low frequency 1/f noise in 2DEG $Al_x Ga_{1-x} As/GaAs$ Hall bar structures

Stephen Collins

Physics REU
University of Michigan
Kurdak Lab

August 8, 2012

Essential Terms

carrier density (n) how many free electrons per unit area

mobility (μ) how easily a electrons can move

2DEG "Two Dimensional Electron Gas"

2DEG Energy Band Diagram

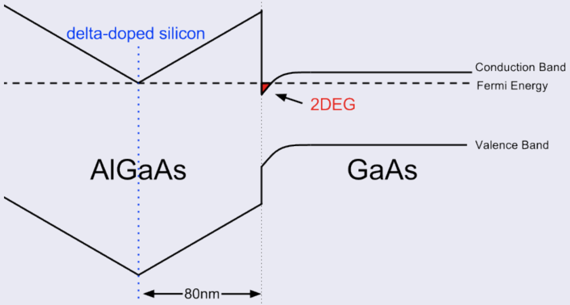
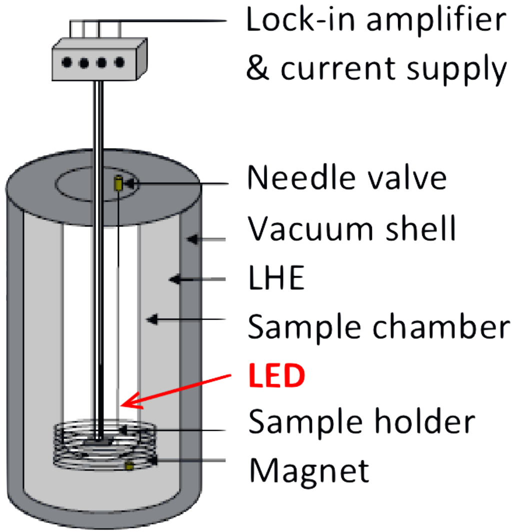
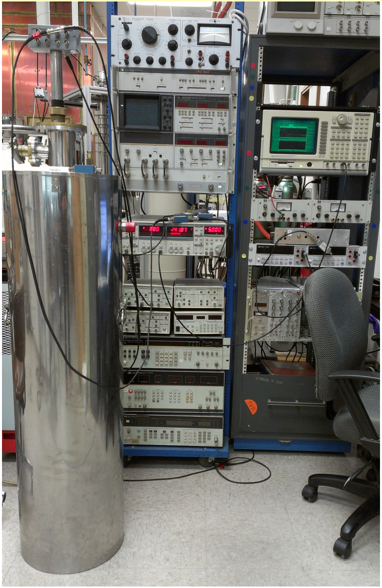


Diagram adapted from "Doping in III-V Semiconductors" by E.F. Schubert, pg. 405

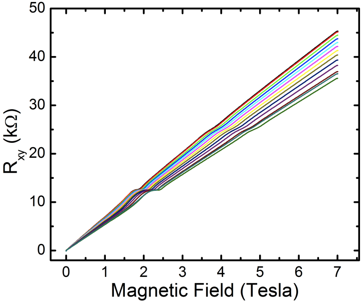
Experimental Setup



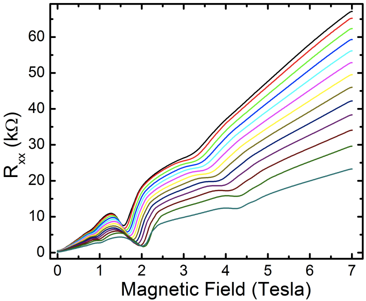


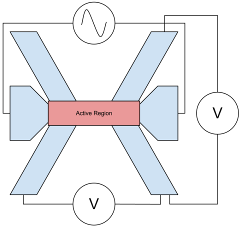
Magnetotransport Measurement

$$R_H = \frac{B}{n_{2D}e}$$



$$B = \frac{hn_{2D}}{en}, R_{xx} = \frac{1}{n_{2D}e\mu}$$





- Hall bar structure (left) used
- PPC a "knob" to vary carrier density
- samples exhibit integer quantum hall effects

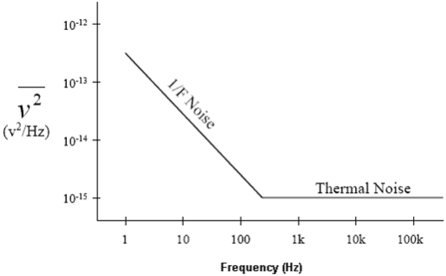
Why study noise?

1. Random fluctuations at the single charge carrier level are becoming a larger problem as devices get smaller
2. Noise analysis provides a unique window into microscopic properties of a material

Hypothesis

Minimizing the $1/f$ noise in a sample is fundamentally different from maximizing mobility

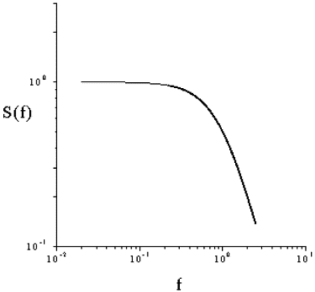
What is 1/f noise?

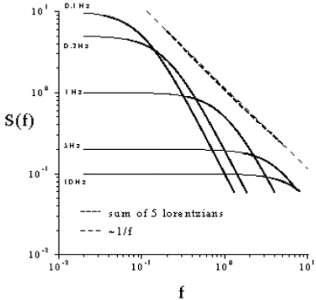


Whooge?

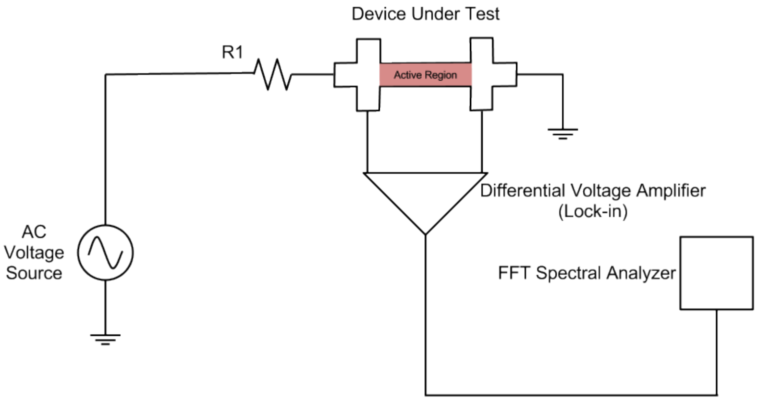
$$\frac{S_V(f)}{V^2} = \frac{S_R(f)}{R^2} = \frac{\alpha_H}{N_C f}$$

α_H is the *Hooge Parameter*, originally thought to be a universal constant

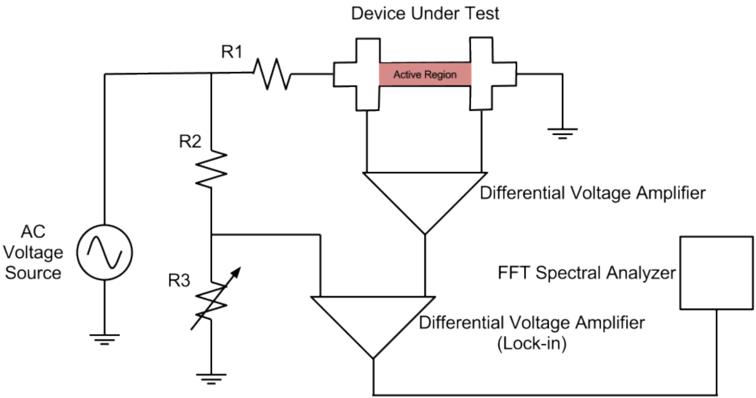




Noise Measurement Circuit



Improved Noise Measurement Circuit

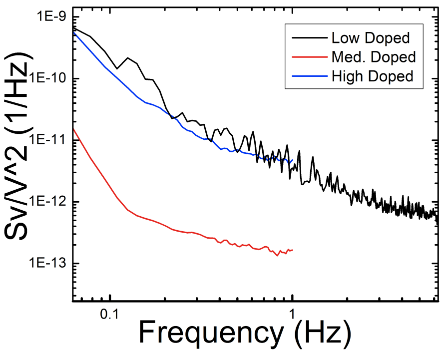


FFT (Fast Fourier Transform) Spectrum Analyzer

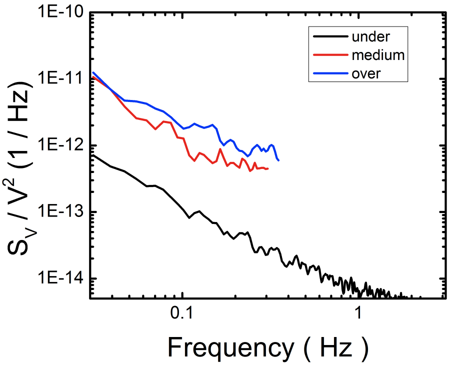
- PSD (Power Spectral Density) Units (for Voltage S_v): $\frac{V^2}{Hz}$

1/f noise

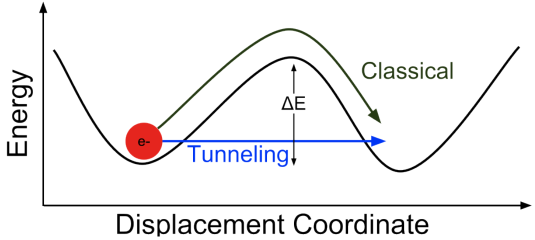
77K (20x220μm hall bar)



4K (50x550 μm hall bar)



Classical vs. Quantum Mechanical state changes

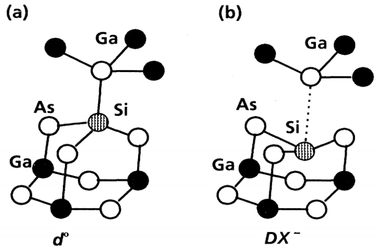


Classical Probability

$$P \propto e^{\frac{-\Delta E}{k_B T}}$$

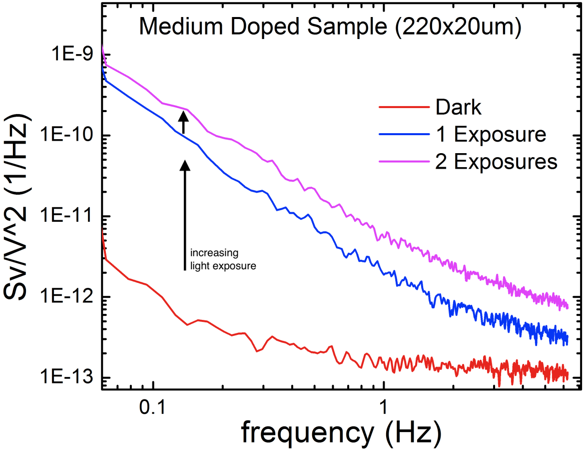
Tunneling Probability

$$P \propto e^{-\Delta E K \Delta x}$$



DX center illustration from Chadi, Chang, PRB 1989.

PPC increases 1/f noise dramatically



What's important?

- 1/f Noise at 77K is predominately from tunneling electrons in the delta-doped layer
- The slope of 1/f noise at 77K is greater than at 4K
  - this may be due to thermally activated electrons
  - analysis with the Hooge parameter is invalid in this regime
- Light exposure greatly increase noise magnitude

Acknowledgements

- Thank you to Dr. Kurdak for inviting me to research in his lab this summer, supervising my project, and giving me so many helpful "physics lessons."
- Thank you to Yun Suk Eo for showing me the ropes... and then showing me the ones I missed... and then fixing the ropes I broke. Also to Steven Wolgast and Richard Field III for answering countless questions and allowing me to continually peer over their shoulders and ask even more.
- Thank you to UMich Physics Department and NSF for organizing the whole experience and providing all of the essentials: food, shelter... and money!