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Nanoscale Currents Improve Understanding of Quantum Phenomena

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Intrinsic currents associated with quantum states can play an important role in designing new quantum technologies.

Besides charge, subatomic particles like electrons also carry a property called spin, which is responsible for magnetism. Novel proposals to use spin to store information have emerged in recent years with the promise to be more energy efficient and to bring new functionalities to devices of communication and sensing. For his PhD research, Adonai Rodrigues Da Cruz studied the spin dynamics in more detail using theory and numerical simulations. He defended his thesis at the department of Applied Physics on May 3rd.

Spin defects

The ability to control single quantum states is crucial for the development of new quantum technologies for future communication, sensing, and information processing devices. In recent years, a number of novel ways of using electron spin to store digital information in such quantum technologies have been proposed.

The use of defects in semiconductor materials carrying spin (so called spin defects) have been promoted as materials to create quantum bits – the key component of any quantum technology.

Sensors based on spin defects, such as the nitrogen-vacancy (NV) center in diamond, are already commercially available and have emerged as the most exciting new technology for nanoscale magnetic measurements. By controlling and interrogating the spin state of this crystal defect, researchers have been able to measure extremely small magnetic fields, and thus study the properties of new materials in more detail.

Understanding orbital effects

Up to now, both experimental and theoretical studies on single defects in semiconductors have focused more on the spin part and largely neglected the orbital contribution to the local properties around the defects.

For his PhD research, Adonai Rodrigues Da Cruz sought a better understand of the orbital effects. This insight was provided through the development of theoretical formalisms to describe circulating currents in different materials. Using numerical simulations and analytic expressions for the propagation of electrons in two-dimensional semiconductors, he accurately predicted how nano-currents distribute according to the surrounding environment.

Fringe magnetic fields can be generated by the circulating currents around single spin defects located inside the semiconductors. One of the main findings of Da Cruz's research is that both the magnitude and spatial dimensions of the fringe magnetic field are within the desired range of sensitivity of current NV-based probes. Therefore, a scanning NV sensor could be used as a direct probe of the internal orbital magnetism associated with single defects.

Da Cruz's work also suggests that the spatial features of the currents can be strongly tuned by external gating, opening up the possibility of electrically control short-distance spin couplings, which is essential for quantum entangling gate, an important operation in quantum computing.

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