Fractionalization of an Electronic Superposition State in Interacting Quantum Hall Edge Channels

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Tomonaga-Luttinger liquid nature of copropagating spin-up and spin-down quantum Hall edge channels lets an electron excitation split into fast and slow coupled excitations straddling between the two channels. In previous works, the fractionalization process was identified by injecting a spin-up or spin-down excitation into one of the copropagating channels and measuring the resultant multiple excitations [1, 2]. In this work, we study how the fractionalized electron superposition state prepared in the interacting channels evolves along the paths. We measure the interference of the fractionalized excitations in a Mach-Zehnder interferometer (MZI) with the interference paths composed of interacting copropagating channels [Fig. 1]. We observe interference visibility oscillations (lobe structure) as a function of the voltage bias applied between the channels. The lobe structure is attributable to the second-order interference in the one-way MZI originating from the difference in the phase evolutions between the fractionalized excitations propagating at different speeds. The observation sheds light on the nature of coherent electron transport under the fractionalization process.

Our MZI, fabricated in a GaAs heterostructure, consists of two beam splitters (BS1 and BS2) of V-shaped apexes that induce inter-channel tunneling by modulating the spin-orbit interaction [3] [Fig. 1(b)]. The center gate voltage V_M changes the area enclosed by the interference paths, resulting in the Aharonov-Bohm oscillations in the output current $I_\downarrow$. Figure 2(a) shows the interference pattern in the differential conductance $g = dI_\downarrow/dV_\mathrm{in}$ as a function of V_M and the source-drain bias voltage V_in. The V_in dependence of the visibility $\mathcal{V} = (g_\mathrm{max} - g_\mathrm{min})/(g_\mathrm{max} + g_\mathrm{min})$ in Fig. 2(b) shows clear dips at $V_\mathrm{in} \cong -75$ µV and $+ 90$ µV, reflecting the destructive interference between the fast and slow excitations and exhibiting the lobe structure of the visibility. We confirmed similar visibility oscillations in the simulations using the bosonization technique for the present setup [Fig. 3]. The results represent the coherent evolution of the fractionalized excitations and is complementary to the previous studies on conventional MZIs [4], where the lobe structure reflects decoherence through fractionalization.

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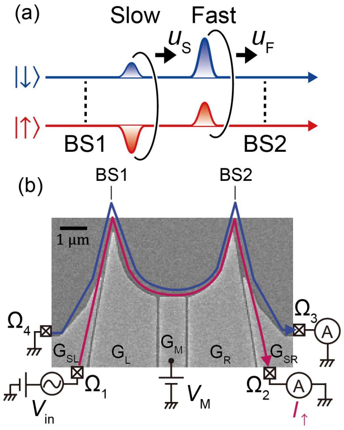

Fig.1. (a) Schematic and (b) scanning electron micrograph of the MZI composed of interacting spin-up and spin-down channels.

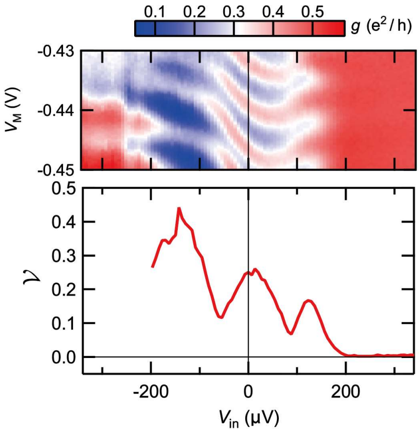

Fig.2. (a) $g = dI_\downarrow/dV_\mathrm{in}$ as a function of V_M and V_in at a perpendicular field $B = 3.9$ T (filling factor $\nu = 4$). (b) Visibility $\mathcal{V}$ as a function of V_in.

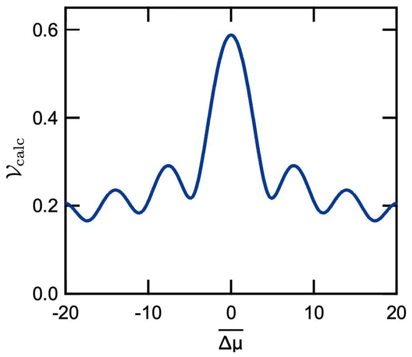

Fig.3. Calculated visibility $\mathcal{V}_\mathrm{calc}$ as a function of dimensionless chemical potential difference $\overline{\Delta\mu}$.