# Magnetoresistance in the irradiated Si microstrip type samples

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The standard Si microstrip detector samples were irradiated to high fluence in TRIGA reactor. The magnetoresistance was investigated at different temperature, and the preliminary results of mobility dependence was obtained. It was found a decrease of magnetoresistance mobility up to 640 cm2/sV @ room T in samples irradiated to 1e17 neutron/cm2 fluence. The mobility was near to the same in both FZ and MCZ Si samples but at the lower fluence the differences between the Si type was bigger. The details of the measurement technique and results needs to discuss.

The discussions on the mobility dependence on irradiation fluence have been started at 26th and 27th RD50 Workshops
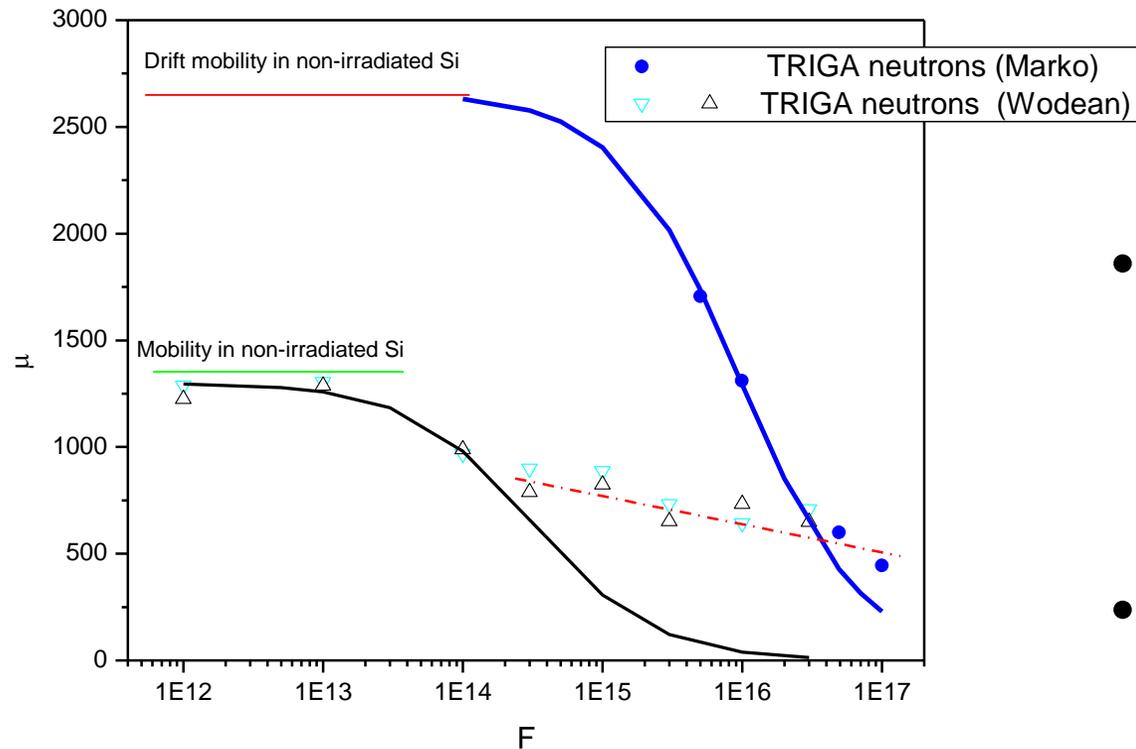
- Marko Mikuz demonstrated the indirect measurement of mobility in the highly irradiated Si, and approximated it as a square root dependence on the fluence.

- The mobility values in the samples irradiated to the fluence 1e16-1e17 cm-2 were similar to our measurements of mobility in low E.

- It was decided to perform more detail measurements in the microstrip samples.

Magnetoresistance mobility

$$\mu_H = r\mu_n \qquad r = \langle \tau^2 \rangle / \langle \tau \rangle^2$$

$$\mu_{\mathrm{GMR}} = \xi \mu_H \qquad \xi = (\langle \tau^3 \rangle \langle \tau \rangle / \langle \tau^2 \rangle^2)^2$$
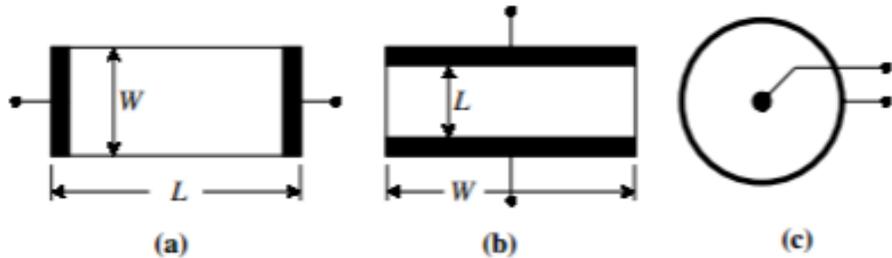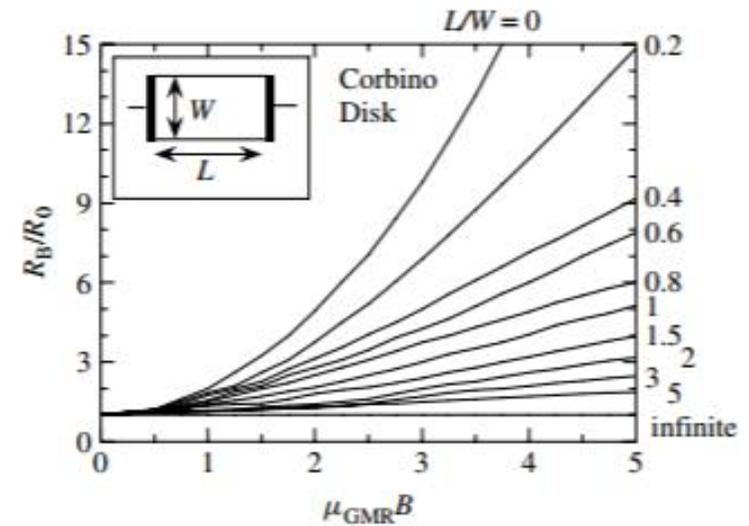

Fig. 8.14 Geometric magnetoresistance ratio of rectangular samples versus $\mu_{\mathrm{GMR}} B$ as a function of the length/width ratio. Reprinted with permission after Lippmann and Kuhrt.[56]

Fig. 8.13 (a) Hall sample, (b) short, wide sample, (c) Corbino disk.

$$\frac{R_B}{R_0} = \frac{\rho_B}{\rho_0}[1 + (\mu_{\mathrm{GMR}} B)^2]$$

$$\mu_p \approx \frac{1}{B}\sqrt{\frac{R_B}{R_0} - 1}$$

The samples: standard microstrips irradiated in TRIGA reactor, Ljubljana.
Silicon strip detectors on Float Zone (FZ) and Magnetic Czochralsky (MCz) were irradiated by fast neutrons with the fluence up to 10^{17} n/cm^2.
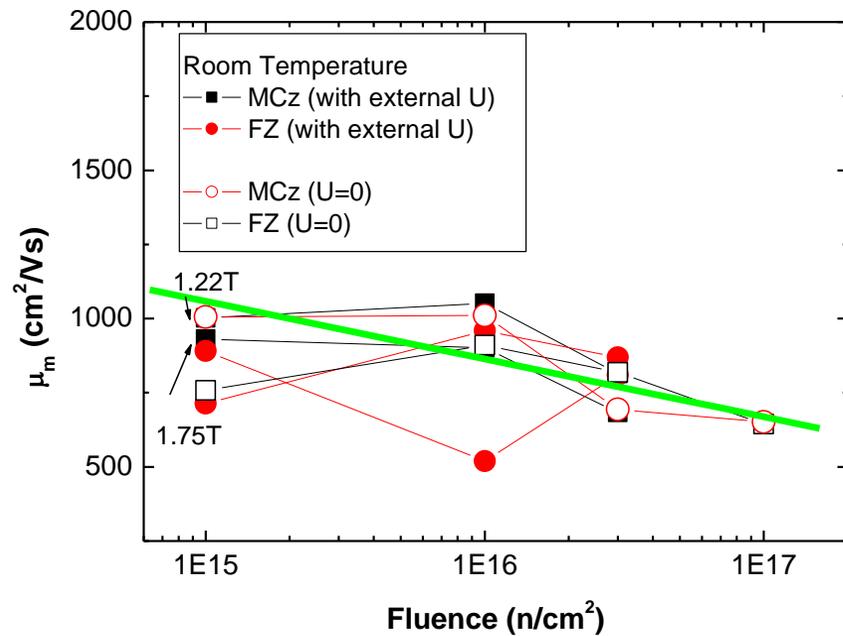
0.00429cm

oxide

n+ implant

polished edge

p+ implant

aluminium
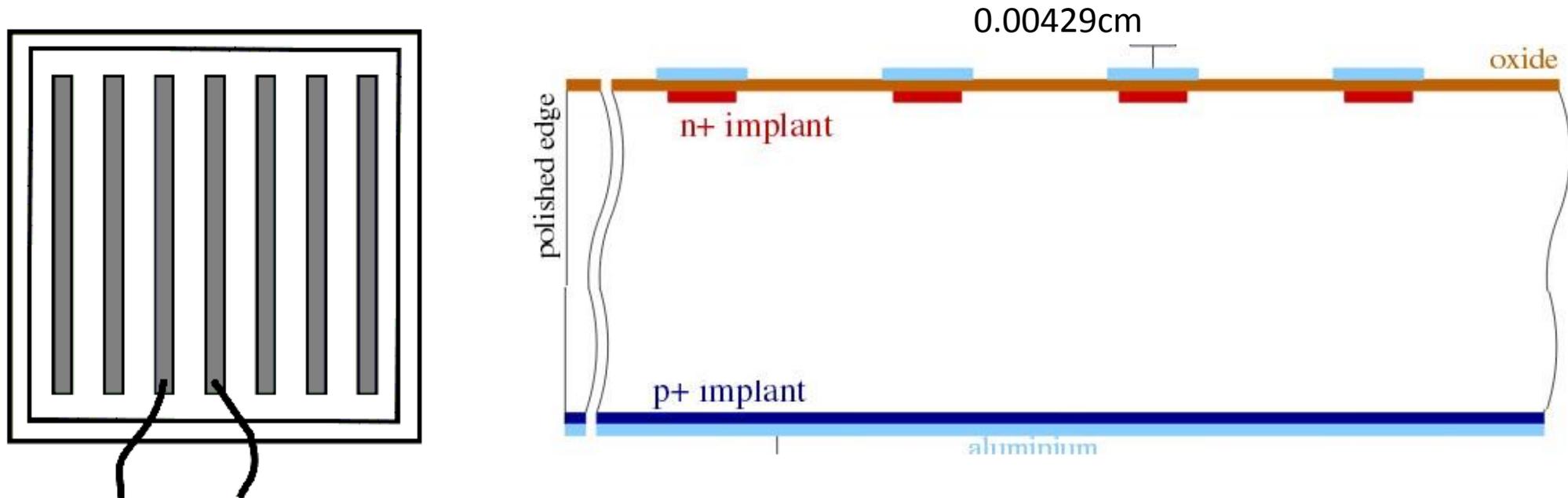
L/W = 0,0043, that is very near to the Corbino dick value, and magnetoresistanse effect will be maximal

I(V), μ_m(V)

$I(V), \quad \mu_m(V)$
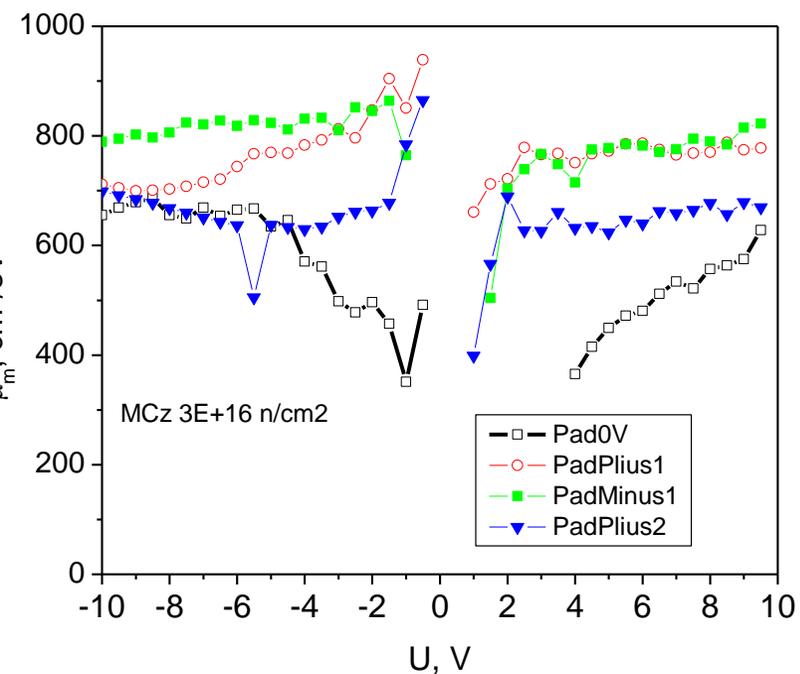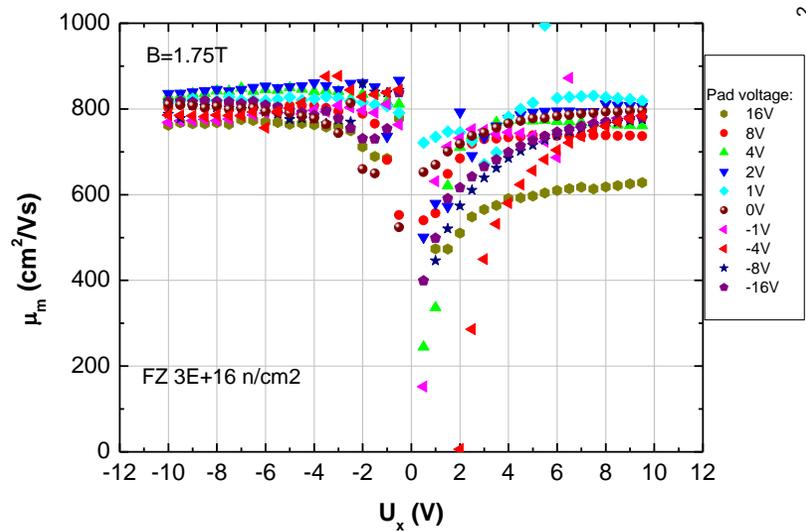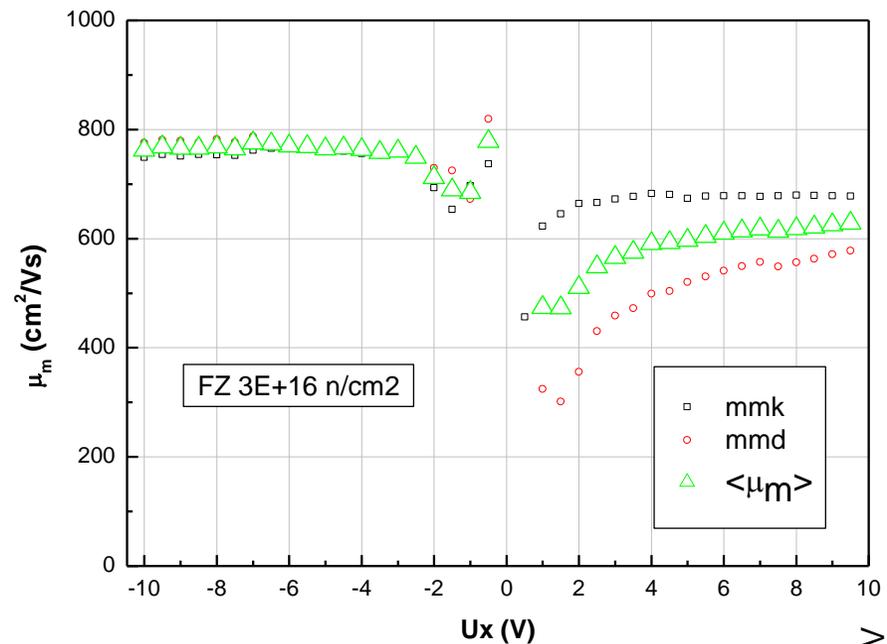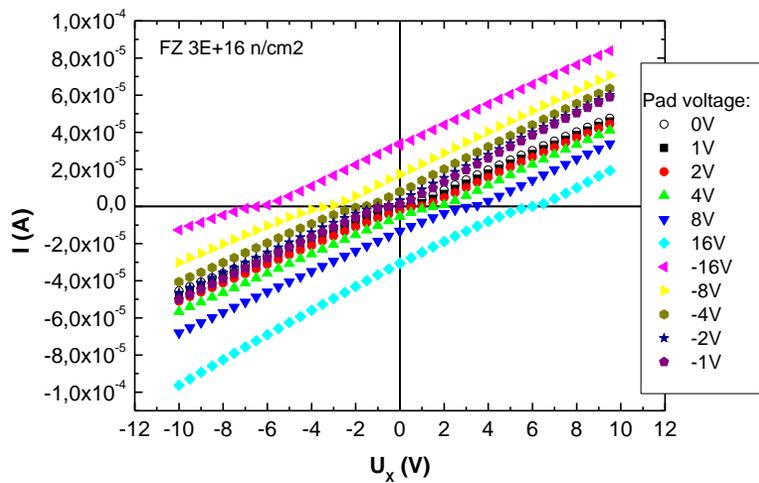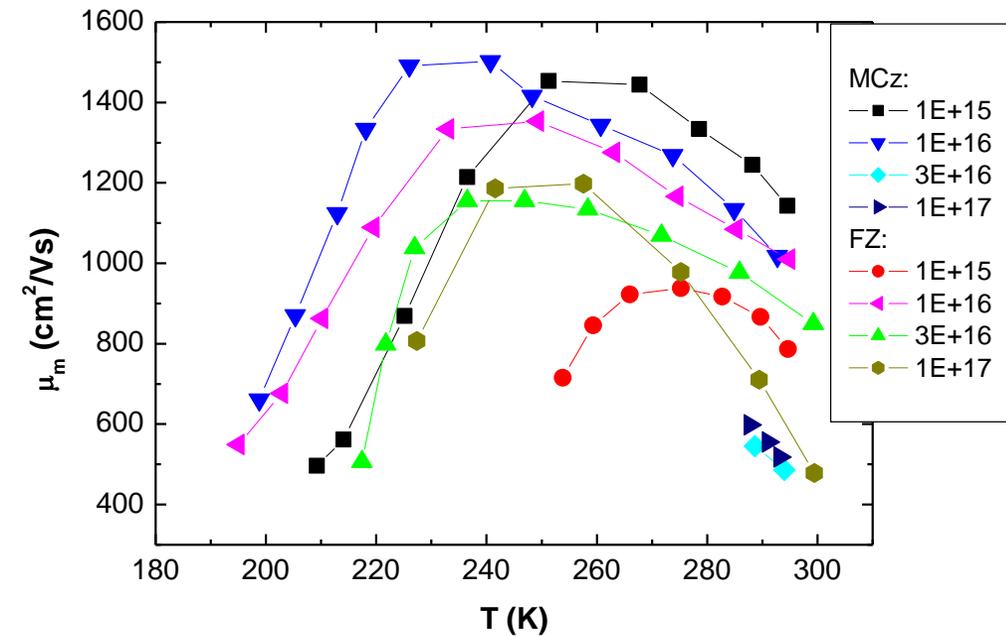
The electrical conductivity and the magnetoresistivity measurements were performed with temperature variation from 200 K to 300 K.
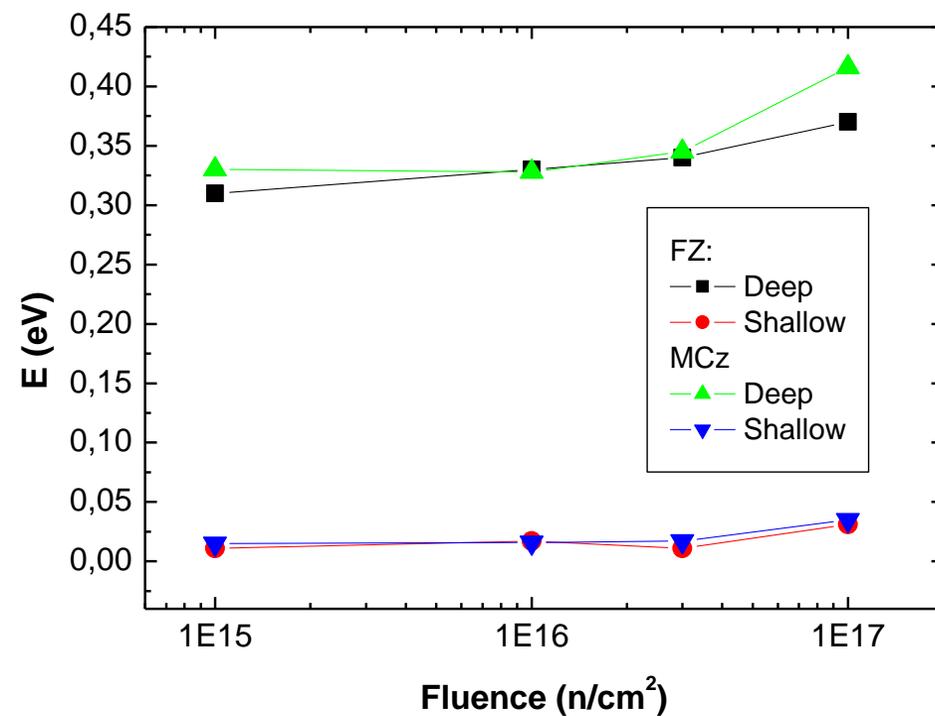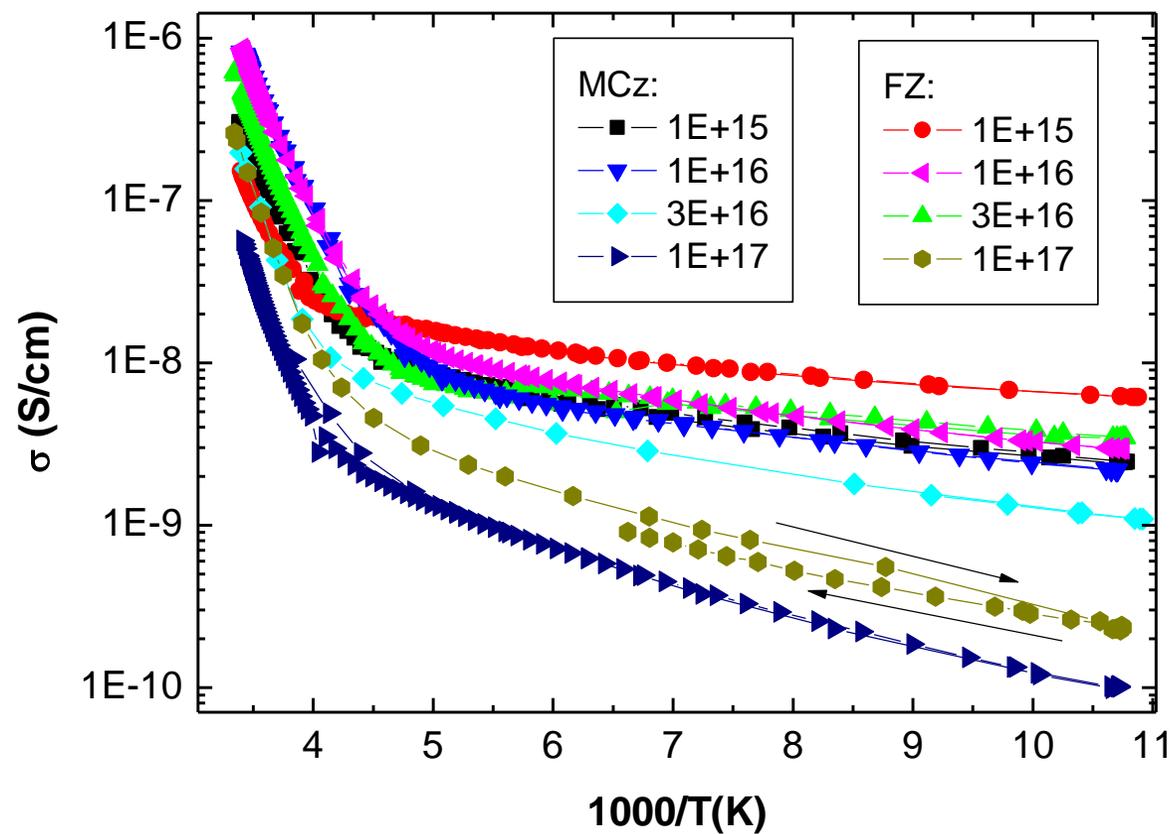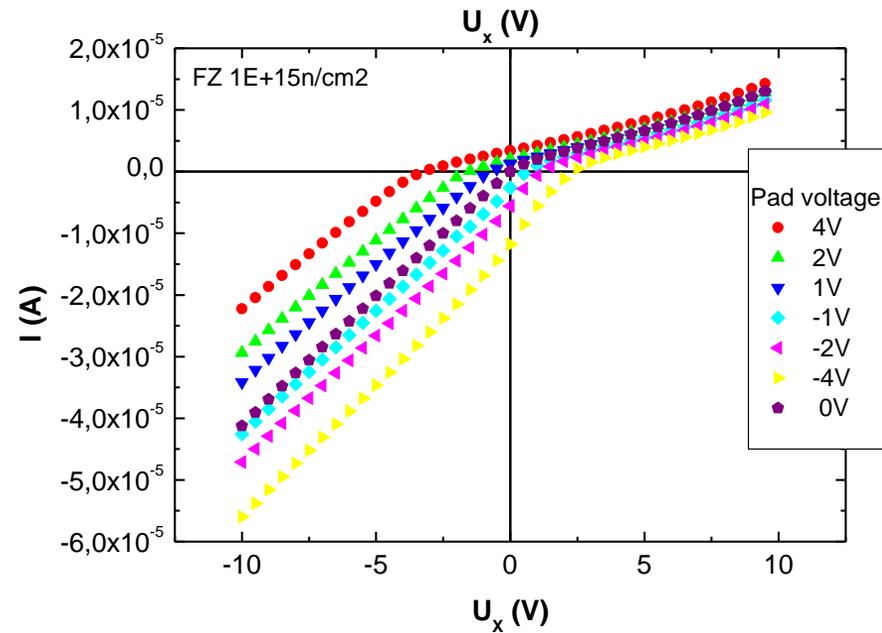

Magnetoresistant mobility dependence on the irradiation fluence.

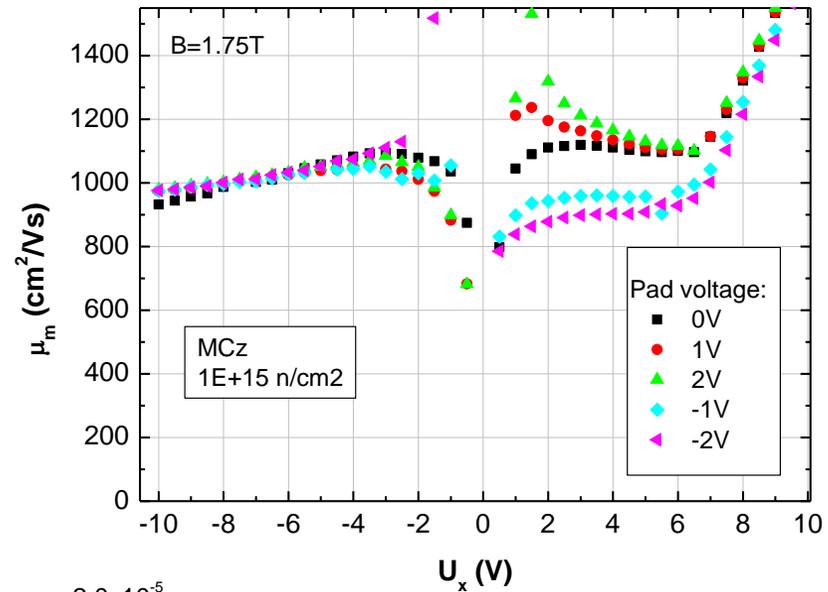
Magnetoresistant mobility dependence on temperature for the different irradiation fluence.

σ (T),   ΔE$_{Act}$ (Φ)

Comparson of MCz and Fz Si samples
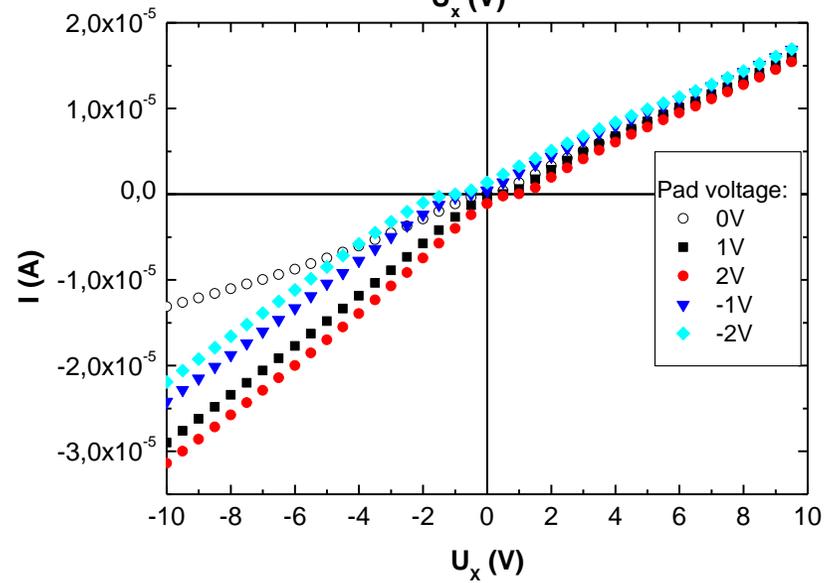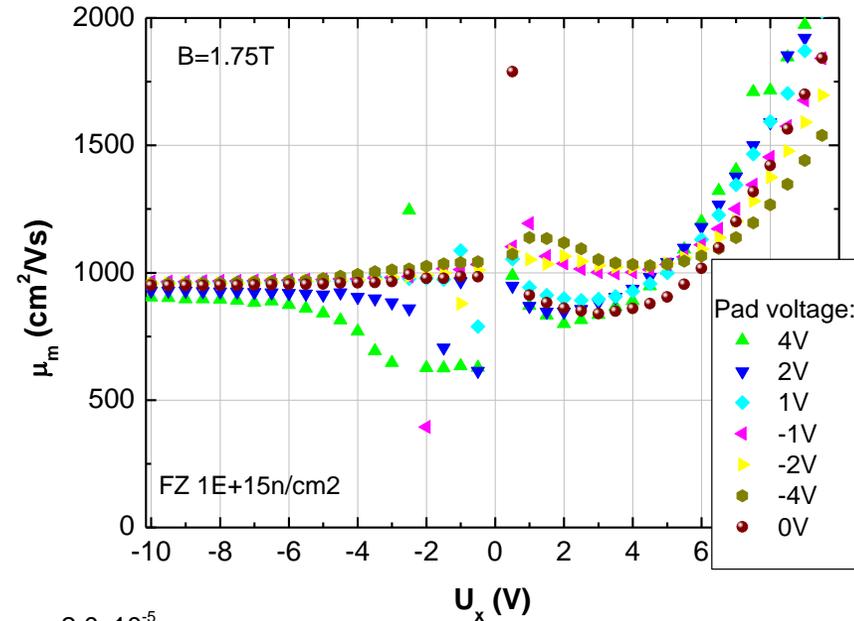
TCAD simulation is done using:
  Hydrodynamic model;
  Mobility high field dependence;
  Galvanic transport model (currents depending on magnetic field)

Magnetic field effect on current density:

$$\vec{J}_\alpha = \mu_\alpha \vec{g}_\alpha + \mu_\alpha \frac{1}{1 + (\mu_\alpha^* B)^2} [\mu_\alpha^* \vec{B} \times \vec{g}_\alpha + \mu_\alpha^* \vec{B} \times (\mu_\alpha^* \vec{B} \times \vec{g}_\alpha)]$$

$\alpha = n, p$ (electrons and holes);　　g_α – current vector without mobility
μ_α^* - Hall mobility,　$\mu_n^* = 1.1\mu_n$,　$\mu_p^* = -0.7\mu_p$,
B - magnetic induction vector

Mobility high field dependence is taken into account by:
(approximation is valid for the high quality Si, for irradiated Si it needs to be upgraded

$$\mu(F) = \frac{(\alpha + 1)\mu_{low}}{\alpha + \left[1 + \left(\frac{(\alpha + 1)\mu_{low} F_{hfs}}{v_{sat}}\right)^\beta\right]^{1/\beta}}$$

α, β, v_{sat} are model parameters for silicon.

μ_{low} – low field mobility.

Values of μ_{low} used in calculations are:
1417, 1250, 1000, 600 [cm^2 /(V s)]

Refere to Sentaurus TCAD manual for more details

z

y ← → x
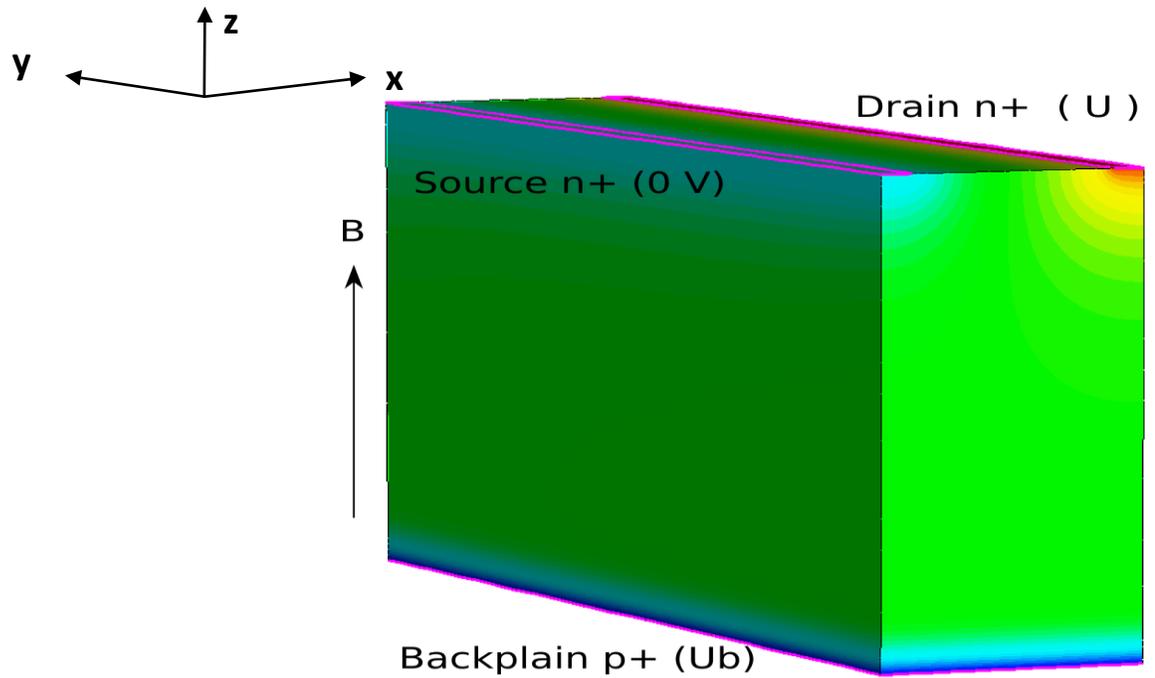
Device and potential distribution at
B = 1.75 T
Ub = 0 V
U = 2 V

Drain n+ (U)

Source n+ (0 V)

B

Backplain p+ (Ub)

ElectrostaticPotential (V)

2.416e+00
1.939e+00
1.463e+00
9.865e-01
5.101e-01
3.375e-02
-4.426e-01
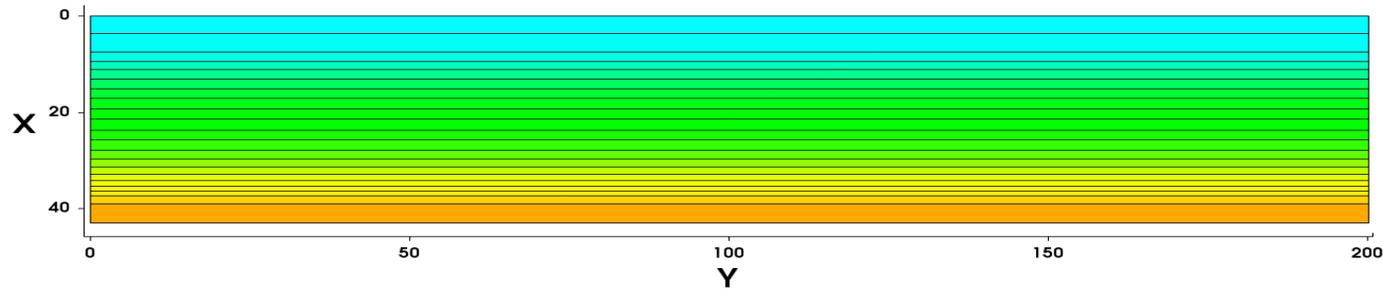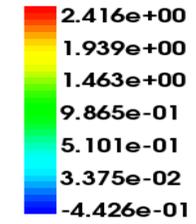
Potential maps in the 2d cut plane
just below top contacts.
(Same voltages as above)

B = 0 T
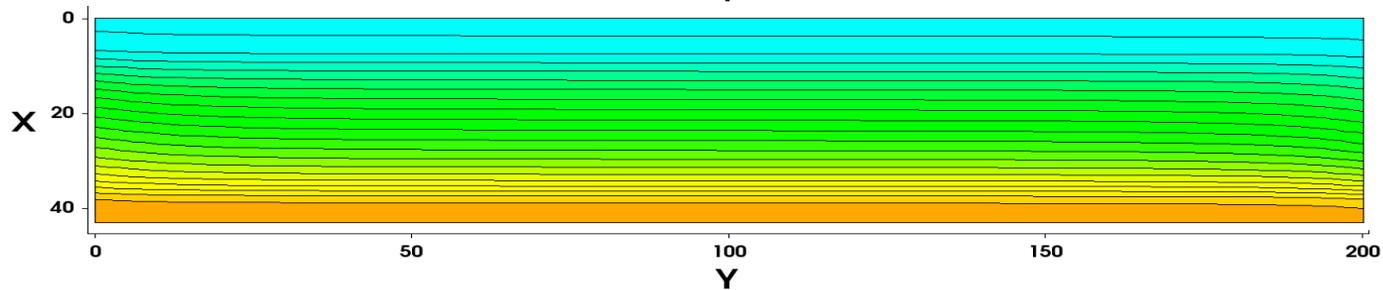
B = 1.75 T
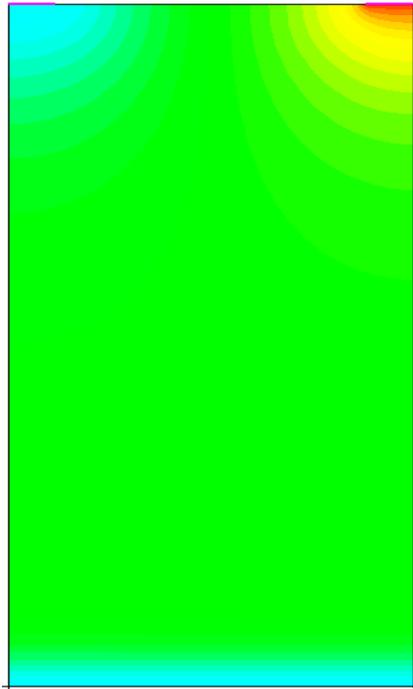
ElectrostaticPotential (V)
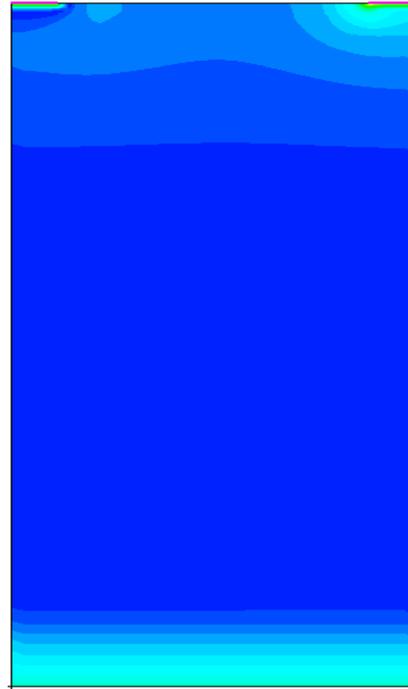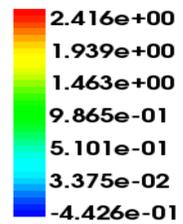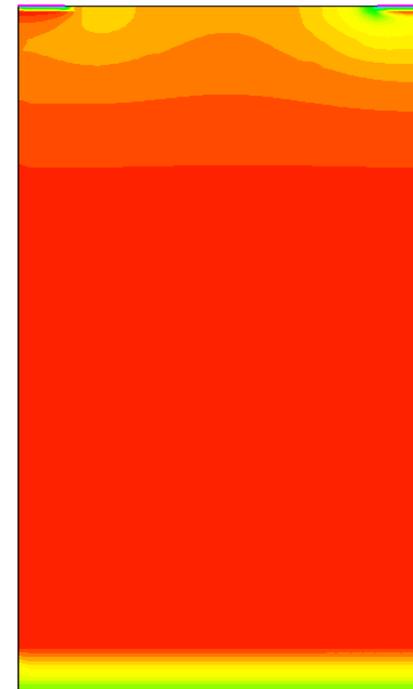
■	2.416e+00
■	1.939e+00
■	1.463e+00
■	9.865e-01
■	5.101e-01
■	3.375e-02
■	-4.426e-01

Abs(ElectricField-V) (V*cm^-1)

■	5.406e+03
■	4.505e+03
■	3.604e+03
■	2.704e+03
■	1.803e+03
■	9.018e+02
■	9.379e-01

eMobility (cm^2*V^-1*s^-1)

■	1.250e+03
■	1.186e+03
■	1.122e+03
■	1.058e+03
■	9.939e+02
■	9.298e+02
■	8.658e+02

Maps of potential, absolute value of electric field and electron mobility distributions
in 2d x-z cut plane (B = 1.75 T,   Ub = 0 V,   U = 2 V)
High mobility (μ = 1250 cm²/(Vs)) sample.
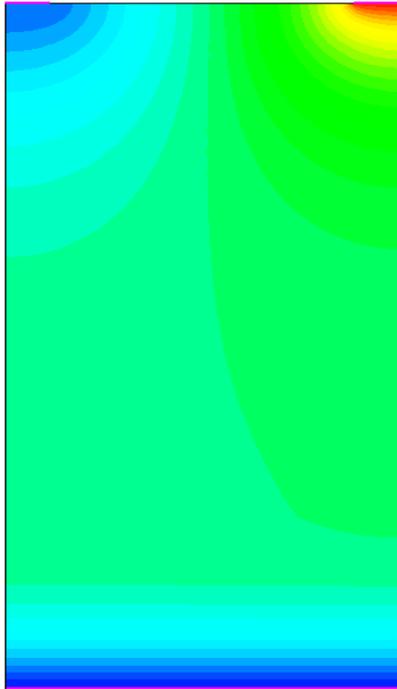
ElectrostaticPotential (V)
- 8.416e+00
- 6.939e+00
- 5.463e+00
- 3.987e+00
- 2.510e+00
- 1.034e+00
- -4.426e-01
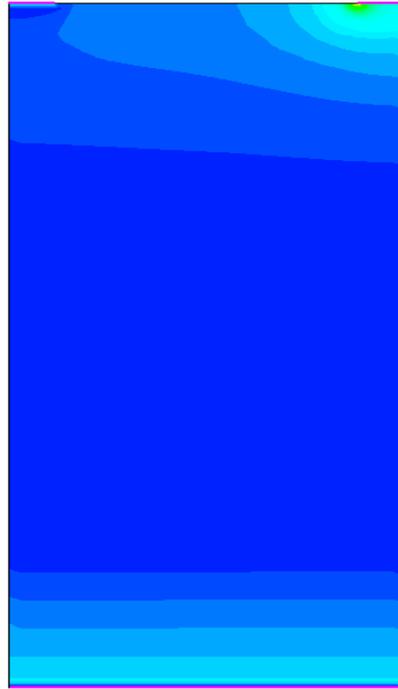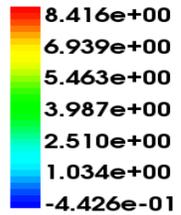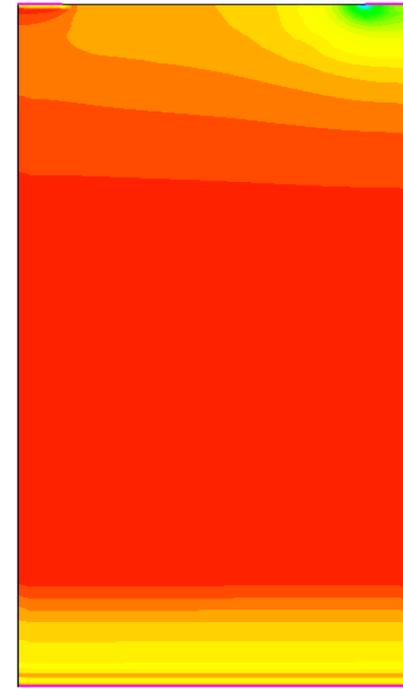
Abs(ElectricField-V) (V*cm^-1)
- 1.832e+04
- 1.527e+04
- 1.221e+04
- 9.160e+03
- 6.108e+03
- 3.056e+03
- 3.117e+00

eMobility (cm^2*V^-1*s^-1)
- 6.000e+02
- 5.537e+02
- 5.074e+02
- 4.611e+02
- 4.148e+02
- 3.685e+02
- 3.222e+02

Maps of potential, absolute value of electric field and electron mobility distributions
in 2d x-z cut plane (B = 1.75 T,   Ub = 0 V,   U = 2 V)
Low mobility (μ = 600 cm^2/(Vs)) sample.

Effect of magnetic field on I-V properties
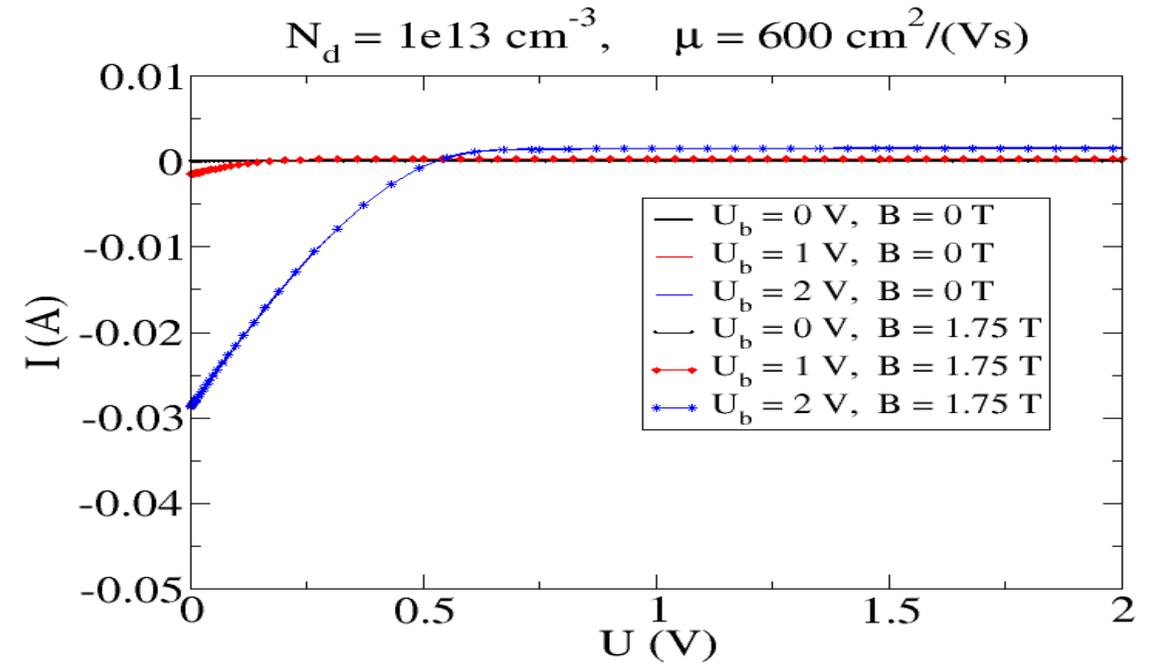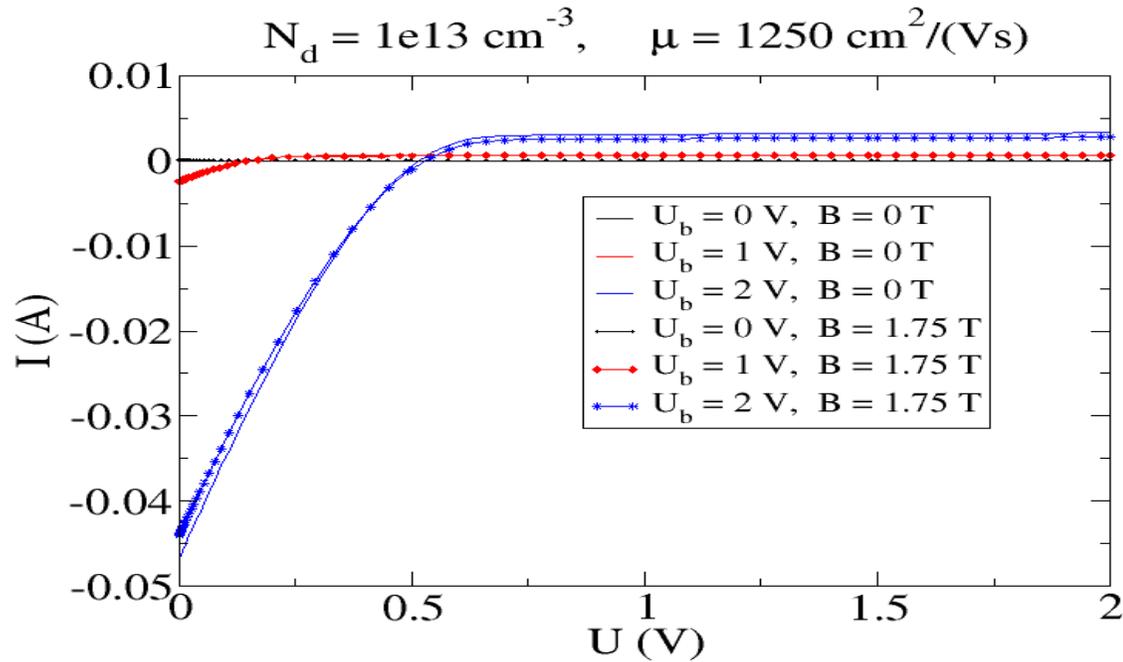
I-V between Source and Drain are calculated at different
Backplain voltages.
Results compared for two samples with electron mobilities
1250 cm^2/(Vs)   and   600 cm^2/(Vs).

On the following slides more detailed analysis is presented for each
Backplain voltage

Source-Drain I-V, at Backplain voltage 0 V

$N_d = 1e13 \text{ cm}^{-3}, \quad \mu = 1250 \text{ cm}^2/(\text{Vs})$

$N_d = 1e13 \text{ cm}^{-3}, \quad \mu = 600 \text{ cm}^2/(\text{Vs})$
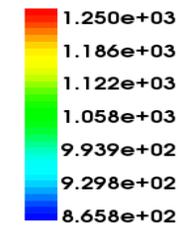

$U_b = 0 \text{ V}$
— $B = 0 \text{ T}$
— $B = 1.75 \text{ T}$

at $U = 0.1 \text{ V}$:
$\Delta I = 1.7952e\text{-}05 * \Delta U$, $(B = 0 \text{ T})$
$\Delta I = 1.7401e\text{-}05 * \Delta U$, $(B = 1.75 \text{ T})$

$U_b = 0 \text{ V}$
— $B = 0 \text{ T}$
— $B = 1.75 \text{ T}$

at $U = 0.1 \text{ V}$:
$\Delta I = 8.6354e\text{-}06 * \Delta U$, $(B = 0 \text{ T})$
$\Delta I = 8.5745e\text{-}06 * \Delta U$, $(B = 1.75 \text{ T})$
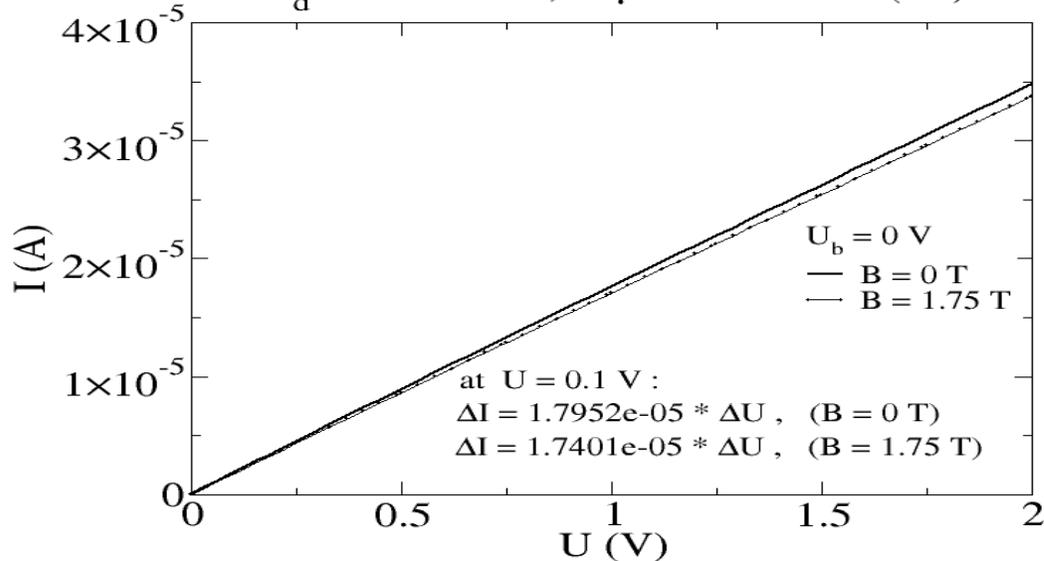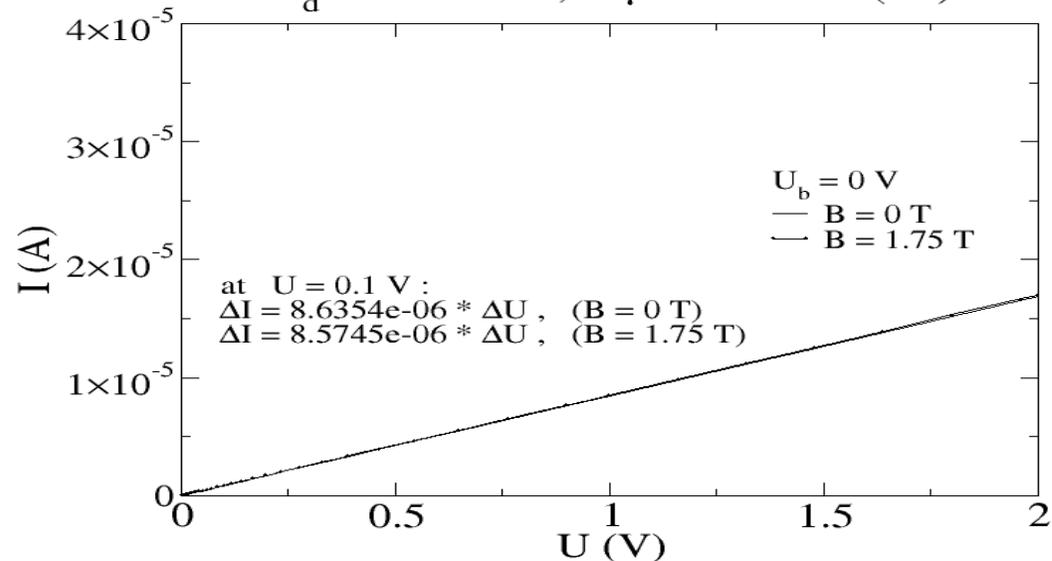
$$\mu_m = \frac{1}{B}\sqrt{\frac{R_B - R_0}{R_0}}$$ - Magnetoresistance mobility

$N_d = 1e13 \text{ cm}^{-3}, \quad \mu = 600 \text{ cm}^2/(\text{Vs})$

at $U = 7 \text{ V}$:
$\Delta I = 9.5873e\text{-}06 * \Delta U$, $(B = 0 \text{ T})$
$\Delta I = 9.5067e\text{-}06 * \Delta U$, $(B = 1.75 \text{ T})$

$U_b = 0 \text{ V}$
— $B = 0 \text{ T}$
— $B = 1.75 \text{ T}$

High mobility ($\mu = 1250 \text{ cm}^2/(\text{Vs})$) sample
$\mu_m = 1016.8 \text{ cm}^2/(\text{Vs})$.

Low mobility ($\mu = 600 \text{ cm}^2/(\text{Vs})$) sample
$\mu_m = 481.6 \text{ cm}^2/(\text{Vs})$ at $U = 0.1V$,
$\mu_m = 526.2 \text{ cm}^2/(\text{Vs})$ at $U = 7V$,

Source-Drain I-V, at Backplain voltage 1 V

$N_d = 1e13 \ cm^{-3}, \quad \mu = 1250 \ cm^2/(Vs)$

$I \ (A)$

$U \ (V)$

at U = 1 V :
$\Delta I = 5.3223e\text{-}05 * \Delta U$, (B = 0 T)
$\Delta I = 5.2319e\text{-}05 * \Delta U$, (B = 1.75 T)

$U_b = 1 V$
— B = 0 T
•—• B = 1.75 T

at U = 0.01 V :
$\Delta I = 0.023146 * \Delta U$, (B = 0 T)
$\Delta I = 0.022435 * \Delta U$, (B = 1.75 T)
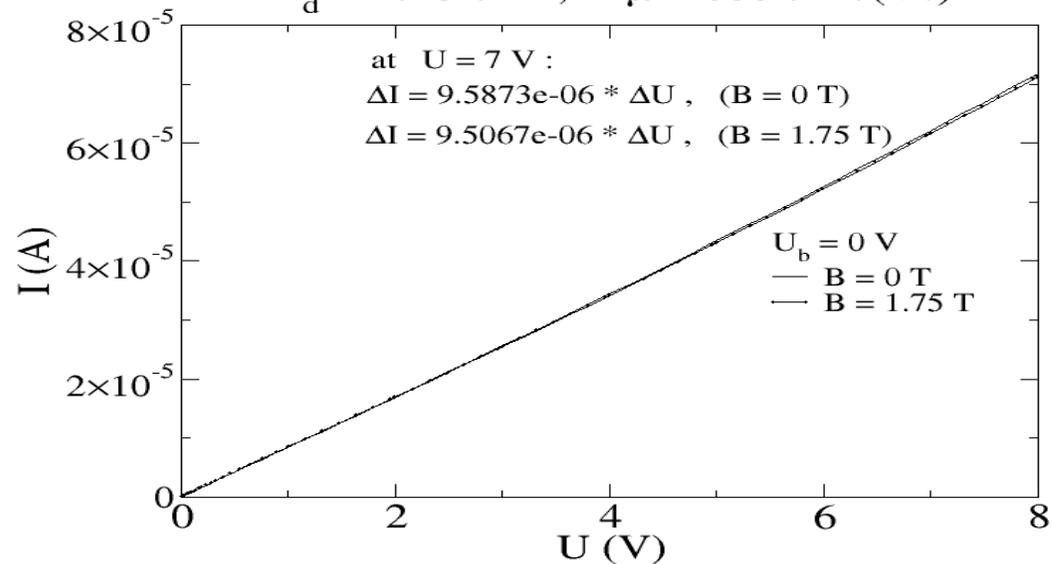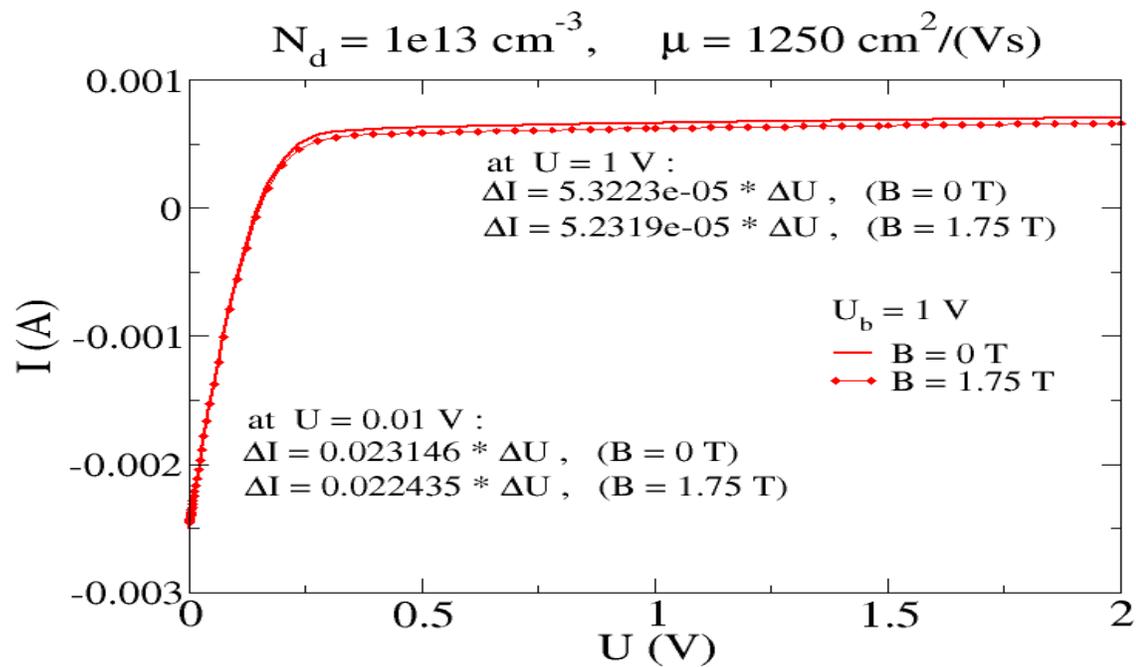
$N_d = 1e13 \ cm^{-3}, \quad \mu = 600 \ cm^2/(Vs)$

$I \ (A)$

$U \ (V)$

at U = 1 V :
$\Delta I = 2.6834e\text{-}05 * \Delta U$, (B = 0 T)
$\Delta I = 2.6690e\text{-}05 * \Delta U$, (B = 1.75 T)

$U_b = 1 V$
— B = 0 T
•—• B = 1.75 T

at U = 0.01 V :
$\Delta I = 0.013618 * \Delta U$, (B = 0 T)
$\Delta I = 0.013532 * \Delta U$, (B = 1.75 T)

High mobility ($\mu = 1250 \ cm^2/(Vs)$) sample
$\mu_m = 1017.3 \ cm^2/(Vs)$ at U = 0.01V,
$\mu_m = 751.1 \ cm^2/(Vs)$ at U = 1V,
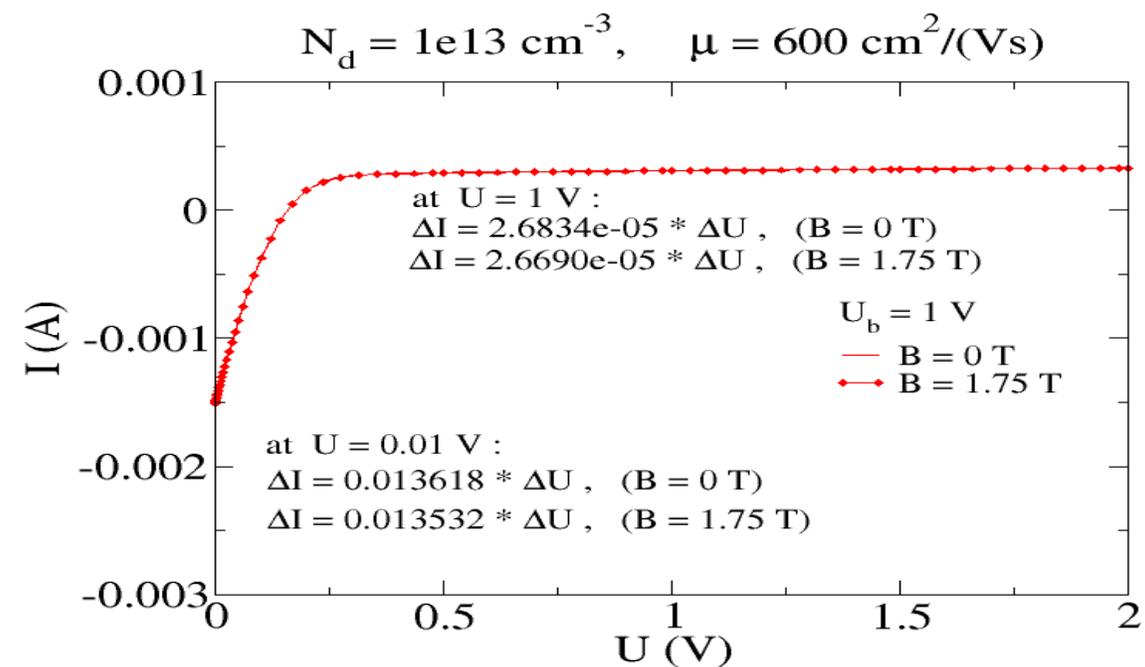
Low mobility ($\mu = 600 \ cm^2/(Vs)$) sample
$\mu_m = 455.5 \ cm^2/(Vs)$ at U = 0.01V,
$\mu_m = 419.7 \ cm^2/(Vs)$ at U = 1V,

Source-Drain I-V, at Backplain voltage 2 V

$N_d = 1e13\ cm^{-3}, \quad \mu = 1250\ cm^2/(Vs)$

at $U = 1\ V$:
$\Delta I = 2.7935e\text{-}04 * \Delta U$, $(B = 0\ T)$
$\Delta I = 2.5876e\text{-}04 * \Delta U$, $(B = 1.75\ T)$

$U_b = 2\ V$
— $B = 0\ T$
—*— $B = 1.75\ T$

at $U = 0.01\ V$:
$\Delta I = 0.12256 * \Delta U$, $(B = 0\ T)$
$\Delta I = 0.11346 * \Delta U$, $(B = 1.75\ T)$

$N_d = 1e13\ cm^{-3}, \quad \mu = 600\ cm^2/(Vs)$

at $U = 1\ V$:
$\Delta I = 1.4488e\text{-}04 * \Delta U$, $(B = 0\ T)$
$\Delta I = 1.4125e\text{-}04 * \Delta U$, $(B = 1.75\ T)$

$U_b = 2\ V$
— $B = 0\ T$
—*— $B = 1.75\ T$

at $U = 0.01\ V$:
$\Delta I = 0.07818 * \Delta U$, $(B = 0\ T)$
$\Delta I = 0.07683 * \Delta U$, $(B = 1.75\ T)$
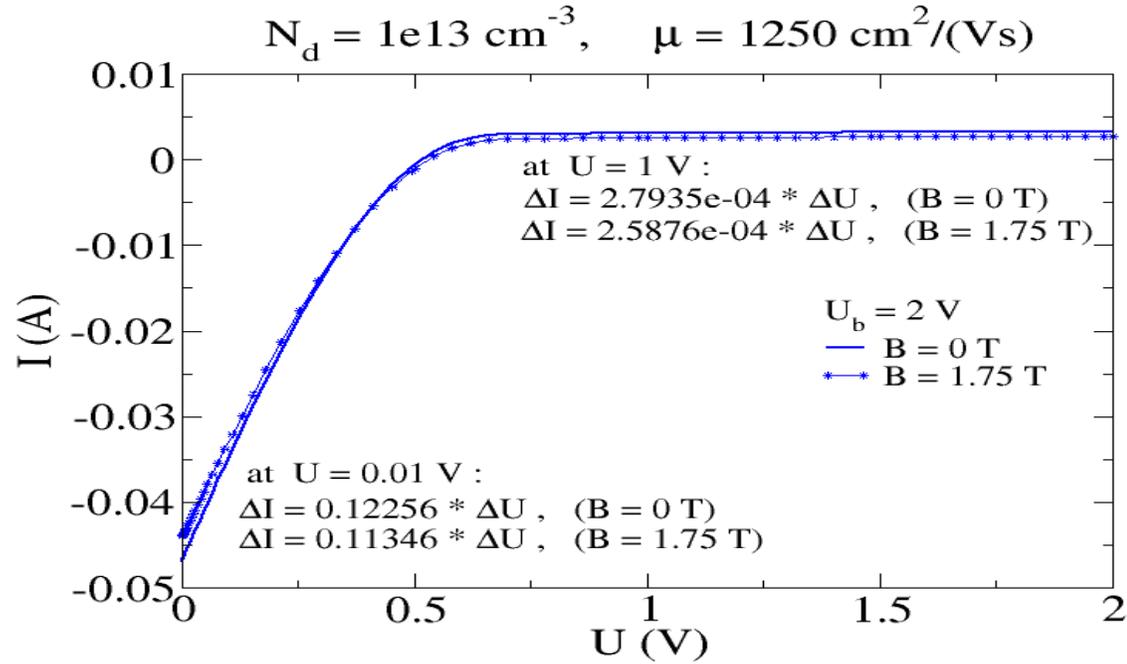
High mobility ($\mu = 1250\ cm^2/(Vs)$) sample
$\mu_m = 1618.3\ cm^2/(Vs)$ at $U = 0.01V$,
$\mu_m = 1611.9\ cm^2/(Vs)$ at $U = 1V$,
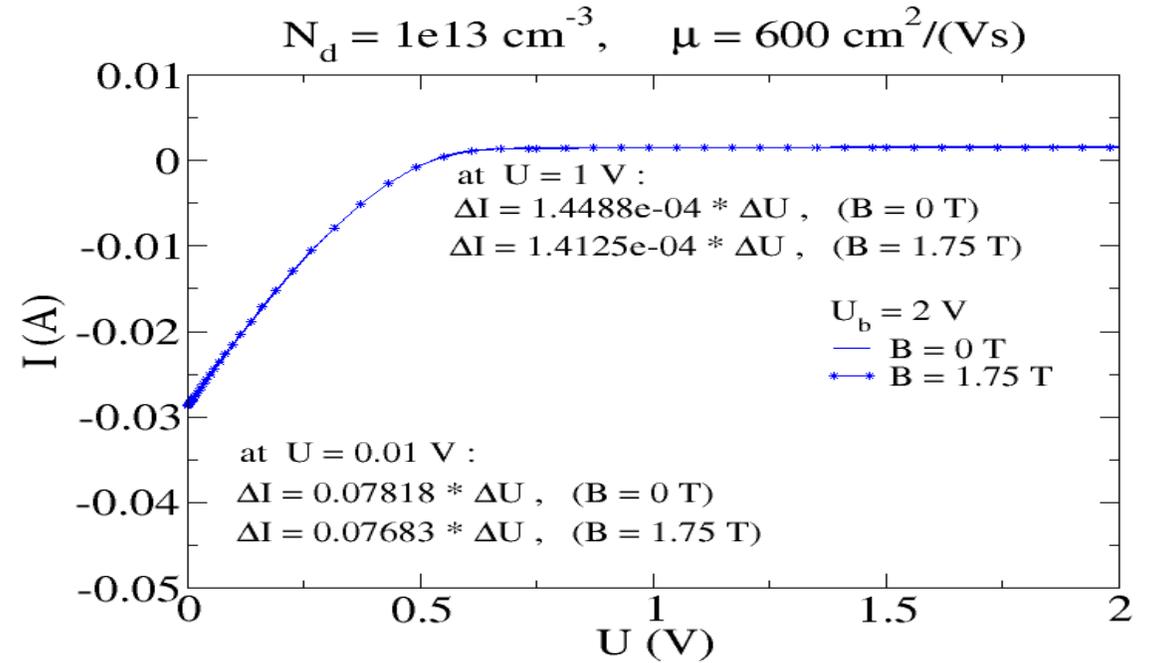
Low mobility ($\mu = 600\ cm^2/(Vs)$) sample
$\mu_m = 757.5\ cm^2/(Vs)$ at $U = 0.01V$,
$\mu_m = 916.1\ cm^2/(Vs)$ at $U = 1V$,

$\mu_m \approx 1{,}3\ \mu$

Conclusions: (preliminary)

- 1. Free carrier mobility decreases due to irradiation by neutrons, and at 1e17 cm-2 fluence it becomes equal to 650 cm2/sV.

- 2. Magnetoresistance effect is suitable to measure the free carrier mobility in the microstrip samples.

- 3. The differences between FZ and MCz Si is intriguing.

- 4. All range of irradiation fluence will be analyzed.

Acknowledgements

Authors are thankfool to AIDA-2020 TNA for the irradiation of samples at TRIGA facility

Vilnius University group thanks LMA-CERN grant for the support

Thank you for your attention!