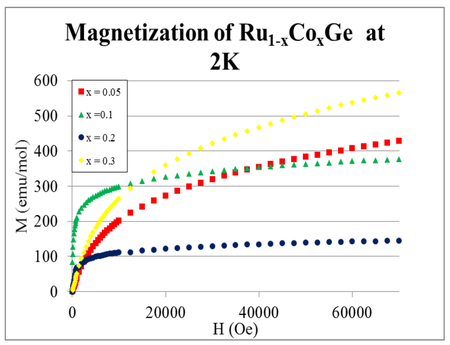
Increased paramagnetism as x is increased consistent with the addition of carriers with doping.





There is a systematic increase in susceptibility with x. While the $Ru_{1-x}Rh_xGe$ samples remain paramagnetic, the $Ru_{1-x}Co_xGe$ samples a magnetic ordering at lower temperatures.





At low temperatures, $Ru_{1-x}Rh_xGe$ remains paramagnetic while $Ru_{1-x}Co_xGe$ displays soft ferromagnetism.

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