Estimation of exchange integral between acceptor centers in silicon from μSR experiments

V.N. Gorelkin

Moscow Institute of Physics and Technology

Plan

- Motivation
- Role of spin exchange with neighbors for doped *p*-type samples with concentration more than 10^{17} cm^{-3}.
- Estimation of exchange integral
- Conclusion

Motivation

- Knowledge of exchange integral between impurities in the semiconductors is extremely important information for development of solid state quantum computer utilizing spins of shallow impurities.
- X.Hu and S. Das Sarma, Phys. Rev. A 64, 042312 (2001).
- B. Koiller, X. Hu, S. Das Sarma, Exchange in silicon-based quantum computer architectures, cond-mat/0106259.

Publication on μ^-SR experiments with silicon

1. V. N. Gorelkin, T. N. Mamedov, D. V. Rubtsov, Hyp. Int. (C) 1, 191 (1996).
2. В. Н. Горелкин, В. Г. Гребинник, К. И. Грицай и др., Ядерная Физика 56, 29 (1993).
3. T. N. Mamedov, V. N. Duginov, V. G. Grebennik et al., Hyp. Int. 86, 717 (1994).
4. Т. Н.Мамедов, В. Н. Горелкин, В. Г. Гребенник, и др., Письма в ЖЭТФ 63, 539 (1996).
5. T. N. Mamedov, I. L. Chaplygin, V. N. Duginov et al., Hyperfine Interactions 105, 345 (1997).
6. Т. Н.Мамедов, В. Н.Дугинов, Д. Герлах и др., Письма в ЖЭТФ 68, 64 (1998).
7. T. N. Mamedov, I. L. Chaplygin, V. N. Duginov et al., J.Phys.: Cond. Matter. 11, 2849 (1999).
8. Т. Н. Мамедов, Д. Г. Андрианов, Д. Герлах и др., Письма в ЖЭТФ 71, 637 (2000).
9. T. N. Mamedov, K. I. Gritsaj, A. V. Stoikov et al, Physica B 289-290, 574 (2000).
10. Т. Н. Мамедов, Д. Г. Андрианов, Д. Герлах и др., ЖЭТФ 119, 1159 (2001).
11. Т. Н. Мамедов, Д. Г. Андрианов, Д. Герлах и др., Письма в ЖЭТФ 73, 759 (2001).

Т. Н.Мамедов, А. В. Стойков, В. Н. Горелкин, Физика элементарных частиц и атомного ядра 33, вып. 4, 1005 (2002).

Muon spin relaxation in silicon

For high relaxation rate of electron shell $\nu_e >> A$

$$\Lambda = \frac{5A^2}{4\nu_e}\left(1 + \frac{1}{1+(\omega_e/\nu_e)^2}\right)$$

V. N. Gorelkin, T. N. Mamedov, A. S. Baturin, Physica B 289-290, 585 (2000).

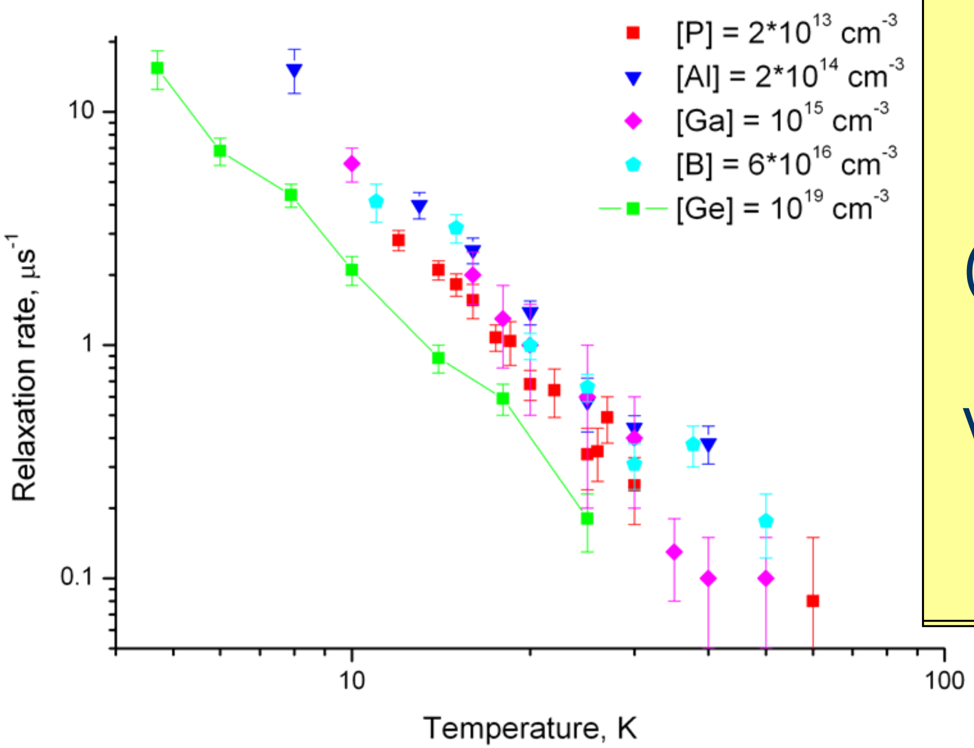
$$\nu_e(T) = CT^q + \nu_0 + \sigma_{ex} v_T(T) n(T)$$

Scattering of acoustic phonons

Exchange with neighbors

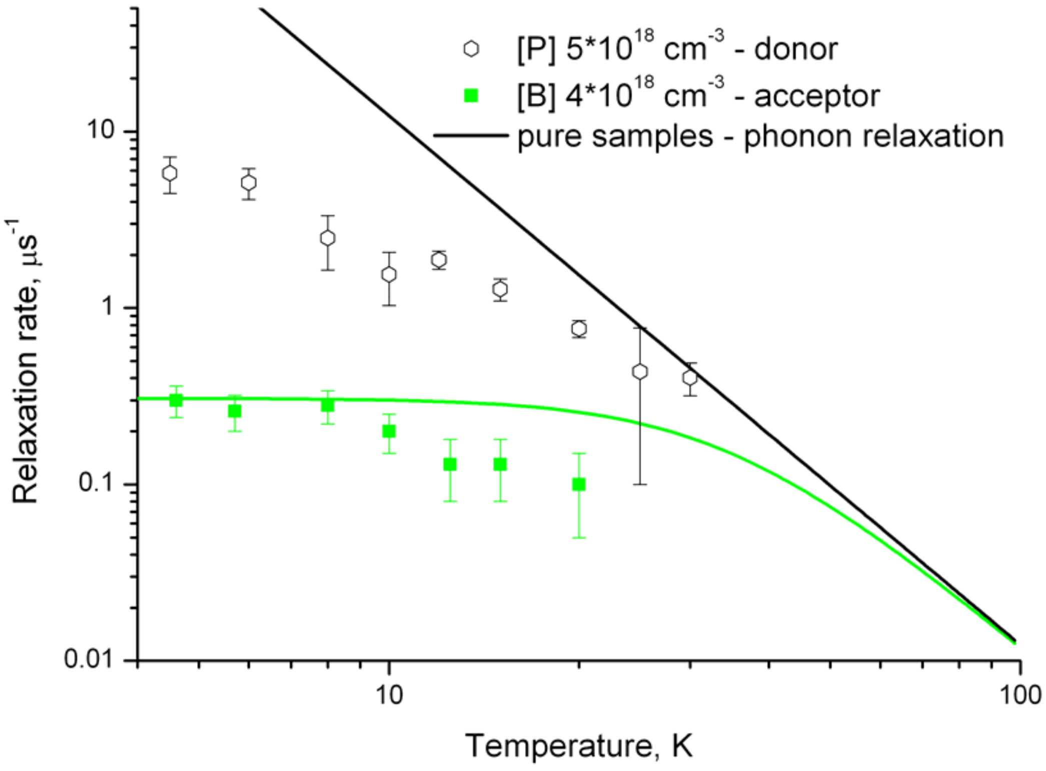
Scattering of free charge carriers

Low impurity concentration

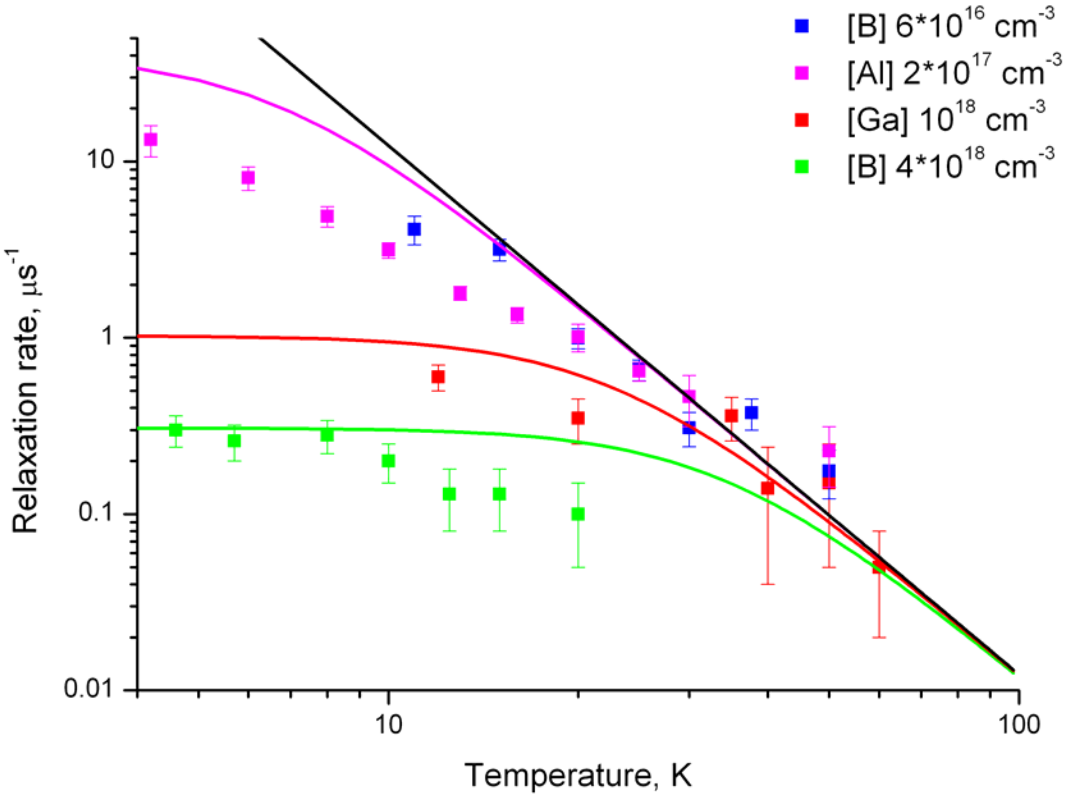


Extremely high concentration of isoelectron impurity (Ge) provides a small variation of sound velocity and relatively large variations of relaxation rate.

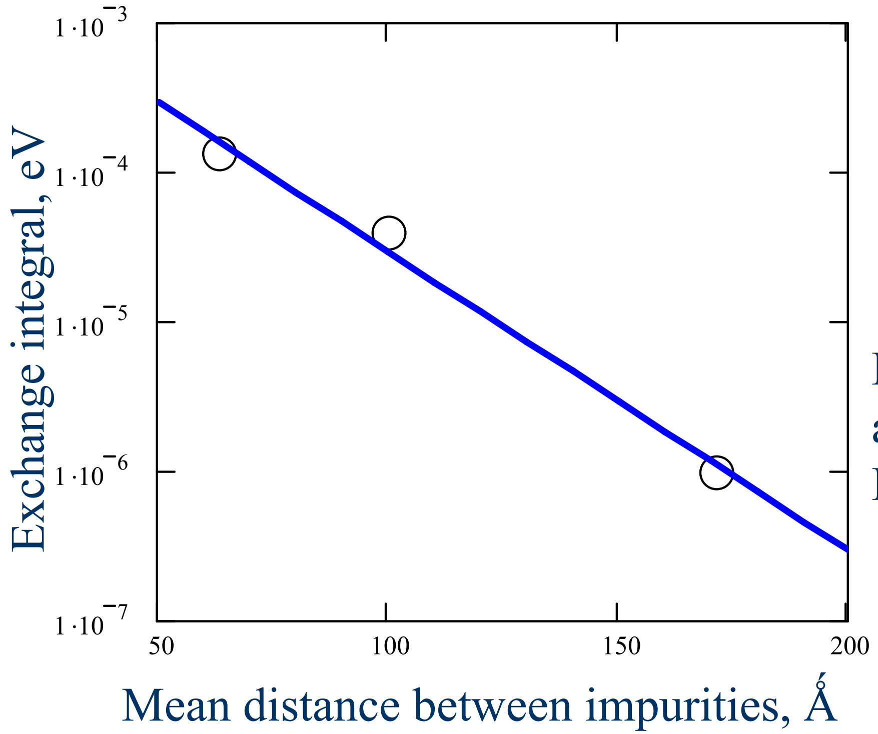
Comparison of exchange interaction with acceptors and donors



High concentration of acceptors
(10^{17} … 10^{18} cm^{-3})



Estimation of exchange integral



$$\nu_e(T) = CT^q + \nu_0 + \sigma_{ex} v_T(T) n(T)$$

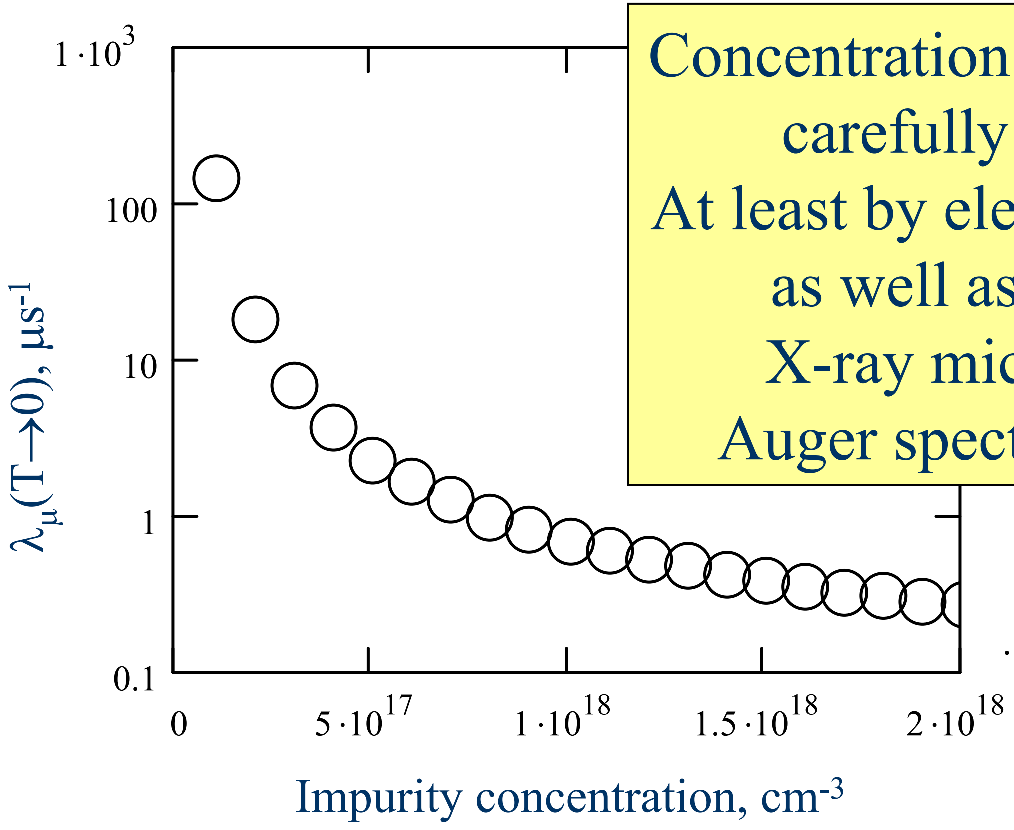
Exchange with neighbors

Dots corresponds to the low temperature asymptotic in the previous figure.
Line is fit by formula

$$\nu_0 = C \exp\left(-\frac{r}{r_0}\right)$$

$C = 4.5*10^{12}$ s^{-1} = 3 meV, $r_0 = 22$ Å

Asymptotic value of muon relaxation rate at low temperature



Concentration should be very carefully measured.
At least by electrical method,
as well as by SIMS,
X-ray microanalysis,
Auger spectroscopy, etc.

$$\nu_e(T) = CT^q + \nu_0 + \sigma_{ex} v_T(T) n(T)$$

Role of different mechanisms
(instead of conclusion)

- Scattering of acoustic phonons play a primary role for a low concentration of impurity (less than 10^{17} cm^{-3}).
- Spin exchange scattering of charge carriers is playing a key role for a high concentration of impurity at **high temperature**
- Exchange with neighbors limits a minimum relaxation rate of electron shell for **low temperatures** and concentration of impurity from 10^{17} cm^{-3} to the Mott-Habbard transition.

Proposal for future experiment

- It would be interesting to measure relaxation rate asymptotic at temperatures below 10K for silicon doped with Al
at concentration from 10^{17} to 10^{18} cm^{-3}.
- This data will allow estimate exchange integral dependence on mean distance between acceptor centers.

Thanks for your attention!

Moscow Institute of Physics and Technology
Institutskij per., 9, Dolgoprudny,
Moscow region, 141700, Russia
Tel. +7 495 408 8766, fax +7 495 409 9543
E-mail: baturin@lafeet.mipt.ru