# Elliot-Yafet Spin Relaxation Time for Elemental Two-dimensional Materials from First-Principles Calculations

We have studied the Elliot-Yafet spin relaxation time for elemental two-dimensional materials, including graphene, silicene, germanene, stanene, arsenene and antimonene. The Elliot-Yafet spin relaxation time is correlated to momentum relaxation time by the spin mixing parameter $\langle b^2 \rangle$. Large anisotropy for Elliot-Yafet spin relaxation time was revealed for these two-dimensional materials between in-plane and out-of-plane directions.

Long spin relaxation times are obviously advantageous for most applications of spintronics. In recent years, the spin relaxation time for two-dimensional materials has attracted the attention from both experimental [1] and theoretical [2] groups. In the commonly used non-local measurements, ferromagnetic metal electrodes inject and detect spins in normal conductors. Spin relaxation in a non-magnetic conductor is the physical process that restores a non-equilibrium spin polarization to the un-polarized equilibrium state. Two spin relaxation mechanisms are considered in normal metals and doped semiconductors: 1) the Elliot-Yafet mechanism, which is caused by ordinary scattering by phonons, impurities, boundaries or interfaces; 2) the D'yakonov-Perel' mechanism, which is important in systems with broken inversion symmetry that generate momentum-dependent internal magnetic fields and cause spin precession.

All elemental two-dimensional materials are inversion symmetric, which means that the D'yakovov Perel' mechanism is extrinsic, i.e. active only in the presence of external fields or due to the interaction with substrates Here we focus on the Elliot-Yafet spin relaxation.time, which can be computed by the simplified relation

$$1/\tau_{s,EY} \approx 4\langle b_{nk}^2 \rangle / \tau_k ,$$

where $\tau_k$ is the momentum relaxation time caused by phonon scattering (for which we assume the typical value of 100 fs). $\langle b_{nk}^2 \rangle$ is the Fermi-Dirac distribution averaged spin-mixing parameter that accounts for the effects of spin-orbit coupling on the electronic eigenstates (which also causes the deviations of the *g*-factor from 2 for electrons in solids).

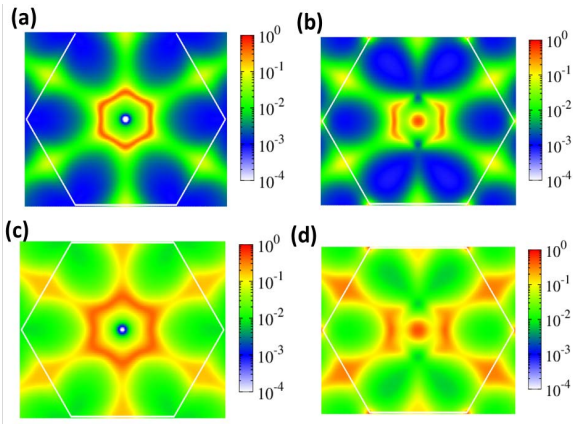


Fig. 1 Spin-mixing parameter $b_k^2$ over the first Brillouin zone of arsenene for holes in (a) the out-of-plane direction and (b) in-plane armchair direction. (c) and (d) same as (a) and (b), respectively, but for antimonene.

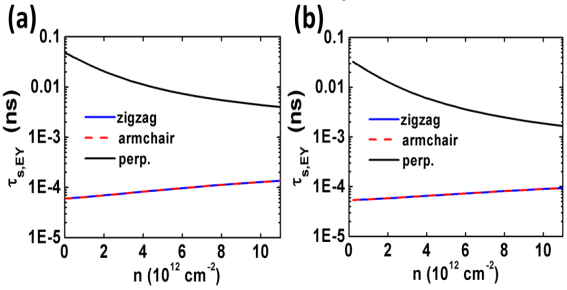


Fig. 2 Elliot-Yafet spin relaxation time as a function of hole density at 300 K in (a) arsenene and (b) antimonene for in-plane (zigzag and armchair) and out-of-plane directions (perp.).

Figs. 1 and 2 show the spin-mixing parameter and spin relaxation time for arsenene and antimonene, respectively. We reveal a large anisotropy between in-plane and out-of-plane directions for the Elliot-Yafet spin relaxation time with $\tau_{\parallel}/\tau_{\perp} \approx 0$ also for the other two-dimensional materials

We plan to also calculate spin relaxation by the D'yakonov-Perel' mechanism in order to be in a position to compare theory with experiments.

## References

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Keywords: spintronic, first principles calculations, elemental

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