Low Temperature and High Frequency Investigation of the Quantum Hall Effect

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1st Draft
February 7, 2009

Abstract

To study the properties of quantum Hall devices at microwave frequencies, I will build a high frequency probe capable of operating at ultra-low temperatures. The probe will be fitted with low loss coax to carry excitation photons at microwave frequencies to samples sitting at a temperature of 10 mK inside a dilution refrigerator. A second coax will bring the resulting signal back to detectors at room temperature. The project will involve the design of such a probe, its construction, and the eventual test of its performance through study of quantum Hall interferometers at ultra-low temperatures. I will look for evidence of quantum Hall-like states that emerge at relatively low magnetic fields when a two-dimensional electron gas is illuminated by microwave photons. A successful observation of this phenomenon will serve to verify the performance of the probe.

Introduction

Quantum Hall Effect

At low temperature and high magnetic fields, the Hall resistance R_H of a 2-dimensional electron system takes the values

$$R_H = \frac{h}{e^2 \nu}$$

Here h is Planck's constant and e is the elementary unit of charge. The quantum Hall effect (QHE) is characterized by integer values of the filling factor ν, and the fractional quantum Hall effect (FQHE) by rational ν. Typically very high magnetic fields are required to see this phenomenon, but there is evidence (Zudov et al) that quantum Hall-like states appear under microwave illumination at relatively low magnetic fields (~ kG).

HF techniques at low temperatures

Heat dissipation is one of the biggest obstacles in the operation of high frequency signals at very low temperatures. For a coaxial wire, the solution is to properly heat sink both inner and outer conductors.

The task is considerably easier for the outer coax. Thermal contact can be established at various stages down the cryostat,

The inner coax presents the most difficulty and requires some carefully consideration, if not ingenuity. A first consideration is minimizing the thermal conductance of the inner wire. High frequency signals tend to travel close to the surface of a conductor, within a skin depth

$$\delta = \sqrt{\frac{2\rho}{\omega\mu}}$$

Where ω is the angular frequency of the signal, ρ the electrical resistivity, and μ the magnetic permeability of the wire. Quoting Kent (Reference 1), at 100 MHz this depth is on the order of microns for good conductors. Thus, a poor thermal conductor coated with a good electrical conductor would serve to minimize the thermal conductivity of the wire without sacrificing electrical conductivity.

This is not sufficient to operate in the mK regime, and heat sinking the wire is necessary. The literature presents a handful of methods for heat sinking, including the following two viable techniques:

a) If a dielectric is placed between the conductors, a section of the dielectric can be replaced at certain stages with a material of high thermal conductivity.

b) For microwave frequencies, the wavelength is small enough that a quarter wavelength ($\lambda/4$) line can be connected in parallel with the inner conductor. This is done by stripping a section of the coax, connecting one end of the $\lambda/4$ to the inner conductor and grounding the other. This creates a good heat sink, but is only viable if the line is operated in a narrow frequency band.

Design and Implementation

The design phase is still under progress, so no construction has taken place.

Results

No results yet.

Conclusion

References

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