Fractionalized Wave Packets from an Artificial Tomonaga-Luttinger Liquid

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An elementary charge excitation can appear at a junction of totally different entities, for example an interacting one-dimensional conductor, giving rise to Tomonaga-Luttinger liquid (TLL) behavior, and non-interacting one. An electron with charge, e, injected into the interacting region from the non-interacting one would break up at the junction into the bosonic collective modes of charge density waves with an effective charge, e^*, and the rest charge ($e - e^*$) reflected back to the non-interacting one. Although this process known as charge fractionalization [1] is consistently understood with a momentum-resolved spectroscopy measurement [2], such single elementary excitation process has never been directly observed. Here we employed time-resolved charge detection technique [3] on an artificial spinless TLL formed in two counter-propagating integer quantum Hall edge channels in close proximity to each other. Injection of a charge wave packet to the TLL connected with non-interacting leads causes multiple reflections of the wave packet at the junctions with a significant time interval. The observed wave packets are informative to investigate the correlated charge dynamics in the TLL.

In our sample fabricated from a GaAs/AlGaAs heterostructure, the artificial TLL consists of two counter-propagating edge channels separated by a gate electrode (1 μm in width and 68 μm in length) with a negative gate voltage V_G, allowing no inter-edge tunneling (Fig. 1). A charge injector is located upstream on the right-moving channel while a time-resolved charge detector [3] is located downstream on the left-moving channel. Figure 2 shows observed waveforms for an incident wave packet of charge Q to the TLL region (upper trace) and extracted wave packets of charges $q_\pm$ from the TLL region (lower trace). Injection of charge Q to the left junction generates a fractionalized charge $+rQ$ reflected back in the left-moving lead and an effective charge $(1-r)Q$ in the TLL, where r is the fractionalization factor. The former is observed as the first packet q_+ while the latter is fractionalized at the right junction to charge $(1-r^2)Q$ in the right-moving lead and an effective charge $-r(1-r)Q$ in the TLL. The third fractionalization process arising at the left junction generates charge $-r(1-r^2)Q$ in the left-moving lead, which is observed as the second packet q_-. The factor r determined by the ratios $q_\pm/Q$ can be quantitatively justified by estimating the interaction parameters with capacitances in realistic quantum Hall devices, and hence, this result indicates that the artificial TLL can be electrostatically controlled.

[1] E. Berg *et al.*, Phys. Rev. Lett. **102**, 236402 (2009).
[2] H. Steinberg *et al.*, Nature Phys. **4**, 116 (2008).
[3] H. Kamata *et al.*, Phys. Rev. B **81**, 085329 (2010).

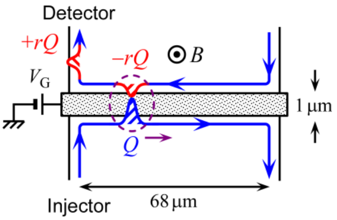

Fig.1: Schematic figure of the artificial TLL and first fractionalization process

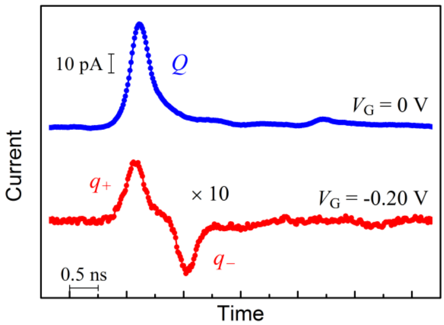

Fig.2: Observed charge waveforms for an incident wave packet Q and extracted wave packets $q_\pm$ from the TLL