Phonon-induced spin depolarization of conduction electrons in silicon crystals

D. Persano Adorno, N. Pizzolato, C. Graceffa
Department of Physics and Chemistry, University of Palermo,
Viale delle Scienze Ed.18, 90128 Palermo, Italy
e-mail: dominique.persanoadorno@unipa.it

INTRODUCTION

In last decade the process of spin relaxation of conduction electrons in semiconductor structures has been widely investigated, in order to use spin polarization as information carrier [1]. However, each initial non-equilibrium orientation decays over time during the transport. Thus, to make feasible the implementation of spin-based electronic devices, the features of spin relaxation at relatively high temperatures, jointly with the influence of transport conditions, should be fully understood [1]. Electrical injection of spin polarization in silicon structures up to room temperature has been experimentally carried out [2]. Despite these promising experimental results, a comprehensive theoretical framework accounting for the spin depolarization process in silicon crystals, in a wide range of temperature values, doping concentration, and amplitude of external fields, is still in a developing stage [3-4].

Here, by using a semiclassical multiparticle Monte Carlo (MC) approach, we simulate spin transport in lightly doped n-type Si samples and calculate the spin lifetimes of conduction electrons. Spin flipping is taken into account through the Elliot-Yafet mechanism, which is dominant in group IV materials.

MODEL

In our MC algorithm, the conduction band of silicon is represented by six equivalent X valleys. The code includes both intervalley and intravalley scattering of electrons in multiple energy valleys. For all the numerical simulations discussed below, we have used the model and the parameters reported in Ref. [5]. All results were obtained in Si with a free electron concentration of 10^{13} cm^{-3} (non-degenerate low-doped n-type). Our model takes into account the effects on spin flipping due to (i) the intravalley acoustic phonons and (ii) the optical phonons related to the transitions between perpendicular valleys (f-processes). More details and the explicit calculation of the spin-flip matrix elements utilized in our code can be found in Refs.[6-7].

RESULTS

The dependence of spin relaxation times on temperature and/or electric field amplitude has been investigated by simulating the dynamics of 5×10^3 electrons initially polarized ($P = 1$) along the x-axis of the crystal at the injection plane. We calculate the polarization P as a function of time by averaging over the ensemble of electrons. The spin lifetime τ_s corresponds to the time necessary to achieve a reduction of the initial spin polarization by a factor 1/e. Our results are shown in Figs. 1-3, where the electron spin total lifetime computed in our simulations is compared with recent theoretical and experimental findings.

CONCLUSION

Our results are in good agreement with both those obtained by using different theoretical approaches and the available experimental data. Furthermore, our Monte Carlo predictions in the ranges of temperature and field amplitude yet unexplored can guide future experimental studies towards a more effective design of efficient room-temperature silicon- based spintronic devices.

REFERENCES

[1] J. Fabian, A. Matos-Abiague, C. Ertier, P. Stano, and I. Zutic, Acta Phys. Slovaca **57**, 565 (2007).
[2] S.P. Dash, S. Sharma, R.S. Patel, M.P. de Jong, and R. Jansen, Nature **462**, 491–494 (2009).
[3] J.L. Cheng, M.W. Wu, and J. Fabian, Phys. Rev. Lett. **104**, 016601-4 (2010).
[4] P. Li and H. Dery, Phys. Rev. Lett. **107**, 107203-5 (2011).
[5] D. Persano Adorno, M. Zarcone, and G. Ferrante, Laser Phys. **11**, 291–295 (2001).
[6] Y. Song and H. Dery, Phys. Rev. B **86**, 085201-28 (2012).
[7] D. Persano Adorno et al, Lith. J. Phys. (in press).

ISBN 978-2-9547858-0-6

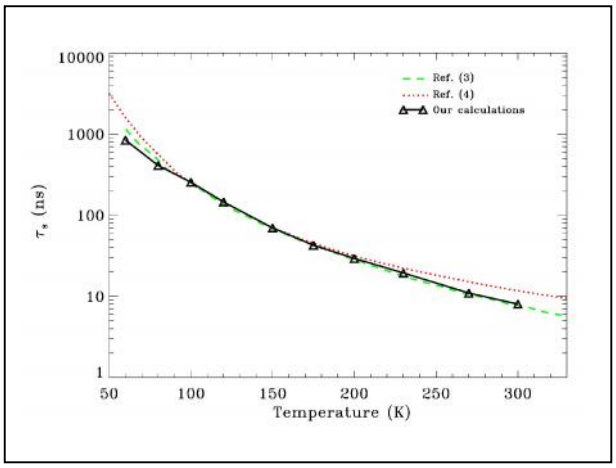

Fig. 1. Comparison between our numerical outcomes and the findings obtained from recent analytical calculations.

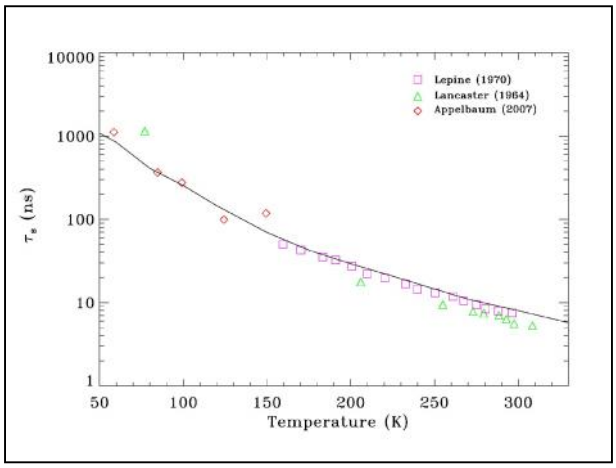

Fig. 2. Comparison between our MC numerical spin lifetimes and the available experimental results, obtained in absence of electric field.

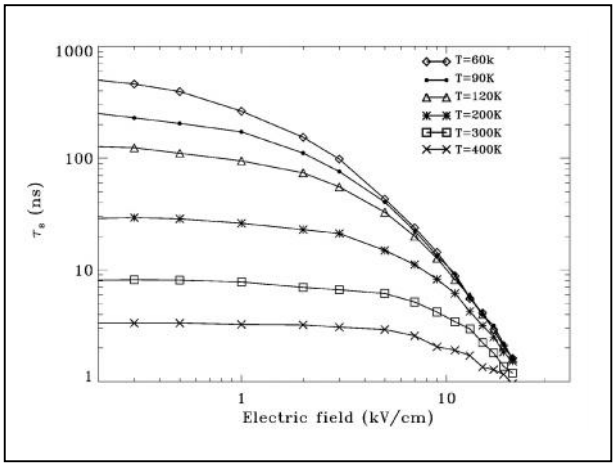

Fig. 3. Estimated spin lifetimes of drifting electrons in n-type Si crystals, at different temperatures and under different electron transport conditions, where up today no experimental data are yet available.