

# Spin Dynamics in High-Quality Graphene: Role of Electron-Hole Puddles and Spin-Pseudospin Coupling

Dinh Van Tuan<sup>1,2</sup>, Frank Ortmann<sup>1,3</sup>, Aron W. Cummings<sup>1</sup>, David Soriano<sup>1</sup>, Sergio O. Valenzuela<sup>1,4</sup> and Stephan Roche<sup>1,4</sup>

<sup>1</sup>ICN2 - Institut Catala de Nanociencia i Nanotecnologia, Campus UAB, 08193 Bellaterra (Barcelona), Spain

<sup>2</sup>Department of Physics, Universitat Autònoma de Barcelona, Campus UAB, 08193 Bellaterra, Spain

<sup>3</sup> Institute for Materials Science and Max Bergmann Center of Biomaterials, Technische Universität Dresden, 01062 Dresden, Germany

<sup>4</sup>ICREA, Institució Catalana de Recerca i Estudis Avançats, 08070 Barcelona, Spain

Contact: [tuan.dinh@icn.cat](mailto:tuan.dinh@icn.cat)

## Abstract

We report a strong spin dephasing effect induced by electron-hole puddles[1, 2] and spin-pseudospin coupling in ultraclean graphene, with long mean free path and uniform Rashba spin-orbit coupling as low as a few tens of  $\mu\text{eV}$  [3]. From the time dependence of spin dynamics of propagating wave packets, spin relaxation times typically on the order of few hundreds of picoseconds to the nanosecond scale are extracted, depending on the substrate-induced electron-hole characteristics. The energy dependence of spin relaxation times[4], together with the obtained ratio for spins pointing out-of-plane to spins in-plane ( $\tau_s^\perp/\tau_s^\parallel$ ), and scaling of spin lifetimes with disorder provide a consistent description of fundamentals of spin lifetimes [5] in the ultraclean graphene limit.

## References

- [1] J. Martin *et al.*, *Nature Physics* **4**, 144-148 (2008)
- [2] Y. Zhang *et al.*, *Nature Physics* **5**, 722 (2009)
- [3] C. R. Ast and I. Gierz, *Phys. Rev. B* **86**, 085105 (2012)
- [4] Dinh Van Tuan, Frank Ortmann, David Soriano, Sergio O. Valenzuela and Stephan Roche, Pseudospin-driven spin relaxation mechanism in graphene. *Nature Physics* **10**, 857-863 (2014).
- [5] Dinh Van Tuan, Frank Ortmann, Aron W. Cummings, David Soriano, Sergio O. Valenzuela and Stephan Roche, Spin Dynamics in High-Quality Graphene: Role of Electron-Hole Puddles and Spin-Pseudospin Coupling. *Submitted to Phys. Rev. Lett.* .

## Figures

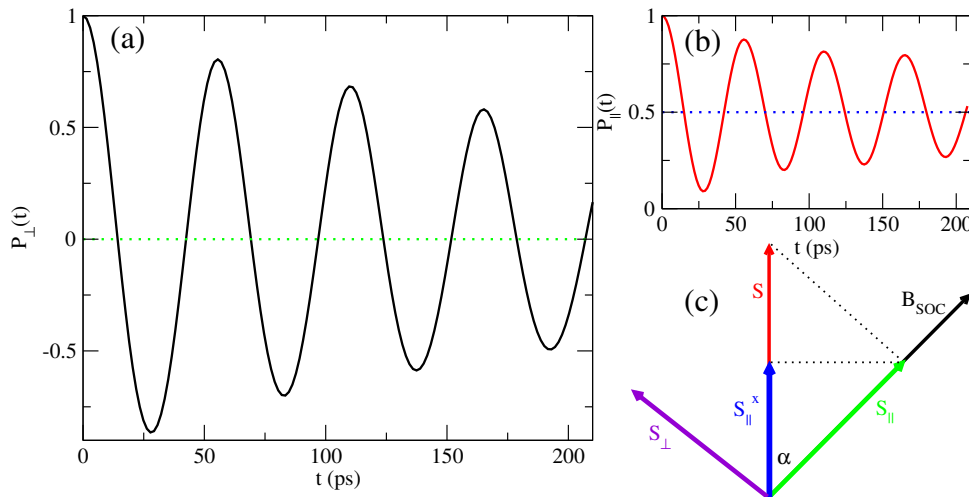


Figure 1: Spin polarizations for out-of-plane (a) and in-plane (b) spin injections. (c): Illustration of parallel (green) and perpendicular (violet) components. The projection of parallel component in x direction is shown in blue.

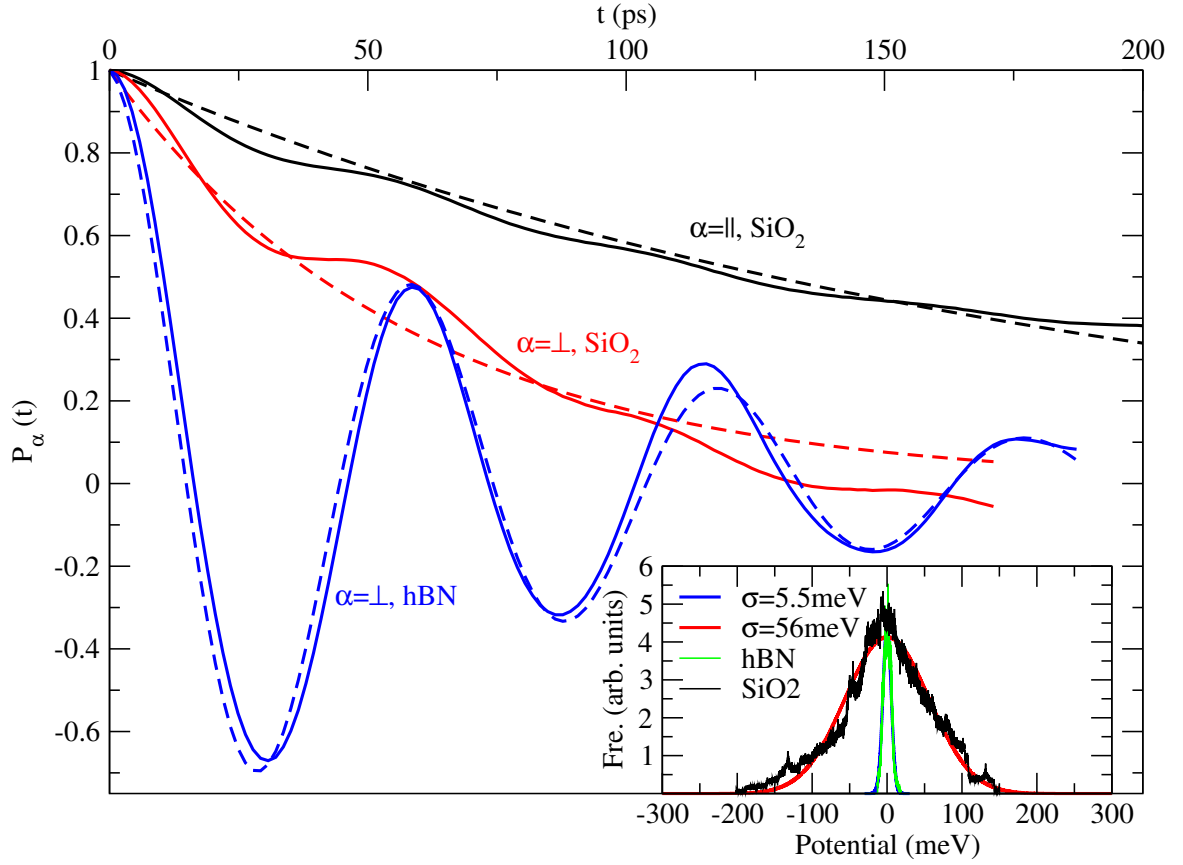


Figure 2: Time-dependent spin polarization for in- plane and out-of-plane polarized wavepacket in graphene on hBN and SiO2 substrates. Inset: Onsite energy distribution of the carbon atoms in the graphene sample, which mimics the chemical potential induced by hBN (green) and SiO2 (black) substrates together with their Gaussian fitting lines.