# The free carrier transport properties in proton and neutron irradiated Si(Ge)

(and comparison with Si)

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**The important questions:**

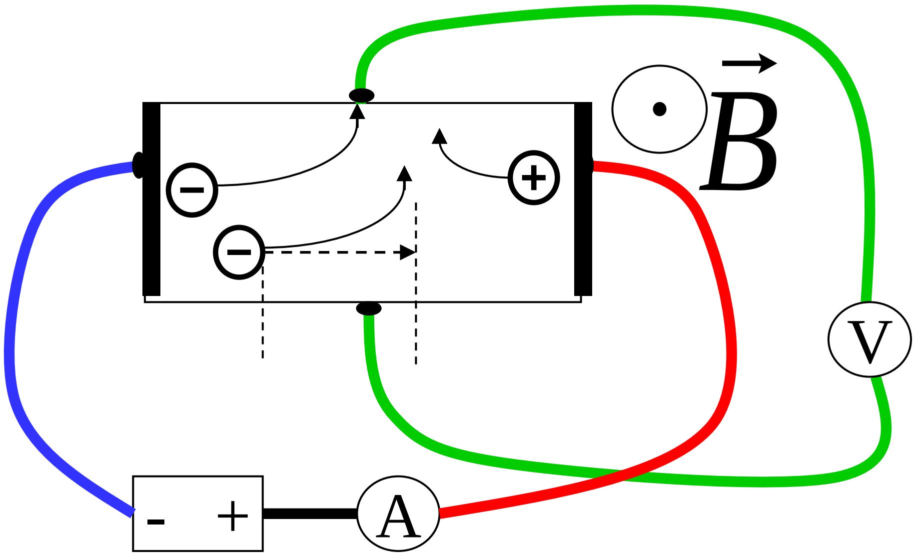
1) Are the changes in the semiconductor homogeneity caused **by the irradiation?**

2) What kind of inhomogeneities are induced by crystal growth (different doping) and treatments?

**The answers** can be find by investigation of the transport properties of free carriers.

# Basic principle

Hall and magnetoresistance effects are “simple classical effects” demonstrating the transport properties of free carrier.

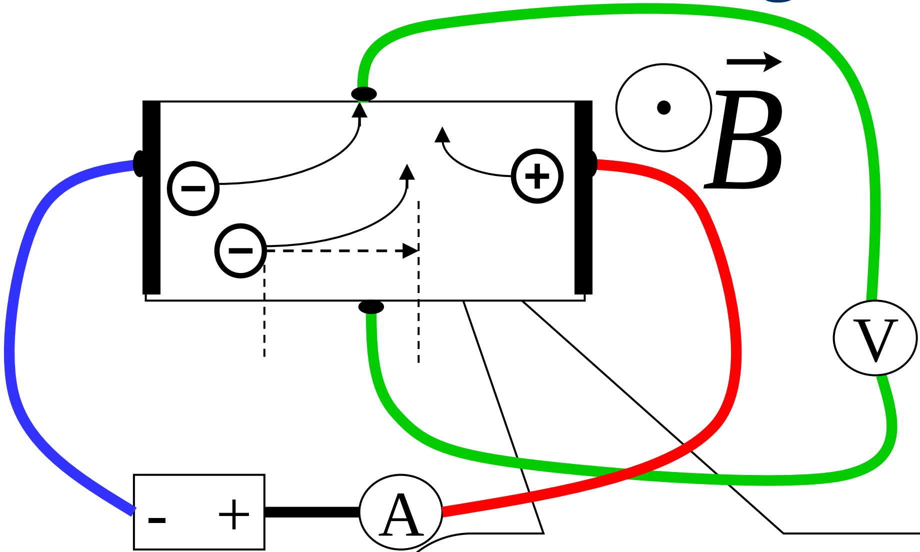



$$\mu_H = \frac{r_H V_H}{B V_X}$$

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

$f$ =1 in a thin sample

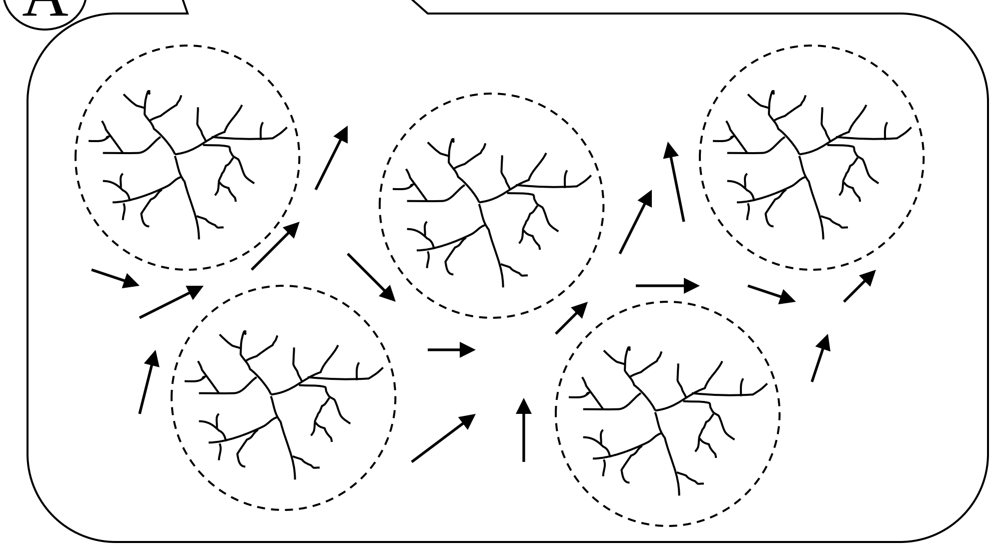
# Complications of the Basic principle in the nonhonogeneous sample




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

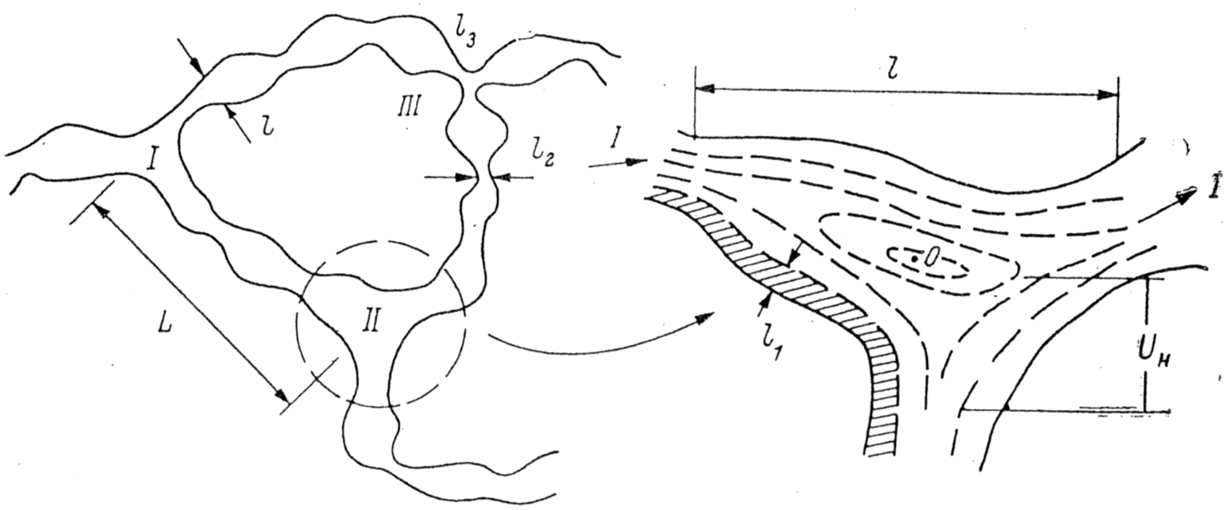
$$\mu_M = \bar{f}\,\frac{r_M}{B}\sqrt{\frac{\rho_B - \rho_0}{\rho_0}}$$

Scattering by large defects:



# Inhomogeneities

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




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

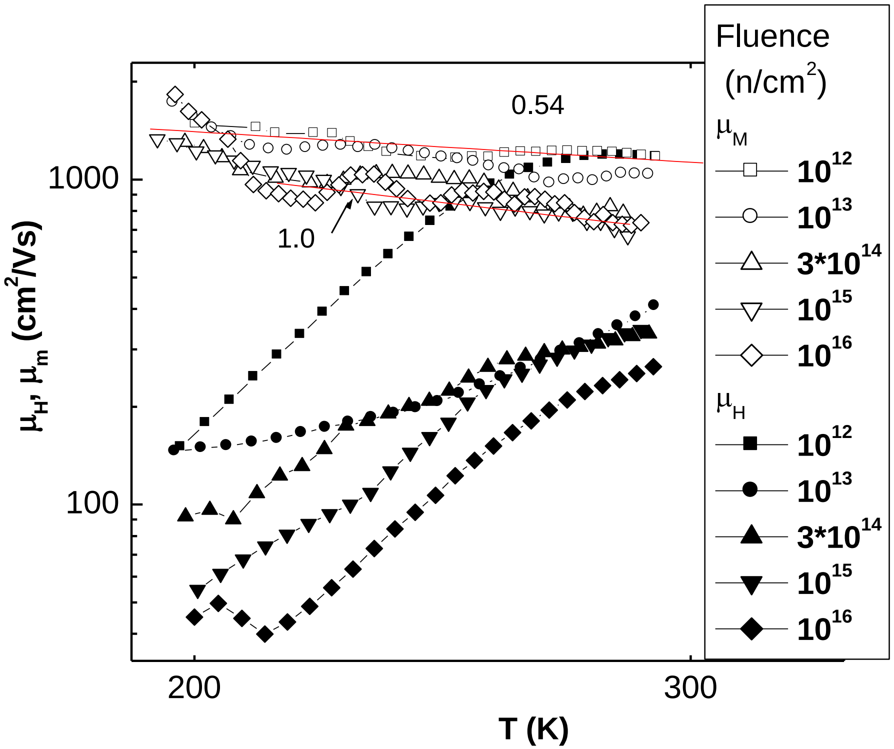
The cells of typical clusters: I, II and III. Dashed lines indicates the equipotential lines

**Also, a bit different analyse:**

**W. Siegel, S. Schulte, C. Reichel, G. Kuhnel, J. Monecke. „Anomalous temperature dependence of the Hall mobility in undoped bulk GaAs“. J. Appl. Phys., Vol. 82, No. 8, pp.3832-3835 (1997)**

# Single crystals Si (WODEAN1 series)

Irradiation by neutrons



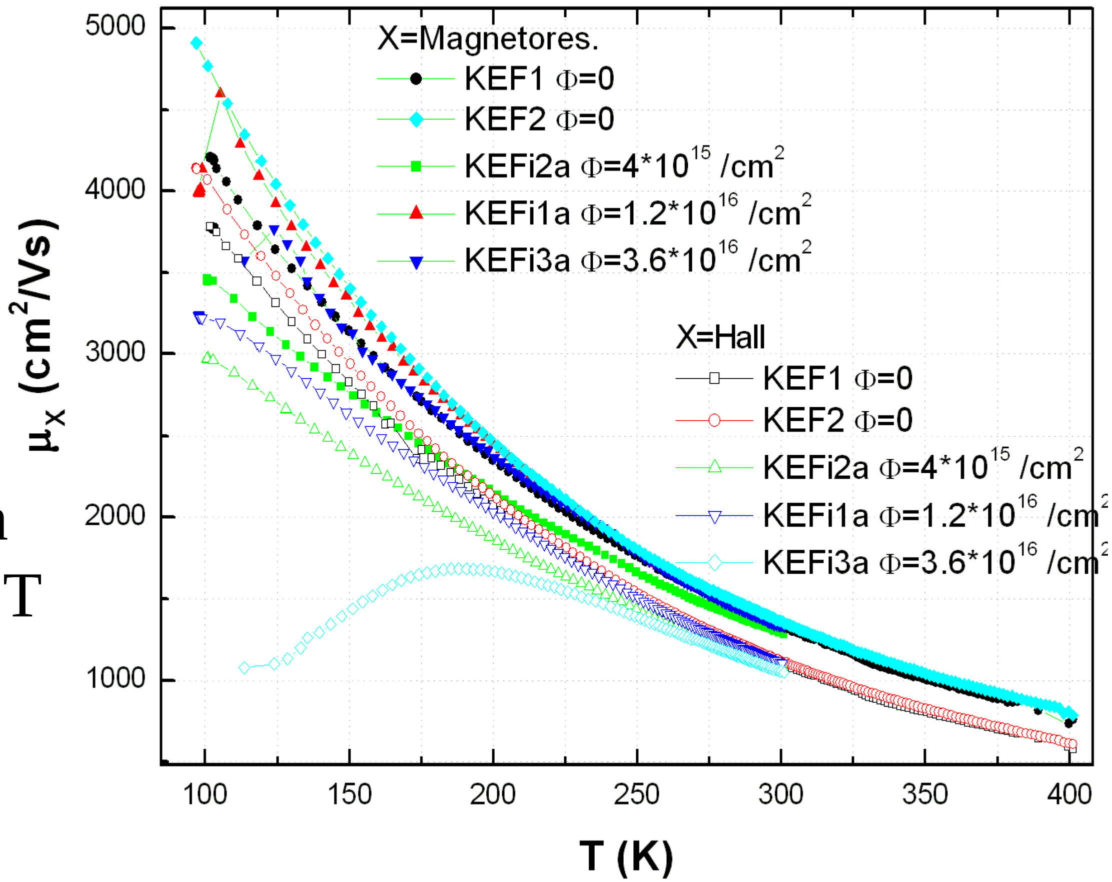

- The weak dependence on T was observed in low irradiated samples
- The Hall and magnetoresistance mobility behavior was different.
- Anomalous Hall mobility dependence on T was observed

# A new series: Minsk-KEF

Irradiation by electrons (6MeV) to create only the point defects

Magnetoresistivity mobility values are typical for good n-type Si.

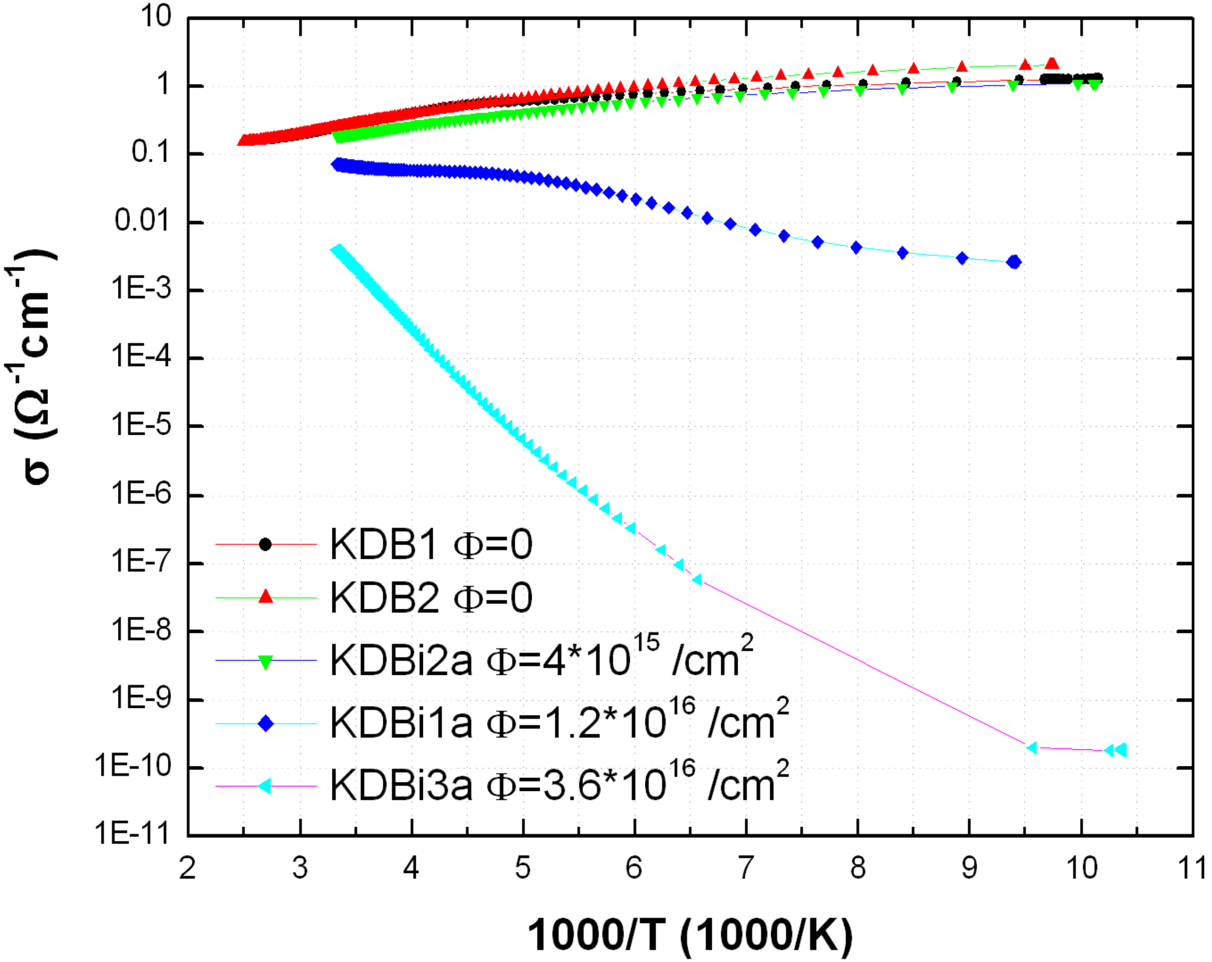
At higher doses of irradiation the Hall signal lowers at low T similarly to the case of clusters. Large scale electric potential disturbance occurs.




**J.Vaitkus, L.Makarenko et all. RD50, CERN, 2012**

# KDB conductivity (irradiated 4 MeV electrons)

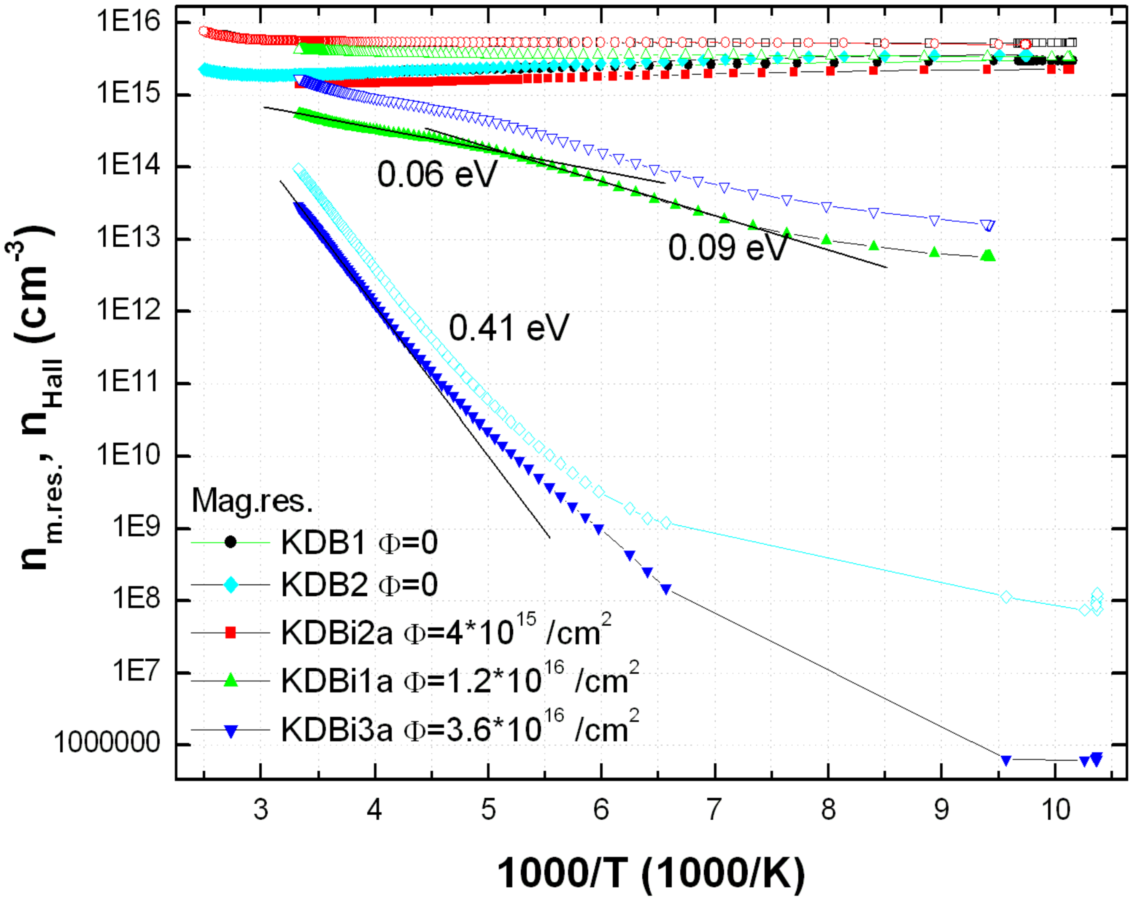
The conductivity in the initial samples decreases with T. This is the case when the carrier density changes less than the mobility.




At the higher irradiation doses the conductivity decreases. The greater sample volume is damaged.

# KDB density

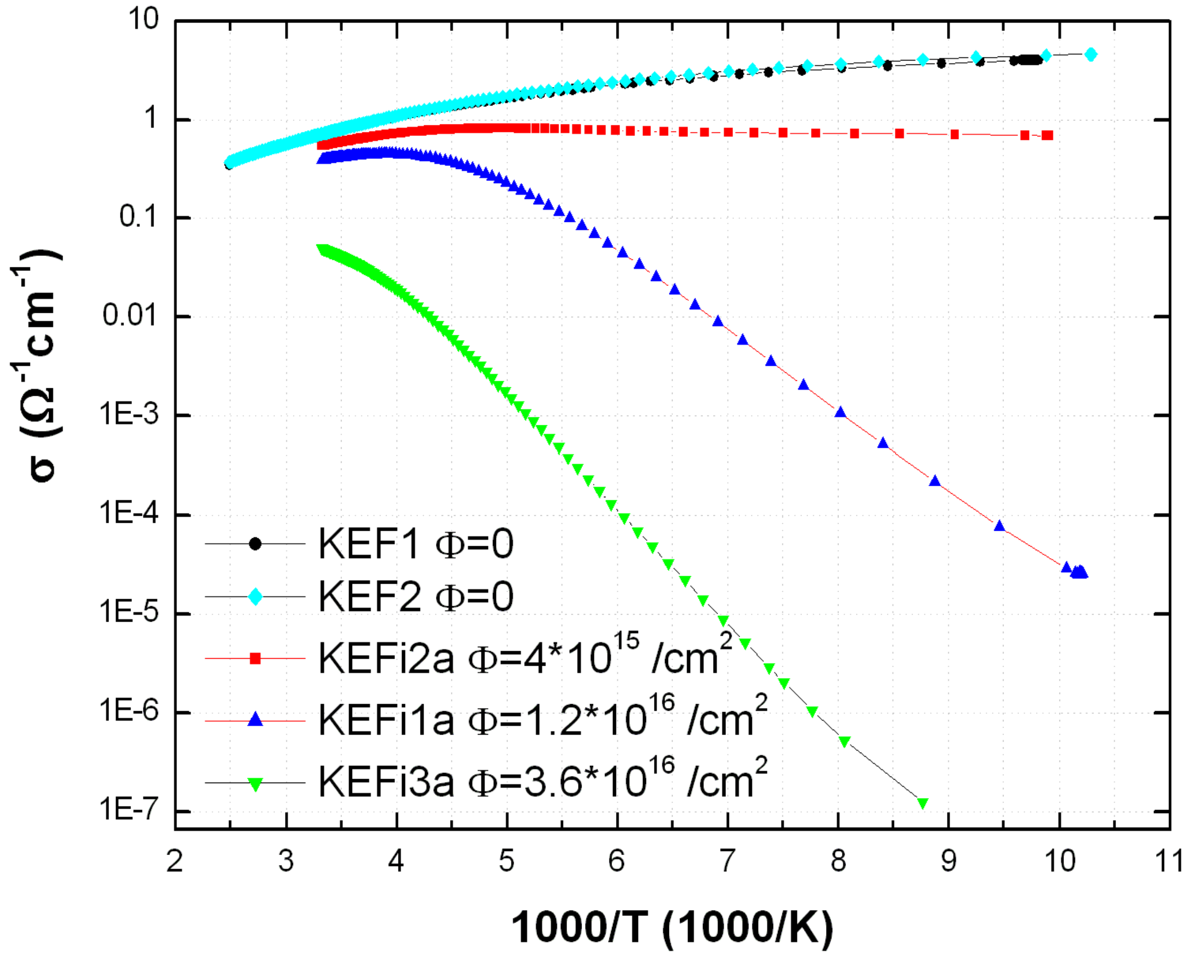
Thermal activation from the density show some clear values.



# KEF conductivity

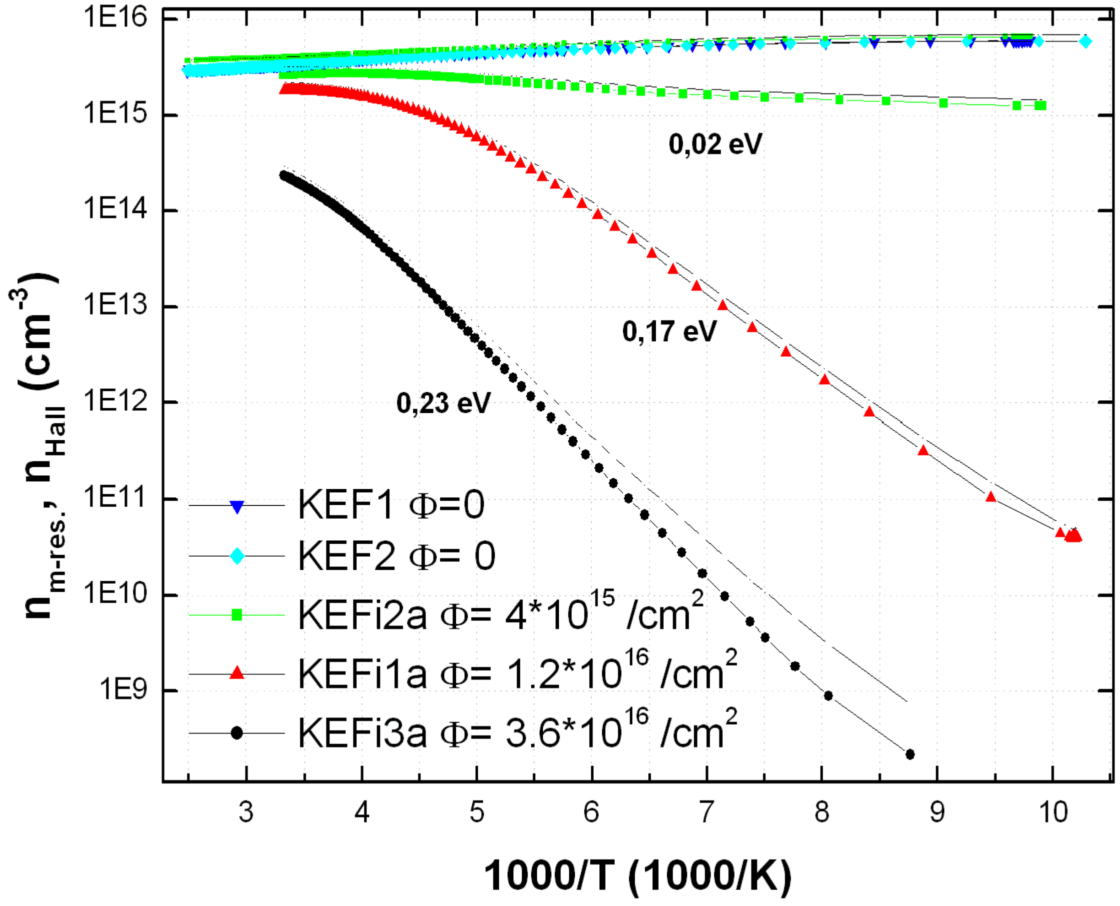
Similar situation as in KDB samples.

But the conductivity decreases less for the greater doses while it decreases more for lower doses.



# KEF density

Thermal activation from the density show some clear values.



# Si(Ge)

Cz SiGe crystals were grown in Leibniz Institute for Crystal Growth, Berlin, Germany by N.V. Abrosimov

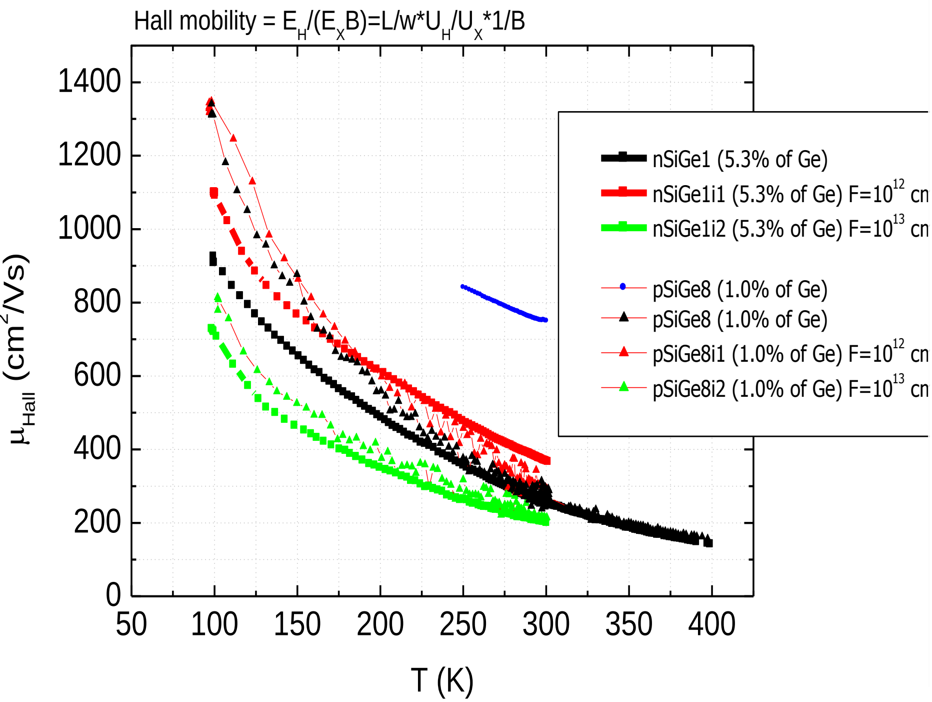
Due to deformation of the lattice the increase of radiation hardness is waited.

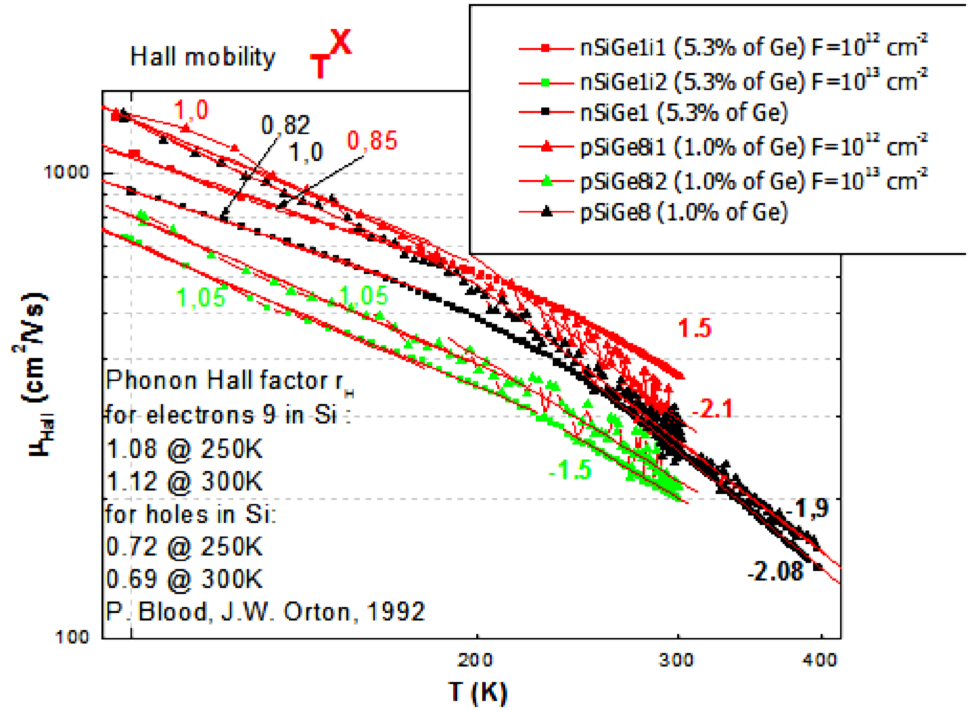
It exists experience to destroy the dislocation net in GaAs by adding isovalent impurity In.

What is happening in transport properties?

The start of the analyze cycle.

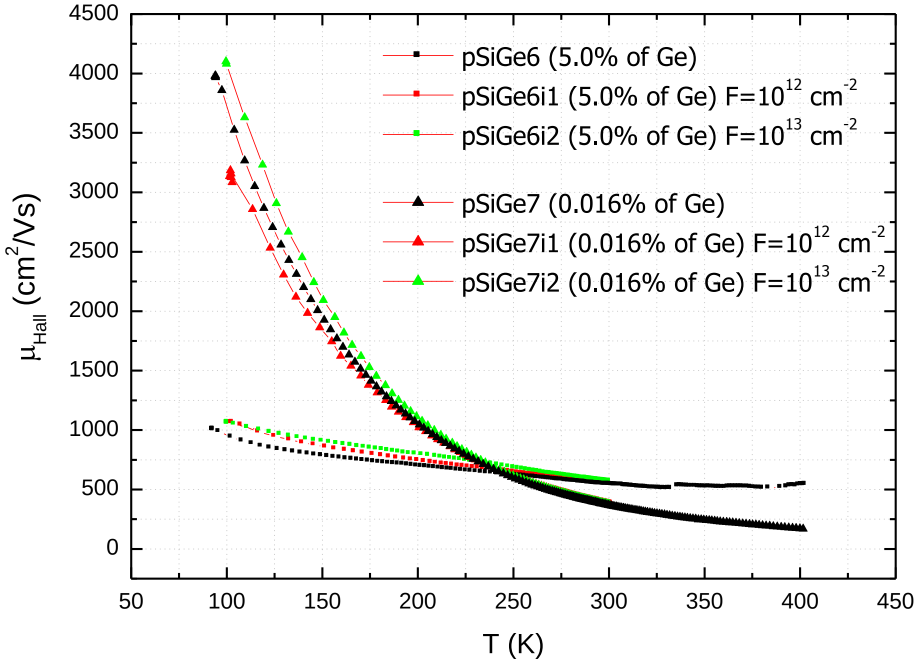
# Hall mobility in Si(Ge) (neutron irradiation)

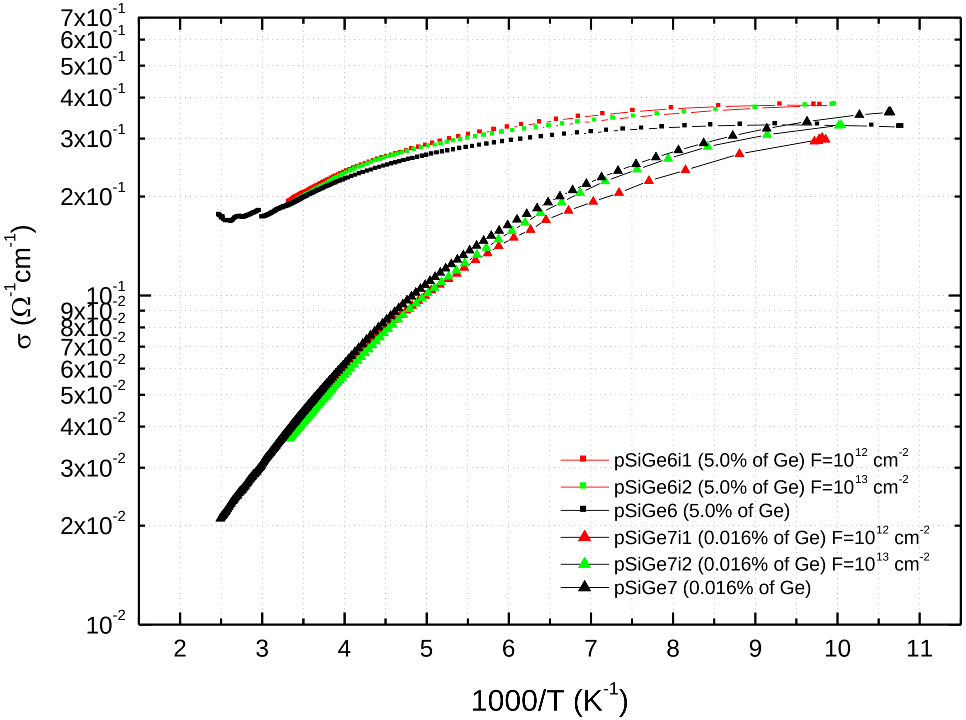



Adding of Ge enhances the hole mobility.
Irradiation 1e12 $cm^{-2}$ increases the Hall mobility but the 1e13 $cm^{-2}$ decreases the Hall mobility in both n-type and p-type (at 200-300$^0$ C)

# Proton irradiated Si(Ge)

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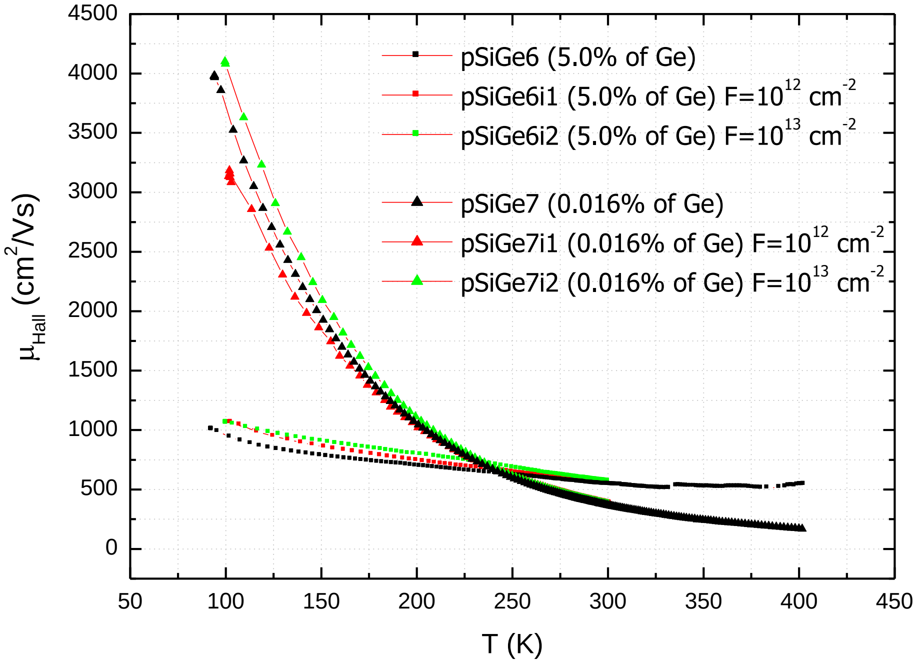
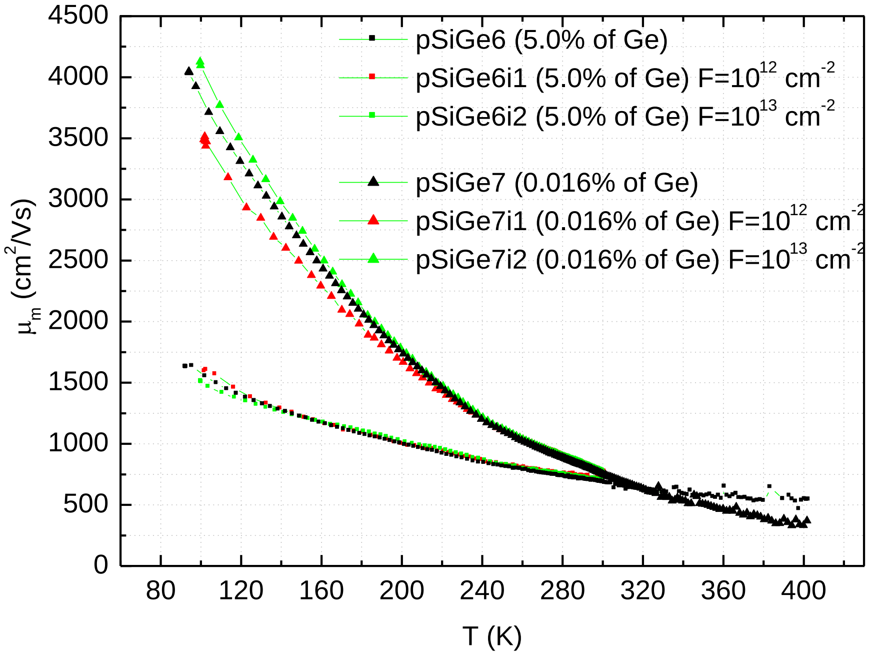
# Proton irradiated Si(Ge)

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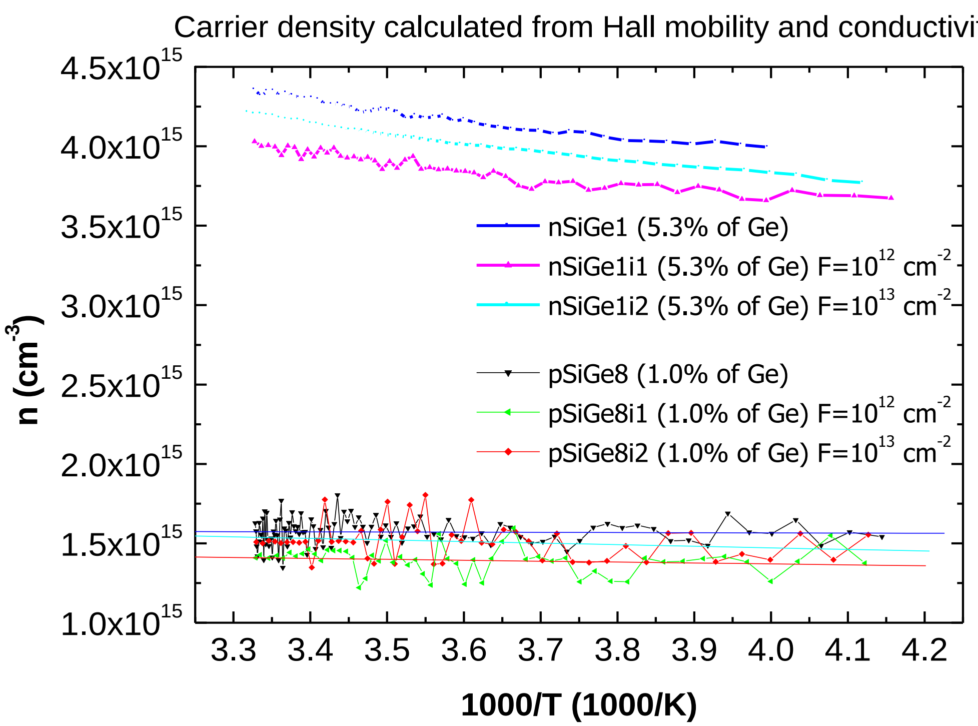
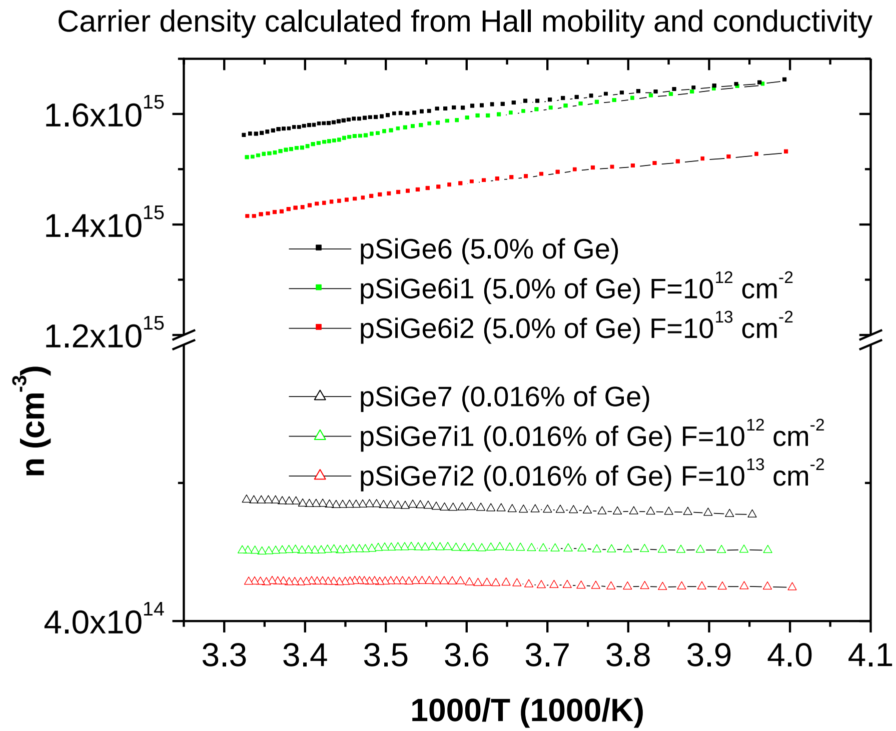
# Si(Ge)

## Neutron irradiation

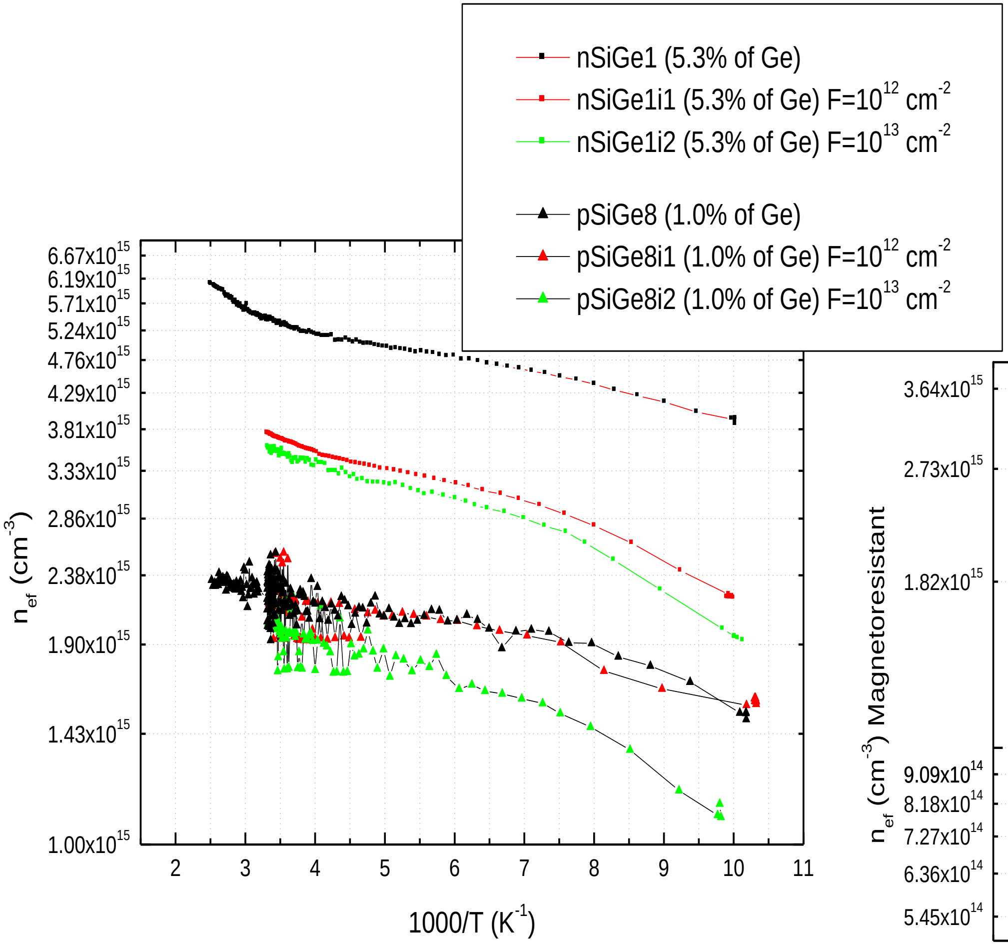



## Proton irradiation

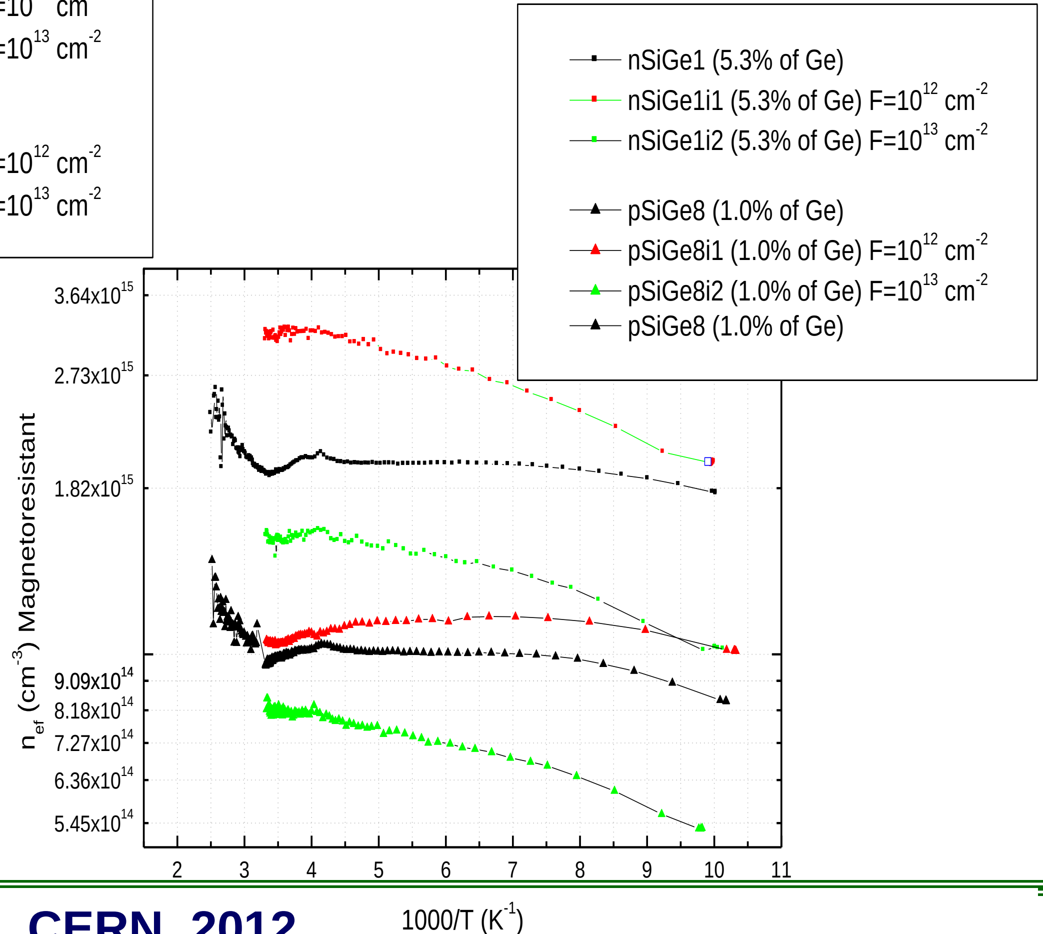


# Neutrons, Si(Ge)

## Hall




## Magnetoresistance

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# Conclusions:

- The main peculiarities of transport phenomena are induced by cluster defects.
- Hall effect and magnetoresistance measurement allow to reveal these inhomogeneities
- The initial studies of low irradiated Si(Ge) were performed.
- The irradiation to the higher fluence is the next step.


THANK YOU
FOR YOUR
ATTENTION

# Hall factor

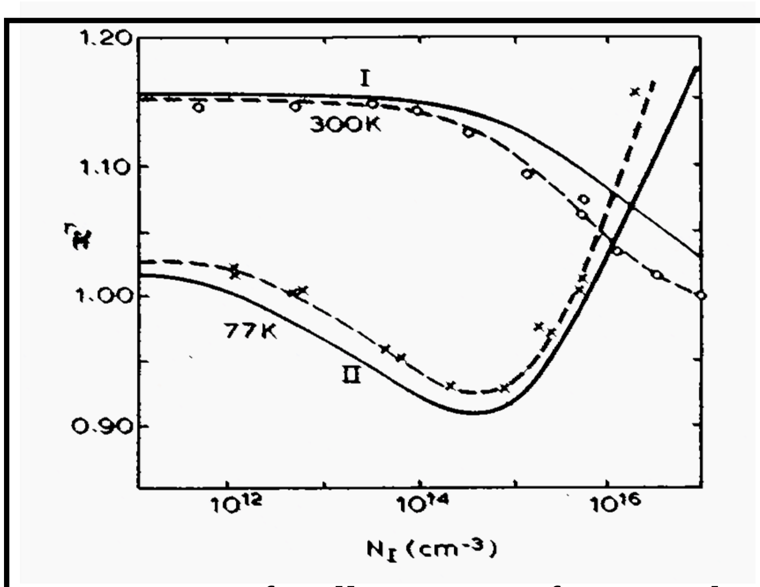
Hall scattering factor $r_H$ is defined by following expressions:

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

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

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

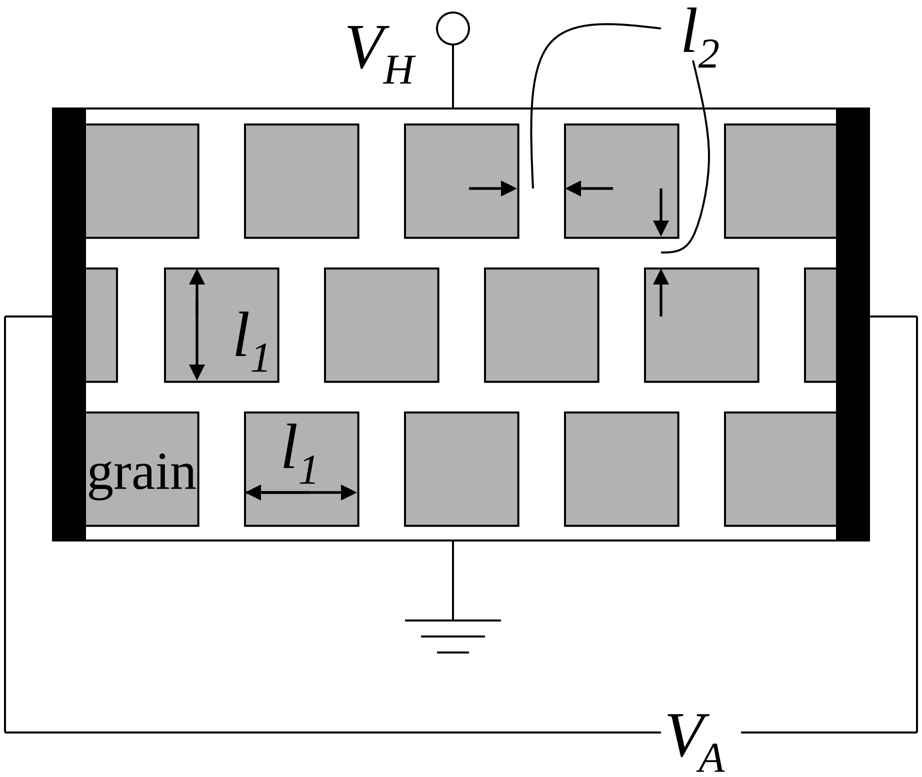
| Mechanism | $s$ | $r_H$ | $r_{MP}$ | $r_{MG}$ |
|---|---|---|---|---|
| Ionized impurities | -3/2 | 1.93 | 2.16 | 5.89 |
| Neutral impurities | 0 | 1 | 0 | 1 |
| Acoustic phonons | +1/2 | 1.18 | 0.38 | 1.77 |
| Etc. | | | | |




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

R. H. Bube 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)]