EVALUATION OF TECHNIQUES FOR BONDING WIRES TO QUANTIZED HALL RESISTORS *

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Abstract

Three different techniques for mounting quantized Hall resistors with AuGe/Ni alloyed contacts were evaluated. The best quality and most robust samples were made by evaporating bonding pads that overlapped the alloyed contacts and the substrate, so that bonds could be made over the substrate rather than over the heterostructure.

Introduction

Quantized Hall resistors made from GaAs/AlGaAs heterostructures with alloyed AuGe/Ni contacts have found wide application as resistance standards because they are of high quality, and can be mass-produced. The close proximity of the electron gas responsible for the quantum Hall effect to the surface of the heterostructure, however, makes it difficult to attach wires to the contacts without degrading them. This problem is made more difficult by the extremes of temperature and fairly high stresses that the samples experience, particularly when inserted into a cold dewar during the cooling process. These conditions require that the wires be attached to the pads firmly enough that gusts of helium gas evolved during the cooling process do not cause the wires to become detached, and that the adhesive used to attach the sample to the header remains adherent between room temperature and liquid helium temperature. In addition, quantized Hall resistance devices to be used as resistance standards should be highly reliable, and be capable of being used for many years without degrading or requiring repairs.

Experimental Techniques

In order to meet these challenging requirements, several different mounting techniques have been devised and evaluated. Wires have been attached to the sample using the following techniques:

1.1. Soldering
1.2. Direct Wire Bonding
1.3. Enlarged Bonding Pads

The samples have been attached to headers using the following techniques:

2.1. Silicone vacuum grease
2.2. Paraffin-impregnated plastic film
2.3. Conductive epoxy

The quantized Hall resistors used in this study were produced by the Laboratoires d'Electronique Philips (LEP) under contract to the EUROMET Consortium [1]. These samples have alloyed AuGe/Ni contacts with a Ti/Pt/Au thickening layer over the contact. Extensive tests on samples mounted using each of the above techniques show that while all can be used to produce standards-quality samples, the first two techniques (1.1 and 1.2) have disadvantages that make them less desirable for mounting samples that are to be used as resistance standards for long periods of time. Samples made using the third technique (1.3) have proven to be the most reliable and of the highest quality. The advantages and disadvantages of each of the three techniques are discussed in the next section.

Summary of Results

Soldering: Gold wires with 25 μm diameter were soldered to the bonding pads using indium solder. The wires attached using this technique are very firmly attached to the pads. This technique does not require that the pads be extremely clean prior to soldering, and any of the three techniques (2.1-2.3 above) for mounting the sample in the header can be used. This is the easiest technique to use, and gives reliable, low resistance contacts. Unfortunately, however, indium and gold readily form intermetallic compounds [2] which are quite brittle and readily fracture under thermal or mechanical stress. Experience at NIST with other samples that have gold-indium solder connections indicates that while the solder connection may be quite strong initially, these intermetallic compounds form over periods of a decade or more, and the connections eventually break. Thus, from the point of view of long-term reliability, this technique is less desirable for mounting resistance standards.

Direct Wire Bonding: Gold wires with 25 μm diameter have been bonded to the gold pads directly above the heterostructure. This, however, is an extremely delicate task. The 2 dimensional electron gas responsible for the quantum Hall effect is only about 60 nm below the surface, so any damage created during wire bonding will directly affect the properties of the device. In fact, bonding pressures of as little as

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73.5 MPa‡ created electrically active defects in GaAs, *even if there was no applied ultrasonic power* [3]. Since the defects act as acceptors, they raise the resistance of the contacts, and can cause them to cease to carry current at low temperatures. In order to successfully bond wires to the pads, therefore, the lightest possible bonding forces must be used. Under these conditions, however, the wire will not stick to the sample unless both the wire and the bonding pads are of the highest cleanliness.

In addition, the sample must be held firmly during bonding, as any movement can result in damage to the sample or even fracture of the GaAs. As a result, it was found necessary to use epoxy to secure the sample to the header (or to a glass or ceramic plate later mounted in the header) during bonding.

In spite of the extreme precautions taken during wire bonding, samples mounted using this technique showed a degradation in room temperature contact resistance after bonding. The samples still proved to be usable as resistance standards. The light pressures used to attach the wires to the sample, however, did not attach them sufficiently well to withstand more than one cool-down. This, together with the slight degradation in the contacts on bonding, makes this technique the least desirable for mounting standards-quality samples.

Enlarged Bonding Pads: The technique that resulted in the highest quality samples was to evaporate gold bonding pads over the existing AuGe/Ni pads in such a manner that they overlapped the substrate outside of the Hall bar, as shown in Fig. 1. Wires could then be bonded to the pads over the substrate, so that any damage produced during bonding would not affect the electrical properties of the contact.

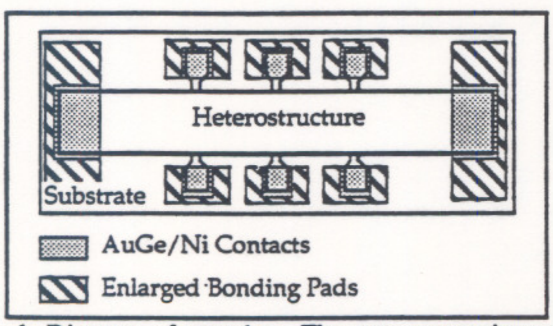

Fig. 1. Diagram of samples. The grey rectangles are the original AuGe/Ni contacts, and the cross-hatched rectangles are the gold bonding pads. The enlarged pads overlapboth the AuGe/Ni contacts and the substrate, eliminating the need to perform the bonding operation over the sensitive heterostructure.

‡ This pressure corresponds to a bonding force of less than 9 gm on a 25 μm diameter wire.

Samples bonded using this technique exhibited no changes in room-temperature contact resistance on bonding, and showed the best contact resistances when measured under quantum Hall effect conditions. Precision tests of these samples show that they are of standards-quality. The wires are very firmly attached to the sample, and can withstand the thermal and mechanical shocks that these samples are exposed to in normal use. Current experience indicates that these contacts should not deteriorate with time, permitting these samples to be used for long periods without the need for repairing leads.

Conclusion

Soldering and wire bonding were evaluated as techniques for attaching wires to high quality quantized Hall resistors with AuGe/Ni alloyed contacts. The soldering technique was the easiest to implement, but samples made using this technique potentially suffer from long-term degradation due to the formation of intermetallic compounds at the gold-solder interface. The highest quality, most resilient samples were prepared by depositing bonding pads that overlapped the AuGe/Ni contacts and the substrate, enabling bonding to be performed over the substrate so that damage to the brittle GaAs during bonding did not effect the electrical quality of the contact. Samples prepared in this manner had the highest breakdown currents and lowest contact resistances of any of the samples made using the other techniques.

References

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