Coulomb drag in graphene-based quantum-dot heterostructures

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The phenomenon of Coulomb drag – i.e. a current (or bias) is induced in an unbiased system solely via its Coulomb interaction with a nearby biased system – has been studied extensively in extended systems such as, e.g., 2DEGs and graphene [1]. Only recently was Coulomb drag observed in quantum-dot (QD) systems – in unique graphene-based quantum-dot structures consisting of two capacitively coupled QDs located in separate graphene layers [2,3]. However, while Coulomb drag in extended systems is usually interpreted as momentum transfer between the subsystems, this interpretation does not apply in QD systems. Here, momentum is not a good quantum number, and Coulomb drag is better viewed as an interaction-mediated energy transfer between the QDs.

The theoretical description of Coulomb drag in strongly coupled QD systems operating in nonequilibrium conditions is challenging. To this end, we introduce a master-equation approach which accounts for the strong correlations between electrons on the two QDs, higher-order tunneling processes, and energy-dependent couplings to the leads [4]. As we demonstrate, this is essential in order for a complete description of Coulomb drag in coupled QD systems. Importantly, in addition to conventional Coulomb drag in QD systems [5], we uncover additional drag mechanisms which are driven by nonlocal multielectron tunneling processes, and which govern the drag current at low bias voltages.

Studying the Coulomb drag in the graphene-based QD heterostructure illustrated in Fig. 1(a)+(b), we establish (i) the conditions for a nonzero drag current as well as its direction in terms of microscopic system parameters, and (ii) the bias dependence of the drag current across different regimes. Interestingly, we find that the drag current is determined by a nontrivial interplay between the energy dependence of the lead couplings and **not** the drive current (see Fig. 1(b)+(c)). Finally, we study the fingerprints of the drag mechanisms in the stability diagram which is characterized by the so-called Coulomb diamonds, and show that the predictions of our theory are consistent with the recent experimental observations [2].

References

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Figure 1: (a) Illustration of a graphene-based quantum-dot heterostructure consisting of two capacitively coupled graphene. A series of top and bottom gates control the electrostatic potentials on the QDs and the adjacent “bulk” graphene leads. (b) Energy-level diagram of the QD heterostructure showing the QD levels and the alignment of the Dirac cones in the leads. Only the bottom dot is biased. (c) Current through the top dot (the drag current) as a function of the gate voltage on the leads.