Electrostatic quantum rings in phosphorene

Tanmay Thakur and Bartłomiej Szafran

AGH University of Science and Technology,
Faculty of Physics and Applied Computer Science,
al. Mickiewicza 30, 30-059 Kraków, Poland

Phosphorene, a monolayer form of black phosphorus is a 2D material that has been extensively studied in recent years [1,2]. The anisotropy in its crystal structure results in anisotropy in the effective masses [3]. Quantum ring confinement allows for formation of persistent currents in the presence of magnetic field and oscillations in the energy spectrum with a periodicity of Aharonov-Bohm periodicity. However, the anisotropy in phosphorene prevents the flow of persistent current and prohibits Aharonov-Bohm oscillations in the energy spectrum for a circular confinement. We investigate a clean quantum ring defined within phosphorene by electrostatic potential and manipulate the confining potential to restore the persistent currents and the oscillations in the energy spectrum. We use a single-band effective mass Hamiltonian [4] and a tight-binding model to evaluate the energy spectrum as a function of the external magnetic field. The confining potential is parametrized with a parameter, which controls the eccentricity of the potential. The effective mass Hamiltonian is diagonalized using the finite difference method and Lanczos algorithm. We indicate an angular-momentum-like operator which commutes with the Hamiltonian for a value of the eccentricity parameter and show analytically that the spectrum becomes identical to the one of a circular quantum ring with isotropic effective masses. We also discuss the limiting case of an ideal 1D ring and the spectrum for two electron states.

[1] Li, L., Yu, Y., Ye, G. et al., *Nature Nanotech* **9**, 372–377 (2014).

[2] Zhang, G., Huang, S., Wang, F., Yan, H., *Laser & Photonics Reviews 2021* **15**, 6, 2000399 (2021).

[3] Xia, F., Wang, H. & Jia, Y., *Nat Commun.* **5**, 4458 (2014).

[4] B. Szafran, *Phys. Rev. B* **101**, 23, 235313 (2020).