Ultra-Sensitive Calorimetry for Microwave Cyclotron Resonance In a Two-Dimensional Electron Gas

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INTRODUCTION

Electron Spin Resonance (ESR) and Cyclotron resonance (CR) are two of the most significant feature of electrons under magnetic field where electrical detection requires contacts on the sample which usually causes damages. We show that CR can be measured via heat generated by resonant absorption of photons. An increase in the lattice temperature can be detected when the energy of the incident microwave photons matches the energy difference between adjacent Landau levels. They will be absorbed converting to phonons via non-radiative relaxation. A nano-calorimetry is constructed which can operate at 300 mK and precision of our thermometer is improved to tens of micro-Kelvins, thereby increasing the sensitivity to several nano-watts. This method opens up the possibility to detect ESR which is the prerequisite for building spintronics.

BACKGROUND

Spin–orbital coupling is essential to resolve ESR in a sense that the spin degree of the electron need to be accessible by reasonable strength of magnetic component. This is usually hard due to the intrinsic properties of spin and its weak coupling to charge or momentum. In order to detect ESR, high sensitive tools are required. As a pretest, CR can be manipulated much easily.

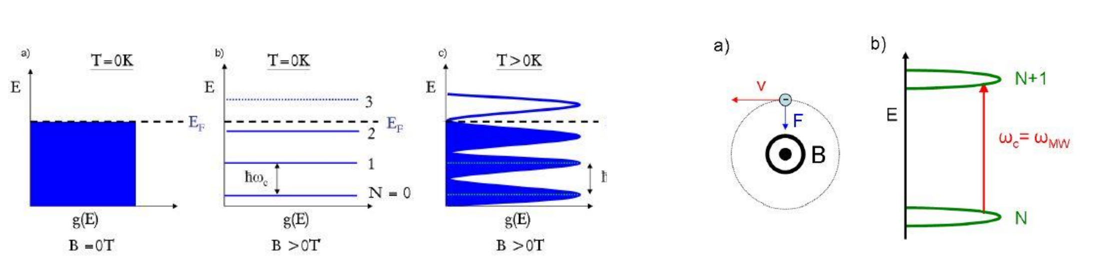
When magnetic field is appled, the density of states of a 2DEG forms Landau Levels (LL) and electrons undergo circular motion during lifetime τ before the next scattering. In order to resolve CR, the following relation need to be satisfied,

$$\omega_c \tau \gg 1$$

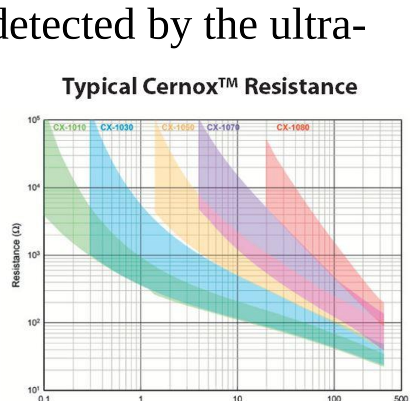
where the CR frequency is defined as

$$\omega_c = \frac{eB}{m^*}$$

with effective mass m^*.



As microwave (MW) is applied, the electrons on the Fermi level will absorb the photon energy and hop to the adjacent LL as long as the energy difference matches with that of the incident MW. Electron on the excited states then falls back to the original state and emit another photon which turns into heat due to phonon coupling. The temperature increase due to this non-radiative process can be detected by the ultra-sensitive thermometer thus resolving CR.



CONSTRUCTION & METHODS

In order to achieve the temperature as low as 300mK, coaxial cable probe and He3 cryostat refrigerator is used.

In stead of immersing sample in He3 liquid as people usually do, the setup need to be in vacuum so that the heat produced by CR won't be carried away and can be detected by highly sensitive thermometer.

To conduct heat from the sample to thermometer, sapphire crystal which has good thermal conductivity is employed. Heat conduction need to be tuned to balance heat generation and absorption.

To improve sensitivity, both differential method and amplitude modulation technique are used where the former is supposed to filter the background noise and the latter is going to quench the asymmetry left in the differential geometry. Identical structures are constructed within the vacuum can and sample is glued to one of them by N-grease, differential method details are described on poster by H.Y Xiong.

Probe Schematics

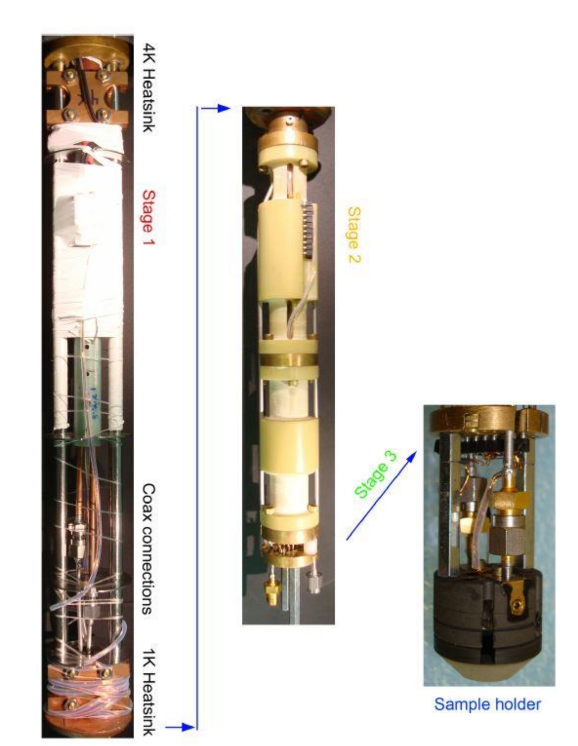
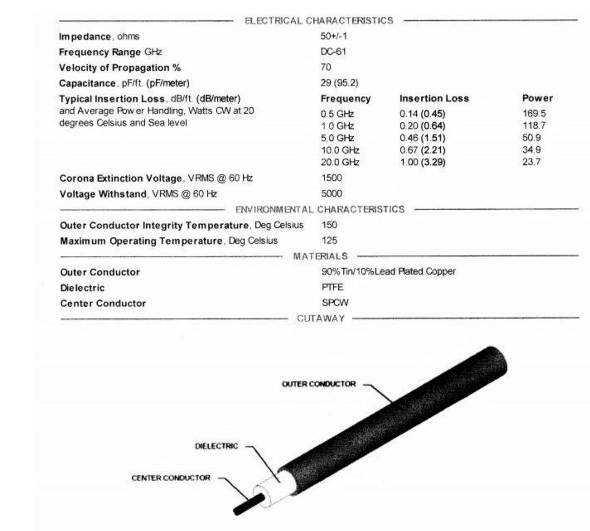


Figure D.1: Pictures of the probe stages: 4K, 1K, and the sample holder.



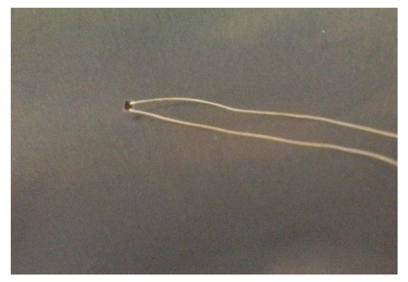
To apply amplitude modulation, two lock-in amplifiers are required. The original signal comes in the form of

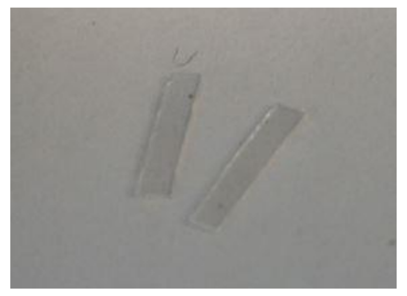
$$f(t) = A(B)\sin\omega_1 t \sin\omega_2 t$$

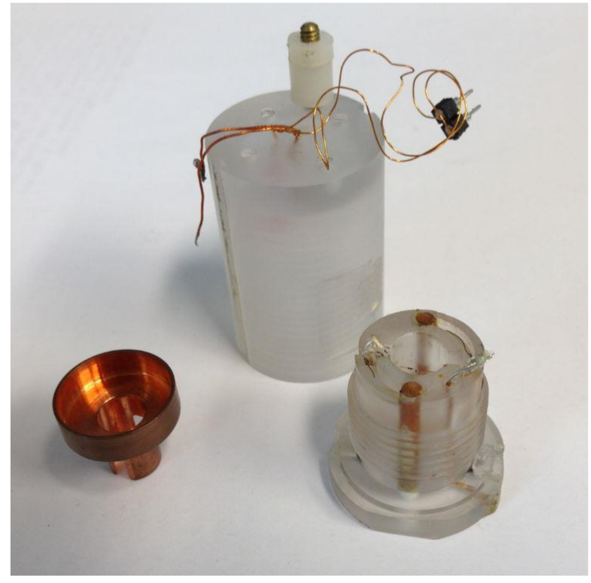
where

$$\omega_1 \gg \omega_2$$

and for each one, integral time constant need to be set much larger than $\frac{1}{\omega}$. Here considering the heat conducting rate on sapphire crystal, we set $\omega_1 = 1Hz, \omega_2 = 500Hz$.







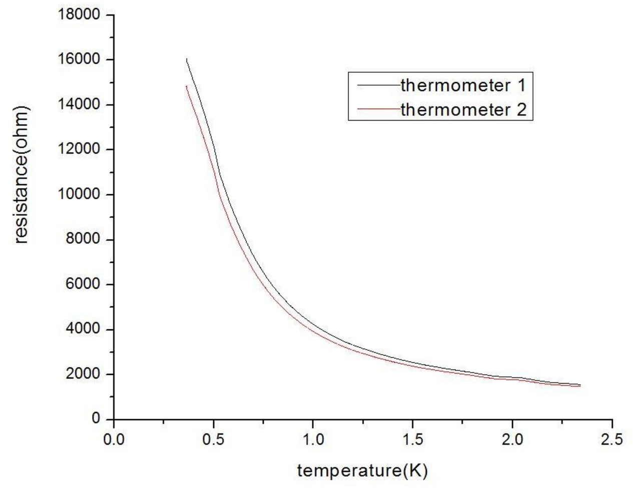
CHARACTERIZATION

R(T) is recorded in figure.a and the sensitivity increases on when temperature goes down. When it reaches 300mK, sensitivity as large as $30k\Omega/K$ is achieved.

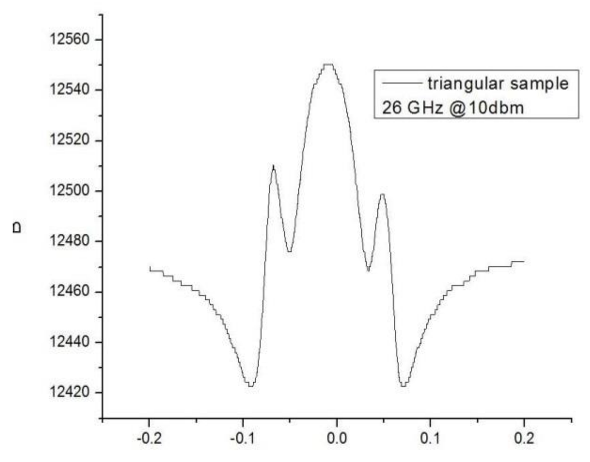
However, in He3 temperature regime, the response of thermometer by magnetic field can't be neglected any more. In fact, due to some magnetic impurities within Cernox sensor, resistance of thermometer has asymmetry response which also depends on the sweeping direction.

Coupling between CR and plasma resonance is Shown in figure.c on a anti-dot patterned sample.

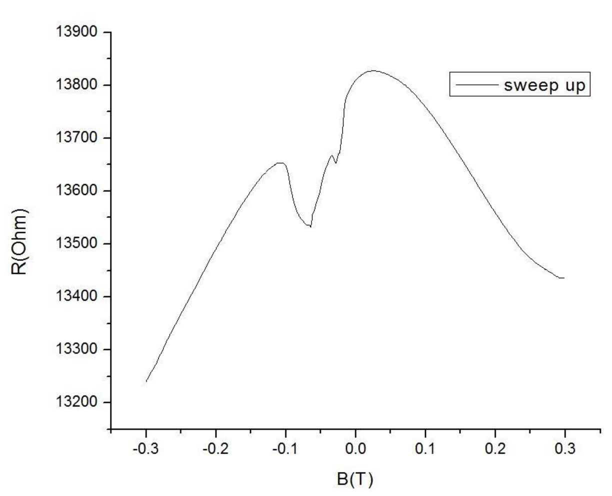
Shubnikov-de Haas oscillation (SdHO) and Microwave Induced Shubnikov-de Haas oscillation (MISdHO) are performed in figure.d to verify the the density and mobility of electrons as well as the properties when microwave is applied.



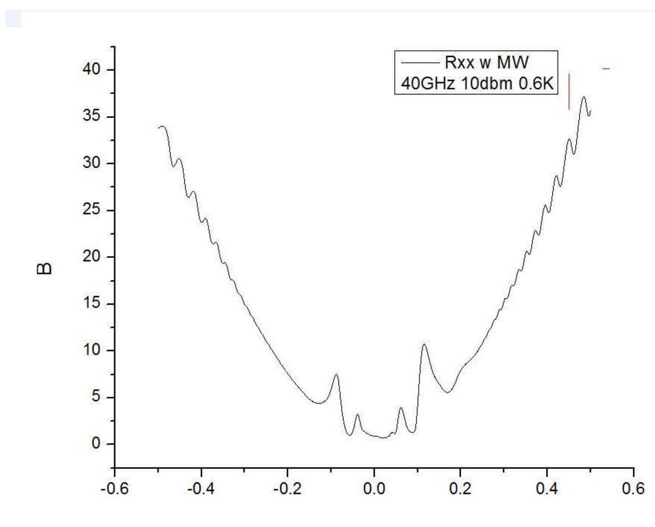
a.



c.



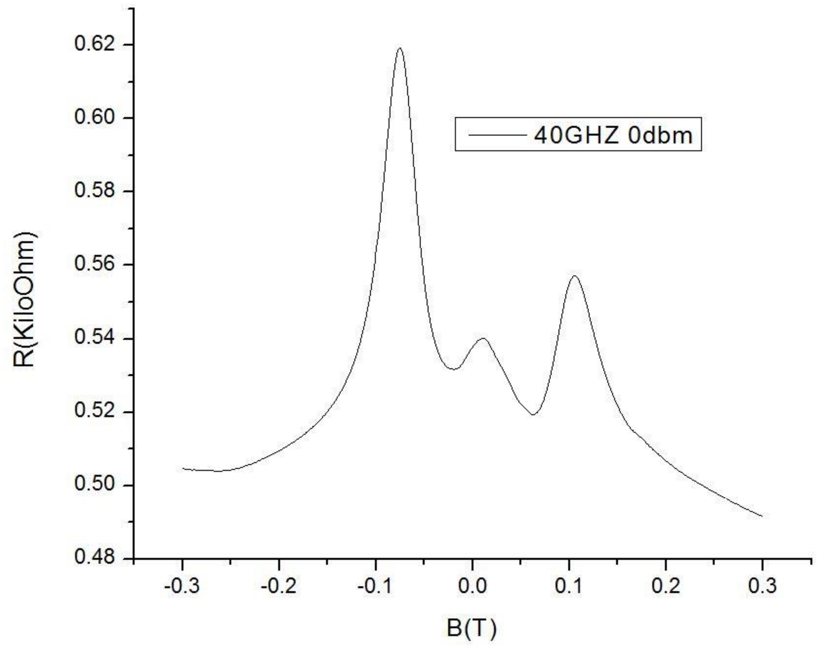
b.

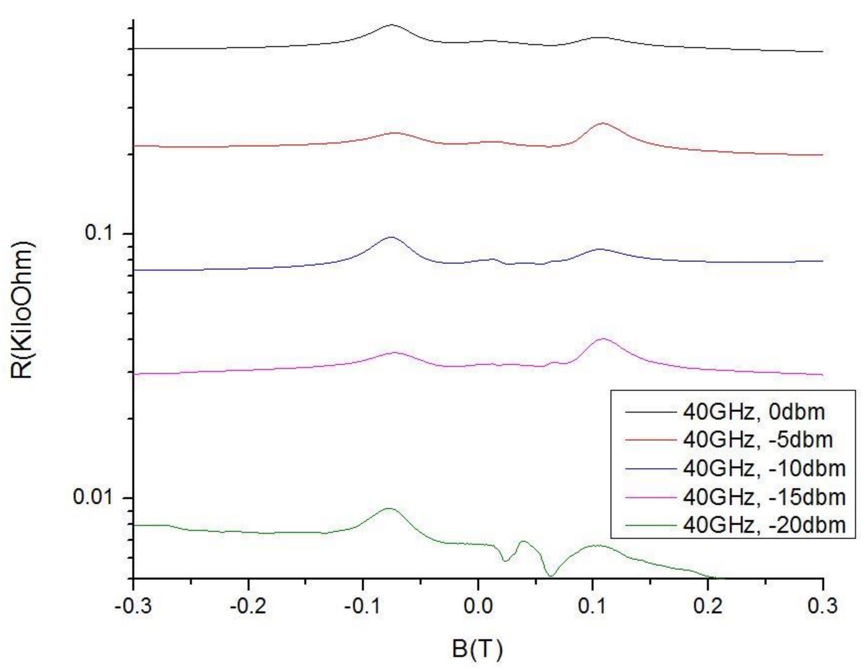


d.

RESULT

Differential method is able to increase the sensitivity by roughly ten times while combined with amplitude modulation, another thirty times of sensitivity can be achieved. Even with microwave power as low as -20dbm which corresponds to 0.01mW, signal can still be resolved. This means our ultra-sensitive calorimetry on two-dimensional gas is successfully built and works well under temperature as low as 300mK.





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CONCLUSIONS

An ultra-sensitive calorimetry is built to detect CR ON 2DEG with microwave power as low as 0.01mW. With such great sensitivity, this method is highly possible to resolve ESR in a way where no contacts are required. It is also promising to measure microscopic samples like a single carbon nanotube and monolayer graphene.

REFERENCES

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[2] S. J. Allen, Jr., H. L. Stormer, and J. C. M. Hwang *Dimensional resonance of the two-dimensional electron gas in selectively doped GaAs/A1GaAs heterostructures* Phys. Rev. B, 28,4875(1983)