Probe testing and improvement of high-precision thermal measurement of Microwave Cyclotron Resonance

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7/12/13

Jason’s masters

- Cyclotron resonance on 2DEG

Microwave frequency = Cyclotron frequency

$\Rightarrow$ Sample absorbs energy

$\Rightarrow$ Temperature increases

- Thermal measurement with high precision

Thermometer CX-BT-1030

Typical value:

305K: 46.6 Ohm

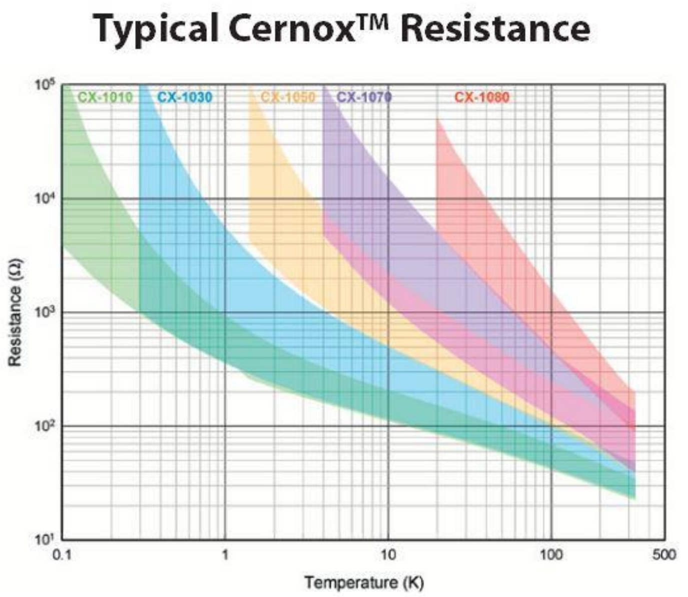
77K: 121Ohm

4.2K: 695Ohm

0.3K: 14KiloOhm

- Experiment done in vacuum with little exchange gas

and sapphire crystal as heat conductor



Geometrical resonance (coupling between CR & PR)

1. Plasmon resonance

$$\boxed{{\omega_0}^2 = \frac{N_s e^2}{2m^* \varepsilon_{eff} r}}$$

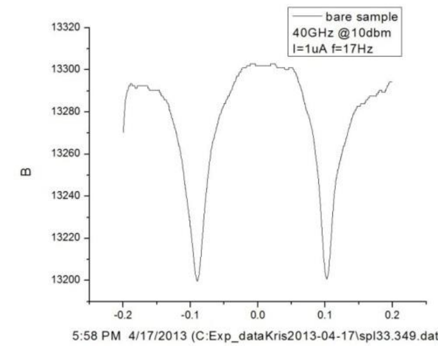
- $N_s = 2.5 \times 10^{11} cm^{-2}$
- $m^* = 0.067 m_e$
- $\varepsilon_{eff} = \frac{1+12}{2} = 6.5$
- $r - \text{radius} \sim \mu m$

2. Cyclotron resonance

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

3. Coupled

$$\boxed{\omega_\pm = \frac{\omega_c}{2} \pm \sqrt{{\omega_0}^2 + (\frac{\omega_c}{2})^2}}$$



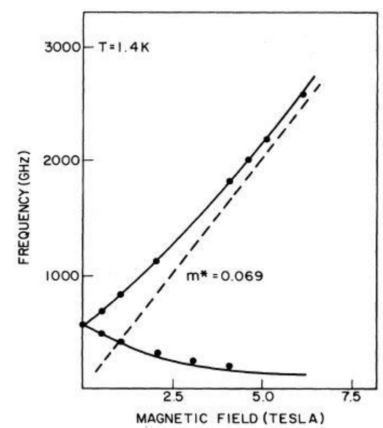
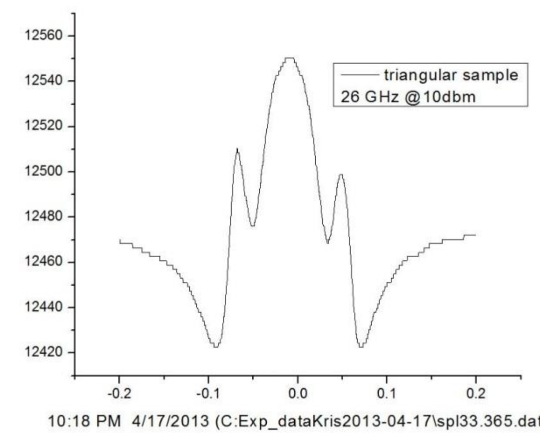
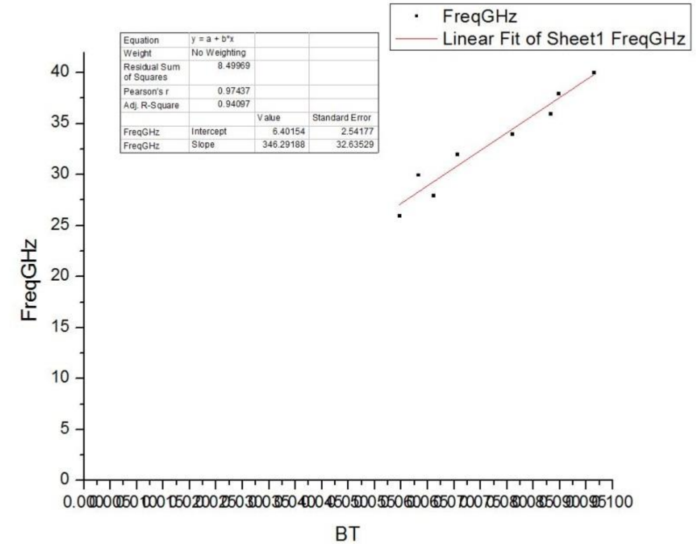


FIG. 4. Effect of magnetic field normal to the surface on resonance. Solid line is the theory in Eq. (4) in text. Dashed line is the cyclotron frequency eH/m^* with $m^* = 0.069$.



Adapted from “Dimensional resonance of the two-dimensional electron gas in selectively doped GaAs/A1GaAs heterostructures”

Fitting & improvement



- Boundary Plasmon Resonance (~GHz)

can be quenched by irregular shaped samples;

- Frequency range (26-40GHz)

can be extended by replacing waveguide with coaxial cable (down to DC)
and adding frequency multiplier (up to 100GHz);

- Standing wave in waveguide can be

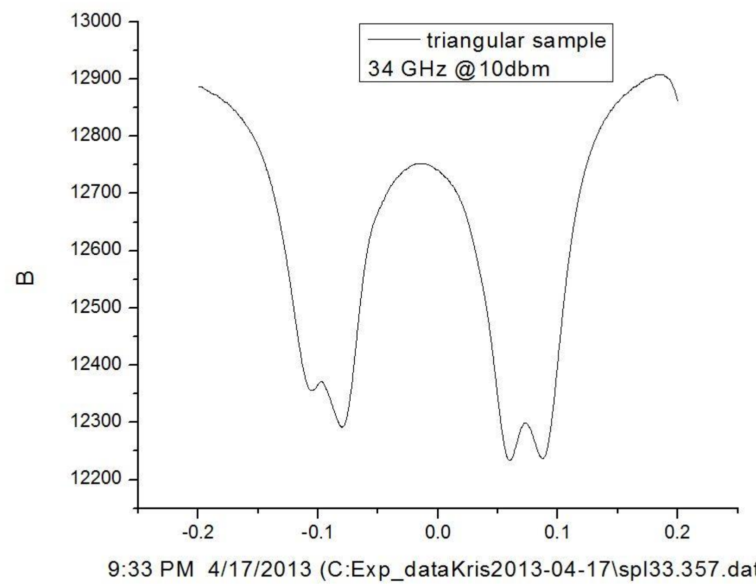
eliminated by shifting the frequency;

- Precision can be increased extensively by

differential measurement (symmetric geometry) and amplitude modulation
lock-in technique;

- Decrease Noise with 300mK temperature

In He3 cryostat;



Probe detail

Adapted from PhD thesis of Kris Stone

D.1 Sample Holder/Block Schematic

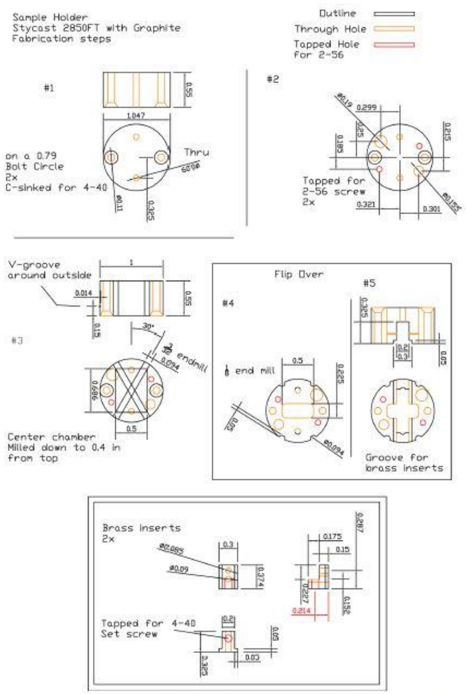


Figure D.5: Stycast 2850FT with graphite sample holder and insert brass inserts. Dimensions in inches.

Probe Schematics

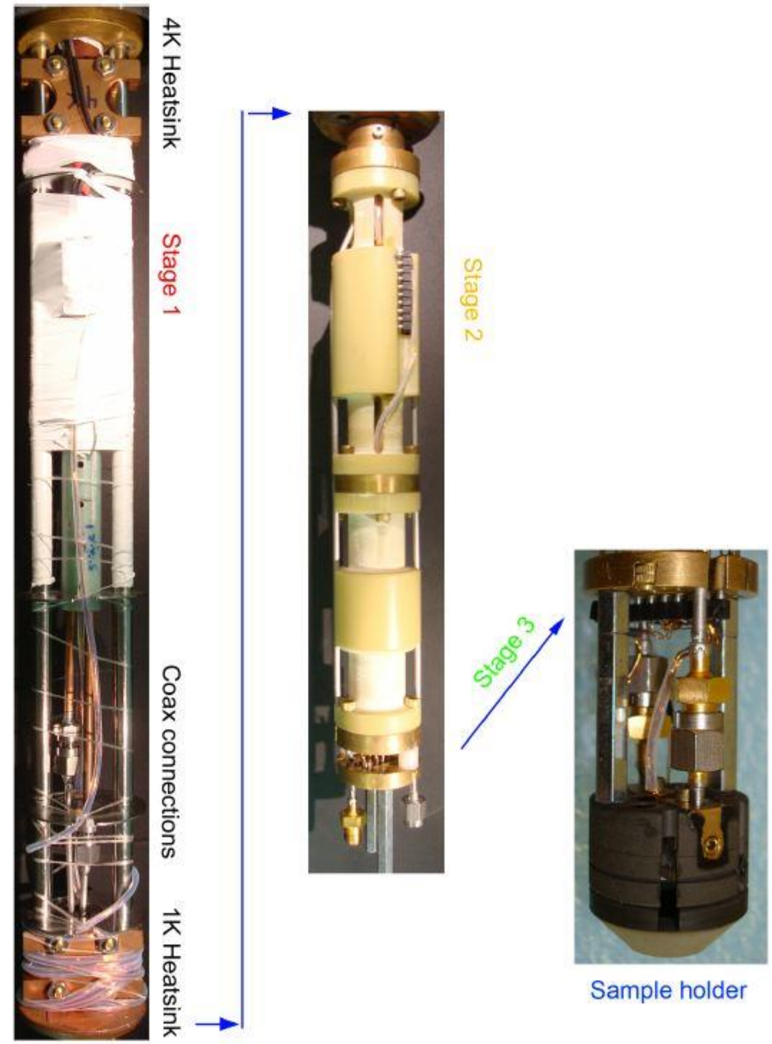
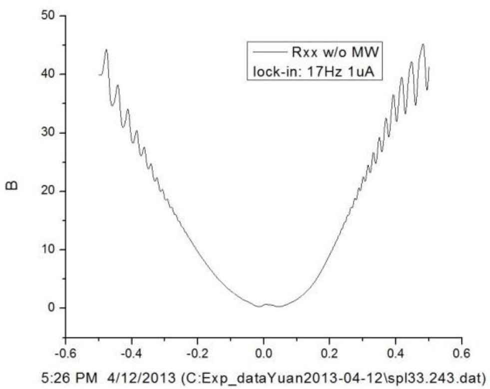
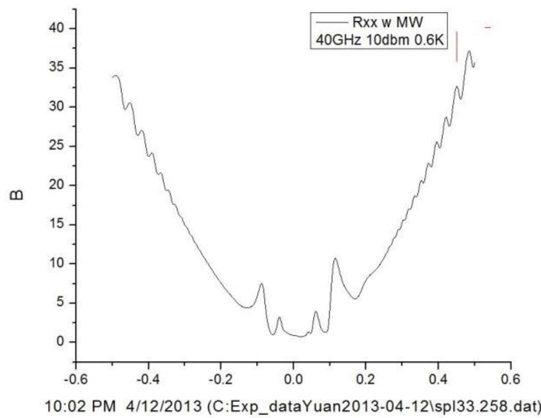


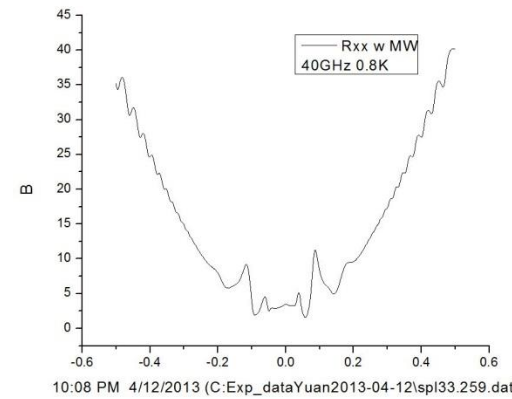
Figure D.1: Pictures of the probe stages: 4K, 1K, and the sample holder.

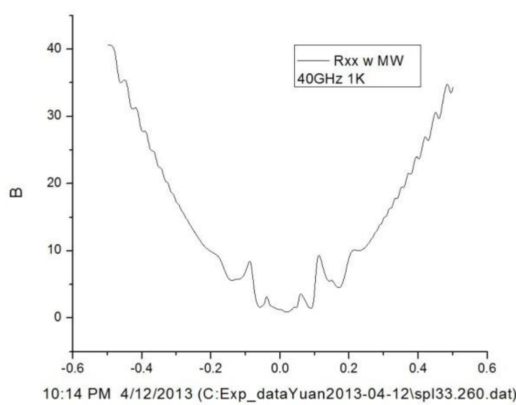
Shubnikov-de Haas oscillations and microwave induced Shubnikov-de Haas oscillations

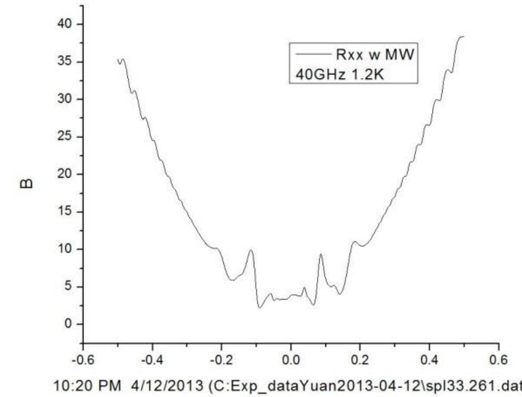
- Microwave level varied



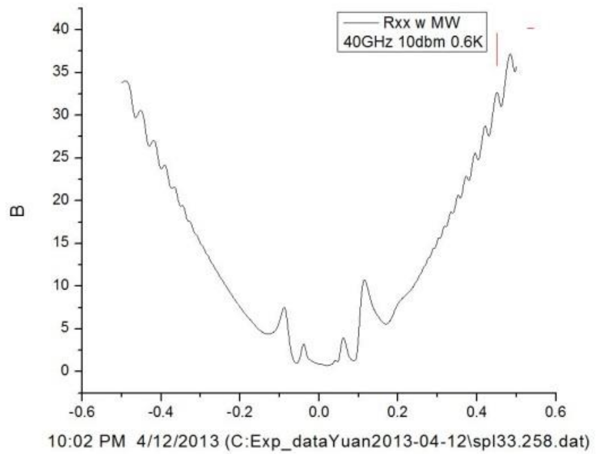


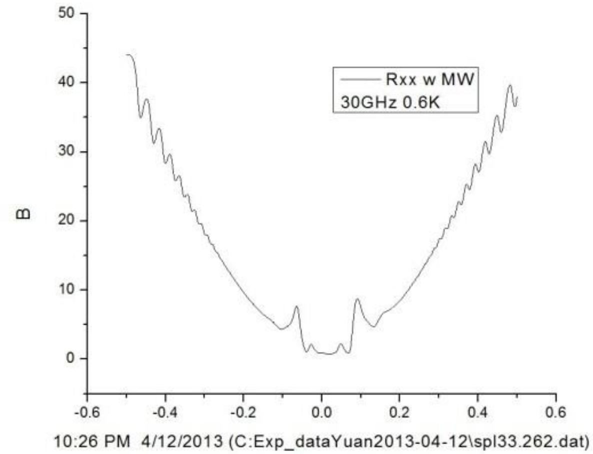


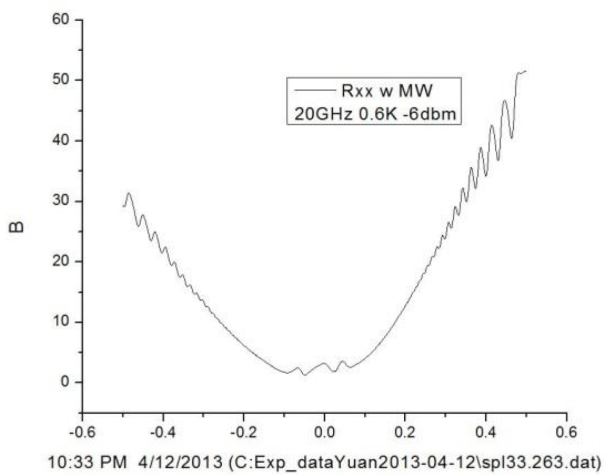


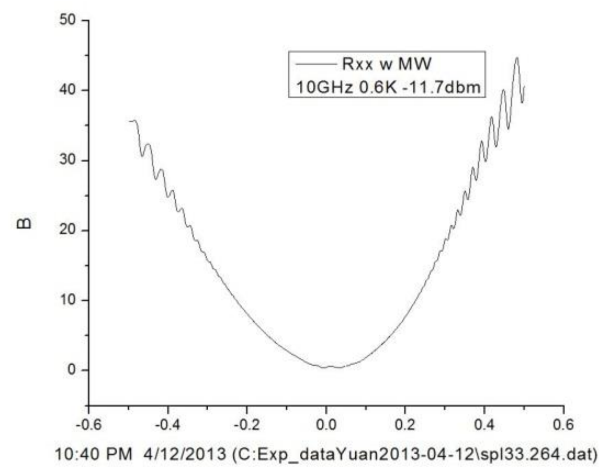


Fix temperature @0.6K & vary Frequency









- Problem

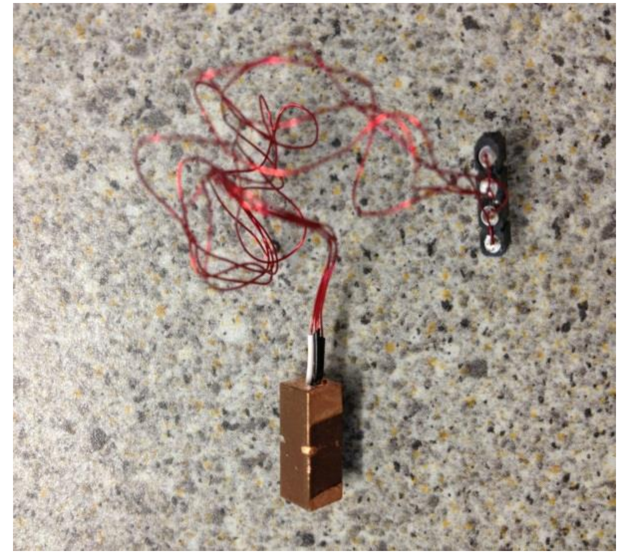
-6dbm=0.2519mW

-11.7dbm=0.0676mW

Improvement

1. Use copper cover on thermometer to avoid being exposed in microwave;
2. Replace stainless steel by alloy (good electrical conductivity and bad thermal conductivity) to shorten the penetration depth in Coaxial cable;

$$\boxed{\delta = \sqrt{\frac{2}{\omega\mu\sigma}}}$$



ELECTRICAL CHARACTERISTICS

Impedance, ohms	50+/-1		
Frequency Range GHz	DC-61		
Velocity of Propagation %	70		
Capacitance, pF/ft. (pF/meter)	29 (95.2)		
Typical Insertion Loss, dB/ft. (dB/meter) and Average Power Handling, Watts CW at 20 degrees Celsius and Sea level	**Frequency**	**Insertion Loss**	**Power**
	0.5 GHz	0.14 (0.45)	169.5
	1.0 GHz	0.20 (0.64)	118.7
	5.0 GHz	0.46 (1.51)	50.9
	10.0 GHz	0.67 (2.21)	34.9
	20.0 GHz	1.00 (3.29)	23.7
Corona Extinction Voltage, VRMS @ 60 Hz	1500		
Voltage Withstand, VRMS @ 60 Hz	5000		

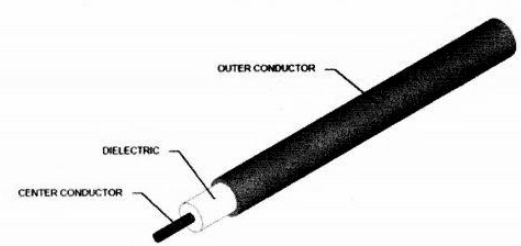
ENVIRONMENTAL CHARACTERISTICS

Outer Conductor Integrity Temperature, Deg Celsius	150
Maximum Operating Temperature, Deg Celsius	125

MATERIALS

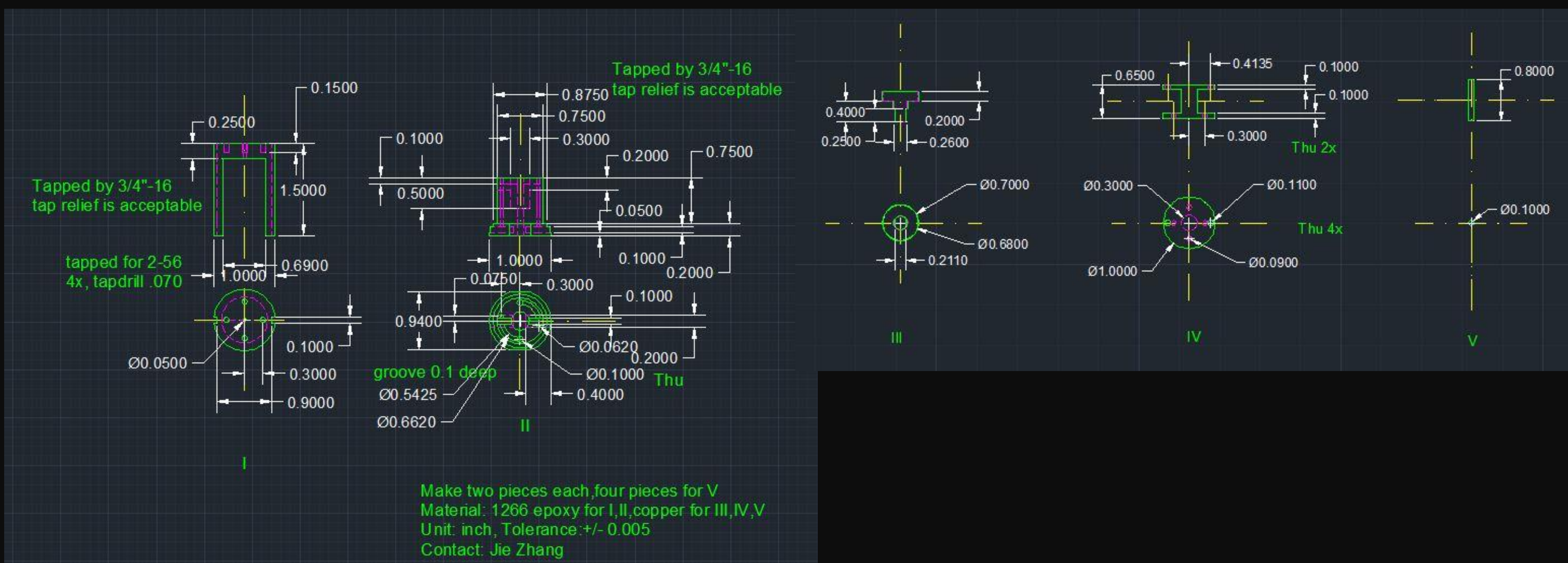
Outer Conductor	90%Tin/10%Lead Plated Copper
Dielectric	PTFE
Center Conductor	SPCW

CUTAWAY

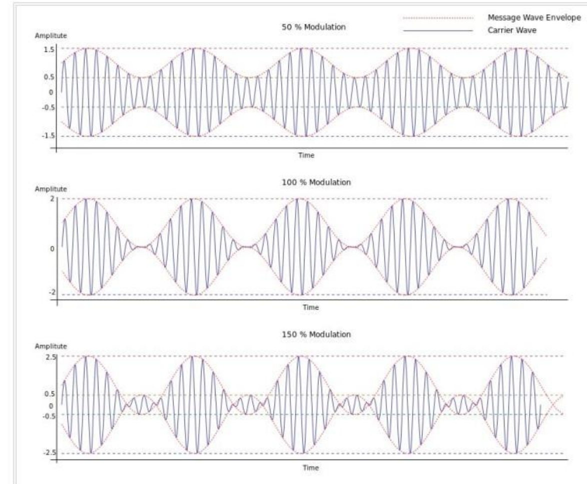


Work done in June

- Adding another four coaxial wire for differential use;
- 100 times thermal shocks on the thermometer to make the behavior stable;
- Vacuum can made of 1266 epoxy (pumped to remove the bubble) in He3;



Amplitude modulation figured out and combined with differential method



- Apply amplitude modulation on microwave;
- 1V ~ 70% depth;
- $R = R_0 + \Delta R sin\omega t$;
- $U = IR = I(R_0 + \Delta R sin\omega t)$;
- Multiplication circuit within lock-in amplifier

  which extract reference frequency component $I\Delta R$

  as long as integral time constant is set to be much larger than $\frac{1}{\omega}$

  and current I is DC within approximation;
- Differential circuit $R = R_0 + \Delta R'$ $\quad U = IR = I(R_0 + \Delta R')$;
- Two methods combined:

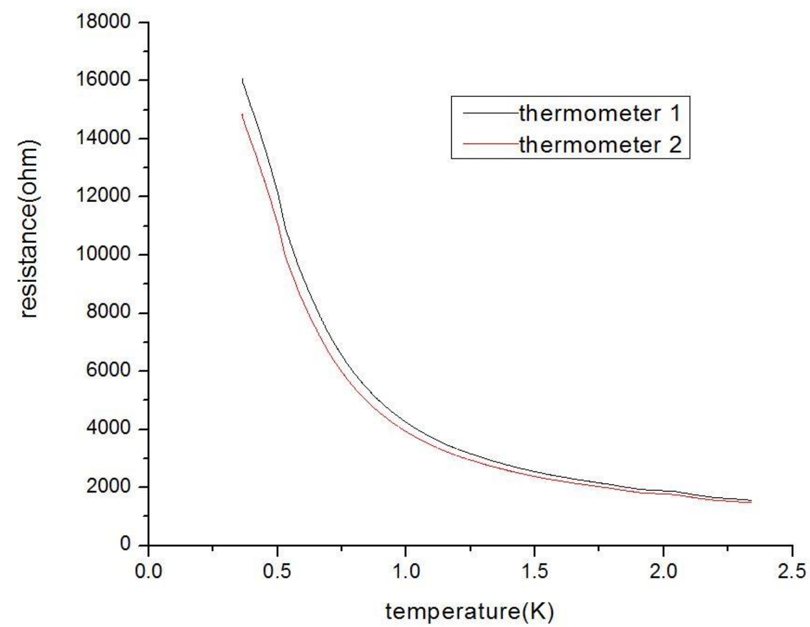
$$f(t) = A(B)\sin\omega_1 t \sin\omega_2 t\,, \omega_1 \gg \omega_2$$

  differential : filter background noise;

  AM : filter the asymmetry left in geometry;
- Precision increased by 300 times with microwave level -15dbm ~ 10-100uW;

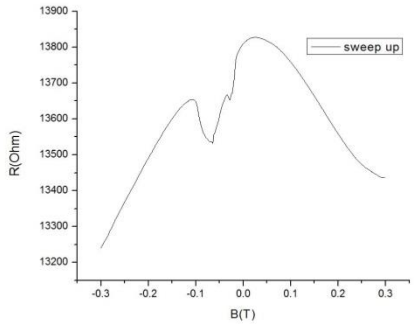
The first fail 06/25

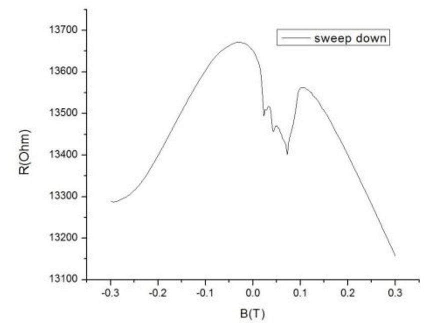
- Heat flow coming from room temperature due to the fact that the probe was 0.7 inch too long, solved by removing the copper connector;
- Vacuum degree of the vacuum can was not good since too much mixture of soap and glycerol was glued to seal;
- Heat conduction from the sapphire crystal to the copper pillar was too good, solved by converting to the thin Manganin wire;
- R(T) was recorded;



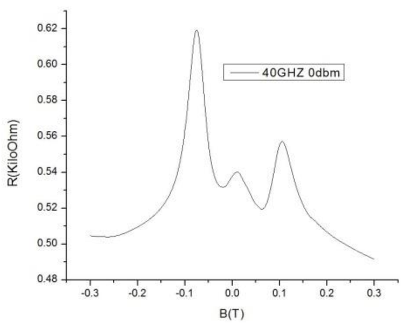
Starting to see cyclotron resonance 06/29

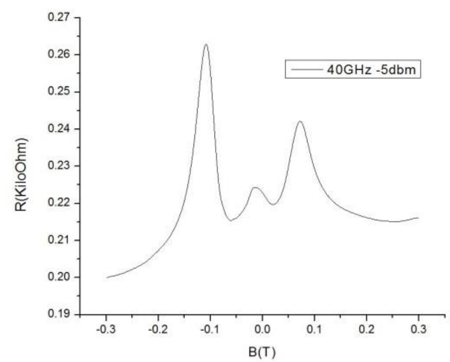
- Response of thermometer as magnetic field is swept;

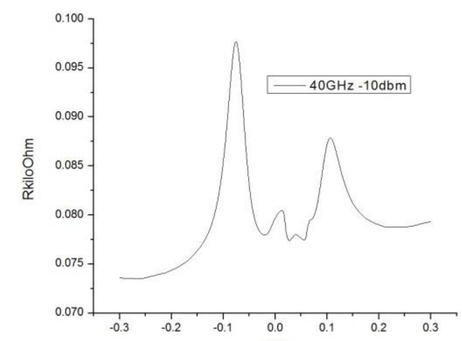


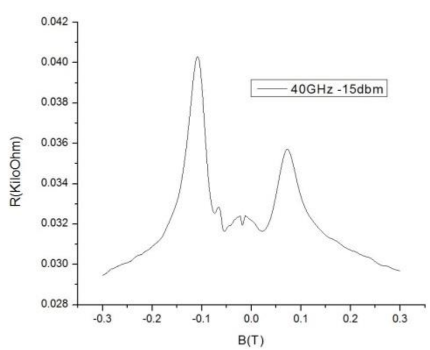


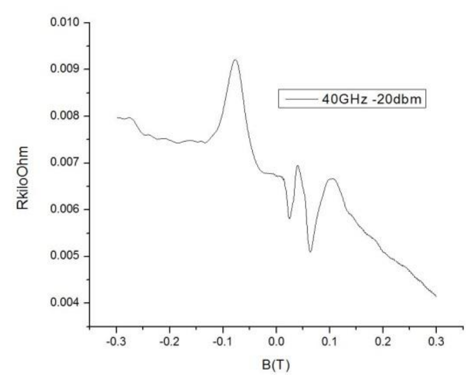
- Amplitude modulated only signal (the other thermometer was messed up) with microwave level down to -20dbm;





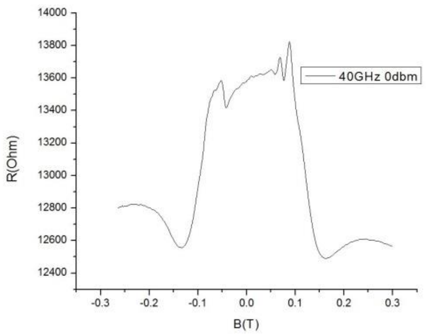




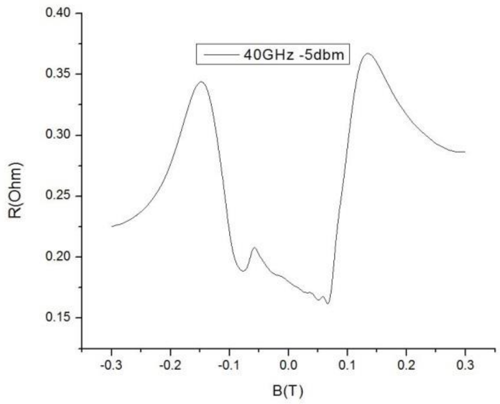


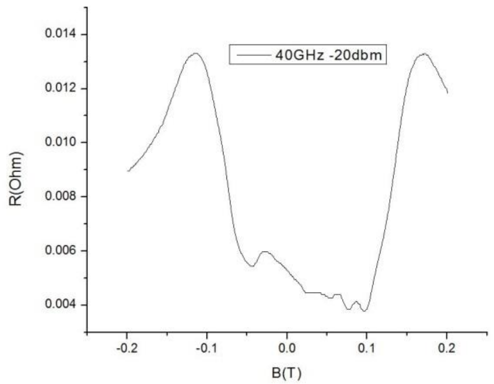
Attempt to see plasma coupling 06/30

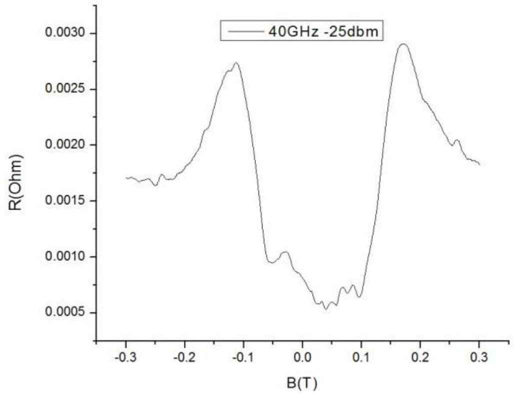
- Background due to the thermometer influenced by magnetic field was too significant for single channel measurement ;



- Sample quality was not good and resulted in multiple peaks and shifting;

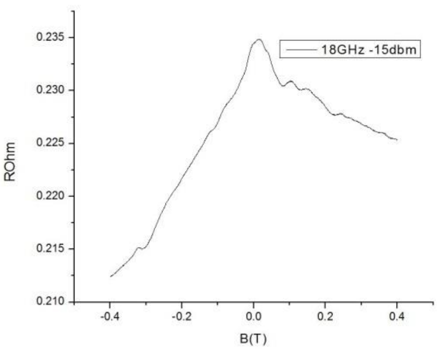


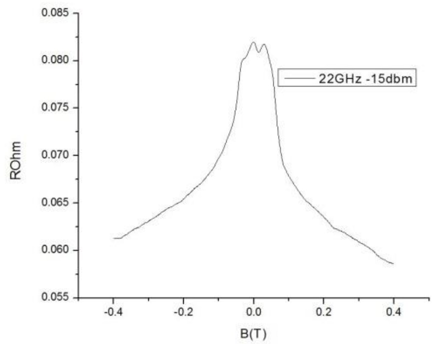


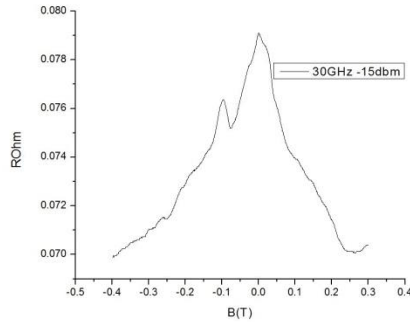


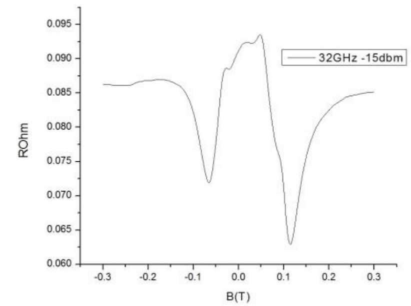
Attempt to see plasma coupling (continued)

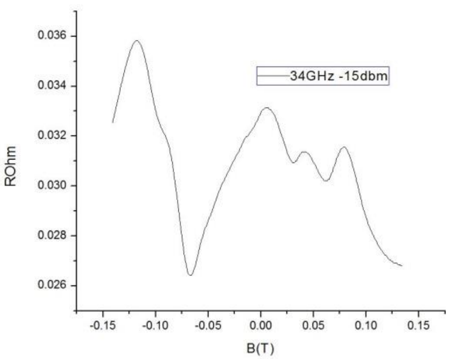
- Visibility of the resonance peak was unstable (even after re-illumination) and frequency dependent;

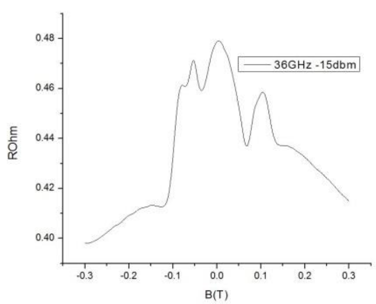


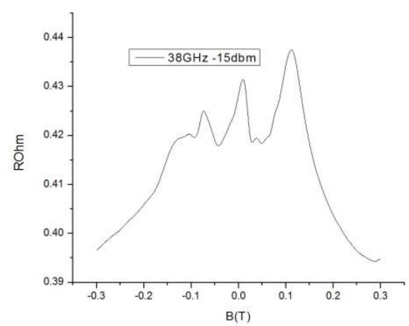


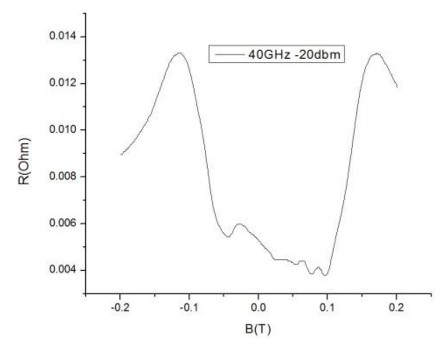






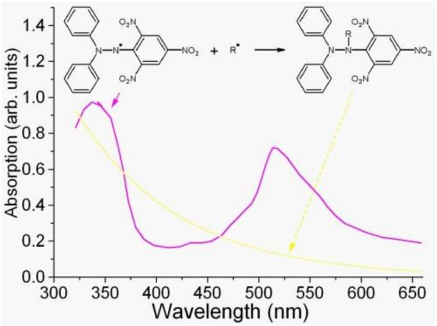






Attempt to see spin resonance with DPPH 07/02

- **DPPH** is a common abbreviation for an organic chemical compound. It is a dark-colored crystalline powder composed of stable free-radical molecules. DPPH has two major applications, both in laboratory research: one is a monitor of chemical reactions involving radicals, most notably it is a common antioxidant assay, and another is a standard of the position and intensity of electron paramagnetic resonance signals.

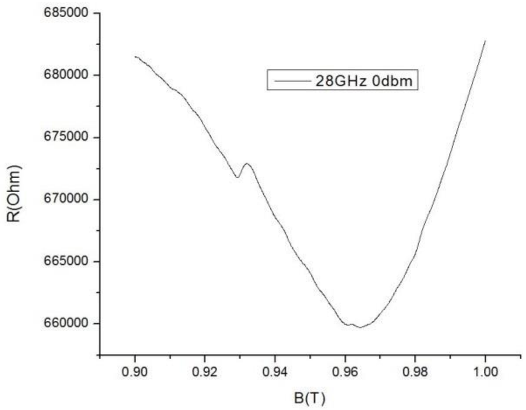


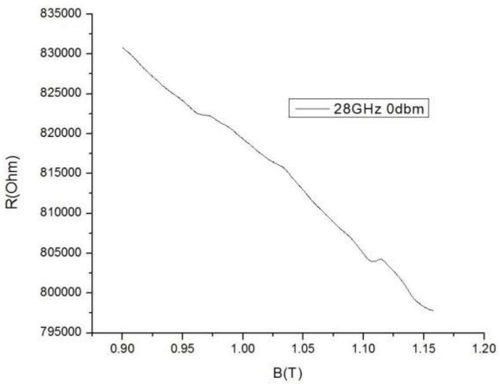
- Typical value:

  g=2.0036

  28GHz/Tesla

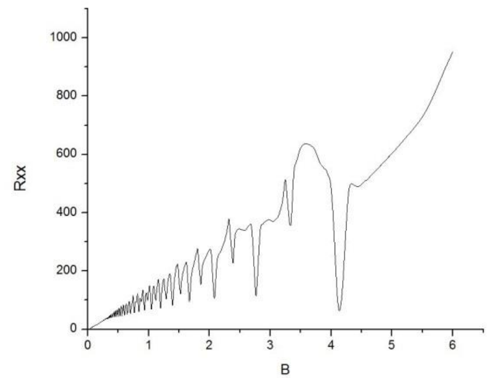
  1.5–4.7 Gauss line width
- Fail to see the peak even with sweeping rate as low as 0.01 Tesla/min.
- Possible reason: not enough DPPH powder; influence of GE vanish





Attempt to see spin resonance with GaAs (electrical) 07/05

- ESR peak can only be resolved in quantum hall region;
- Fail to recover the ESR peak;



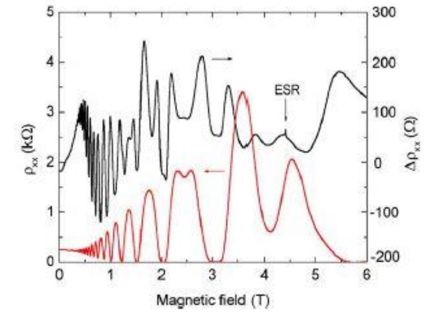


Fig. 1. Longitudinal resistance (ρ_{xx}) vs. magnetic field without microwave radiation (lower curve) and its change ($\Delta\rho_{xx}$) with microwave radiation (upper curve).

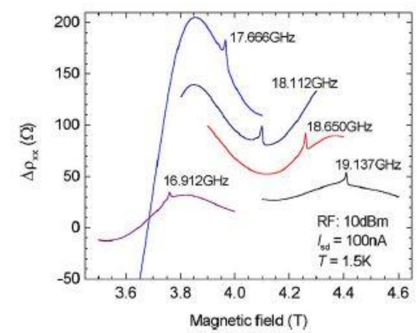
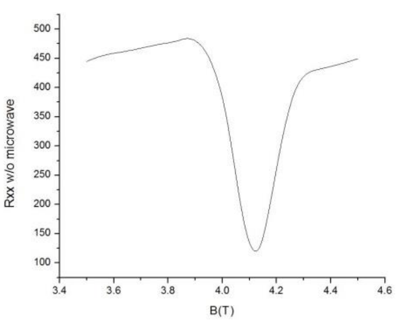
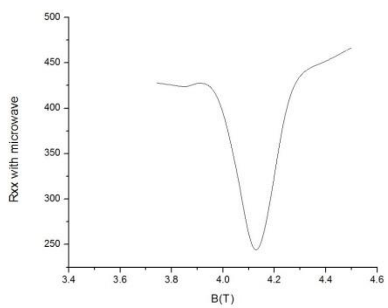
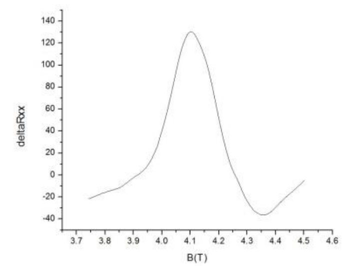


Fig. 2. ESR peaks observed in the $\Delta\rho_{xx}$ curves for various microwave frequencies.

$R_{xx}\ w/o\ microwave \quad R_{xx}\ with\ microwave \quad \delta R_{xx}$







Adapted from “Electron spin resonance and nuclear spin pumping in 2DEG quantum Hall system”

Future work

- Improve the setup with the other thermometer;
- Calibration;
- Try on graphene and carbon nanotube;