Lecture 1

Why transport in ferromagnetic films ?

→ Expts at UF (Hebard's group)

SHIVA : allows in-situ measurements for air-sensitive films (Fe oxidizes quickly !)

→ measures temperature as well as disorder dependence of longitudinal as well as transverse (Hall) conductivity in ultra-thin (< 100 Å) Fe and Gd films.

1.1 : Anomalous Hall Effect in Fe films :

AHE → Hall effect without magnetic field, arises due to spin-orbit coupling.

controversy about different possible mechanisms

contradicts earlier interpretation of lnT dependence

Both R_{xx} & R_{xy} has lnT temp dependence → hallmark of quantum corrections in 2d.

Define

$$\Delta^N(R_{xx}) \equiv \frac{1}{L_{00}R_0}\,\frac{R_{xx}(T)-R_{xx}(T_0)}{R_{xx}(T)} \equiv -A_R \ln\frac{T}{T_0}$$

$$\Delta^N(R_{xy}) \equiv \frac{1}{L_{00}R_0}\,\frac{R_{xy}(T)-R_{xy}(T_0)}{R_{xy}(T)} \equiv -A_{AH} \ln\frac{T}{T_0}$$

where $T_0 = 5K$ is the lowest measuring temperature and $R_0 \equiv R_{xx}(T_0)$ characterizes the disorder.

Observation : For $5K < T < 20K$ and $R_0 < 3\,k\Omega$

(i) $A_{AH} = A_R$ for film on glass substrate

(ii) $A_{AH} = 2A_R$ for film on sapphire substrate

(i) contradicts earlier experiments, (ii) agrees.

(iii) For $R_0 > 3k\Omega$ both A_R & A_{AH} decreases, but at different rates.

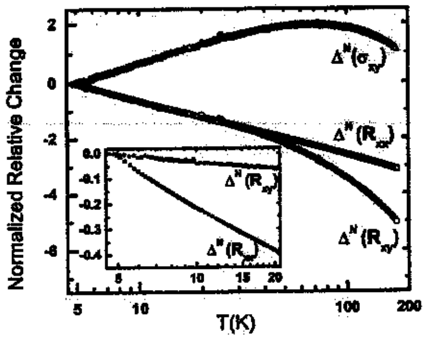

FIG. 1 (color online). ln(T) dependence of R_{xx} and R_{xy} for $T <$ 20 K for a type A sample with $R_0 = 2733\ \Omega$. Inset: $R_0 =$ 49 kΩ.

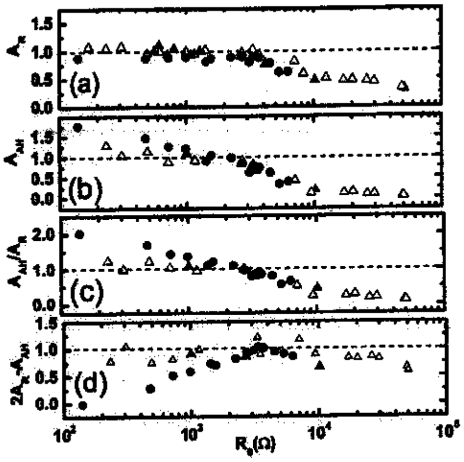

FIG. 2 (color online). Coefficients A_R and $A_{\rm AH}$ as defined in Eq. (1) for type A (triangles) and type B (circles) samples. Solid triangles represent type A samples that have undergone surface modification and conductance changes associated with postdeposition ion milling as described in text.

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Challenge: Reconcile two samples/experiments for low R_0.
Model for large R_0.

1.2: Novel T-dependence of σ_{xx} in Gd:

In addition to the ln T dependence, Gd films show a linear T-dependence, for 3K < T < 30K.

Fitting function: $R_0 < 3k\Omega$

$$\frac{\sigma_{xx}}{L_{00}} = P_1 + P_2 \ln\frac{T}{T_0} + P_3\left(\frac{T}{T_0}\right)^{p} \qquad p \approx 1$$

$R_0(\Omega)$	P_1	P_2	P_3	p
428	187.88(1)	0.79(1)	0.97(1)	1.039(6)
652	123.24(1)	0.67(1)	1.03(1)	0.976(5)
928	86.47(1)	0.71(1)	0.72(2)	0.934(8)
2203	36.10(2)	0.75(1)	0.65(2)	0.84(1)
2613	30.25(1)	0.70(1)	0.72(1)	0.818(4)

TABLE I: Fitting parameters defined in Eq. (1) used in Fig. 1

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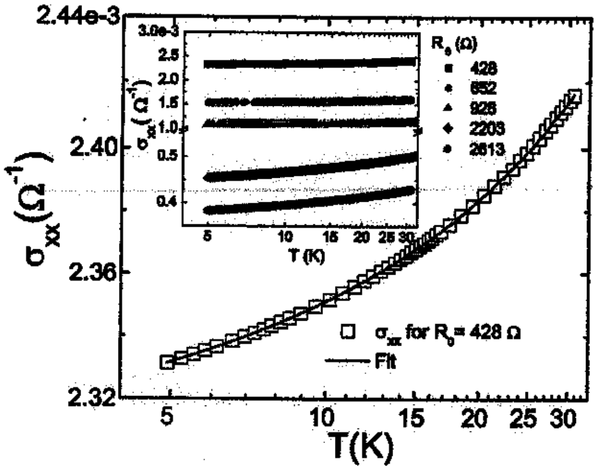

FIG. 1: Temperature dependence of σ_{xx} for a series of Gd thin films (inset) with various sheet resistances R_0 listed in the legend. Note that the temperature scales are logarithmic. The fits for each curve are obtained using Eq. (1), with fitting parameters listed in Table I. The main panel in an expanded view shows the quality of fit for the $R_0 = 428\Omega$ data.

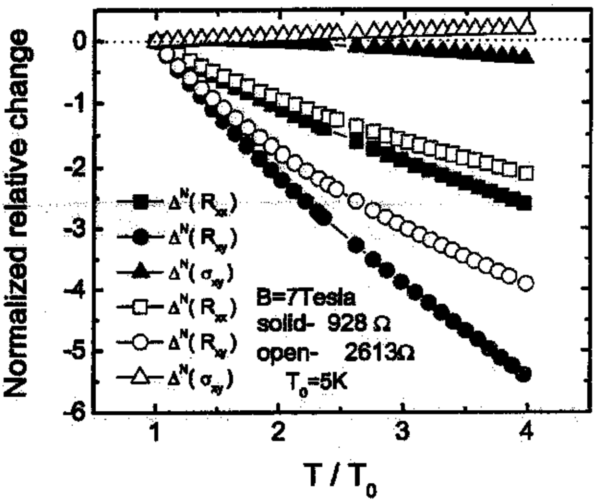

FIG. 2: Normalized relative changes $\Delta^N(\sigma_{xy})$, defined in Eq. (2), for two different sheet resistances. For comparison we also show $\Delta^N(R_{xx})$ and $\Delta^N(R_{xy})$.

Challenge : No known quantum correction in 2d giving a linear T contribution to σ_{xx}

Note : σ_{xy} just like Fe.