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Diffusion thermopower of quantum Hall systems measured in Hall-bar and Corbino geometry

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ABSTRACT

We have measured the diffusion contribution to the thermopower of quantum Hall systems in both Hall-bar and Corbino geometries. We employ microwave heating, using coplanar waveguide, to introduce the temperature gradient. The technique sets up the gradient only to the *electron temperature* without affecting the lattice temperature, thereby eliminating the phonon-drag contribution, which is usually the dominant contribution to the thermopower in GaAs/AlGaAs 2DEGs.

In the Corbino geometry, we observe the radial thermovoltages S_{rr} to exhibit saw-tooth like oscillations, taking large positive (negative) values just below (above) integer fillings with sign reversal at the center of the quantum Hall plateaus [1]. The behavior is in agreement with a recent theory [2], which treats disorder within self-consistent Born approximation.

In the Hall-bar geometry, admixtures of the longitudinal (S_{xx}, Seebeck) and transverse (S_{yx}, Nernst) components are observed for the voltage probes designated to measure either S_{xx} or S_{yx}, suggesting the heavy distortion of the electron-temperature gradient in a strong magnetic field.

Thermopower

Thermopower has been attracting interest as a probe to have an access to

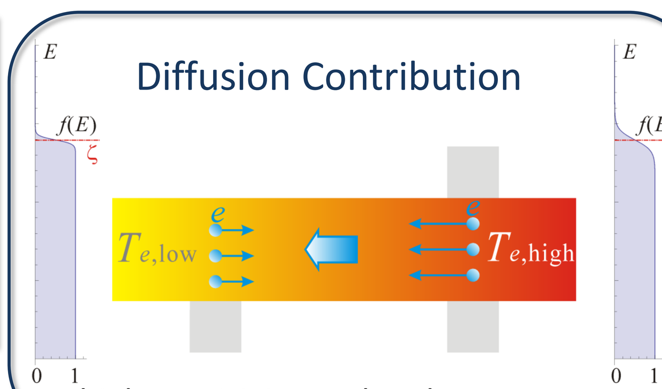
(1) *Energy derivative*
fine structures in DOS

(2) *Entropy of the system*
non-Abelian statistics of quasi-particles in ν=5/2 FQHE [2,3]

> Apply only to the **diffusion contribution**

Two distinct mechanisms

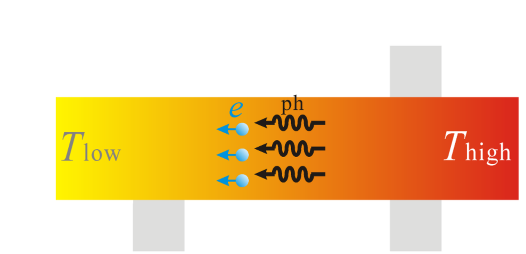
Diffusion Contribution



high sensitivity to the electron system

Target in the present study

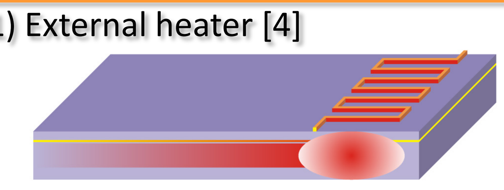
Phonon-Drag Contribution



Heating methods for thermopower measurement

GaAs/AlGaAs 2DEG
2DEG (wavefunction thickness ~10 nm) embedded in thick (> 100 μm) wafer

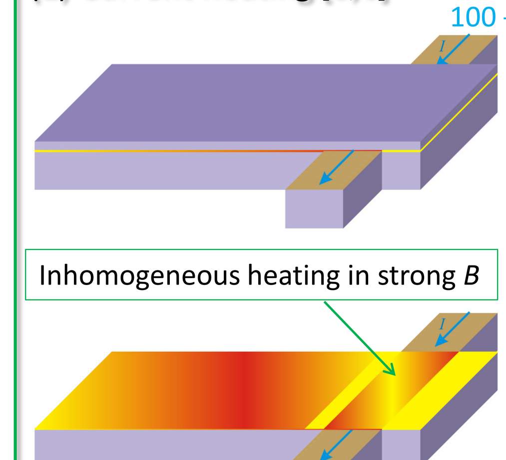
(1) External heater [4]



Predominantly phonon-drag
(despite the weakness of e-ph interaction)

(2) Current heating [5,6]

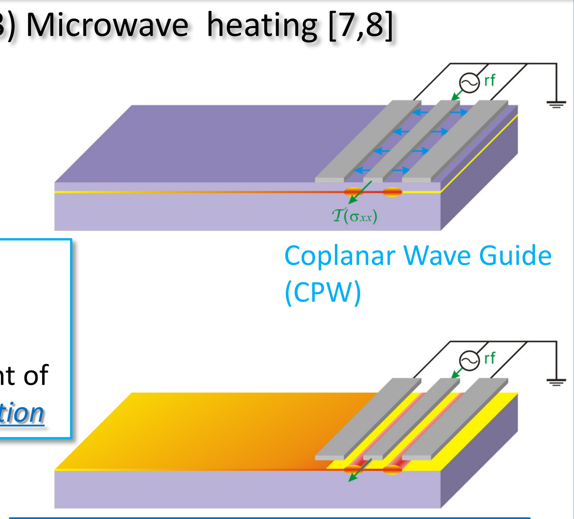
heating current 100 – 500 nA



Inhomogeneous heating in strong B

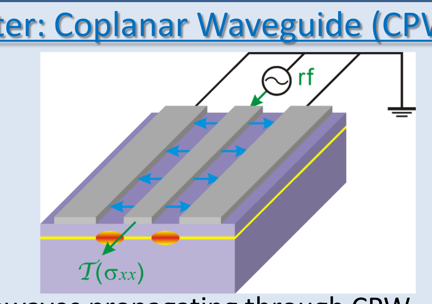
Gradient in electron temperature only
Selective measurement of the diffusion contribution

(3) Microwave heating [7,8]

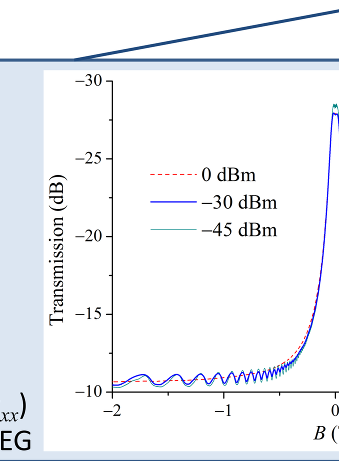


The method in the present study

Heater: Coplanar Waveguide (CPW)



microwaves propagating through CPW are partially absorbed by 2DEG (depending on σ_{xx}) beneath the slot of CPW and locally heat the 2DEG

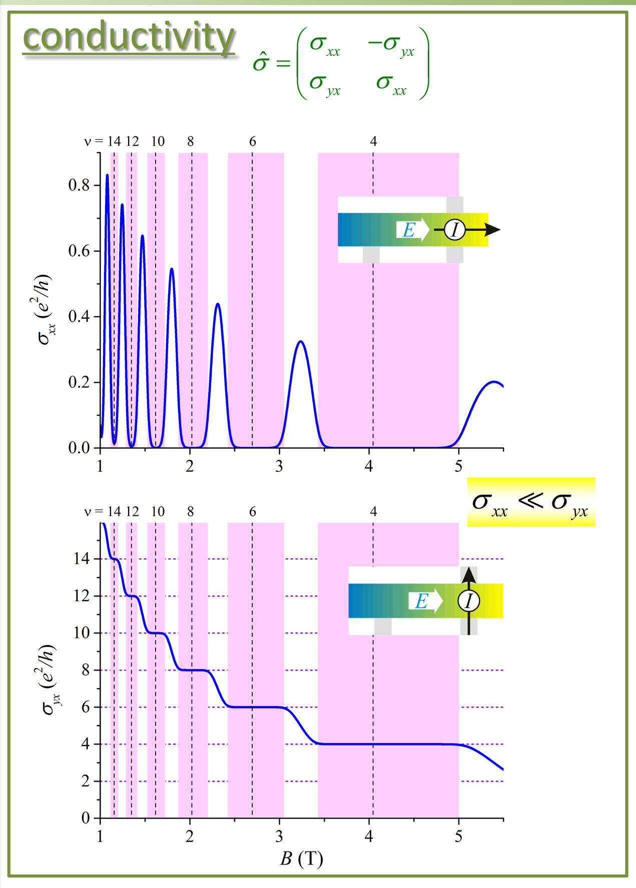


$$\sigma_{xx} = -\frac{w}{2lZ_0}\ln\left(\frac{P_{\mathrm{out}}}{P_{\mathrm{in}}}\right)\sqrt{1+\left[\frac{v_{\mathrm{ph}}}{2l\omega}\ln\left(\frac{P_{\mathrm{out}}}{P_{\mathrm{in}}}\right)\right]^2} \approx -\frac{w}{2lZ_0}\ln\left(\frac{P_{\mathrm{out}}}{P_{\mathrm{in}}}\right)$$

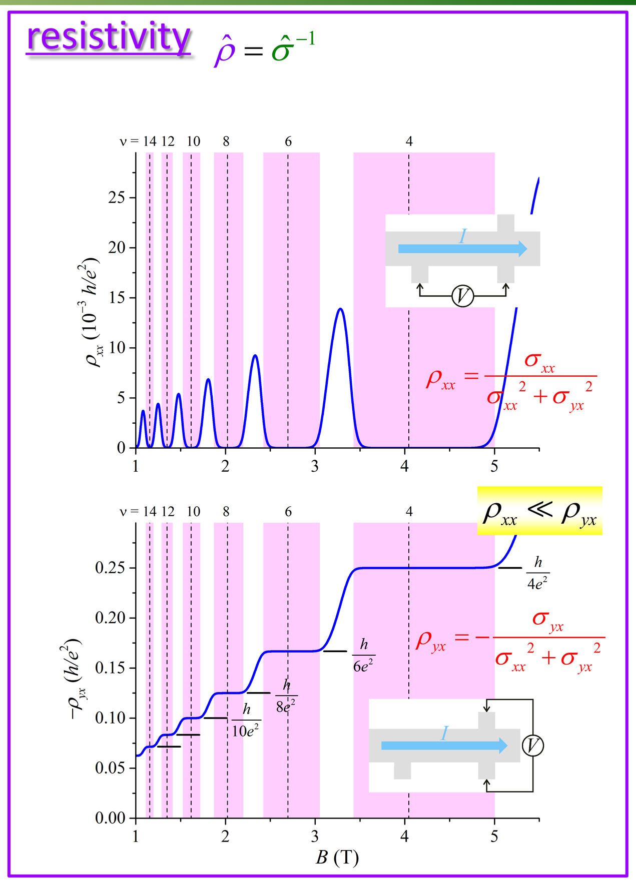
$\ln(P_{\mathrm{out}}/P_{\mathrm{in}}) = (\ln 10/10)(\mathcal{T} - \mathcal{T}_{\sigma_{xx}=0})$

Electrical conductivity and resistivity

conductivity $\hat{\sigma} = \begin{pmatrix}\sigma_{xx} & -\sigma_{yx}\\ \sigma_{yx} & \sigma_{xx}\end{pmatrix}$



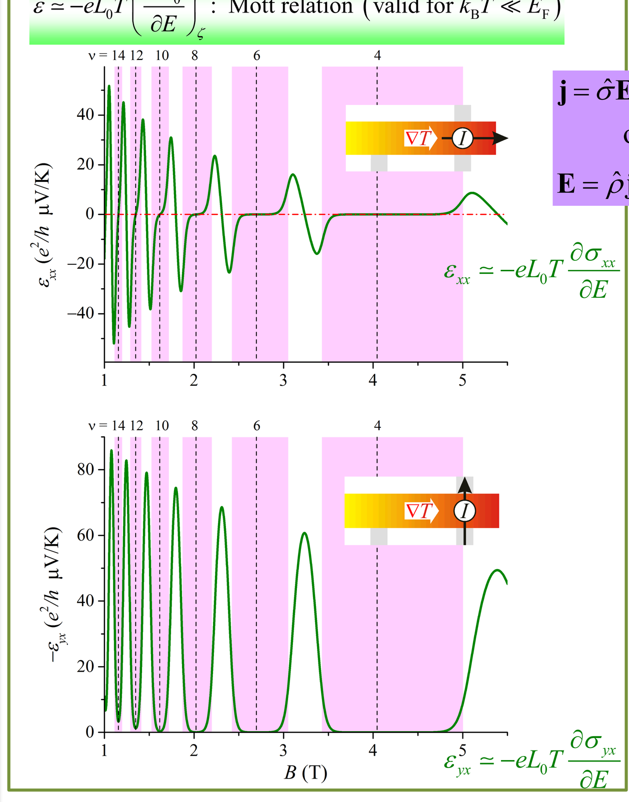
resistivity $\hat{\rho} = \hat{\sigma}^{-1}$



Thermopower in Hall-bar geometry

thermoelectric conductivity $\hat{\varepsilon}$

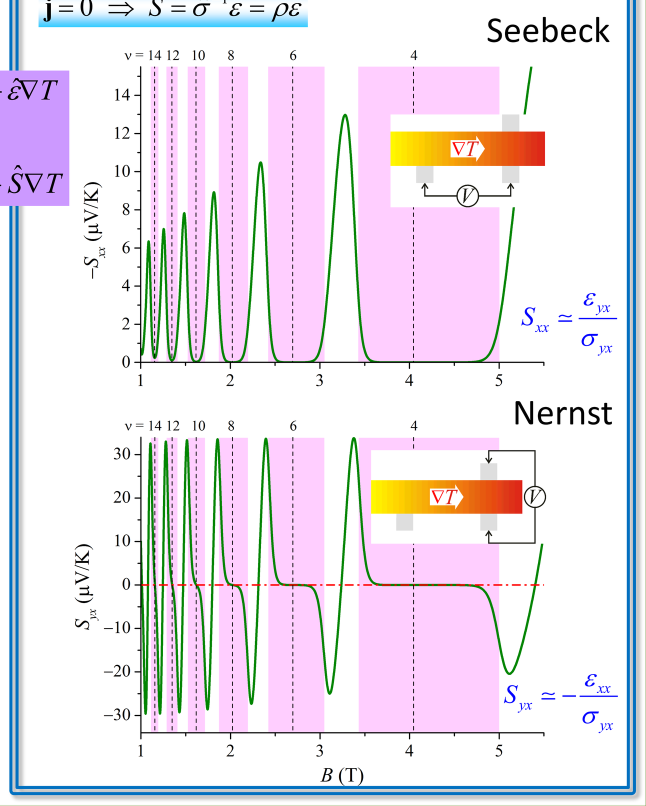
$\hat{\varepsilon} = -eL_0T\left(\frac{\partial\hat{\sigma}_0}{\partial E}\right)_{E_F}$: Mott relation (valid for $k_BT \ll E_F$)



$\mathbf{j} = \hat{\sigma}\mathbf{E} - \hat{\varepsilon}\nabla T$
or
$\mathbf{E} = \hat{\rho}\mathbf{j} + \hat{S}\nabla T$

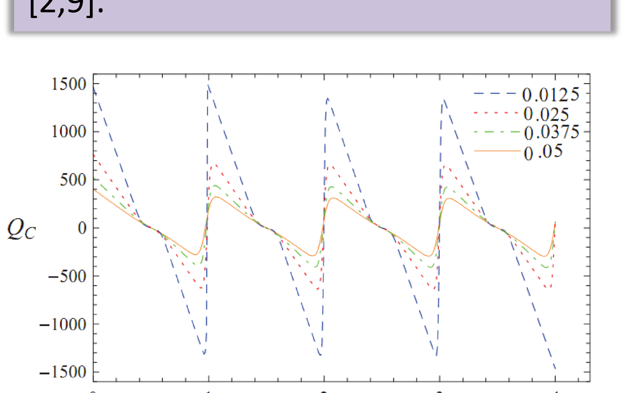
thermopower $\hat{S}$

$\mathbf{j} = 0 \Rightarrow \hat{S} = \hat{\sigma}^{-1}\hat{\varepsilon} = \hat{\rho}\hat{\varepsilon}$



Thermopower in Corbino Geometry

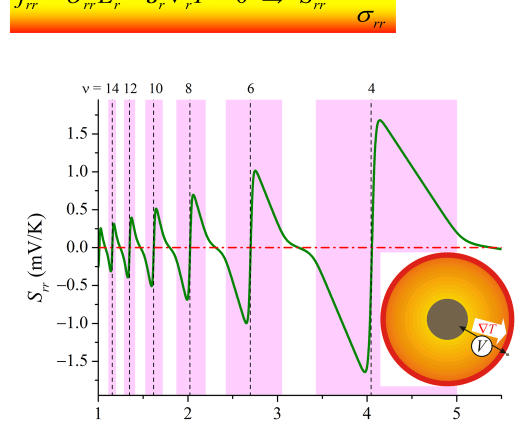
The radial thermopower S_{rr} measured in the Corbino geometry is expected to be *totally different from* the longitudinal thermopower S_{xx} measured in the Hall-bar geometry [2,9].



Y. Barlas and K. Yang (2012)
Calculation treating disorder in SCBA[2]

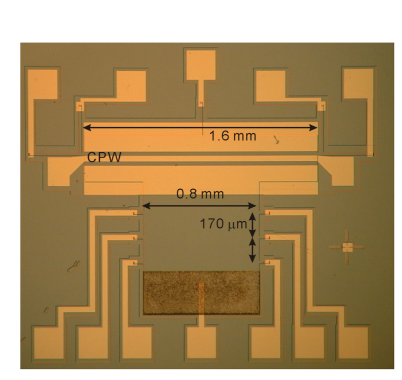
Corbino thermopower S_{rr}

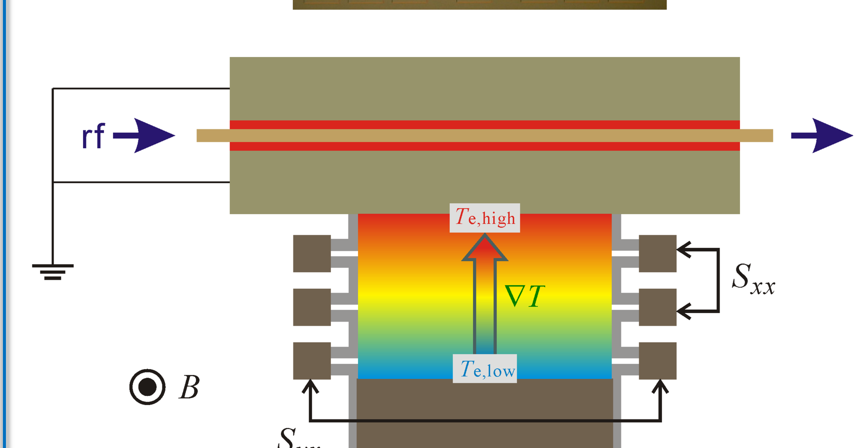
$j_{rr} = \sigma_{rr}E_r - \varepsilon_{rr}\nabla_r T = 0 \Rightarrow S_{rr} = \frac{\varepsilon_{rr}}{\sigma_{rr}}$



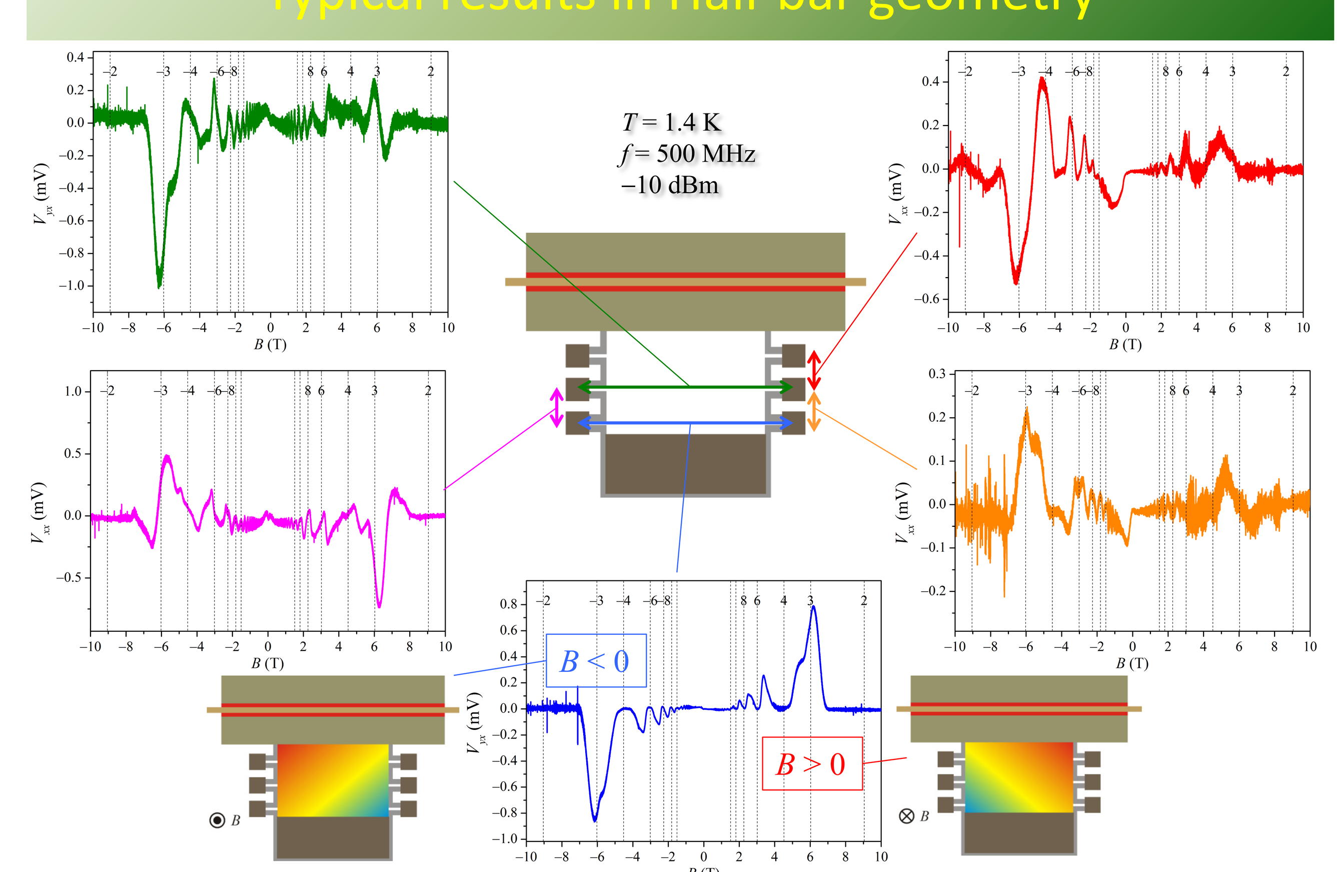
- non-zero, large values at QH states (orders of magnitude larger than maximum values in the Hall-bar geometry)
- sign reversal at exact integer fillings

Hall-bar Device



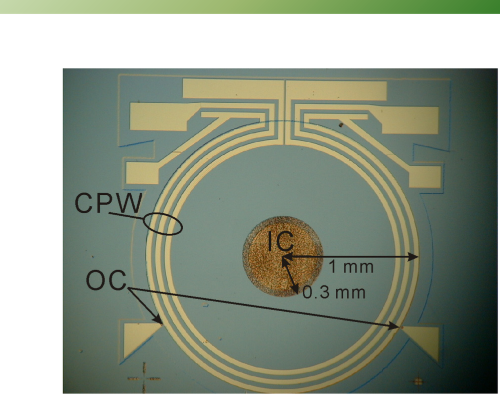


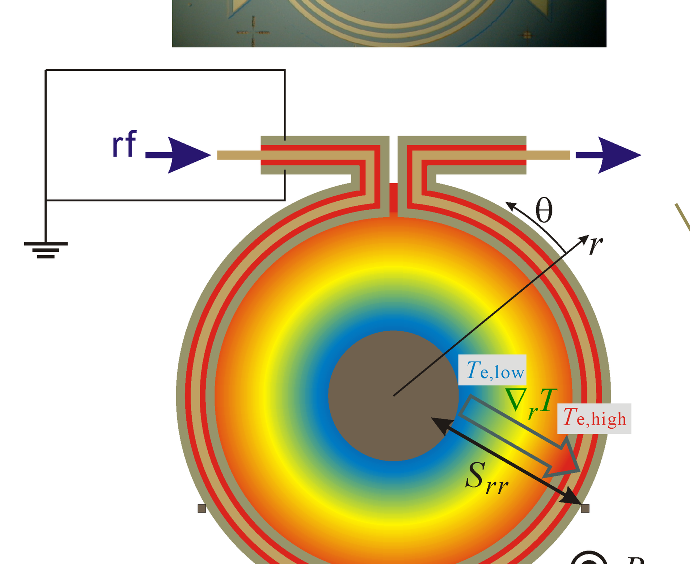
Typical results in Hall-bar geometry

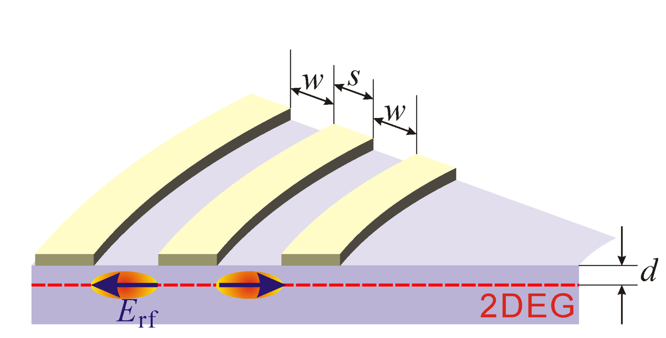


Mixing of S_{xx} and S_{yx} components due to the distortion of the temperature gradient in the strong magnetic field

Corbino Device

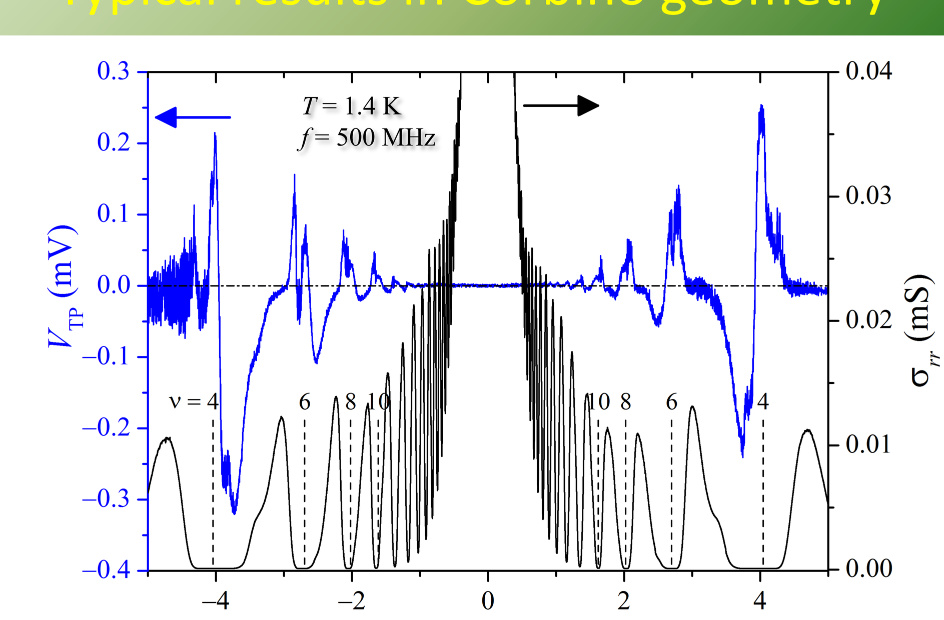






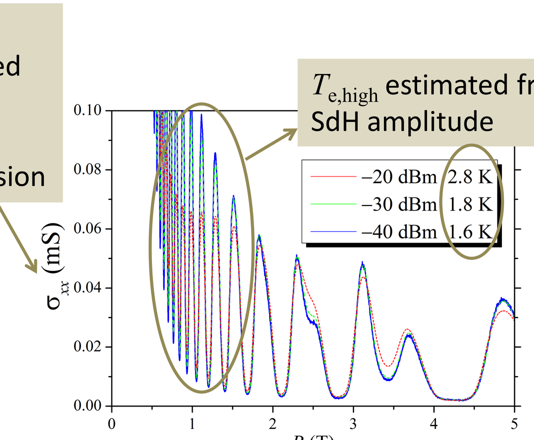
w = 28 μm, s = 40 μm, d = 60 nm

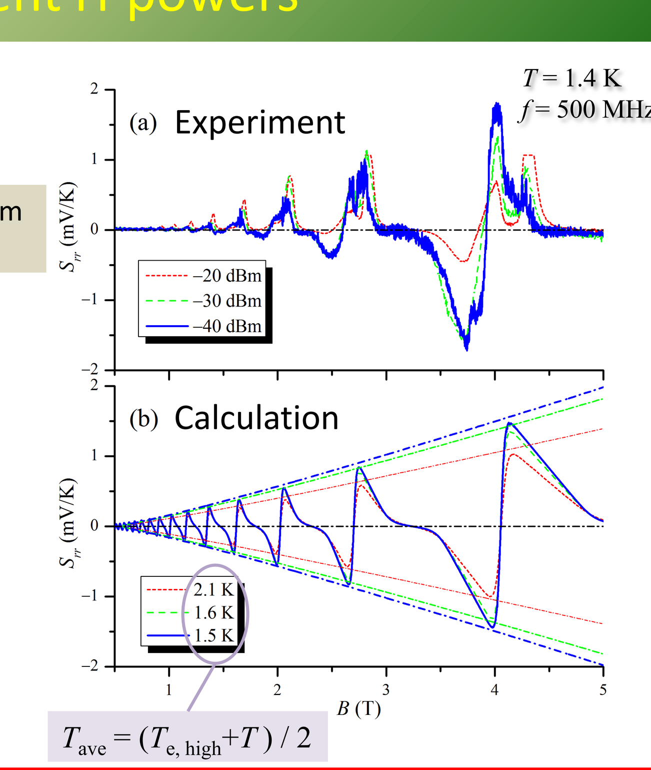
Typical results in Corbino geometry



Different rf powers

σ_{xx} deduced from CPW transmission





$T_{\mathrm{ave}} = (T_{e,\mathrm{high}} + T)/2$

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