Plasmon resonances in current between parallel wires of finite length

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Recent technological progress in creation of clean one-dimensional wires, either as carbon nanotubes [1] or as a part of semiconducting structures [2] has attracted much attention to the study of transport through quasi-one-dimensional systems, both experimentally and theoretically [1, 2]. Transport through clean quasi-one dimensional systems probes the main consequences of the Luttinger liquid (LL) theory [3], the spin-charge separation and the charge fractionalization. Experimentally, quasi-1d systems have a finite length, or they are effectively divided into finite size fragments by impurities. If the length is not very large, the quasi-1d systems actually represent one-dimensional quantum dots, with finite charging energy and discrete spectrum [1, 4]. Therefore, the theoretical study of finite-size effects on transport through wires of finite length L that form the LL in the limit $L \to \infty$ is of much importance for the interpretation of experiments.

In this paper, we address those features of a LL that can be seen in experiments on perpendicular transport through two coupled quantum wires of finite length L, analyzing the current–voltage (IV) characteristics of the circuit consisting of the left reservoir, two quantum wires, and the right reservoir, coupled in sequence (see the inset in Fig. 1). The reservoirs are assumed to be noninteracting. There is a magnetic field applied perpendicular to the plane of the wires. Such system can be realized in form of two carbon nanotubes. A similar geometry has been employed in experiments on semiconductor structures [2] with the difference that only one of the wires is of finite length there. Since the discreteness of the spectrum is explicitely taken into account, the results presented here may find analogies in experiments on double quantum dots [5]. We do not consider spin effects, the Luttinger liquids are assumed to be spinless. We derive an analytical expression for the current-voltage characteristics in the lowest order in tunneling to the reservoirs, concentrating on the region within a single Coulomb blockade step.

We found that the interwire interactions facilitate transport at finite bias voltages, as well as thermally activated transport. Our results on IV characteristics are summarized in Fig. 1. The discreteness of the spectrum of a finite-length wire transforms the power-law singularities, typical for the LL, into a series of discrete steps with envelope described by the power-law function of the infinite system. Each step in the IV characteristics corresponds to a plasmon resonance between the LL wires. The *positions* of the steps of the IV curve reflect the quantization of the *charge-mode* of the LL, in particular, the energies of two independent bosonic modes, propagating on the length L with velocities u_1 and u_2 [6]. One of the velocities (u_2 in our case) always renormalizes down by interwire interactions, which results in the lowering of plasmon excitation energies, and hence the facilitation of transport through excited states as compared to the noninteracting wires. The height of each step reflects the strength of the corresponding plasmon resonance, and is also controlled by LL interaction constants. Therefore, IV characteristics should clearly demonstrate the effect of LL interactions. The outlined features are rather insensitive to the geometry of the reservoirs. They can be seen in the case of two- and three-dimensional reservoirs contacted along a whole wire, as well as for a circuit with point-like coupling between the reservoirs and the wires, such as that realized in STM experiments [1]. In contrast, due to strong restrictions imposed by momentum conservation by

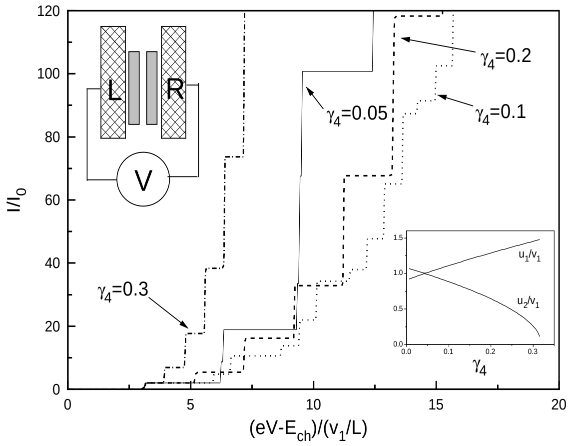

Figure 1: IV characteristics for different interwire interaction constants γ_4. The position of the second step reflecting the current through the first excited plasmon mode shifts to lower voltages with growing γ_4, which indicates the facilitation of current by interactions.

tunneling, the interaction effects can hardly be seen in the case of one-dimensional reservoirs parallel to the wires.

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