Analysis of microinhomogeneity of irradiated Si by Hall and magnetoresistance effects

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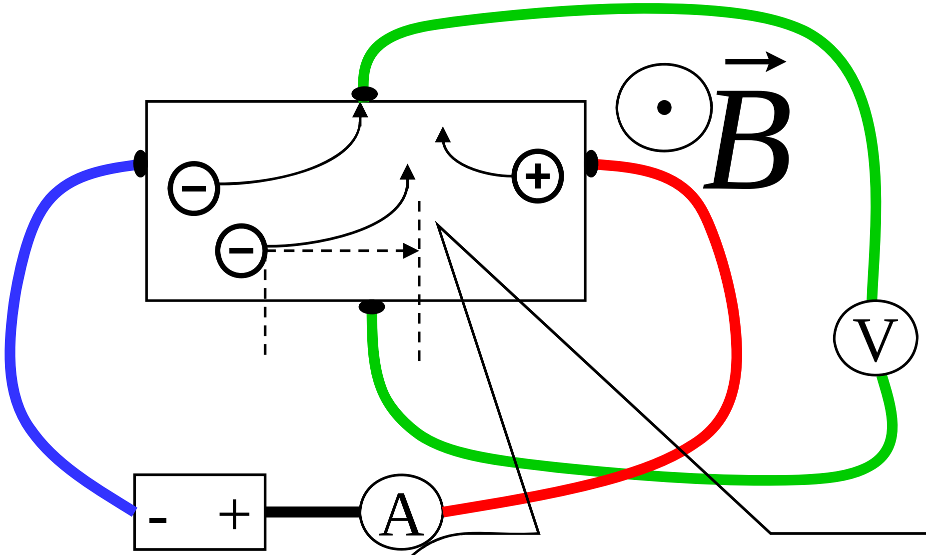
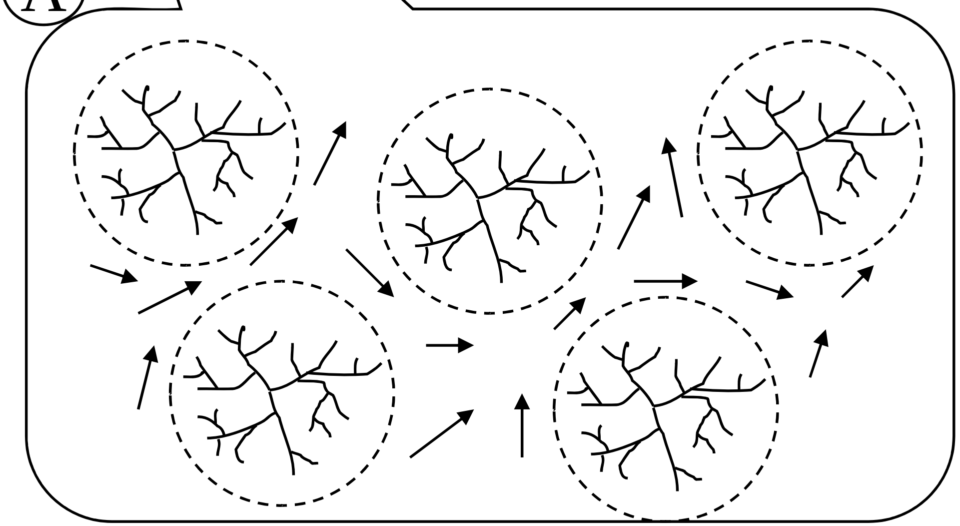
Basic principle



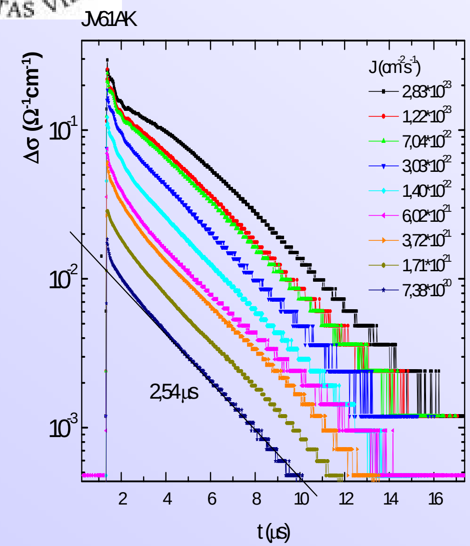
$$\mu_H = f\,\frac{r_H V_H}{B V_X}$$

$$\mu_M = \frac{r_M}{B}\sqrt{\frac{\rho_B - \rho_0}{\rho_0}}$$

Scattering by clusters:



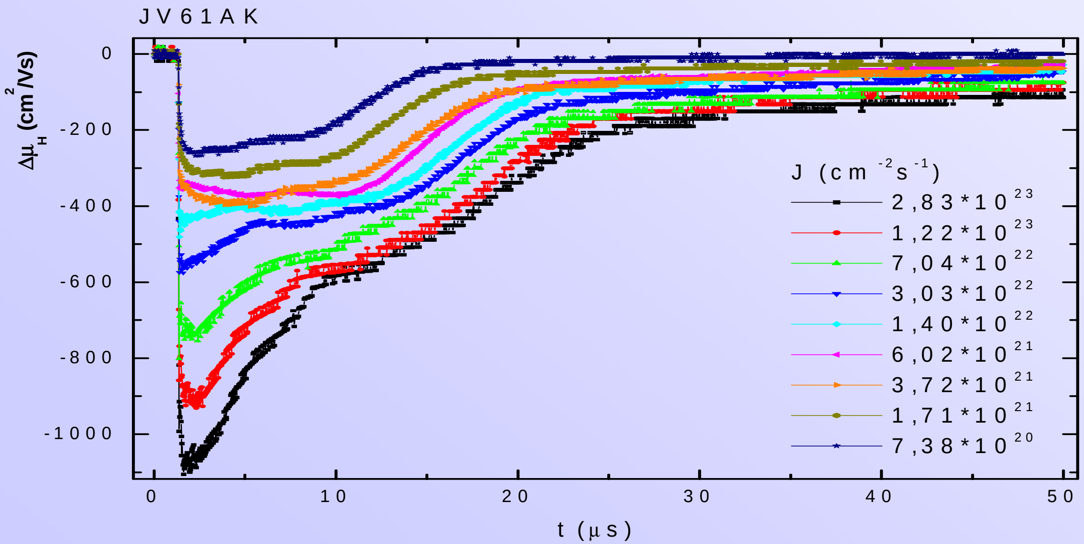
Transient photo-Hall



$$E_H(t) = \frac{\sum_i (-1) e_i n_i(t) A_i \mu_i^2(t)}{\sum_i |e_i| n_i(t) \mu_i(t)} B E_x$$

$$\frac{1}{\mu_H(t)} = \frac{1}{\mu_0} + \beta v S(t) N(t)$$

$$\beta = m^* / e$$

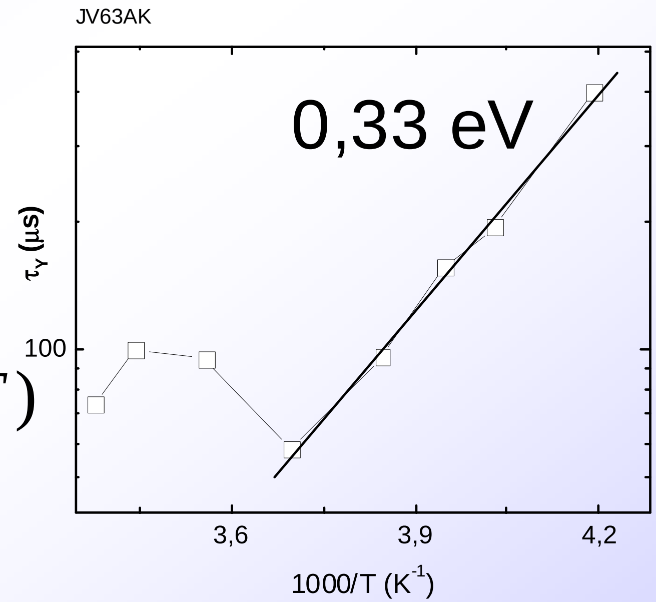


Calculation scheme

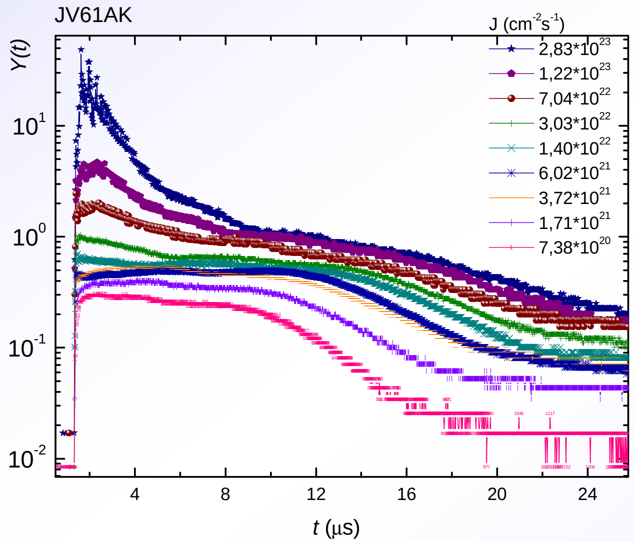
$$\Delta(SN) = S_0 N_0 - SN = \frac{1}{\beta v}\Delta\left(\frac{1}{\mu_0} - \frac{1}{\mu(t)}\right) = \frac{wBE}{\beta v U_{H0}}\left(1 + \frac{U_{H0}}{\pm \Delta U_H}\right)^{-1}$$

$$Y(t) = \left(1 + \frac{U_{H0}}{\Delta U_H}\right)^{-1}$$

$$\Delta[S(t)N(t)] = const \cdot Y(t)$$



$$\tau_Y \sim \exp(-E/kT)$$



$$\frac{Y}{\Delta n} = \mu_{0H} A_s \beta v\left(2Z_0 + \frac{\Delta n}{N_s}\right) = \left(\frac{Y}{\Delta n}\right)_{t\to\infty} - \frac{\sim \Delta n}{N_s}$$

$A_s = 10^{-12}\mathrm{cm}^{-2}$ for ionized scattering center.

Hall factor

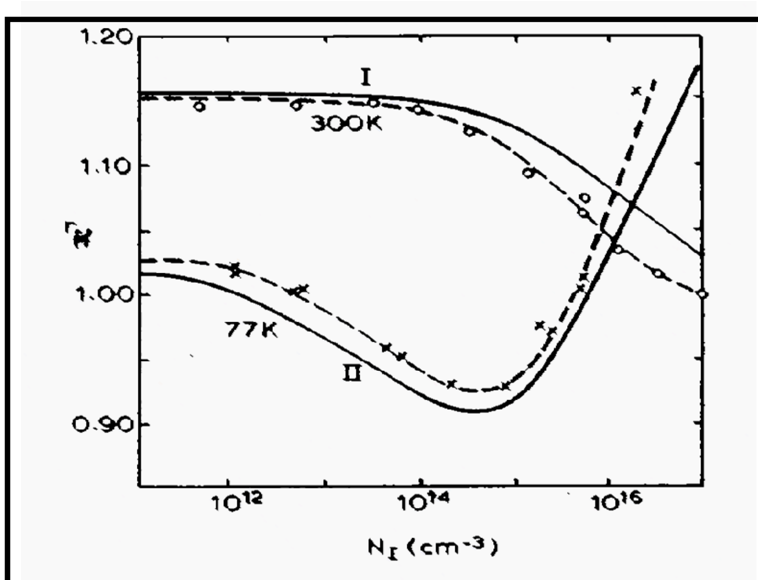
Hall scattering factor r_H is defined by following expressions:

$$r_H = \mu_H / \mu_C = \langle \tau^2 \rangle / \langle \tau \rangle^2$$

The relaxation time for individual scattering process often follows a power law:

$$\tau(E) \propto E^{-s}$$

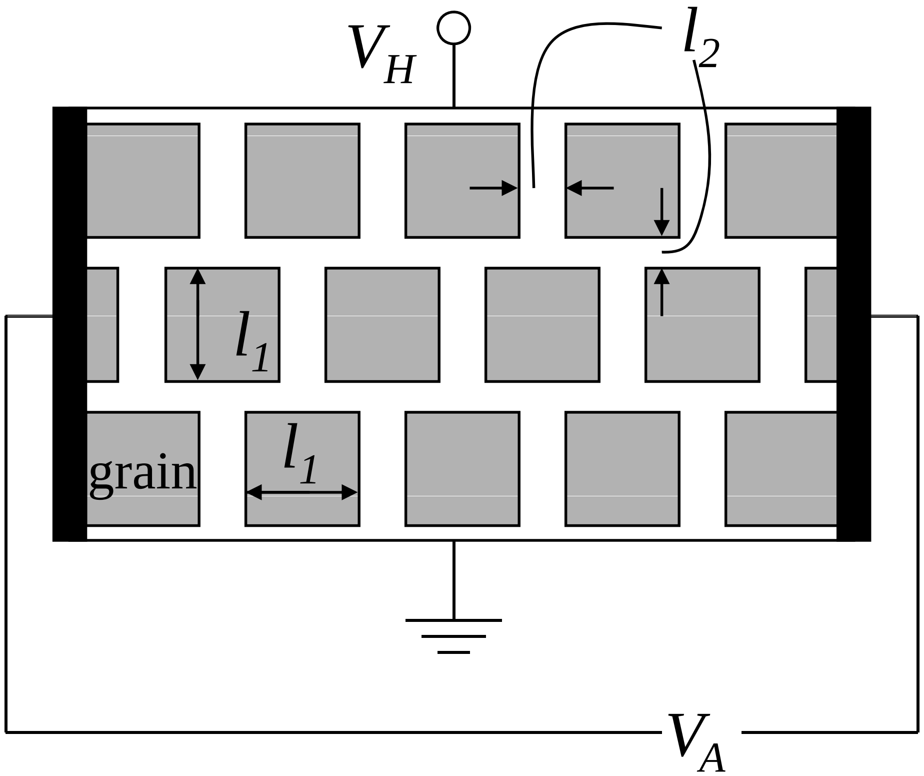
Mechanism	s	r_H	r_{MP}	r_{MG}
Ionized impurities	-3/2	1.93	2.16	5.89
Neutral impurities	0	1	0	1
Acoustic phonons	+1/2	1.18	0.38	1.77
Etc.				



Variation of Hall scattering factor with total impurity density $N_{imp.}$ In *n*-type Si. Experimantal points: -x- 77K, -o- 300K. Solid curves: calculated (from Kirnas et al., 1974)

Inhomogeneities

<u>R. H. Bube</u> model :



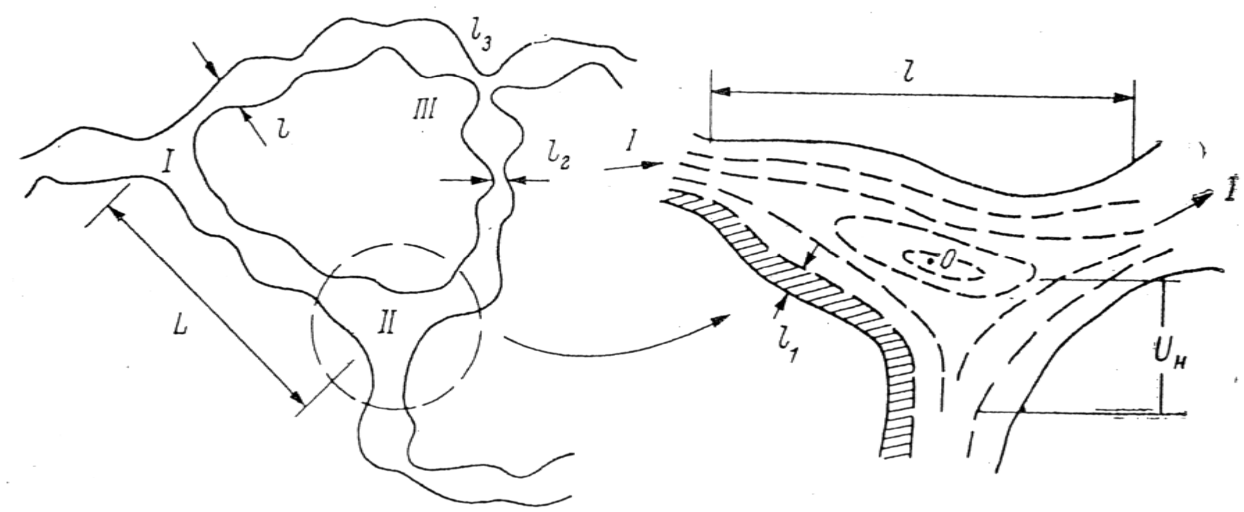
$$\rho_1 < \rho_2$$

$$r_H = 1 + \left(\frac{l_2}{l_1}\right)^2 \frac{\rho_2}{\rho_1}$$

[R. H. Bube, Appl. Phys. Lett. 13, 136 (1968)]

Inhomogeneities

V. G. Karpov, A. J. Shik and B. I. Schklovskij (1982):



The cells of typical clusters: I, II and III. Dashed lines indicates the equipotential lines

$$\mu_H = \mu_0 \exp\left(-\frac{\varphi_b}{kT}\right)$$

Inhomogeneities

J. D. Albrecht et al. (1999):

When the mobility is limited solely by dislocation scattering and this process can be modeled by scattering form a line charge, r_H can be estimated by computing the average momentum relaxation time. It follows from the analytic expression:

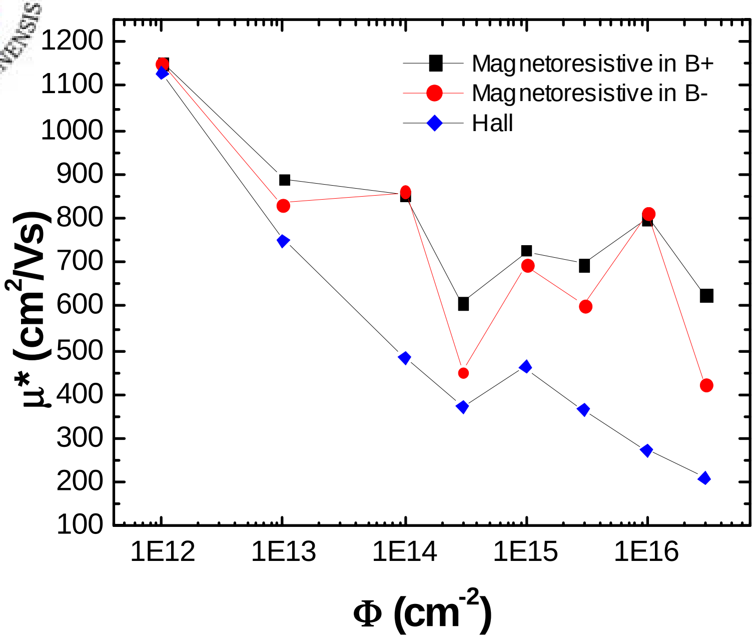
$$r_H = \frac{\pi}{8}\gamma \exp(-1/\gamma)[K_2(1/(2\gamma))]^{-2}[8 + 60\gamma + 210\gamma^2 + 315\gamma^3]$$

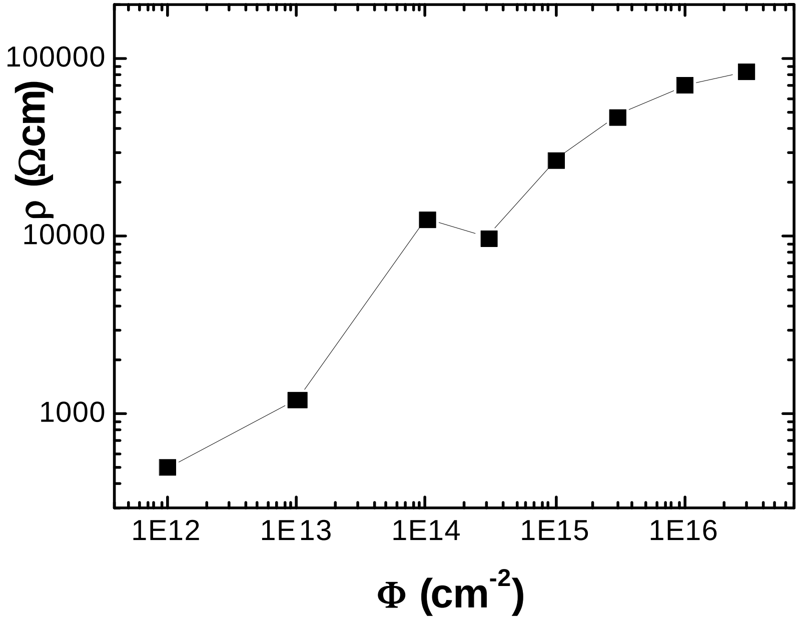
$$\gamma = \frac{8m^*\lambda^2 k_B}{\hbar^2}$$

K_2 is the second order modified Bessel function and λ is the Debye screening length

Specifically, r_H is smaller than but close to 1.93

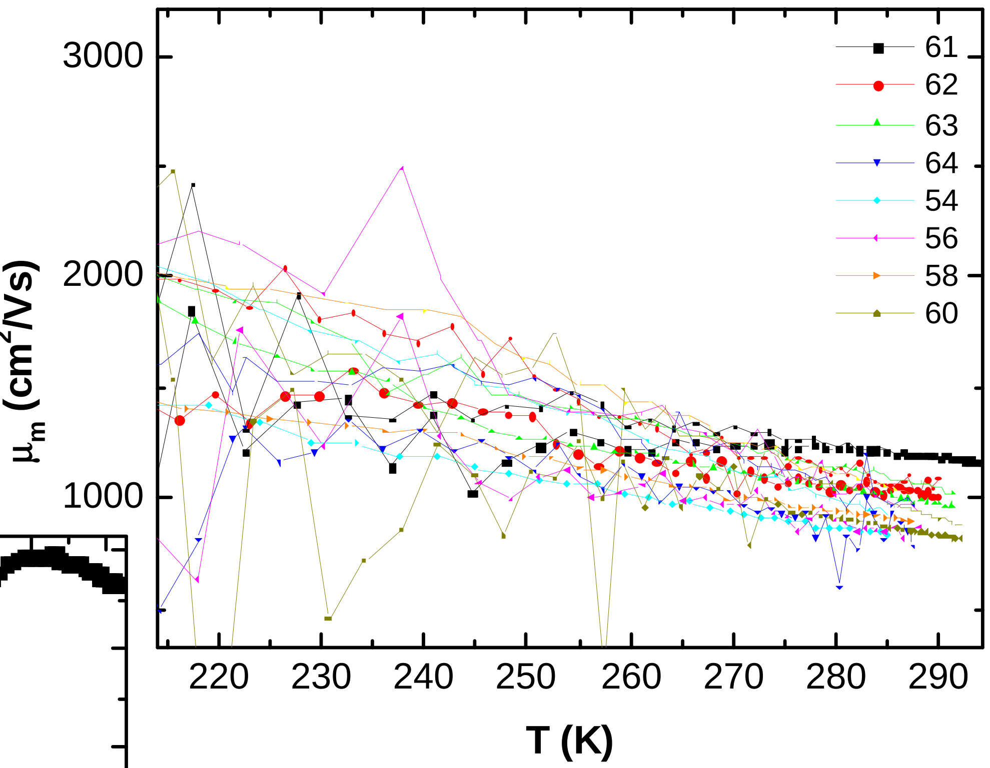
In summary, it is clear that to assume r_H =1 in analyzing low-field Hall data often leads to errors of 30% (and occasionally as much as 100%) in carrier density and mobility

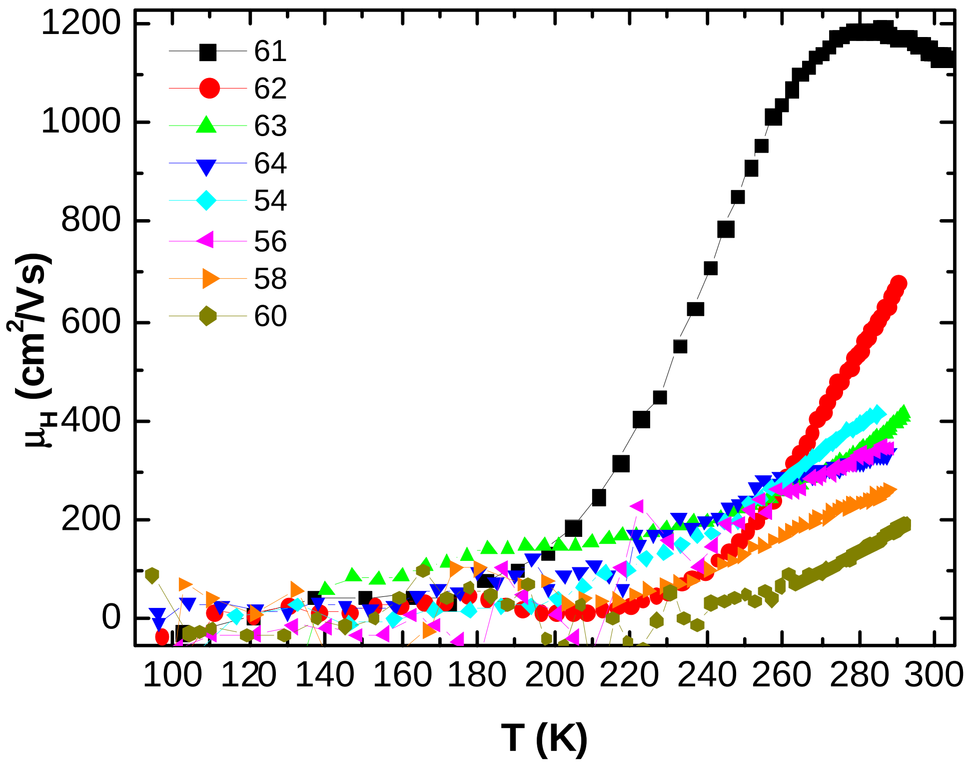




Sample No.	Dose (cm^{-2})	Hall mobility (cm^2/Vs)	Mobility from magnetoresistivity (cm^2/Vs) at different B direction		Conductivity (μS/cm)	Resistivity (kΩcm)
			"B+"	"B-"		
61	1E12	1128	1152	1150	2000	0.500
62	1E13	748	891	832	833	1,201
63	1E14	483	850	860	79,2	12,62
64	3E14	374	608	451	102	9,771
54	1E15	461	727	693	37,2	26,90
56	3E15	366	695	602	20,9	47,92
58	1E16	275	800	810	14,0	71,28
60	3E16	209	627	421	11,8	84,58

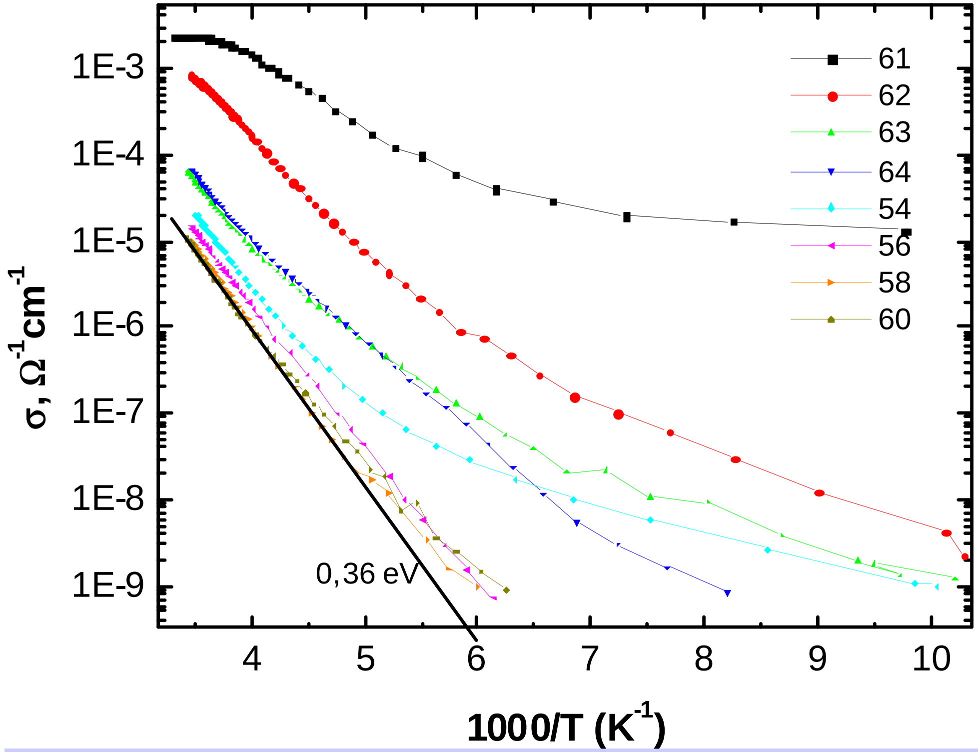
This is not bipolarity, clusters barriers block the Hall voltage.

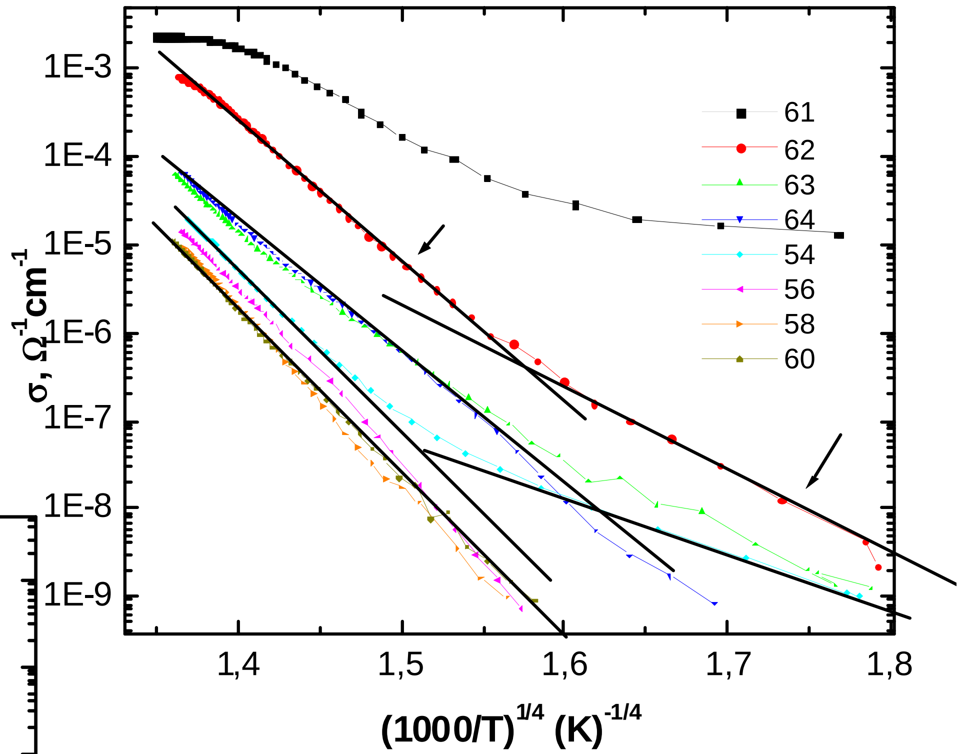




Magnetoresistivity does not see the ionized scattering centers –regions where the the current flows are scatters different way.

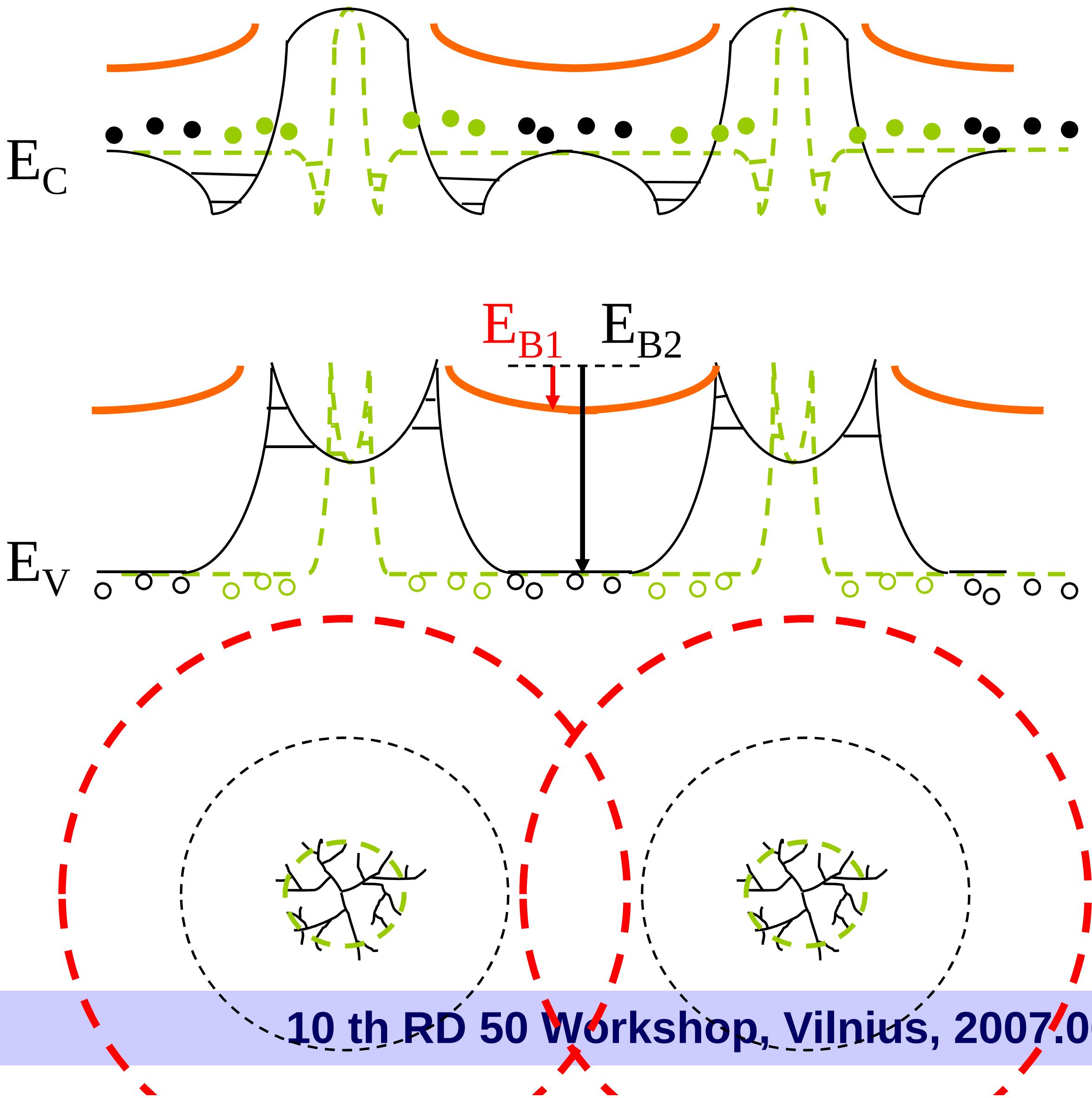
~0,36 eV activation found at the highest irradiation doze. The activation developed from lower value – that is not doping level, that is barrier.





Mr. Mott was here…
At higher dozes, amorphous zones appeared.

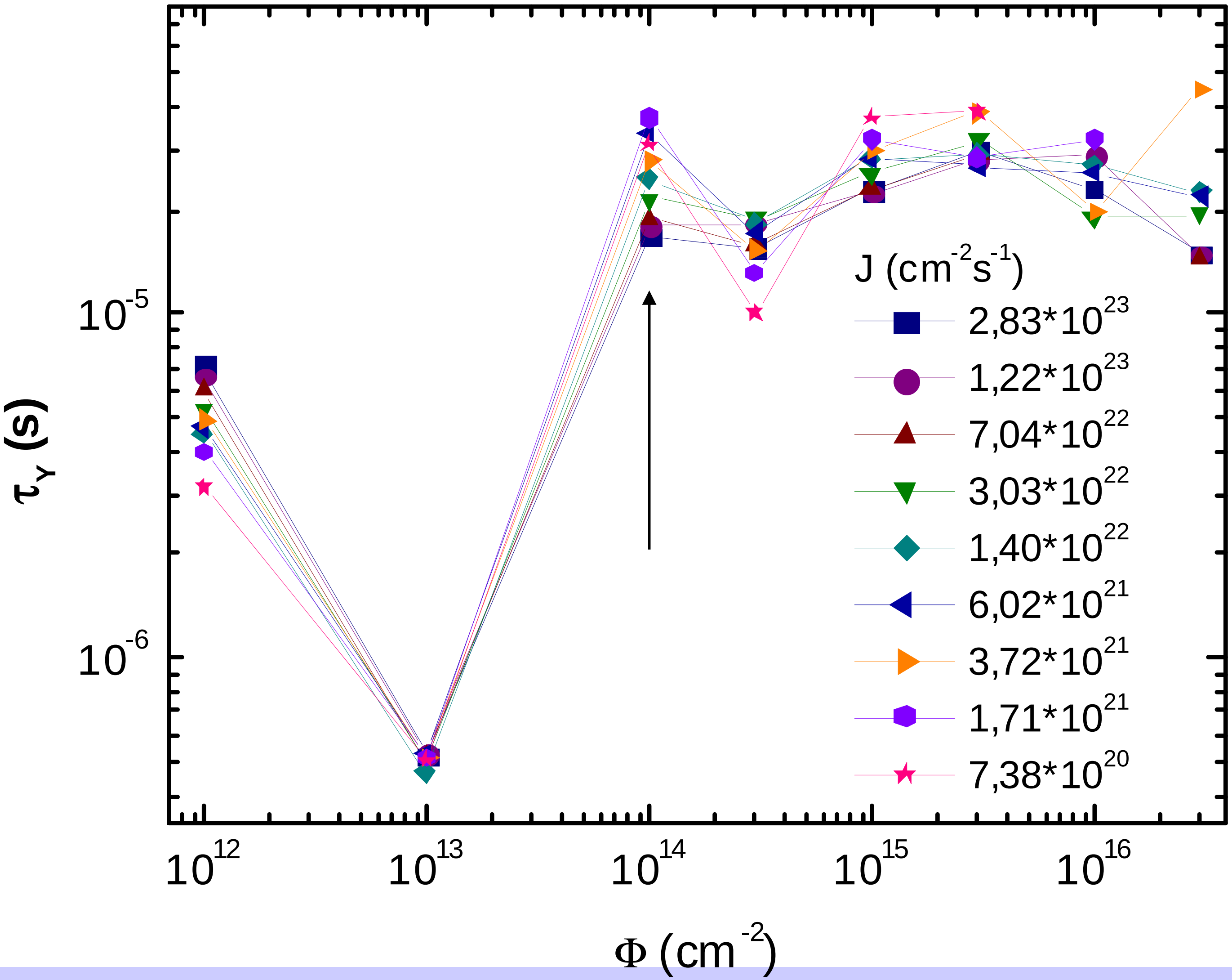
Screening



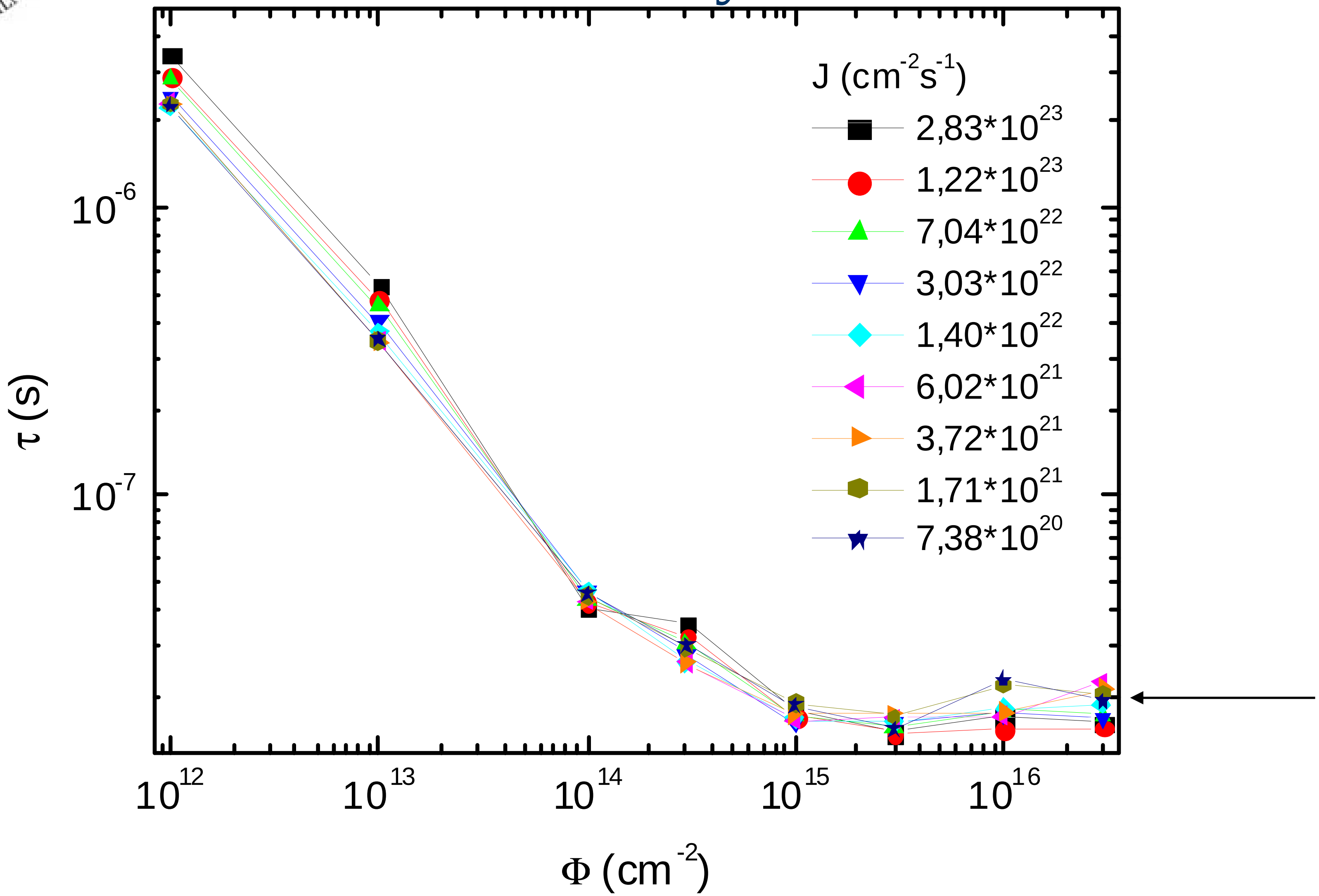
$$r_{Debye} = \sqrt{\frac{\varepsilon\varepsilon_0 kT}{4\pi e^2 n'}}$$

Cluster's potential overlaps when *n'* decreases to 10^{11} cm^{-3} at irradiation doses above 10^{14} cm^{-2}

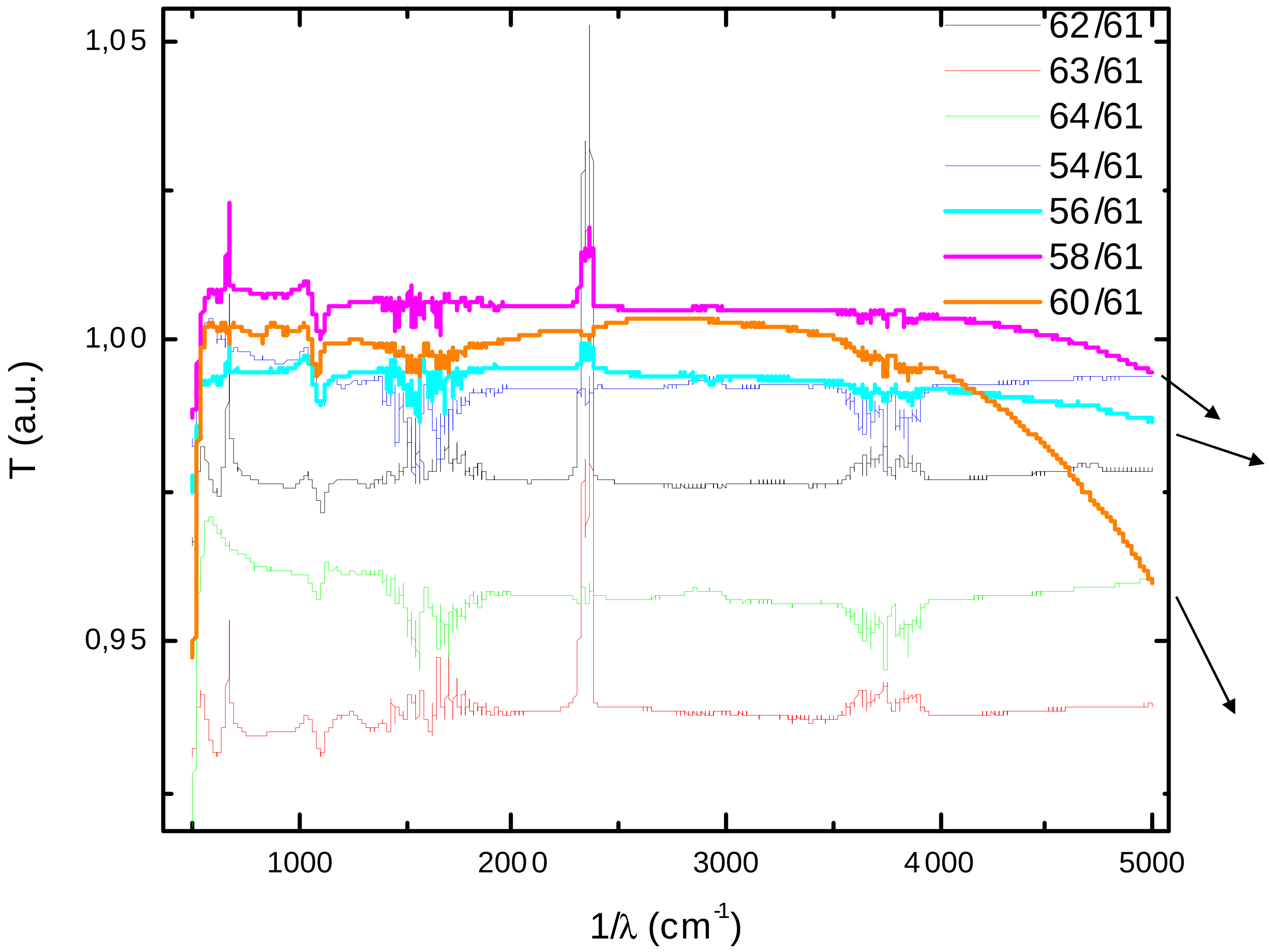
The photo-carriers are trapped between barriers that they screen! EFFECTIVE darkness concentration seems low.



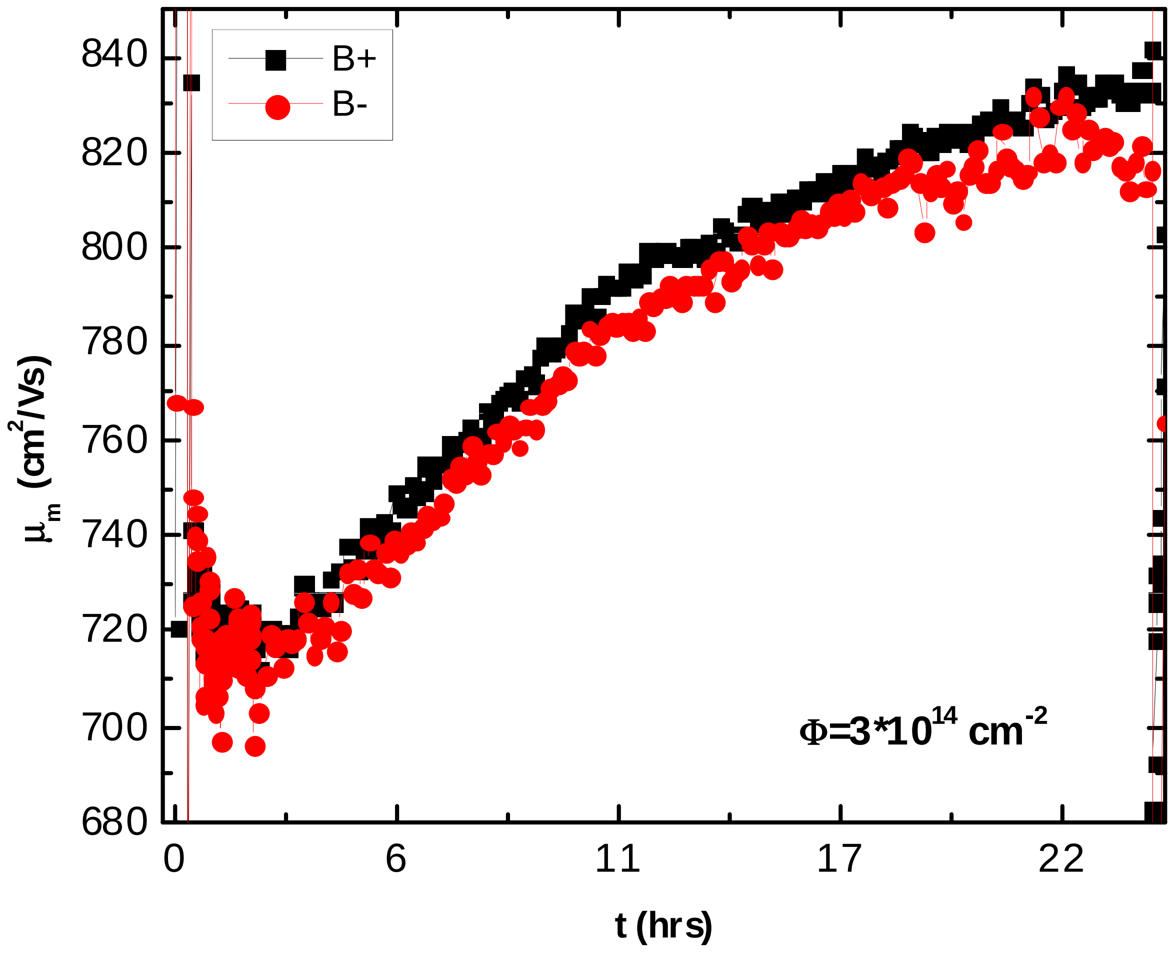
Photoconductivity relaxation

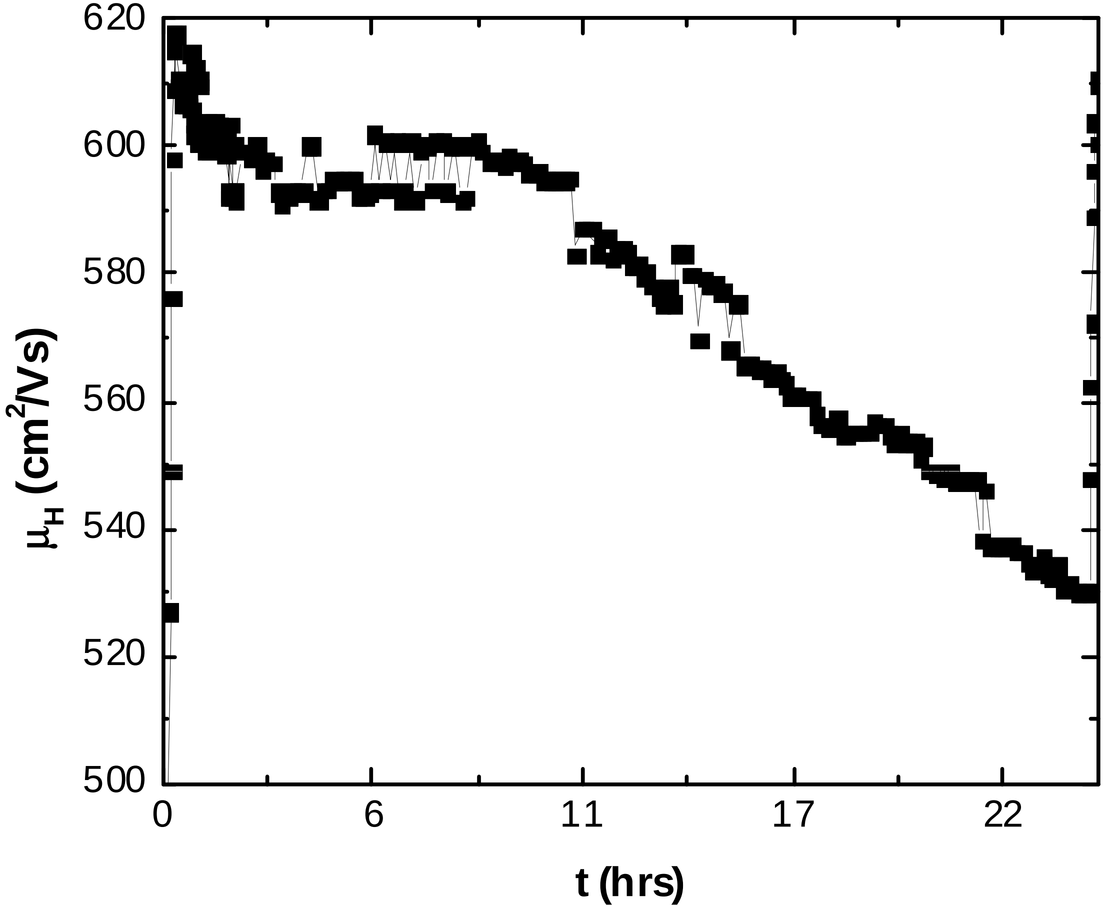


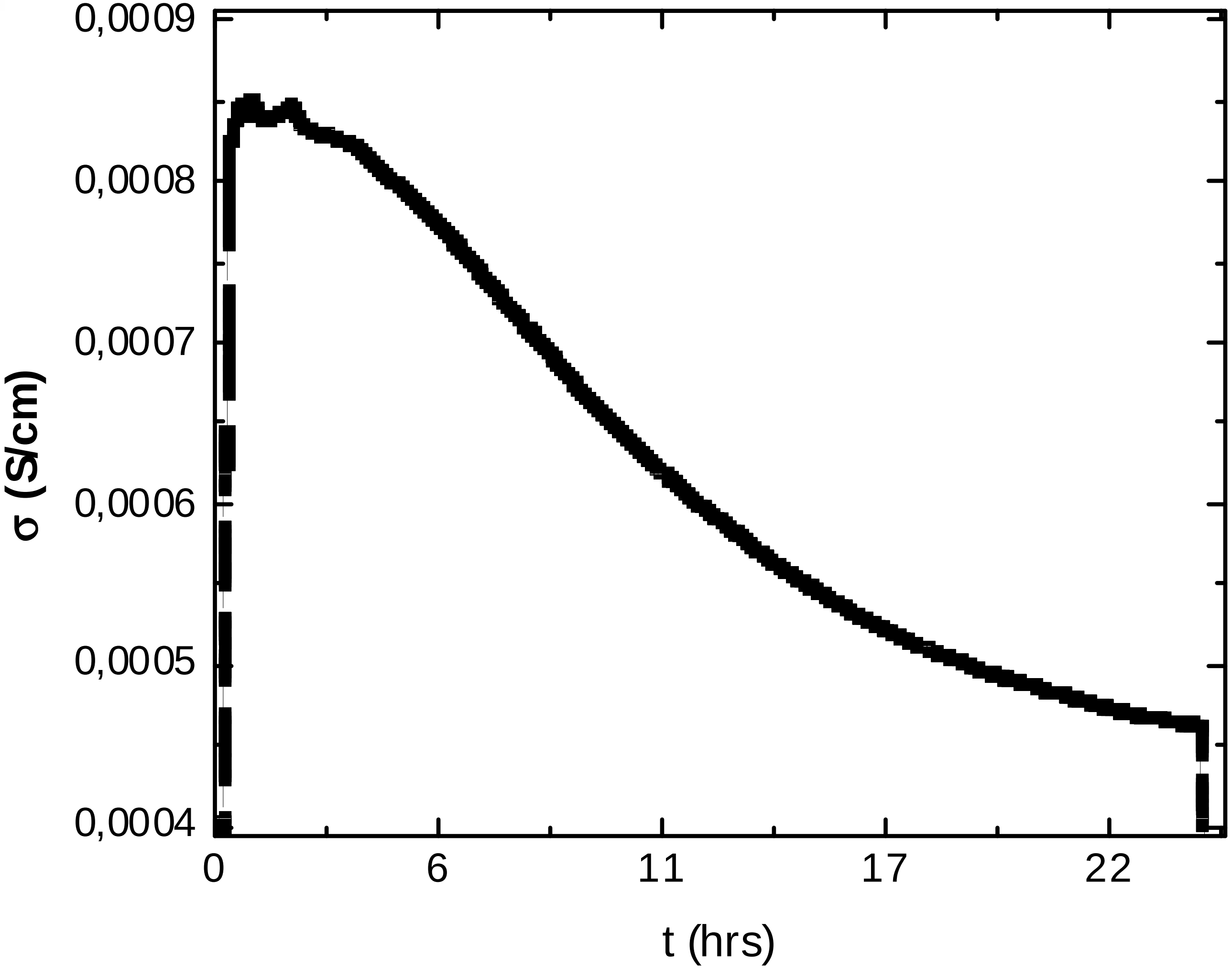
FTIR

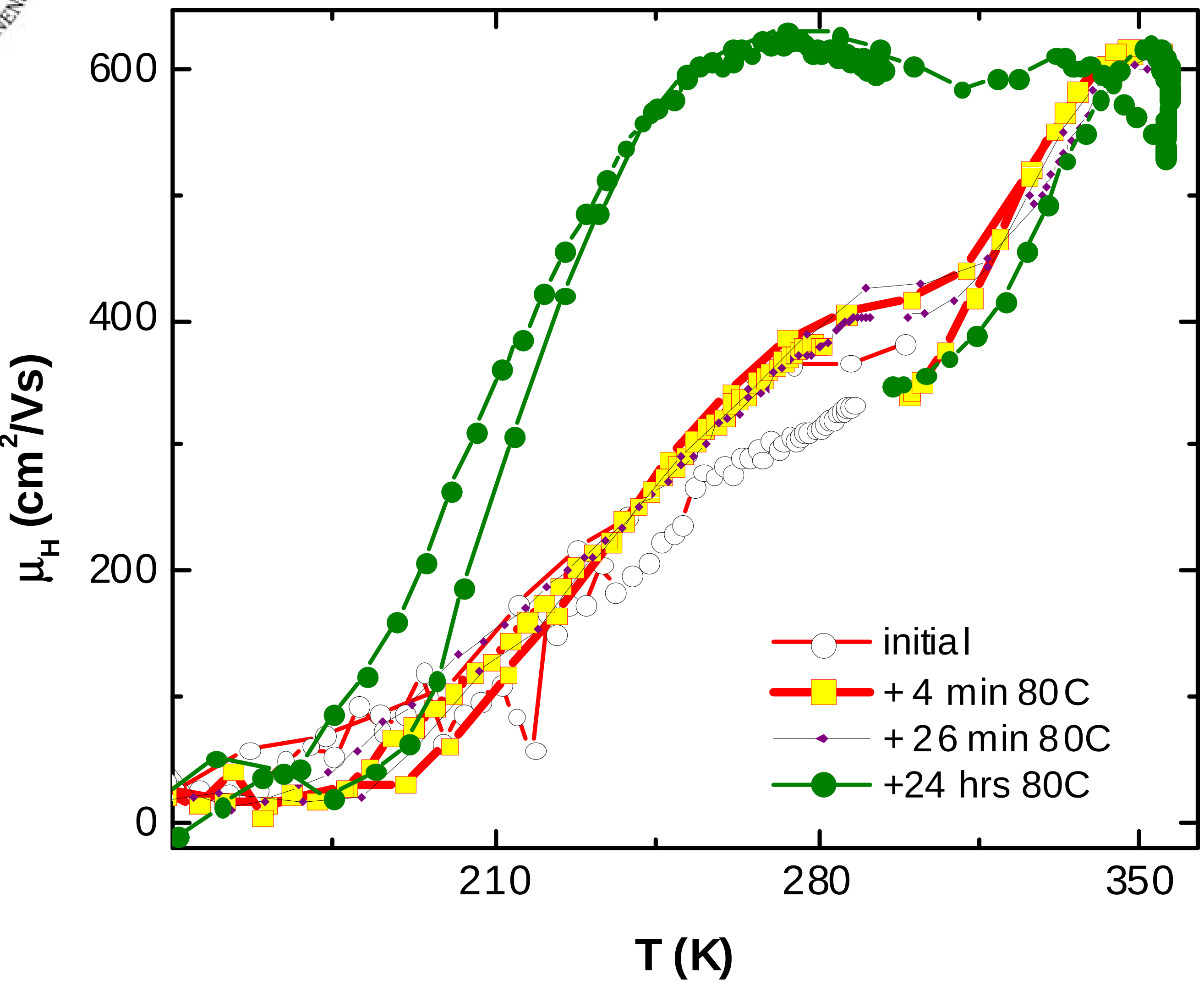

62/61
63/61
64/61
54/61
56/61
58/61
60/61
1,05
1,00
0,95
T (a.u.)
1000
2000
3000
4000
5000
1/λ (cm-1)

Annealing 80C



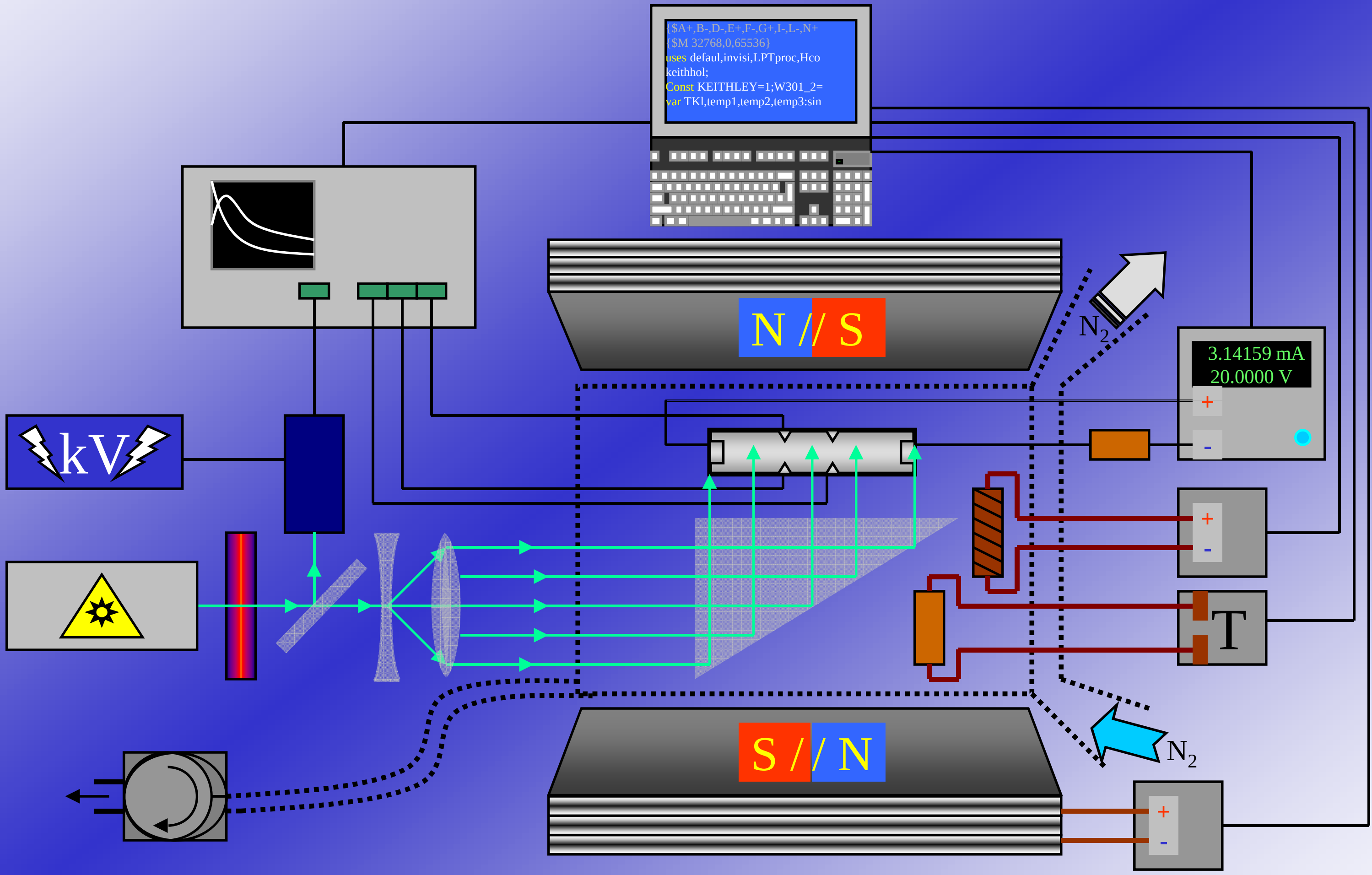

620
600
580
560
540
520
500
μH (cm2/Vs)
0
6
11
17
22
t (hrs)

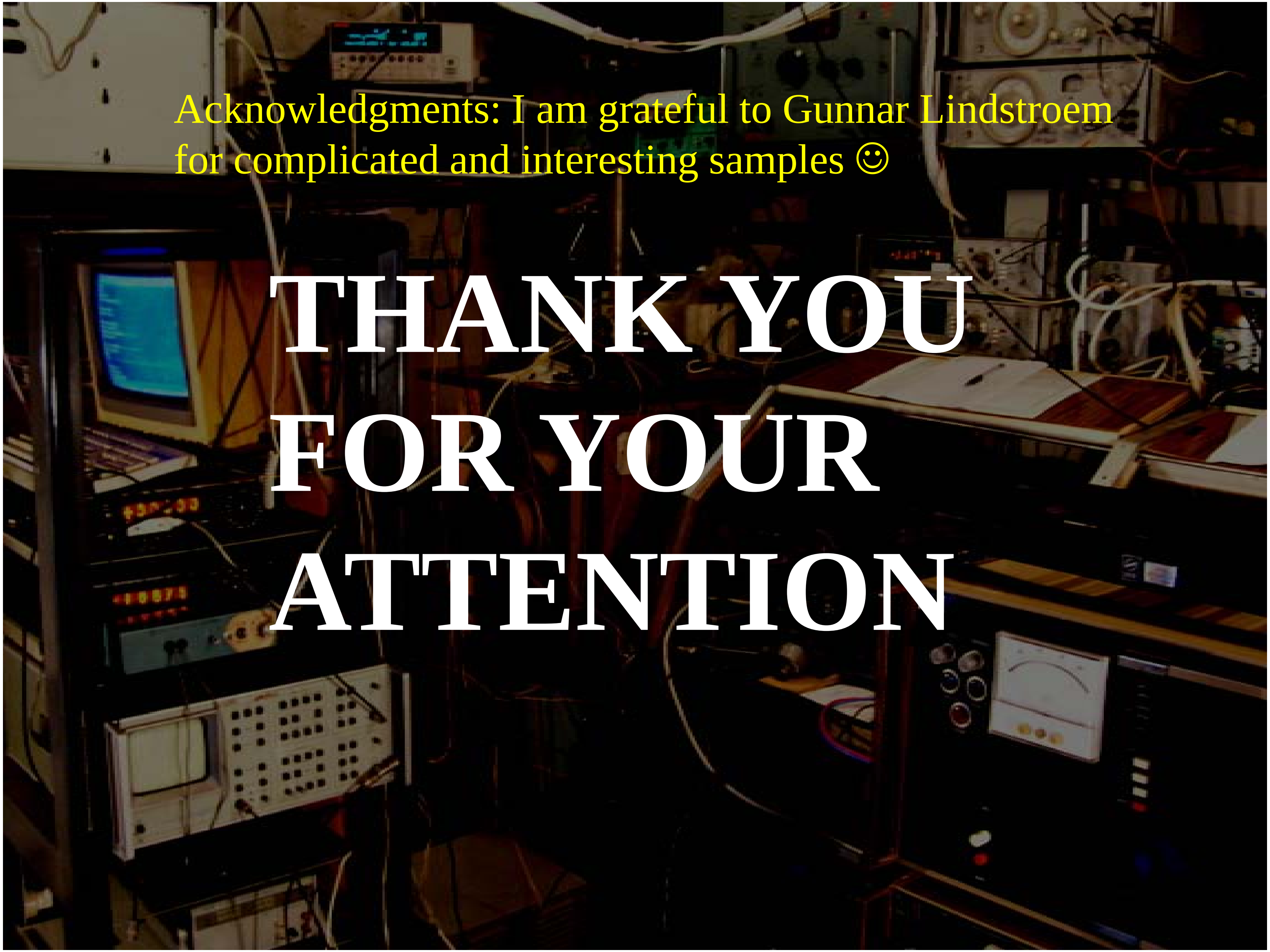

0,0009
0,0008
0,0007
0,0006
0,0005
0,0004
σ (S/cm)
0
6
11
17
22
t (hrs)



600
400
200
0
210
280
350
μ_H (cm^2/Vs)
T (K)
initial
+ 4 min 80C
+ 26 min 80C
+24 hrs 80C

Time resolved photo-Hall





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THANK YOU FOR YOUR ATTENTION