Graphene based integrated electronic, photonic and spintronic circuit

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At present information processing is divided into three physically separate functions realized with three different classes of materials – information processing with silicon transistors, communication with photons using compound semiconductors, and information storage with ferromagnetic metals. Such division is inefficient and, with some materials (like In) in limited quantities, not sustainable. It has been recently predicted theoretically [1-9] that there exists a special class of nanoscale graphene triangular quantum dots (GTQDs) with zigzag edges that fulfils all three functions needed for information processing: (1) size quantization turns graphene, a semimetal, into a semiconductor, with bandgap tunable from THz to UV, hence GTQDs can be used for information processing; (2) GTQDs are equivalent to direct gap semiconductors and hence can be used for optical communication; and (3) GTQDs exhibit voltage tunable magnetic moment hence can be used for information storage. Therefore, it appears feasible that graphene quantum dots can form the basis of new sustainable green nano-electronics and potentially photovoltaics and molecular scale sensing. Since carbon does not have nuclear spin, graphene based chips could form the basis of quantum technology.

These claims are based on our recent work on gated graphene quantum dots. The effect of Coulomb interactions, size, shape, edge and carrier density on the electronic, magnetic and optical properties of GTQDs will be described. Such structures lead to a shell of degenerate zero-energy states at the Fermi level (Dirac point) [1-4]. The degeneracy is proportional to the edge size and can be made macroscopic [5]. Using a combination of tight-binding, density functional, Hartree-Fock and configuration interaction methods we will describe the strongly interacting electronic system, a degenerate shell, as a function of the fractional filling, drawing on analogy with the FQHE [4-9]. In particular, we will show that at half-filling the shell is fully spin polarised but spin polarization can be modulated by controlling the filling of the shell with the external gate. The effect of shell filling and magnetic moment on transport [4] and optical properties [6] of a single quantum dot will be described. When the two dots are stacked vertically in a bi-layer quantum dot the magnetic moments of triangular quantum dots are shown to interact ferromagnetically [9]. The tunability of this magnetic moment with vertical electric field and the possibility of isolating a single electron spin will be demonstrated [9]. These results show [4-9] that it is possible to combine electronic, photonic and magnetic functionalities in a single material system by engineering graphene quantum dot size, shape and character of the edge.

* work in collaboration with A. D. Güçlü, P. Potasz ,O. Voznyy, and M.Korkusinski.

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