

Magnetotransport properties of ferromagnetic GaAs/Mn digital alloys

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Background

- **Much work on random alloys of IIIMnV materials, particularly GaMnAs (T_C and metallicity improve with annealing – $T_C \gg 150$ K) (*Samarth, Schiffer and others*)**
- **Interstitials play major role** (*Furdyna, Walukiewicz et al.*)
- **Digital Alloys (fractional monolayers of Mn sandwiched between spacer layers of GaAs in superlattice config.**
Control ave. Mn separation in plane (coverage) and separation between Mn containing layers
- **Our previous work: as-grown samples - relatively low T_C 's (< 40K), hopping conduction over wide range of parameters**

Conduction mechanisms and high field (33 T) magnetotransport – additional sample

Samples/Experiment

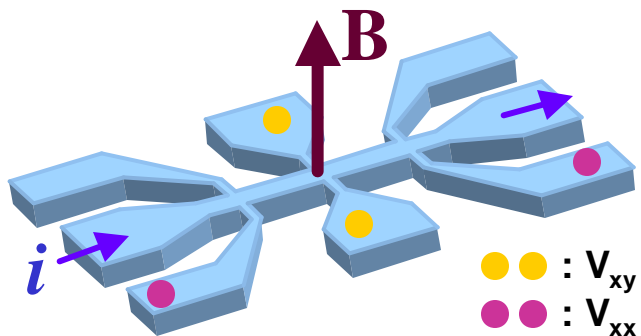
GaAs/Mn digital alloys

MBE Growth

GaAs
GaAs/Mn
GaAs, 45 nm
GaAs, 60nm
SI-GaAs

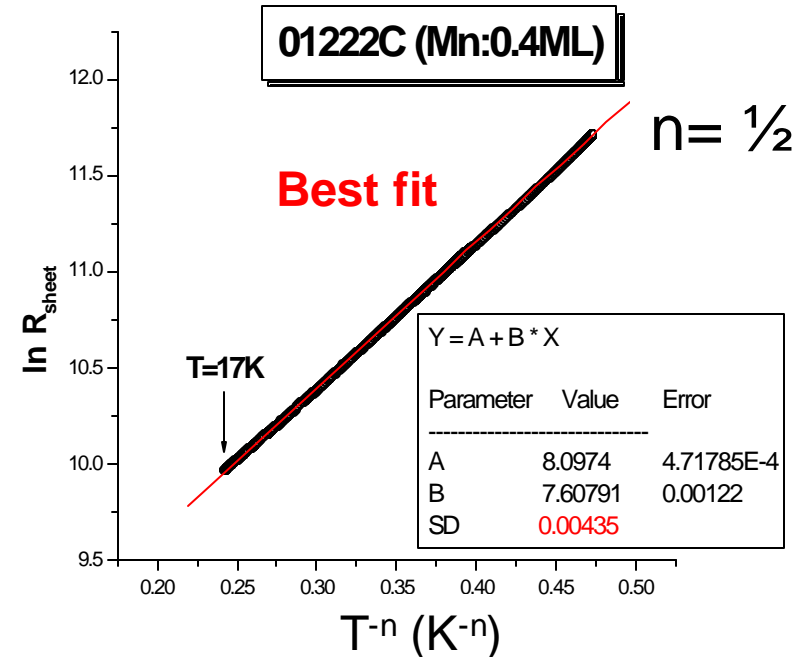
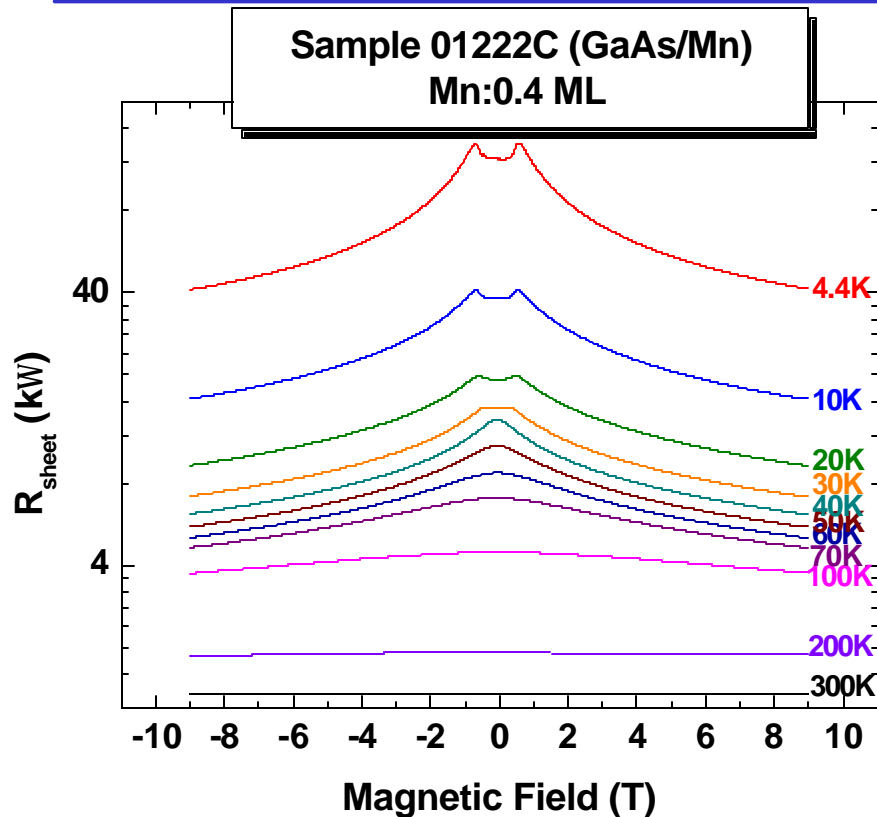
Sample ID	Mn Coverage	GaAs spacer	SL	T _{growth}	T _{Mn}
Sample 1 (01221A)	0.15 ML	9 ML	100	275°C	805°C
Sample 2 (01221C)	0.23 ML	9 ML	100	275°C	805°C
Sample 3 (01222C)	0.40 ML	9 ML	50	275°C	830°C
Sample 4 (01222B)	0.50 ML	9 ML	50	275°C	830°C
Sample 5 (11216G)	0.50 ML	14 ML	50	275°C	790°C

Magnetotransport



- Investigation of magnetotransport characteristics of GaAs/Mn digital alloys up to 15 T (UB) and 33 T (NHMFL)
- Determination of hole concentration from Hall Res. at high B and low T

Transport and Magnetotransport (Low B)



- Peak in R_{sheet} around T_C
- $T < T_C$, $\ln R_{\text{sheet}} \propto T^{-1/2}$

General behavior for all samples

- Initial small pos. MR (“ears”) followed by negative MR (large for samples with thermally activated conductivity)
- Pos. MR disappears at T_C ; negative MR persists above T_C
- Decrease in resistance with B (very strong for samples with thermally activated conductivity)

High Field Hall Resistance

Hall Resistance

$$R_{Hall} = \frac{R_0}{d} B + \frac{R_s}{d} M$$

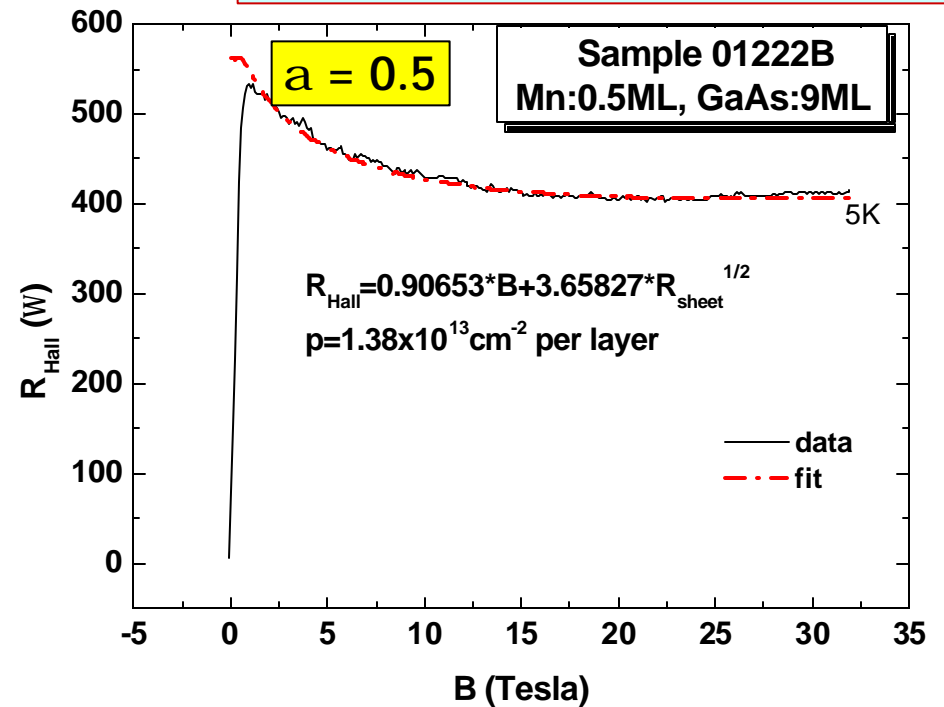
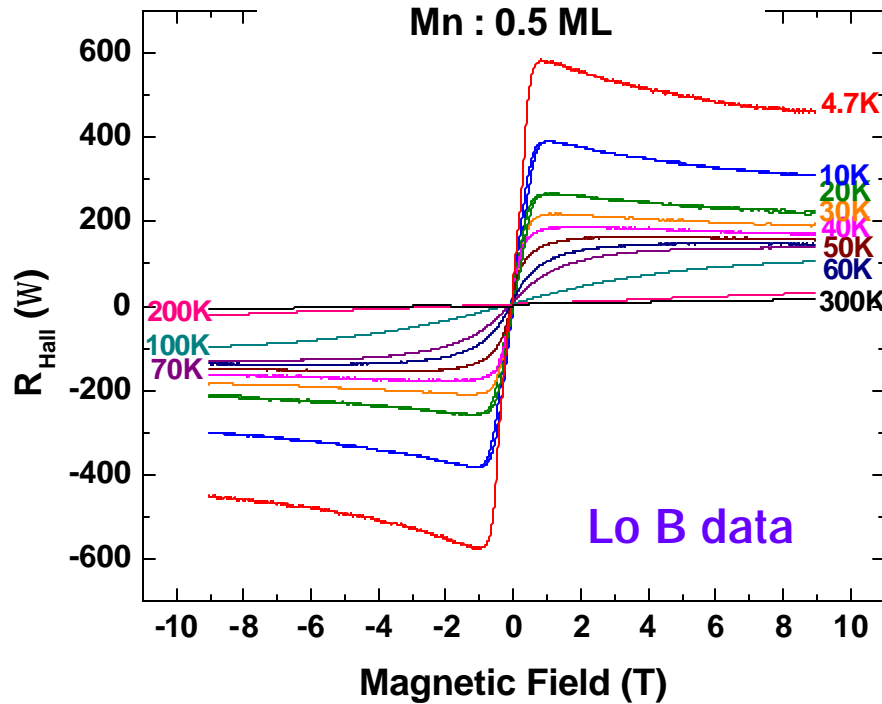
Samples showing strongly activated conductivity

$R_s \propto R_{sheet}^a$ for metals $a = 1$ (skew scattering) or 2 (side-jump scattering). **High** fields, low T, when $R_0 B$ term dominates – carrier density from slope. 30 T not **high** enough; fit data \rightarrow p and a .

Example of High B data for sample showing strong thermally activated conductivity

Sample 01222B (GaAs/Mn)

Mn : 0.5 ML



Summary (activated conductivity samples)

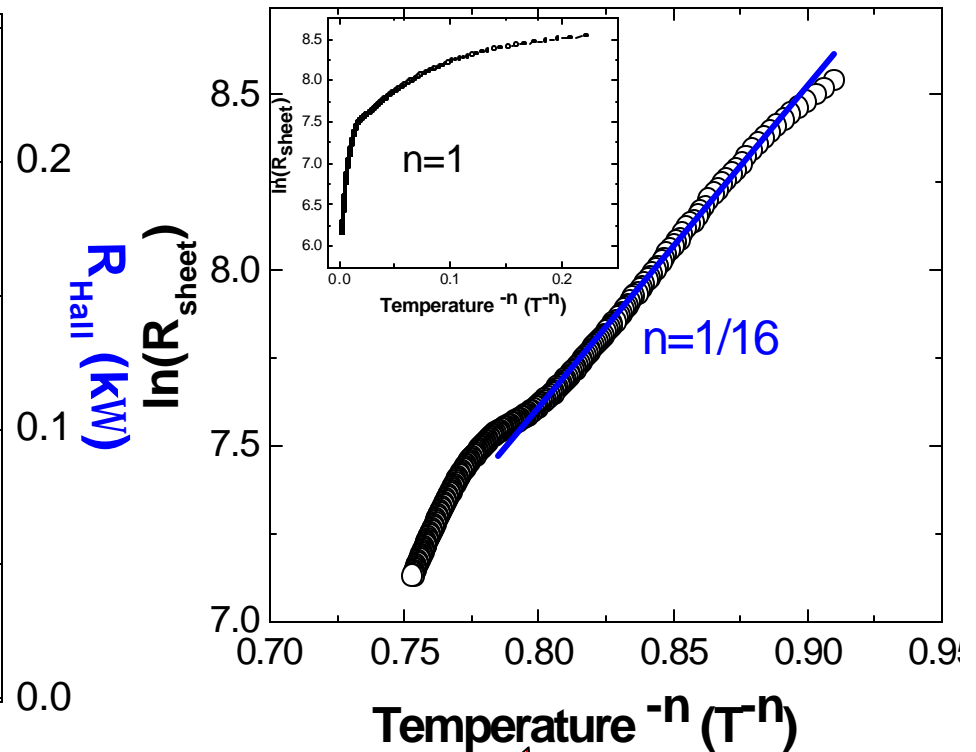
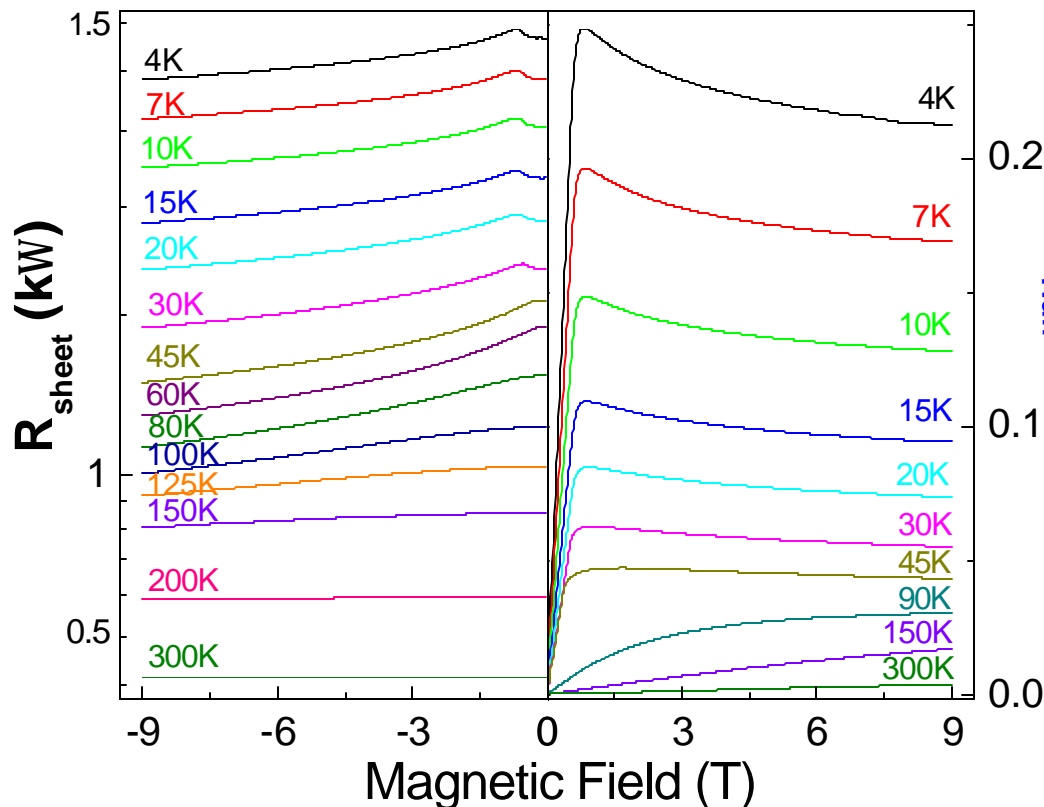
T-dep. of R_{sheet} & Anomalous Hall Coefficient $R_S \mu R^a_{sheet}$

	n ($T < T_c$)	a
Sample 1 (0.15 ML Mn)	1/4 or 1/3	0.25
Sample 2 (0.23 ML Mn)	1/2	0.3
Sample 3 (0.4 ML Mn)	1/2	0.3
Sample 4 (0.5 ML Mn)	1/2	0.5

- Hopping conduction $\rightarrow R_S \mu$ **fractional** power of R_{sheet}
Contrast with predictions for metals

Transport and Magnetotransport (Lo B)- Sample 5

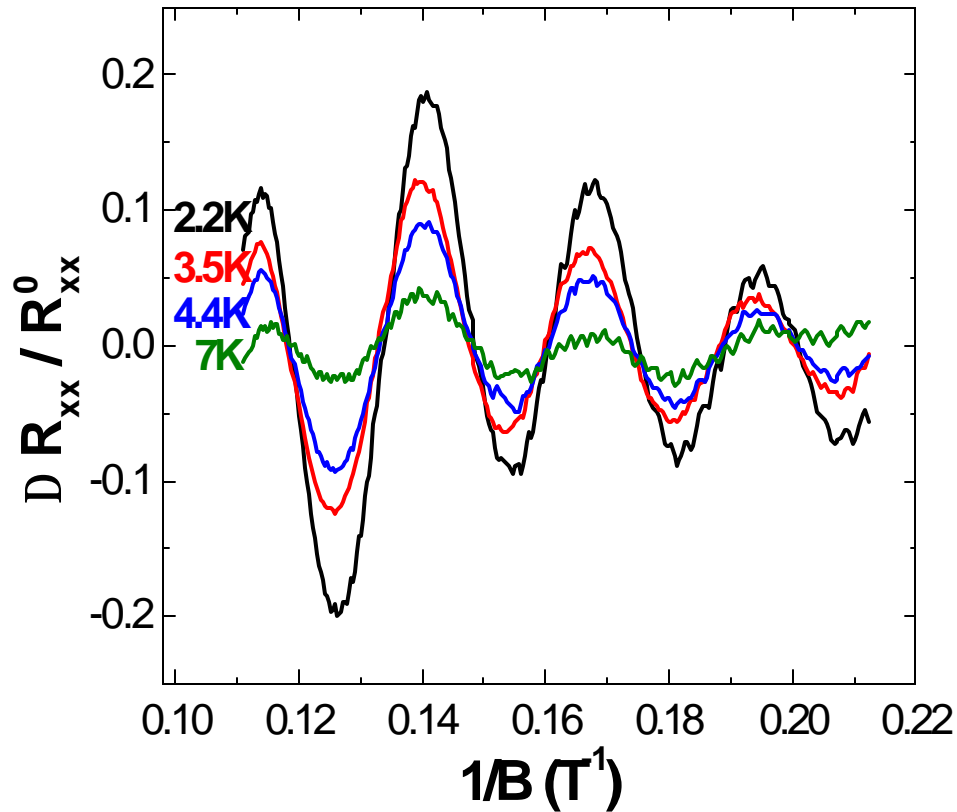
Low-field Magnetotransport



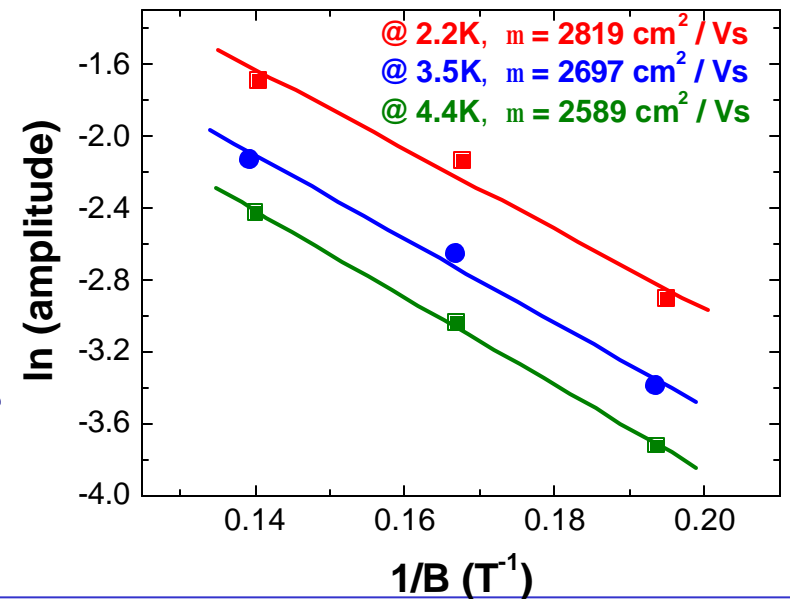
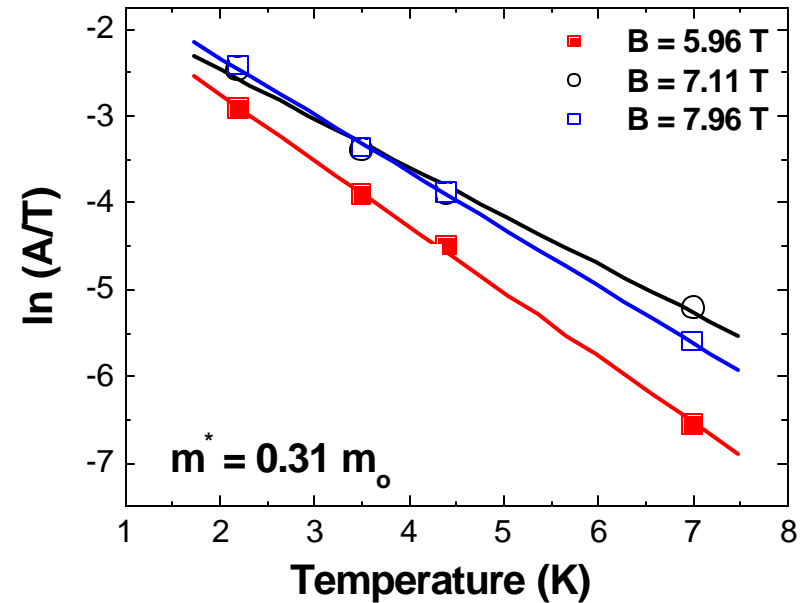
- Initial small pos. MR (“ears”) followed by **weak** negative MR
- Negative MR disappears above 150 K; pos. MR disappears above 60K ($T_C = 65$ K)
- Peak in R_{sheet} around T_C (also more metallic behavior from T dep. of R_{sheet})
 - $T < T_C$, $\ln R_{\text{sheet}} \propto T^{-1/16}$ to $-1/25$ (can't fit with single value of n)

Magnetotransport on Sample 5

Shubnikov-de Haas Oscillations



- SdH oscillations at low temp. (2 ~ 7 K)
- m^* has value heavy hole mass of GaAs
- High mobility ($\gg 2700 \text{ cm}^2/\text{Vs}$)



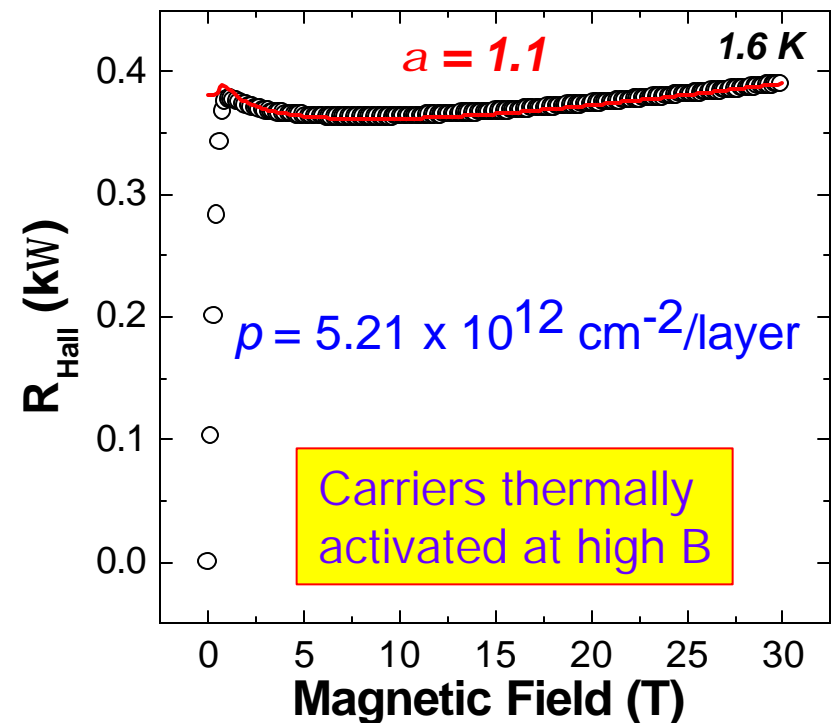
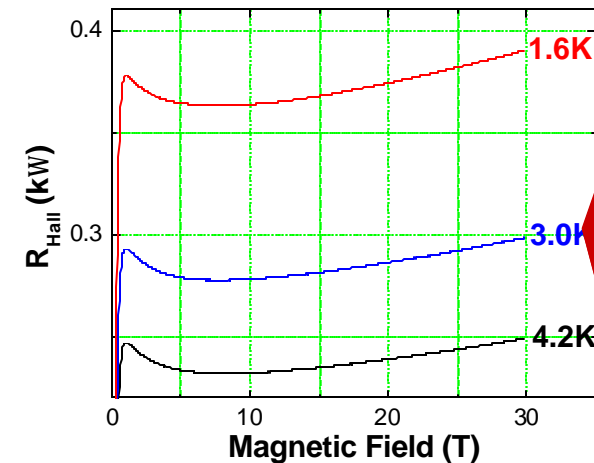
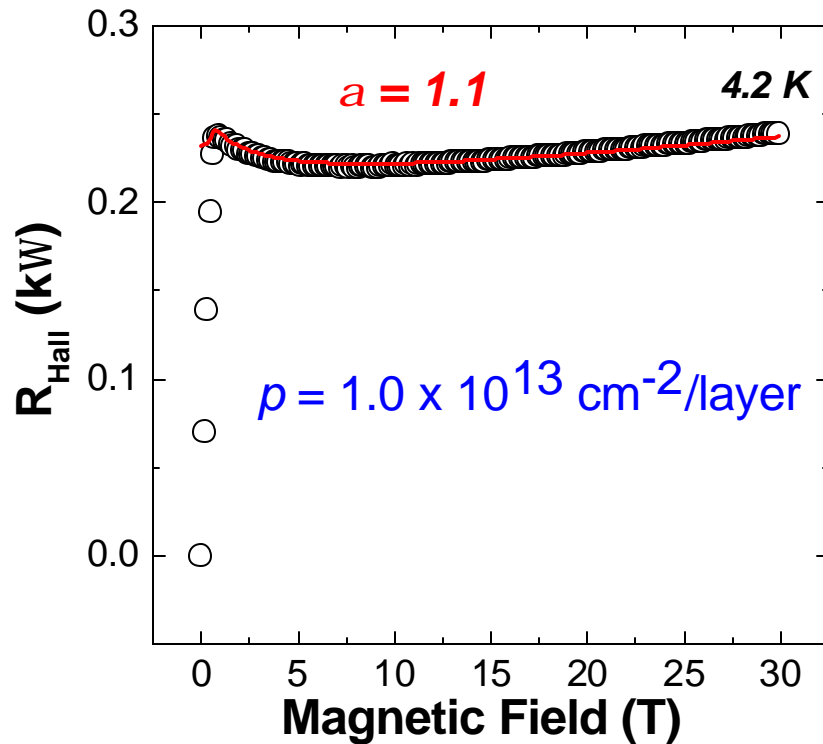
High Field Hall Effect on Sample 5

Hall Resistance

$$R_{Hall} = \frac{R_0}{d} B + \frac{R_s}{d} M$$

$R_s \propto R_{sheet}^a$ for metals $a = 1$ (skew scattering) or 2 (side-jump scattering or "intrinsic"). Fit data \rightarrow
 ρ and a .

Similar hole density



Summary

T-dep. of R_{sheet} & Anomalous Hall Coefficient $R_S \mu R^a_{sheet}$

	$n (T < T_c)$	a
Sample 1 (0.15 ML Mn)	1/4 or 1/3	0.25
Sample 2 (0.23 ML Mn)	1/2	0.3
Sample 3 (0.4 ML Mn)	1/2	0.3
Sample 4 (0.5 ML Mn)	1/2	0.5
Sample 5 (0.5 ML Mn)	1/16 - 1/25	1.1

Hole density in sample 5 is comparable to that in samples 3 and 4

Summary/Conclusions

- **Ferromagnetic Digital GaAs/Mn Alloys**
 - Constant spacer & Mn fractional ML coverage (0.14 – 0.5)
 - 0.5 ML Mn with 14 ML spacer (and different Mn source T)
- **Most samples - Hopping conduction:** $\ln R_{\text{sheet}} \propto T^{-n}$, with $n = 1/4$ or $1/2$ for $T < T_c$; impurity band: at low T variable range hopping or Coulomb gap (for Mn coverage > 0.2 ML) ?
- **Sample 5 (Lower Mn source T, larger spacer)** – very weakly activated conductivity
- **Anomalous Hall Effect to 33 T (NHMFL)**
 - Fit to obtain hole density and dependence of Anomalous Hall coefficient on R_{sheet} : $R_S \propto R_{\text{sheet}}^\alpha$ - $0.25 < \alpha < 0.5$ (activated conductivity sample) and $a = 1.1$ (“metallic” sample)
- **Much more metallic behavior in sample 5**
hole freeze out at high B; similar hole density but **higher T_c** (metallicity)