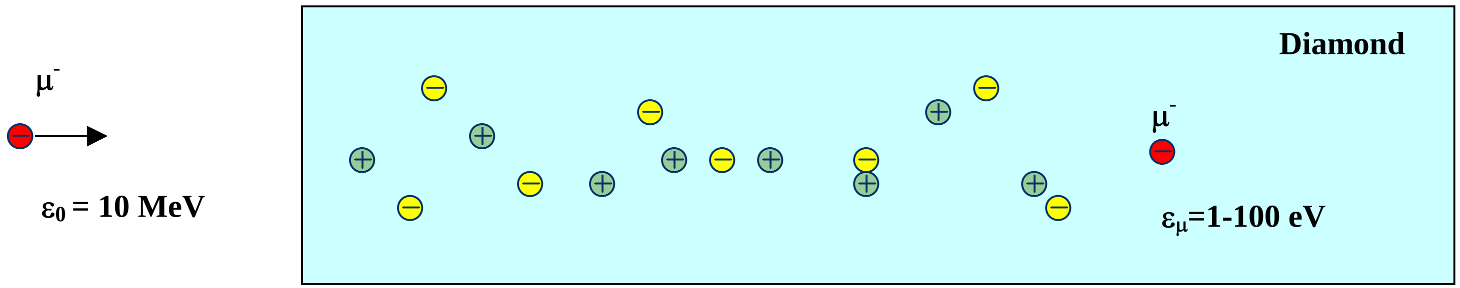
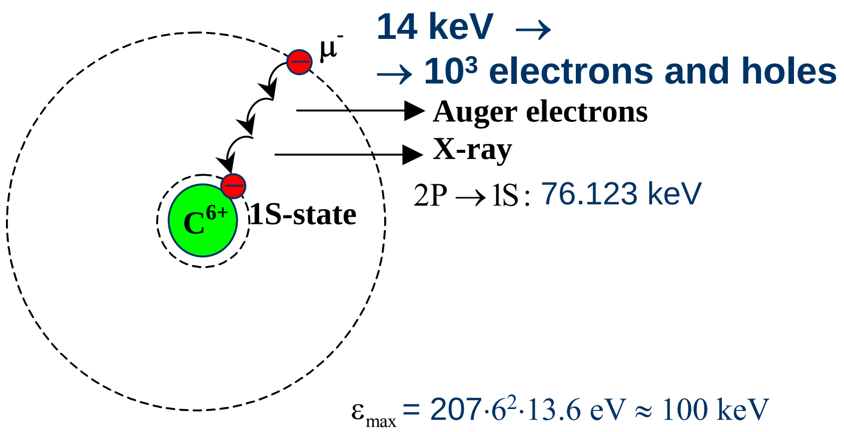
Some remarks on relaxation in diamond

V.N. Gorelkin

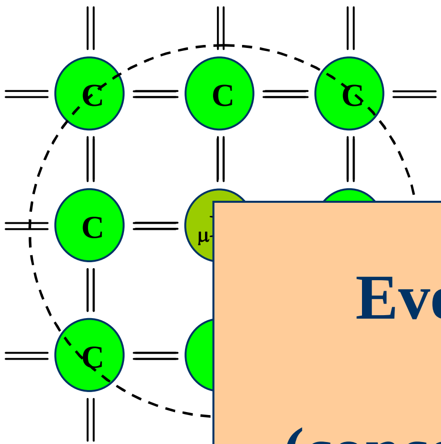
What does it happen with negative muon in diamond?





Negative muon will be stopped in diamond and captured by a carbon atom into 1S state.

Acceptor center in diamond



$_{\mu}$B muonic atom is a substitution impurity (acceptor) in diamond.

Everything discussed is valid only for pure samples (concentration less than 10^{17}cm^{-3})! Will be discussed in details later.

$A_{\mu B\_diamon}$

$\varepsilon_{\mu B\_diamond}$

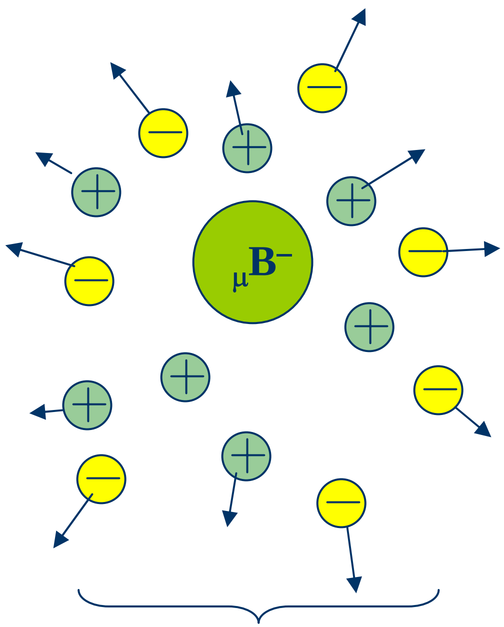
High relaxation rate of muon polarization in paramagnetic state

$A_{\mu Al\_Si} = 25$ MHz $a_{\mu Al\_Si} = 30$ Å

$A_{Mu} = 4.46$ GHz $a_{Mu} = 0.5$ Å

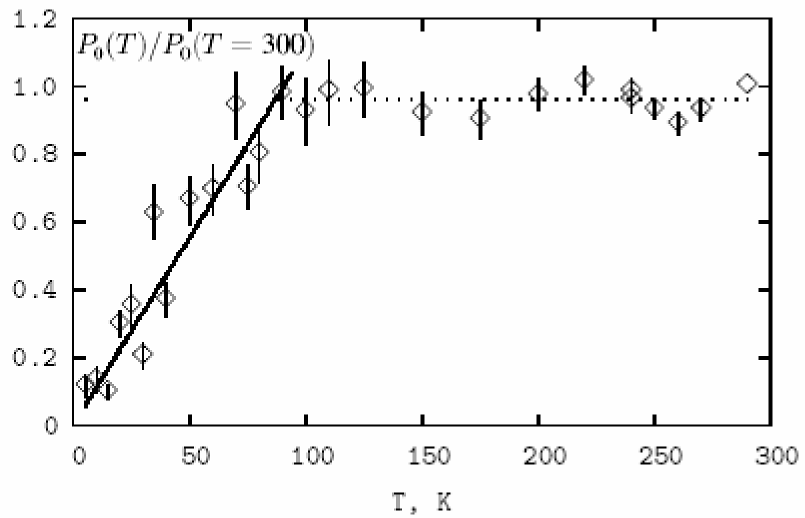
Muonic boron acceptor in diamond

$t \sim 10^{-16} – 10^{-14}$ s → Diamagnetic state



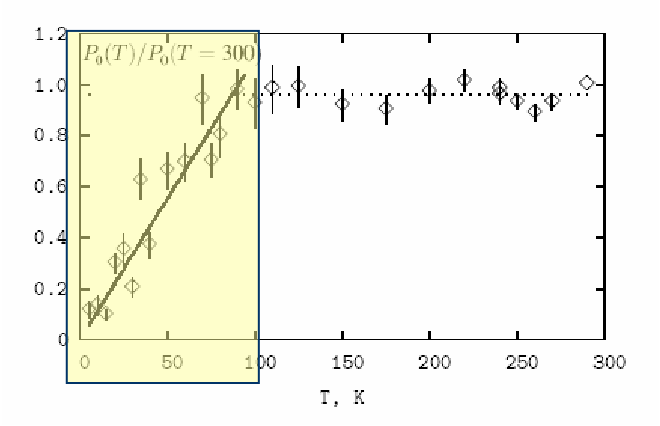
Charges produced by Auger electrons

Typical temperature dependence of μ$^-$ polarization amplitude



- T.N. Mamedov et al, JINR Preprint, P14-2004-104, Dubna (2004).
- T.N. Mamedov, D. Andreica, A.S. Baturin, D. Herlach, V.N. Gorelkin, K.I. Gritsaj, V.G. Ralchenko, A.V. Stoykov, V.A. Zhukov, U. Zimmermann, ”Behavior of shallow acceptor impurity in uniaxially stressed silicon and in synthetic diamond studied by μ$^-$SR”, μSR2005, poster P80 (2005), submitted to Physica B.

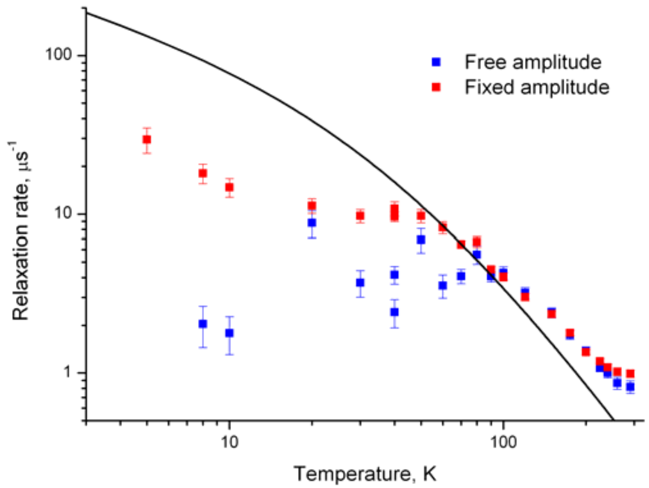
Low temperature region

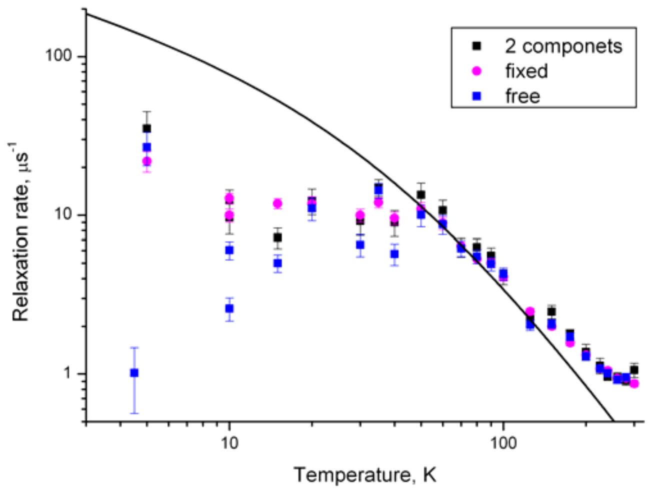


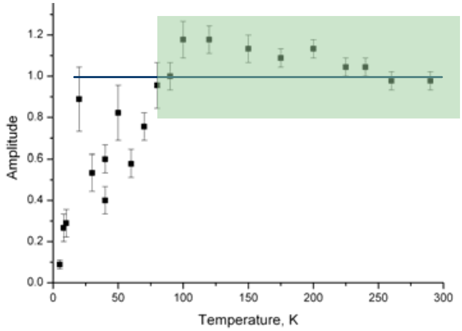
Negative mobility of electrons and holes at low temperature provides fast (less than 10^{-9} sec) and unobservable in μSR "relaxation" (damping of polarization). One can detect it as a reduction of polarization amplitude.

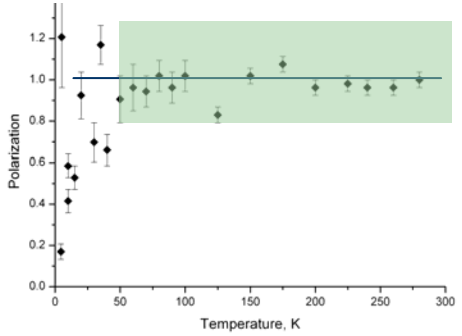
Experiment of Mamedov et al (2005)
Based on material of previous report

High temperature region









Capture of charge carrier on the Columb center

Tompson's radius

$$-U\left(r_T\right) \approx \frac{3}{2} kT \longrightarrow r_T = \frac{e^2}{\varepsilon\, kT}$$

Cross section of carrier capture ($r_T < l_0$)

l_0 – length of energy loss,

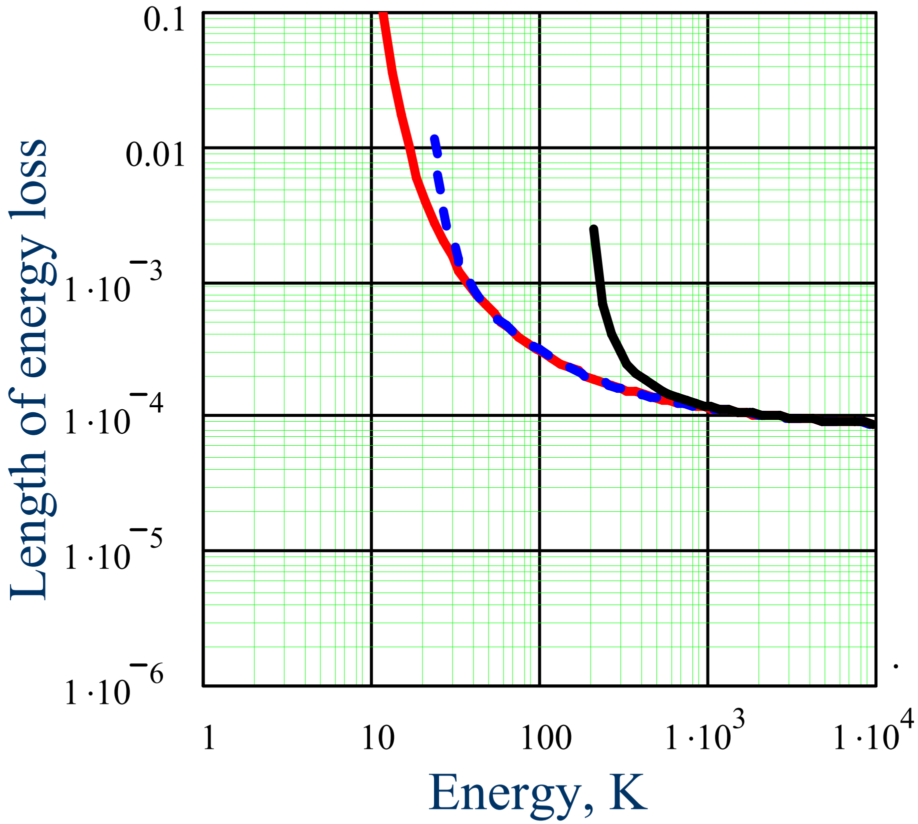
s – speed of sound, m – effective mass

$$\sigma \approx \frac{r_T}{l_0} r_T^{\ 2}$$

$$\sigma = \frac{4\pi}{3 l_0} \frac{e^2}{\varepsilon\, kT} \left(\frac{e^2}{\varepsilon\left(kT + 2.74 m s^2\right)} \right)^2 \qquad K = \sigma \sqrt{\frac{8kT}{\pi m}}$$

V.N. Abakumov, V.I. Perel et al, Sov. Phys.Tech.Semicond. 12 (1978) p.3

Length of hole energy loss
(acoustic phonon emission)



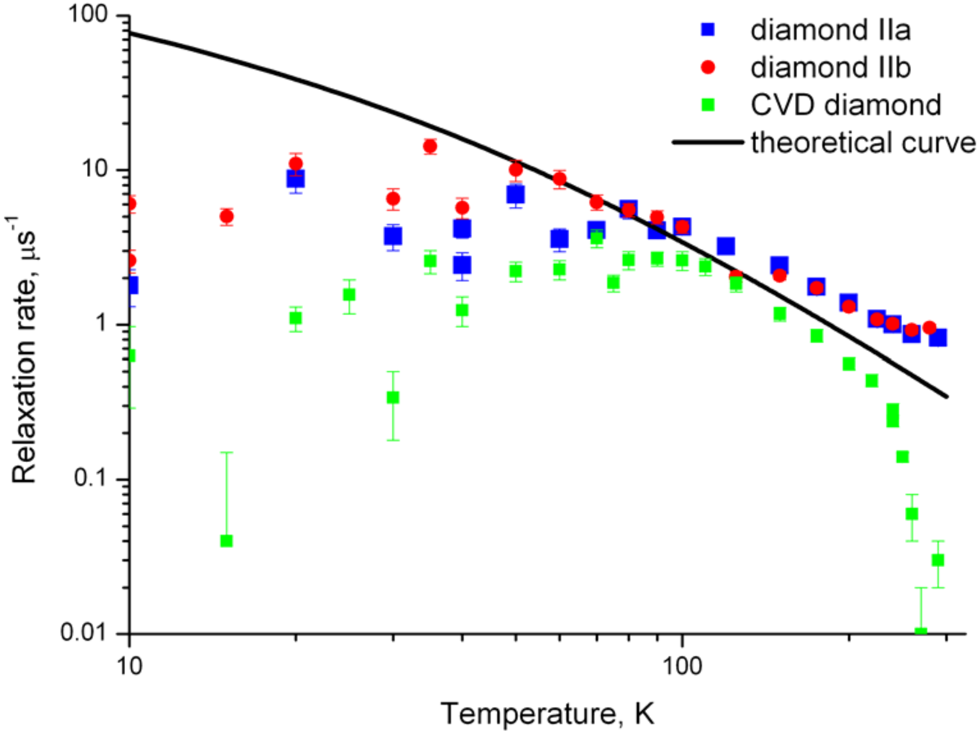
$\Xi = 11.5$ eV

$m_p = 0.7\ m_{e0}$

$s = 1.86 \cdot 10^6$ cm/s

$l_0 = 10^{-4}$ cm

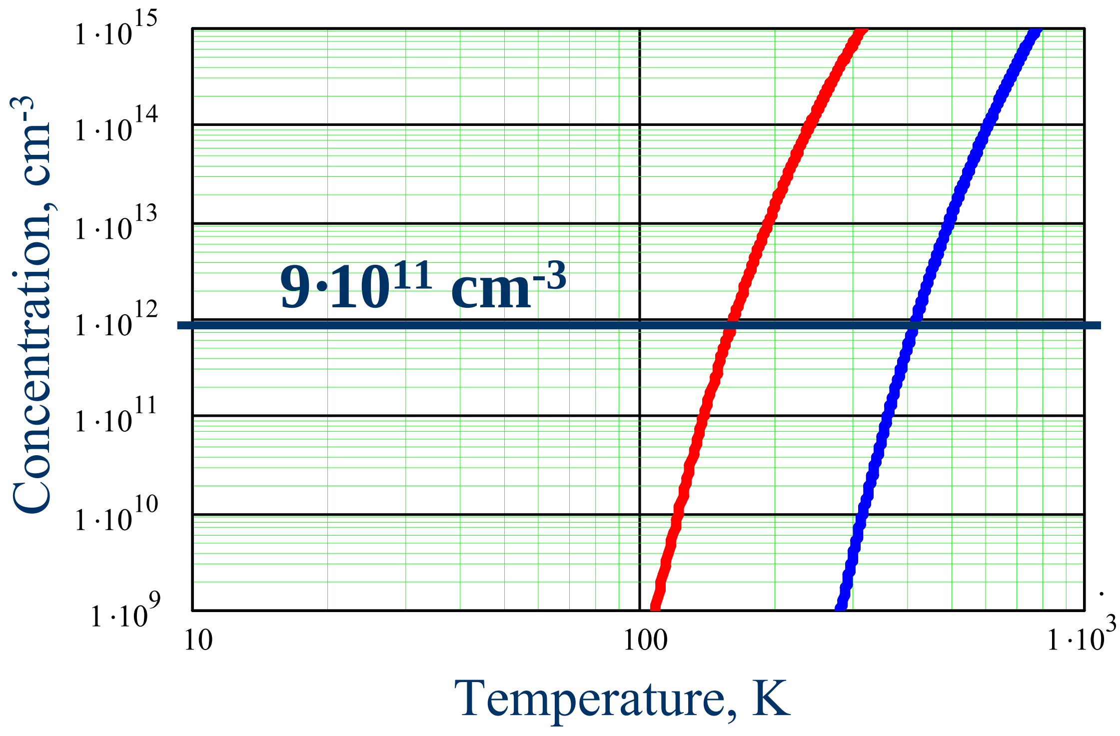
Comparison of theoretical prediction and experiments



$$\lambda = nK = n\sigma v$$

$$n = 9\cdot10^{11}\ \text{cm}^{-3}$$

Thermal concentration



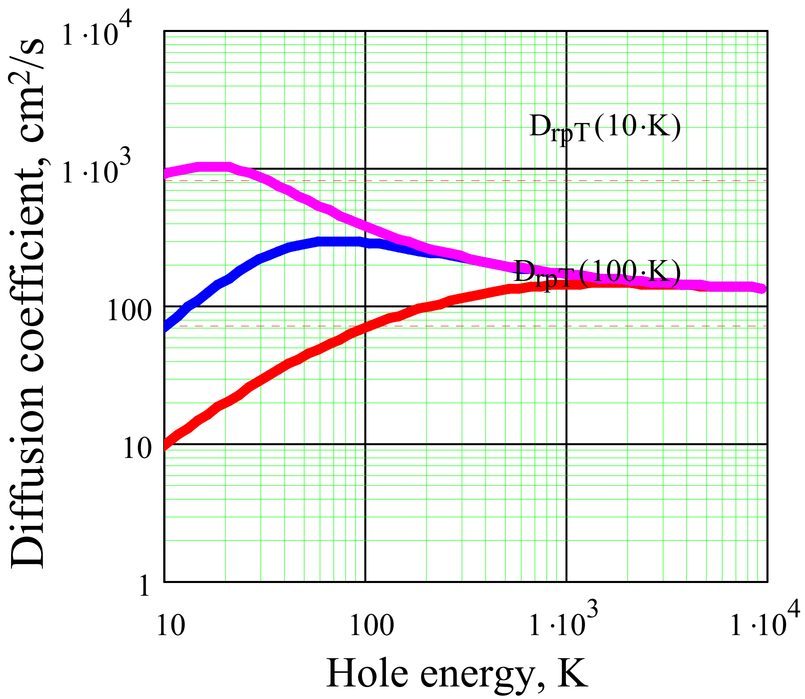
$N_0 = 10^{17}$ cm^{-3}

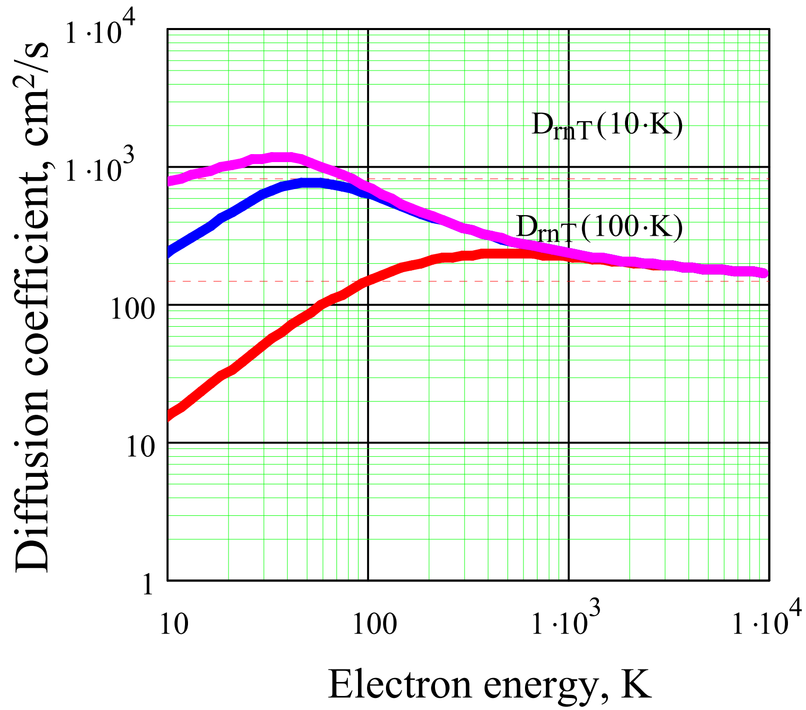
Red – 0.37 eV

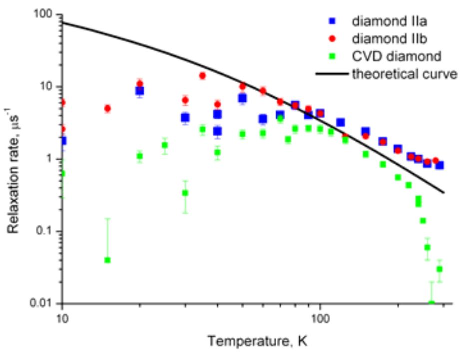
Blue – 1 eV

Diffusion coefficient vs. energy at the different temperatures

Red – 10 K, blue – 30 K, magenta – 100 K

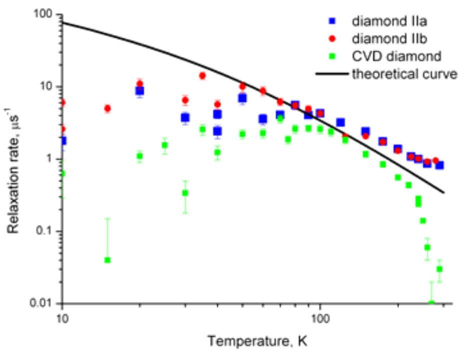






Conclusion I

- At all temperatures CAPTURE of holes is a primary mechanist of “relaxation” (damping of polarization).
- There are two temperature regions with quite different mechanism of temperature dependence of observables.
- At **low temperatures (<50K)** there is a very fast “relaxation”, which could not be resolved in µSR experiment, and effective reduction of amplitude is registered.



Conclusion II

- At temperatures **50K – 100 K** the relaxation is determined by capture of the non-equilibrium holes (influence of track).
- At temperatures **more than 100 K** the equilibrium holes will also determine the capture rate.
- NOTE! The pure relaxation (phonon mechanisms) should be taken into account at the temperatures more than 100 K
- NOTE! The pure relaxation (exchange with neighbors) should be taken into account at high concentration of impurities (more than 10^{17} cm^{-3}).

Acknowledgments

I would like to thank Tair Mamedov for presenting the experimental data prior to publication.

Thank you

for your attention!

How to find the parameter Ξ?

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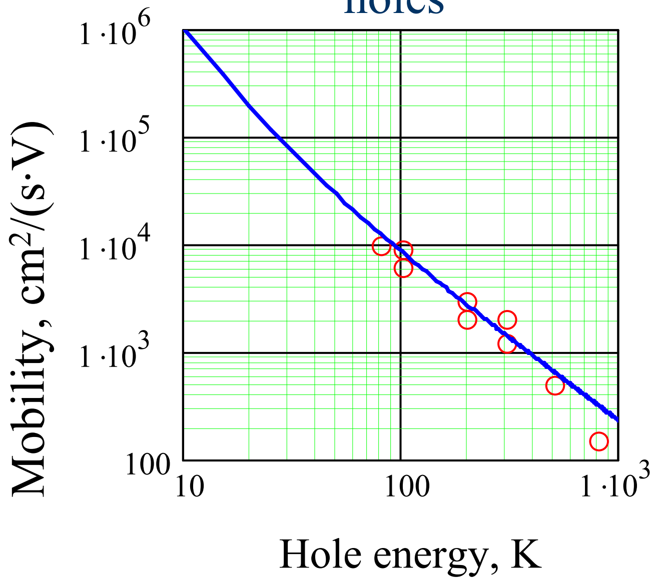
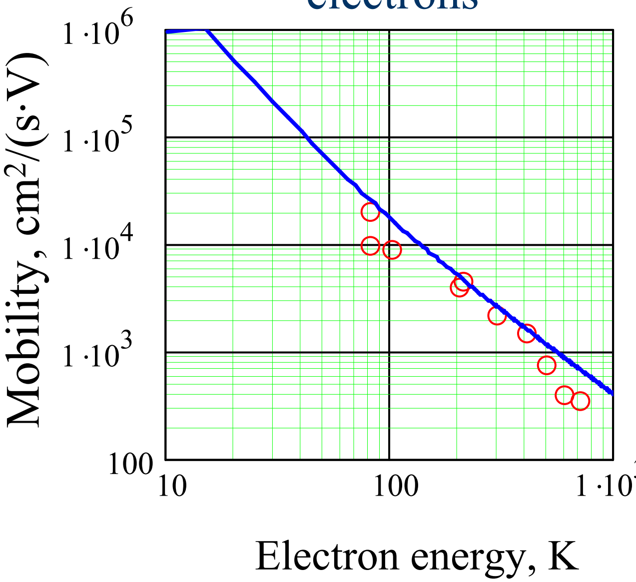
Fitting of known data for mobility of thermalized

holes and electrons





$$b_{\mathrm{T}} = 2.15\cdot 10^{4}\,\frac{\mathrm{cm}^2}{\mathrm{V\cdot s}}\left(\frac{m_{\mathrm{e}}}{m_{\mathrm{eff}}}\right)^{2.5}\left(\frac{\mathrm{eV}}{\Xi}\right)^{2}\left(\frac{c}{10^{6}\,\frac{\mathrm{cm}}{\mathrm{s}}}\right)^{2}\left(\frac{300\mathrm{K}}{T}\right)^{1.5}\left(1+\frac{m_{\mathrm{eff}}c^2}{kT}+2\left(\frac{m_{\mathrm{eff}}c^2}{kT}\right)^{2}\right)$$