Breakdown of the Quantum Hall Effect

CMX Journal Club Talk, 18 May 2004

G. Steele

Experimental Paper: P.M. Mensz, D.C. Tsui PRB 40 3919 (1989)
The Quantum Hall Effect

A Hall Bar

Dissipationless current due to suppression of backscattering

Quantized Hall voltage understood as the quantization of conductance through ballistic one dimensional edge channels
Breakdown of the Quantum Hall Effect at Large Currents

Sudden break down of dissipationless state upon increasing current

Also see an associated loss in quantization of hall voltage
Experiments

- Scaling with Hall Bar Width

- Voltage Steps in the breakdown

- Transient Fluctuations in $R_{xx}$ near transition and hysteresis
Scaling With Sample Width

TABLE I. Summary of the properties of the materials used in different experiments to determine the dependence of $I_c$ vs $W$: $n$ ($10^{11}$ cm$^{-2}$), $\mu$ ($10^5$ cm$^2$/Vs), and $s$ (nm). Sublinear dependence is observed in samples having large spacers and high mobility.

<table>
<thead>
<tr>
<th></th>
<th>Ref. 11</th>
<th>Ref. 10</th>
<th>Ref. 15</th>
<th>Ref. 17</th>
<th>This work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Before illumination</td>
<td>After illumination</td>
</tr>
<tr>
<td>$n$</td>
<td>2.6</td>
<td>2.1</td>
<td>4.7</td>
<td>2.5</td>
<td>1.3</td>
</tr>
<tr>
<td>$\mu$</td>
<td>9.0</td>
<td>7.0</td>
<td>2.1</td>
<td>0.5</td>
<td>1.2</td>
</tr>
<tr>
<td>$s$</td>
<td>54</td>
<td>36</td>
<td>6</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>$I_c$ vs $W$</td>
<td>sublinear</td>
<td>sublinear</td>
<td>linear</td>
<td>linear</td>
<td>linear</td>
</tr>
</tbody>
</table>

Fig. 6. Critical current $I_c$ versus device width $w$ for a wafer with a mobility of $\mu_{\text{el}} = 2.1 \times 10^5$ cm$^2$/Vs. The slope of the full line corresponds to a critical current density of 1.6 A/m. Data from Kawaji et al. [13].

FIG. 1. Critical current vs the channel width measured in the samples of Ref. 11 for filling factors $\nu = 1$ (●) and 2 (■). The dashed lines are logarithmic fits.
Steps in Voltage Breakdown

Fig. 13. Current–voltage characteristics (2nd QH plateau, \( B = 6 \, T \)) of a Hall bar \((w = 380 \, \mu m, \mu_{el} = 3.8 \times 10^4 \, cm^2/V \, s)\) at different lattice temperatures \( T_L \) (inset: critical current density versus \( T_L \)). Several jump-like transitions are visible for \( T_L \leq 5.87 \, K \). Data from Ebert et al. [3].

Fig. 1. Voltage measured at \( B = 5.7 \, T \) and \( T = 1.2 \, K \) across the different probes \( A \) and \( L \), \( M \) and \( L \), \( A \) and \( M \), and the Hall probes \( M \) and \( D \) plotted as a function of current \( I \). \( \Delta V_{MD} = V_{MD} - (h/2e^2)I \). The value of the magnetic field \( B \) was chosen to set a condition for the IQHE with Landau filling factor \( i = 2 \) at \( n_s = 2.8 \times 10^{11} / cm^2 \). Inset: the probe arrangement along the narrow section of sample 1. The bar indicates 10 \( \mu m \) distance.
Fig. 14. Time-dependent fluctuations of the longitudinal voltage $V_l$ measured on a Hall bar ($w = 380 \mu m$, $\mu_H > 1 \times 10^5 cm^2/Vs$) near the breakdown of the 4th QH plateau ($B = 5.65 T$, $T_L = 1.1 K$), a source-drain current of $I = 325 \mu A$. Data from Cage et al. [4]
Possible Mechanisms for Breakdown

(a) 

(b) 

(c) 

Energy: (before connection)