Analysis of electron mobility dependence on electron and neutron irradiation in silicon

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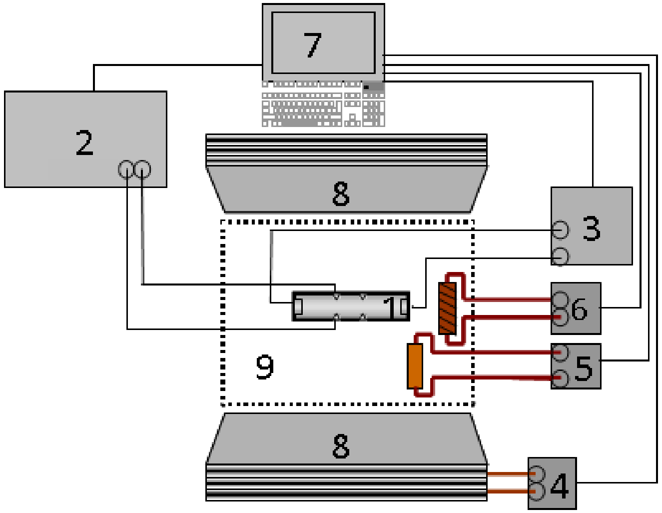
Classical effects, that works well in the classical situations, can be used for analyze conditions in the samples that are not traditional: **irradiated-Si**

The free carrier mobility is on of most important parameters in radiation detector analyze because as usually it goes together with the electric field:

$$v_{drift}=\mu E.$$

Therefore the knowledge of mobility predicts a correct values of electric field in the devices.

Our attempts: an investigation of low field electron mobility in the irradiated by neutrons Si, taking in account that at high fluence sample may became inhomogeneous due to overlap of the clusters space charge regions, therefore we measured the Hall and magnetoresistance mobilities.



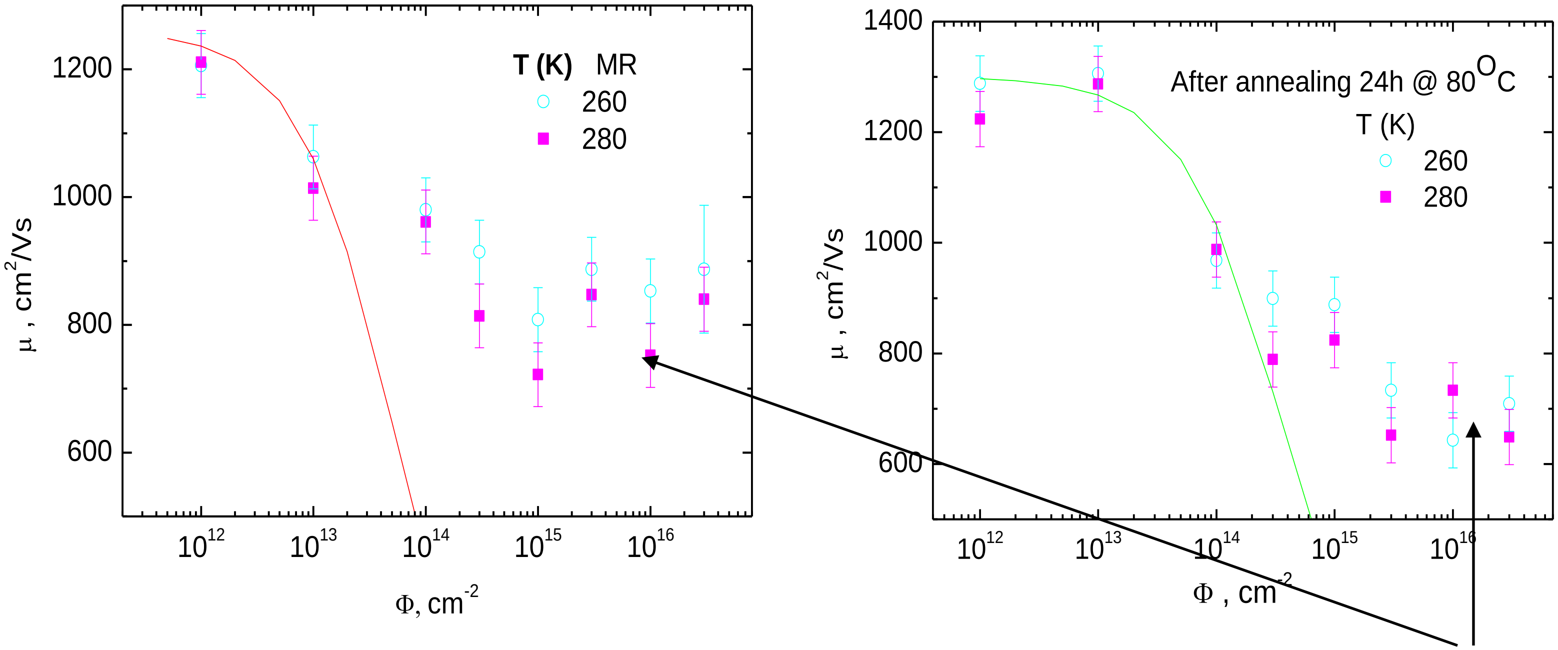
Hall effect measurement scheme. 1- Sample; 2- electrometer (KEITHLEY 6514); 3- source meter (KEITHLEY 6430); 4- magnet source; 5- thermo resistance meter (Agilent 34401A); 6- heater source (TTi QL564P); 7- computer; 8- magnet; 9- cryostat.

$$\mu_H = r_H \mu, \mu_M = r_H \zeta \mu = r_M \mu.$$

It was found the ratio of magnetoresistance and Hall mobilities $\mu_M/\mu_H = 1.15$.

[A. Mekys, V. Rumbauskas, J. Storasta, L. Makarenko, N. Kazuchits, J.V. Vaitkus. Hall effect and magnetoresistance investigation of fast electron irradiated silicon. Lithuanian Journal of Physics, 54, 94–98 (2014)]. (And presented earlier RD50 Workshop.)

Electron mobility dependence on the fluence in the irradiated and annealed Si samples.



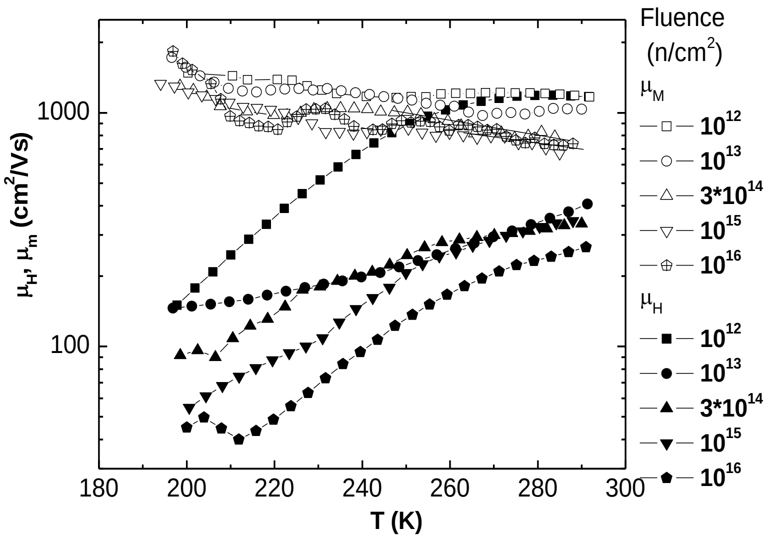
$$1/\mu = 1/\mu_{phon(i.e., independent-on-fluence)} + S\Phi$$

Probably the crystal became similar to the disordered media.

μ_{phon} = 1260 cm^2/sV & S=1.5·10^{-17} sV in the just-irradiated Si μ_{phon} = 1300 cm^2/sV & S=0.2·10^{-17} sV in the annealed for 24 h@80^0.

Hall and magnetoresistance dependence on T

(the Fig. was presented in the previous workshops)

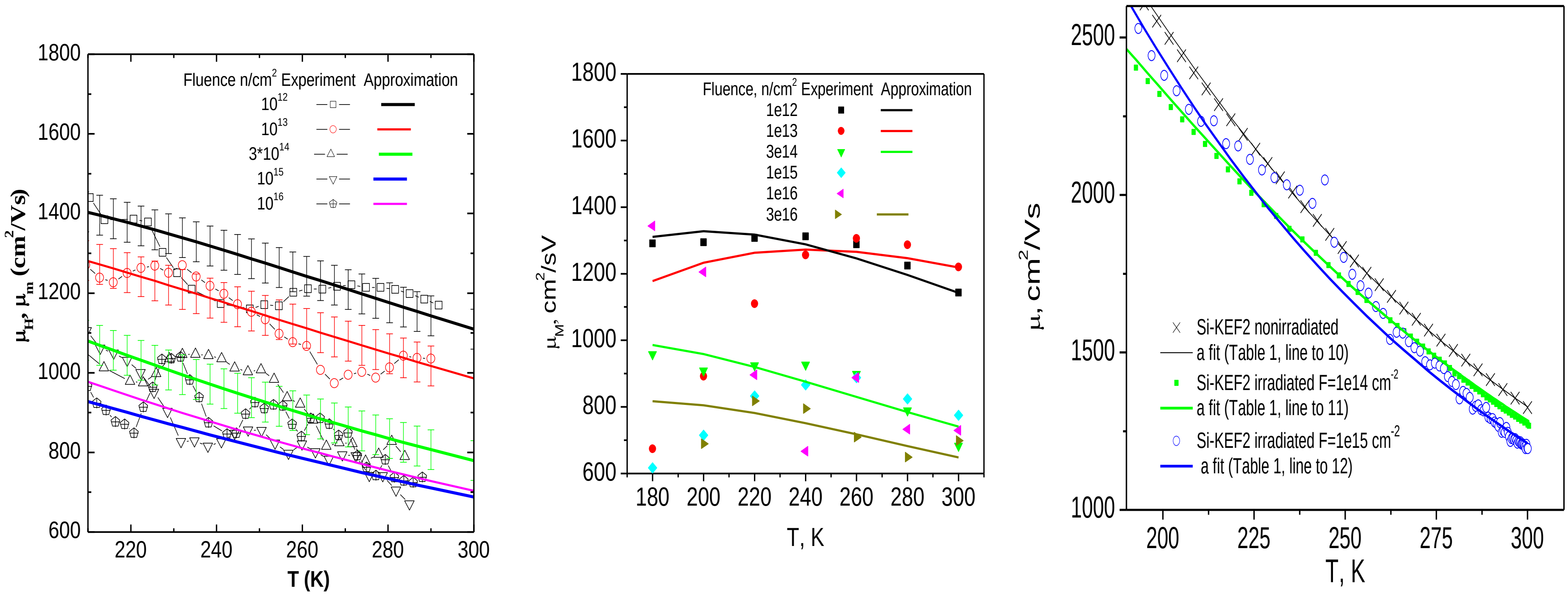


The magnetoresistance mobility dependence on temperature was similar to predicted for scattering on the clusters, however the mobility value at room temperature was not far away from limited by scattering by phonons.

Therefore it was necessary to analyse contributions of all possible scattering processes using the Matthiesen rule and to use the approximation of mobility dependence on temperature as μ=aT^{α}, where α index depends on the scattering mechanism, and analyse performed in a narrow range of temperature.

- As the simulation [Huhtinen] showed the neutron irradiation creates rather compact generation of defects, and a remaining material volume is free from the defects.
- Therefore the simulation of mobility dependence on temperature has to take into account the scattering of carriers as in a high quality silicon crystal that could be approximated by a power law μ=a$T\alpha$ with α=(-2.4), but in the compensated samples α=(-1.4) was observed, that could be a result of additional scattering on the ionized impurities.
- For the scattering on the point defects that can be charged α=1.5.
- If the defects are neutral, their contribution can be independent on temperature with α=0.
- The scattering of clusters is most indefinite:
  - it could follow the same dependences with α= (-1.0) or (-5/6)
  - the contribution of dipole scattering that could appear due to difference of vacancies and interstitials location inside the cluster. The dipole scattering can be approximated by $\mu \sim T^{0.5}$.

Fitting of mobility dependence on T



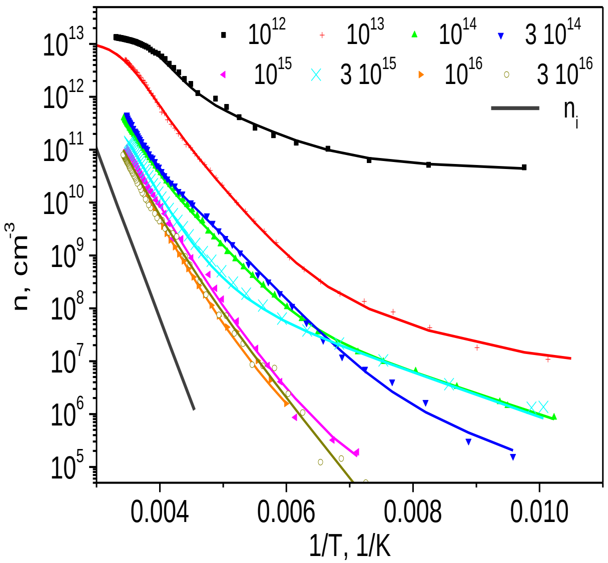
Hall mobility and magnetoresistive mobility dependence on temperature in the neutron irradiated samples. The fluence and the mobility type are shown in the inset. a. – the high resistivity Si samples, b. annealed samples, c – the low resistivity Si samples.

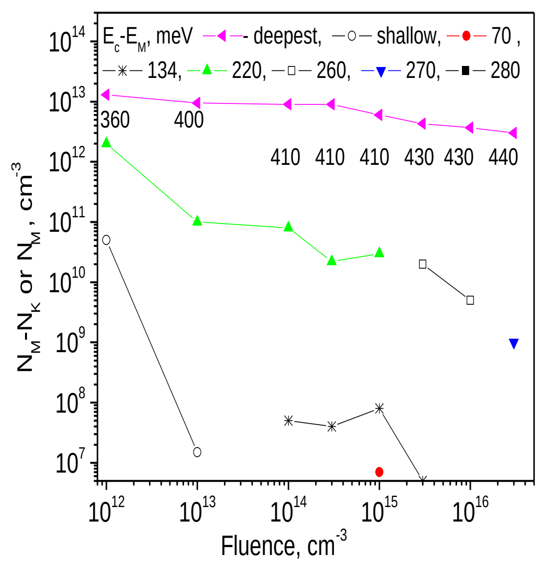
Table 1. The parameters used for a fit of experimental data to the relation:

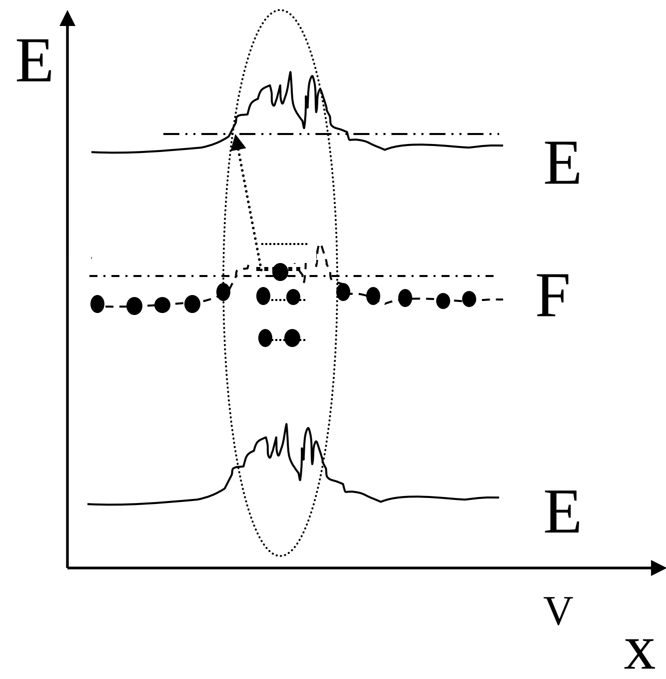
$$\mu = 1/(1/\mu_{phon} + 1/\mu_{ionized} + 1/\mu_{clusters} + 1/\mu_{dipoles}) =$$
$$= 1/(1/aT^{\alpha} + 1/bT^{1.5} + 1/cT^{-1} + 1/dT^{0.5})$$

Fluence cm^{-2}	Sample	Phonons (α value before irradiation)		Ionized point defects	Clusters	Dipoles
		α	a	b	c	D
$1\cdot10^{12}$	J-I HR	-1.4	$4.2\cdot10^{6}$	1.5	$0.8\cdot10^{7}$	$1.6\cdot10^{3}$
$1\cdot10^{12}$	Annealed HR	-1.4	$4.6\cdot10^{6}$	1	$1\cdot10^{7}$	$4\cdot10^{3}$
$1\cdot10^{13}$	J-I HR	-1.4	$4.2\cdot10^{6}$	1.8	$2\cdot10^{6}$	$1\cdot10^{3}$
$3\cdot10^{14}$	J-I HR	-1.4	$4.2\cdot10^{6}$	3	$6.5\cdot10^{5}$	$1\cdot10^{3}$
$3\cdot10^{14}$	Annealed HR	-1.4	$4.2\cdot10^{6}$	1.1	$6.5\cdot10^{5}$	$4\cdot10^{3}$
$1\cdot10^{15}$	J-I HR	-1.4	$4.2\cdot10^{6}$	2	$5\cdot10^{5}$	$1\cdot10^{3}$
$1\cdot10^{15}$	Annealed HR	-1.4	$4.2\cdot10^{6}$	1	$6.5\cdot10^{5}$	$4\cdot10^{3}$
$1\cdot10^{16}$	J-I HR	-1.4	$4.2\cdot10^{6}$	3	$5\cdot10^{5}$	$1\cdot10^{3}$
$3\cdot10^{16}$	Annealed HR	-1.4	$4.2\cdot10^{6}$	0.8	$5\cdot10^{5}$	$2\cdot10^{4}$
nonirradiated	KEF2	-2	$1.1\cdot10^{8}$	4	0	0
$1\cdot10^{14}$	KEF2	-2	$1.1\cdot10^{8}$	3.3	$1.2\cdot10^{8}$	$3.4\cdot10^{3}$
$1\cdot10^{15}$	KEF2	-2	$1.15\cdot10^{8}$	8	$4\cdot10^{7}$	$5\cdot10^{3}$

The cluster model



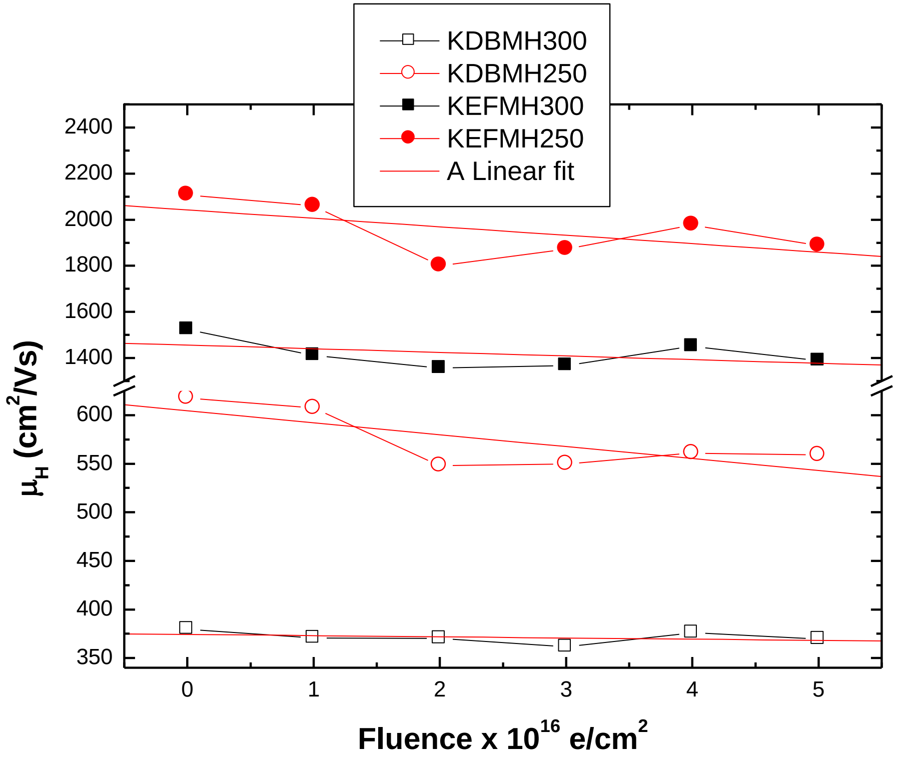




The temperature dependence of the electron concentration in the irradiated samples. The fluence value in neutrons/cm^2 is given in the insets. The lines correspond to the result of fitting to the experimental data.

The cluster model that allows an existence of the dipole

Electron irradiation (6,6 MeV, “low resistivity” Si)

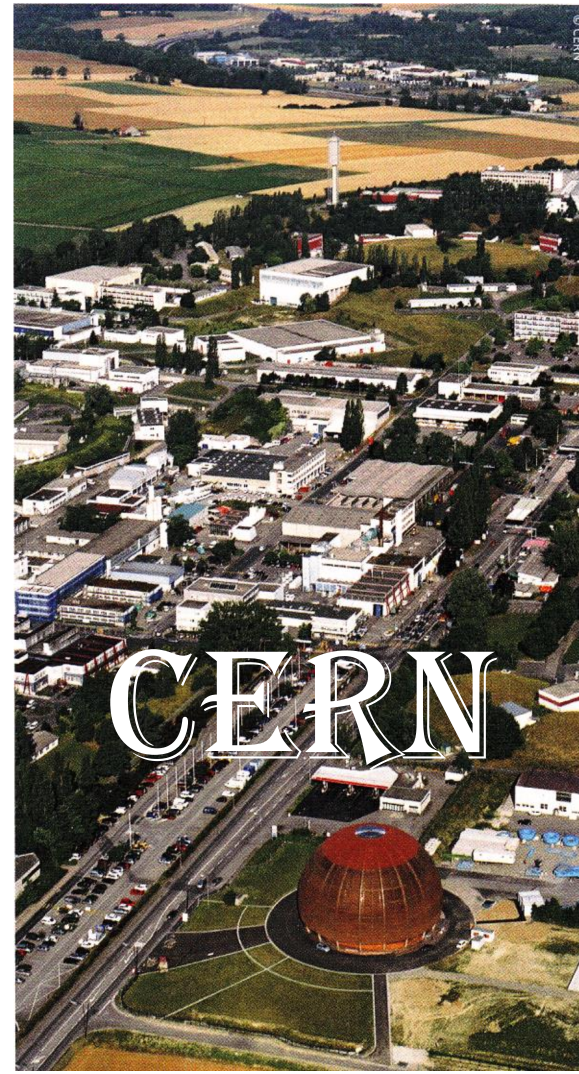


A.Mekys, V.Rumbauskas, J.Storasta, L.Makarenko, J.V.Vaitkus. Defect analysis in fast electron irradiated silicon by Hall and magnetoresistivity means. NIMB 338, 95-100 (2014)

This work is performed in frame of CERN RD50 collaboration. Thanks to Lithuanian Science Council for the grant TAK-10001 and Lithuanian Academy of Sciences for continuing support of

this research and grants CERN-VU-2013-2015.

THANK YOU FOR YOUR ATTENTION!



Mobilities:

- Magnetoresistant mobility in this work was calculated using the following relation:

$$\mu_m = \frac{1}{B}\sqrt{\frac{I_0}{I_B} - 1}\,.$$

(1)

- Here *B* is the magnetic field induction, *I0* is the electric current in the sample when magnetic field is not present and *IB* is the same

  current with the presence of the magnetic field.

- The Hall mobility was calculated using:

$$\mu_H = \frac{1}{B}\frac{l}{w}\frac{U_H}{U_X}\,.$$

(2)

- Here *l* is the distance between the electric current contacts (1,2) and *UX* is the voltage applied, *w* is the distance between the Hall contacts (3,4).