Bulk Nature of Sub-linear Width Dependent Breakdown of Quantum Hall Effect

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The breakdown phenomenon of quantum Hall effect (QHE) is one of the important problems, which is closely related with the electronic properties of two-dimensional electron system (2DES) and the current distribution in QHE regime. It is known that there are two types of QHE breakdown as shown in Fig.1. One is that the breakdown current scales linearly with the sample width. The other is that the breakdown current increases sub-linearly with the sample width and the value of critical current remains only several μA although the sample width exceeds 50 μm[1]. In the "sub-linear" type samples, the current density is thought to be localized near the edge region, however, it is still unclear that the breakdown current is affected by the properties of edge state and the confinement potential at the sample boundary. In this work, we have investigated the QHE breakdown by using samples whose confinement potential at the sample boundary is tunable. The Hall bar shaped samples are made of two types of the GaAs/AlGaAs 2DES wafers, where linear or sub-linear width dependent QHE breakdown have been observed. The sample surface of mesa etched 2DES boundary is covered with Schottky gate (Fig. 2, Side Gate) and the center part of the Hall bar channel (width 50 μm) is not covered with the gate. We have measured the current-voltage characteristics of the longitudinal resistance varying the side gate voltage (V_{SG}) at the QHE plateau of filling factor 2. In both linear and sub-linear type of samples, the value of breakdown current is scarcely affected by changing V_{SG} (Fig. 3), which suggests that the QHE breakdown is almost independent of the confinement potential at the 2DEG edge.

We have measured the voltage-current characteristics at QHE condition with Corbino shaped samples where the edge state is absent since the 2DES boundary is surrounded by the ohmic contact (Fig. 4). In the linear type sample, the critical voltage is proportional to the 2DES ring width (W) and the measured critical electric field of the QHE breakdown is 9.2 kV/m, which is usually observed in conventional GaAs/AlGaAs 2DES samples. On the other hand, the critical voltage in the sub-linear type sample is much smaller (<3 kV/m) than those in the linear type samples, and the width dependence of critical voltage shows nonlinear feature (Fig. 4, W<20 μm). It is demonstrated that the origin of the sub-linear type QHE breakdown is not "edge effect" but the properties of bulk 2DES. One of the possible origin of the sub-linear type QHE breakdown; the potential fluctuation in the 2DES; is discussed.

[1] N. Q. Balaban, et al., Phys. Rev. Lett. **71** (1993) 1443.

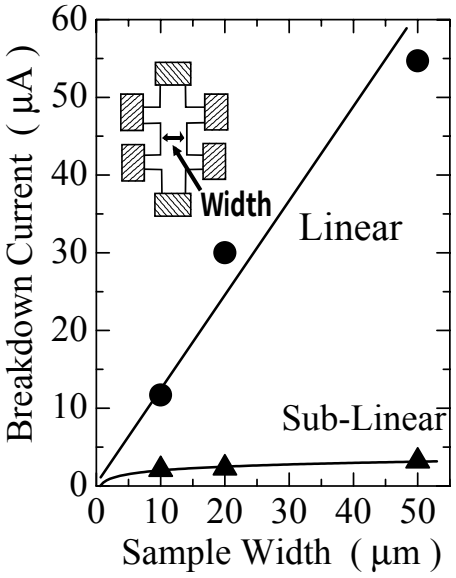

Fig. 1: The sample width dependence of the critical current at ν=2 QHE plateau. Lines are guide for the eyes.

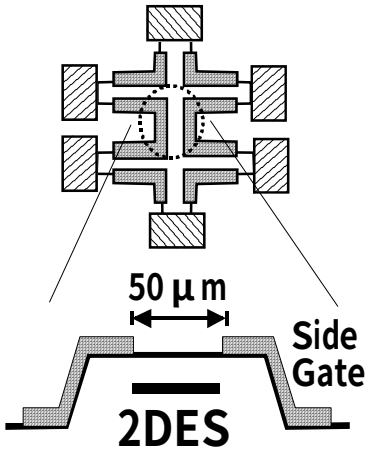

Fig. 2: Schematic view of the sample with the side gates (dotted area). The confinement potential can be controlled by applying negative side gate voltage.

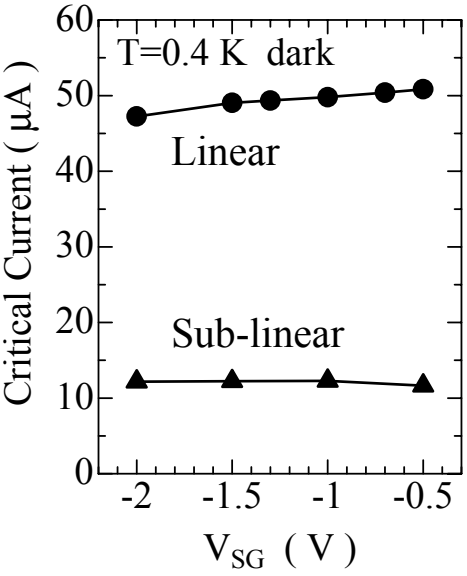

Fig. 3: Side gate voltage dependence of the breakdown current at ν=2. Both in the linear and sub-linear type samples, the V_{SG} dependence is almost absent.

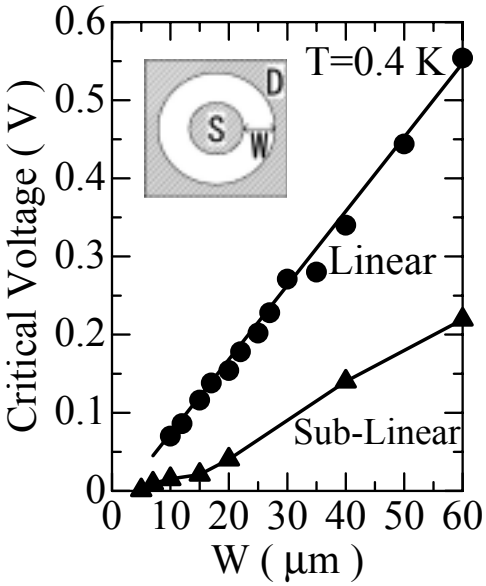

Fig. 4: Size dependence of QHE breakdown at ν=2 measured by Corbino sample without edge state.