TH2B-4.

DEPENDENCE OF CONTACT RESISTANCE ON CURRENT FOR GOOD AND BAD OHMIC CONTACTS TO QUANTIZED HALL RESISTORS

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Abstract

Dependence of contact resistance on current has been measured for a large number of ohmic contacts to quantized Hall resistors under quantum Hall effect conditions. A definite trend is observed in the current dependences of resistances of good and bad contacts, regardless of the physical cause of the poor contact.

Introduction

While the guidelines for use of Quantized Hall resistors (QHRs) as resistance standards [1] do not place any explicit requirements on contact resistances, excessive resistance in the contacts can cause an increased load on the current source, noisy Hall voltages, and deviations of the measured Hall voltage from its ideal value [2,3] making the device unsuitable for use as a resistance standard. It is important to measure all contact resistances over a range of current from 0 µA to at least 100 µA, for while the contact resistances at the measurement current must clearly be known, high contact resistances at lower currents have a significant effect on measurements, particularly when multiple series connections are used [4]. In this work, the resistances of potential probe contacts on over 15 QHRs with alloyed ohmic contacts prepared in different manners and with widely varying quality were measured. The physical causes for the poor contacts varied from corrosion to mechanical damage. The current dependences of the contact resistances in all cases, however, appear to follow a common trend. This paper describes this trend and shows that it is consistent with the effects of increasing disorder in the contact that causes increased scattering within the 2-dimensional electron gas (2-DEG).

Experimental Procedure

Most of the QHRs tested in this work were prepared by the Laboratoire d' Electronique Philips (LEP) under contract to the EUROMET consortium [5]. In addition, several samples were prepared at NIST by alloying indium to $GaAs/Al_xGa_{1-x}As$ heterostructures grown using Molecular Beam Epitaxy.

These devices were cooled in a cryostat to a temperature of between 1.1 K and 1.4 K in magnetic flux densities between 4 T and 8 T, as required to observe the $i = 4$ (6453.20175 Ω) quantum Hall resistance plateau. Current was passed between a contact "A" and a second contact, usually the source or drain at the end of the Hall bar. The potential V_{AB} was measured between contact "A" and a second contact, "B", that did not carry current and which was at nominally the same potential as contact "A". V_{AB} was measured with one value of current; the current was then increased by a small increment ΔI, usually between 1 µA and 10 µA, and V_{AB} was measured again. The contact resistance, $R_c = dV/dI$, was determined by computing the ratio $[V_{AB}(I+\Delta I)-V_{AB}(I)]/\Delta I$; the standard uncertainty was 0.3 Ω. This procedure eliminates the effect of thermal voltages. The voltage across the contact was measured, and the current was increased in steps from zero to a positive limit I_{max}, usually 100 µA; the current was then reset to zero, and the contact resistance measured as the current was decreased from 0 to $-I_{max}$.

Results

The measured dependence of contact resistance on current for all of the contacts measured fell into one of five different categories.

1. IDEAL CONTACT: The contact resistance vanishes for currents less than a critical current, I_c, which on the best samples is between 35 µA and 55 µA for potential probes and is proportional to the width of the narrowest part of heterostructure through which current must flow. At currents above I_c, the contact resistance abruptly increases (see Fig. 1), probably due to breakdown [6], usually to several hundred ohms and seldom more than 1 kΩ.

2. NEARLY IDEAL CONTACT: Contacts which are of slightly worse quality exhibit the same general form of current dependence: the contact resistance vanishes for currents $|I| \le I_c$, but I_c is smaller, varying

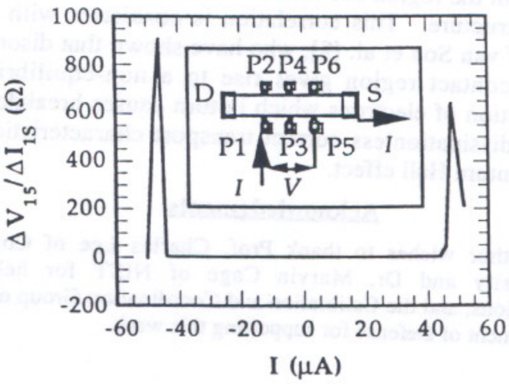

Fig. 1: Contact resistance vs current for type 1 contact. Data from LEP sample with Si_3N_4 coating, serial # E7C. Inset shows probe numbering.

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between 0 μA and 30 μA for potential probe contacts.

3. LIMITING CASE #1: In the limiting case, the contact resistance vanishes only at zero current, as shown in Fig. 2.

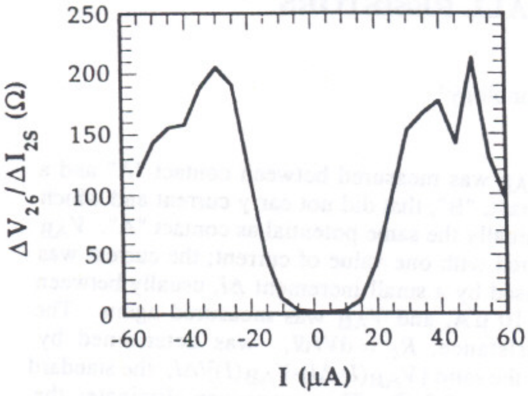

Fig. 2. Contact resistance vs. current for type 3 contact: Data from LEP sample without Si_3N_4 coating, serial # E6.

4. POOR QUALITY CONTACT: Contacts with worse quality exhibit a current dependence similar to that of "Limiting Case #1": the contact resistance decreases at low currents but it does not vanish. While the value of the contact resistance and range over which it varies can differ widely from contact to contact, in all cases, the *form* of the current dependence is essentially the same.

5. LIMITING CASE #2: Contacts with the worst quality exhibit contact resistances that actually reach a *maximum* when the lowest currents are passed through the device, as shown in Fig. 3. As with type 4 contacts, the resistance and range over which it varies can differ widely from contact to contact: resistances can vary from ≈ 20 Ω at 0 μA to ≈ 0 Ω at 100 μA; or can be as high as several thousands of ohms throughout the range ±100 μA.

Conclusion

The current dependences of contacts to QHRs subjected to damage-inducing treatments including corrosion and mechanical damage [7] exhibit a definite trend which has been correlated with different levels of electrically active defects in the region between the metallic contact and the heterostructure. This correlation is consistent with the work of van Son et al. [8], who have shown that disorder in the contact region gives rise to a non-equilibrium distribution of electrons which in turn causes breakdown of the dissipationless current transport characteristic of the quantum Hall effect.

Acknowledgments

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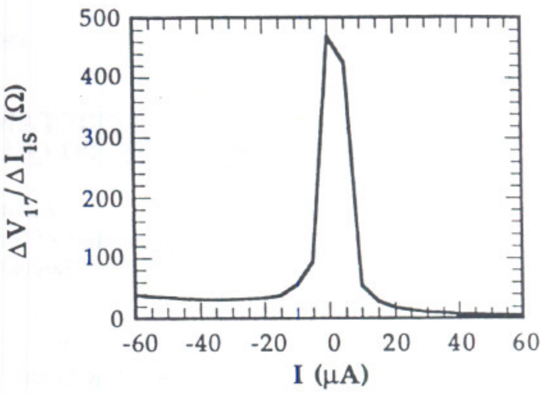

Fig. 3: Contact resistance vs current for type 5 contact. Data from sample PG1825-2.4, with alloyed indium contacts. N.B.: This sample had 10 potential probe contacts.

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