Electrical detection of THz Ramsey interference for orbital transitions in silicon donor impurities

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Shallow donor impurities in silicon, once frozen out at low temperature, share many properties in common with free hydrogen atoms [1]. They have long been the subject of spectroscopic investigation, but it is only very recently [2,3] that it has been possible to investigate the time-domain dynamics of orbital excitations such as the 1s to 2p, due to the difficulty of obtaining short, intense pulses in the relevant wavelength range, around 10THz. These new techniques make shallow donors (and also acceptors [4]) attractive for studying atomic physics effects, and for applications in quantum information. We have measured the population dynamics of electrons orbiting around phosphorus impurities in commercially-available silicon, using a free electron laser as the THz source, and shown that the lattice relaxation lifetime is about 200ps, only 1 order of magnitude shorter than the radiative lifetime of free hydrogen.

Coherent oscillation, where many particles cycle in phase, is responsible for classical phenomena like the emission of strong radio waves by many individual electrons in an antenna. At the quantum scale, coherent superposition of spin polarisations are central to Magnetic Resonance Imaging and its analogues, in which coherence is excited and then reappears later producing a delayed radio pulse (the spin “echo”). Quantum computer logic will also rely on coherence, and spins are often chosen as “qubits” because they are only weakly connected to, and disturbed by, the environment. Paradoxically, connection with the outside world is crucial for control, making charge (i.e. orbital) oscillations in semiconductors attractive. We have shown that silicon donor electrons can be put into a coherent superposition of orbital states that lasts for nearly as long as the lattice relaxation time [3,5]. The result of sequences of coherent control can also be read out simply using a voltmeter. Our results pave the way for new devices where information is stored in single electron orbits (“coherent orbitronics”) in silicon, the material that has dominated the classical computing industry for half a century.

References

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