PERSISTENT PHOTOCONDUCTIVITY IN GaAs/AlGaAs HETEROSTRUCTURES MEASURED BY CONTACTLESS CORBINO CAPACITANCE TECHNIQUE

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In the contactless Corbino capacitance technique the heterostructure sample is placed flat on top of, and insulated from, the Corbino electrodes. The electrical impedance of the Corbino sample assembly is measured at audio frequencies and at liquid Helium temperatures as a function of a dc magnetic field. The impedance versus magnetic field exhibits a Shubnikov-deHaas pattern from which the carrier density in the high mobility channel is extracted. Illumination with a red light emitting diode is observed to increase the carrier density in a persistent and accumulative way. Due to the absence of contacts, the technique offers a possibility to test whether these are essential for carriers from photo excited DX centres in the AlGaAs to reach the high mobility channel.

1. Introduction

The conventional sample geometries: Hall bar, van der Pauw, and Corbino, have one feature in common, namely the attachment of contacts and leads, and hereby the possibility of exchange of charge carriers between the sample and the surroundings. The contactless Corbino capacitance technique is different: the surroundings couple to the sample charge carriers only via electromagnetic fields, i.e. the sample can be viewed as a subsystem with a conserved number of particles. The technique was suggested by Templeton [1].

Below we present an investigation of GaAs/AlGaAs heterostructures, making first a comparison between results obtained by the contactless Corbino and the conventional Hall bar. When using the contactless technique to investigate persistent photoconductivity in heterostructures we have especially in mind the suggestion by Kastalsky and Hwang [2] that electrons excited from DX centres in the AlGaAs will penetrate into the high mobility channel through the contacts. This possibility does not exist in the present contactless technique.

The light source used is a red light emitting diode with wavelength of 635 nm, equivalent to a photon energy of 1.95 eV. As the mole fraction of Al in the AlGaAs layer is 0.28, this material has an energy gap of 1.85 eV, and electrons can be excited from the AlGaAs as well from the GaAs.

2. The Corbino sample configuration and the ac-bridge

In fig. 1 we show a sketch of the Corbino electrodes and the ac-bridge. The electrodes (fig. 1a) are made from a piece of printboard. The centre disk has a diameter of 2.0 mm while the surrounding ring has inner and outer diameters of 2.5 mm and 3.4 mm respectively. Leads are soldered from beneath to the centre disk and to the ring.

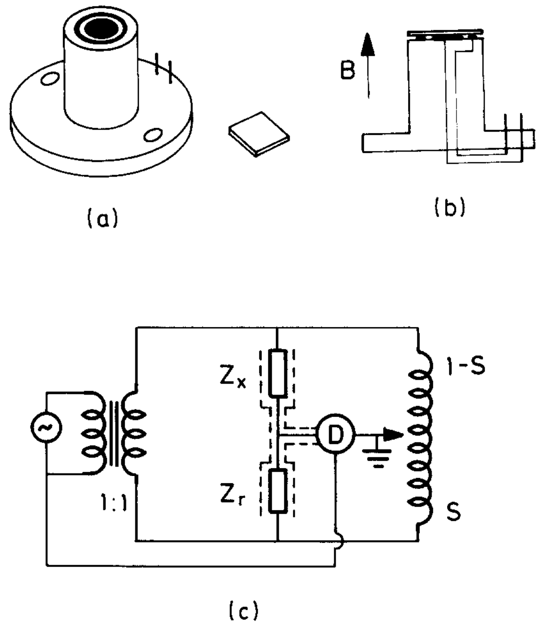

Figure 1: *(a) The Corbino electrodes and the sample. (b) The mounted sample and the direction of the magnetic field. (c) The ac-bridge.*

The sample is a 3.5×3.5 mm^2 piece of a GaAs/AlGaAs wafer bought from Picogiga: 10 nm n^+ GaAs cap layer doped with $2 \cdot 10^{18}$ Si/cm^3, 35 nm $Al_{0.28}Ga_{0.72}As$ with the same Si-doping, 15 nm undoped $Al_{0.28}Ga_{0.72}As$, and finally a 1 μm thick undoped (p-) GaAs buffer layer grown on top of a LEC GaAs undoped substrate. The total thickness is 630 μm.

During measurements the sample is placed on top of the Corbino electrodes (fig. 1b), held by photoresist. The Corbino sample assembly is placed in a superconducting solenoid producing a magnetic field B perpendicular to the sample. The assembly constitutes the unknown impedance Z_x in the ratio arms bridge [3] shown in fig 1c.

The bridge detector is a two-phase lock-in amplifier (EG&G 5206). A five decade ratiotransformer (inductive voltage divider) is used to generate the ratio $(1-S)/S$. The reference capacitance, Z_r, is a 10 pF, three terminal capacitor. The oscillator terminal voltage was usually set at 10 V peak-to-peak, and frequencies in the range 2.5 kHz to 20 kHz were used. If the ratio Z_x/Z_r is real, then the bridge is balanced by the setting S_0 where

$$\frac{Z_x}{Z_r} = \frac{1-S_0}{S_0}. \tag{1}$$

As the unknown impedance Z_x consists of the capacitance of the two Corbino electrodes coupled capacitively to the electrons in the heterostructure, Z_x is not a pure capacitance, and only one of the two phase channels of the lock-in amplifier can be nulled. The other channel will display a voltage, V_D, which is recorded as a function of the magnetic field B.

To obtain persistent photoconductivity, a red light emitting diode was placed a few millimeters above the sample. The diode has a 4.2 K spectrum peaking around 635 nm. Illumination times in the range 10 μs to 1 s was controlled by a separate circuit. The photon flux was not calibrated.

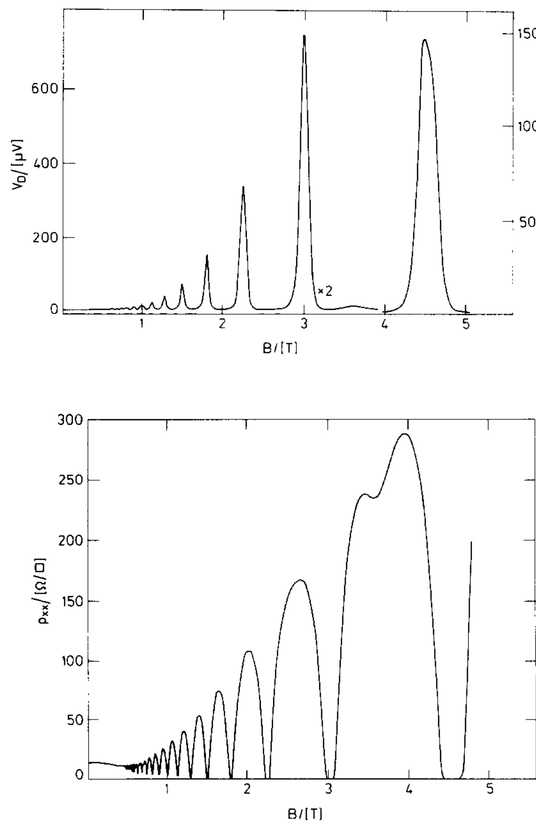

Figure 2: *Measurements in the dark at a temperature of 1.3 K on GaAs/AlGaAs samples cut from the same wafer. (a) Bridge imbalance, V_D, in a Corbino measurement. The ac-frequency is 10 kHz, and the oscillator voltage is 10 V_{p-p}. Shubnikov-deHaas analysis gives a carrier density of* $4.3 \cdot 10^{15}$ m^{-2}. *(b) The longitudinal square resistance, ρ_{xx}, of a Hall bar mesa. The dc transport current is 52.5 μA. The values of the carrier density and the mobility has been determined to be* $4.4 \cdot 10^{15} m^{-2}$ *and 99 m^2/Vs respectively.*

3. Measurements and interpretation of V_D versus B

Fig. 2a shows V_D versus B measured in the dark at 1.3 K. For comparison we present in fig. 2b the result of Hall bar measurements of ρ_{xx} on a sample cut from the same wafer. The ρ_{xy} measurements (not shown) clearly display integer quantum Hall plateaus.

We note that the two curves closely follow each other. Each time V_D peaks there is a dip in ρ_{xx}. As an example, the weak peak/dip at 3.6 T corresponds to five filled Landau levels (spin degeneracy included).

The above observation we interpret as follows: V_D is a measure of the inverse diagonal conductivity, and this is related to the resistivity elements in the usual way,

$$V_D \sim \frac{1}{\sigma_{rr}} = \frac{\rho_{rr}^2 + \rho_{r\theta}^2}{\rho_{rr}}, \tag{2}$$

so, as $\rho_{r\theta}$ takes on one of the quantum Hall effect values, and simultaneously ρ_{rr} becomes very small, V_D will peak at the ρ_{rr}-minima,

$$V_{D,peak} \sim \frac{\rho_{r\theta}^2}{\rho_{rr}}. \tag{3}$$

At the ρ_{rr}-minimum the Hall angle approaches $\pi/2$, and this implies that the Corbino current path changes from being roughly radial to become spiral-like, almost circular.

In accordance with this interpretation carrier densities are found from Shubnikov-deHaas analysis (inverse magnetic field versus V_D-peak number).

4. Persistent photoconductivity

The measurements displayed in fig. 2 were made in the dark. It was observed however, that light pulses from the red LED change the SdH-pattern of V_D versus B in a persistent and accumulative way. After each pulse of light, the subsequent magnetic field sweep showed a shift in the SdH pattern of V_D to the right.

An example of measurements at 4.2 K and 20 kHz is shown in fig. 3. The numbers at the curves are integrated illumination times in ms, e.g. the number 1.16

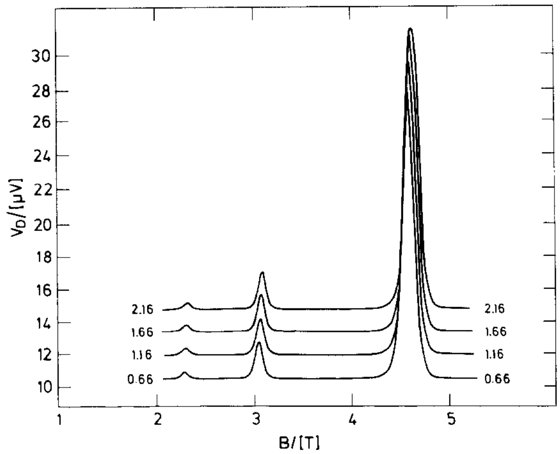

Figure 3: *Bridge imbalance, V_D, versus magnetic field B at 4.2 K and 20 kHz. The numbers at the curves are integrated illumination times.*

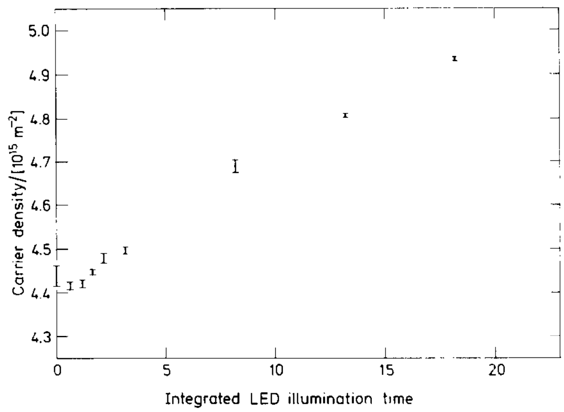

Figure 4: *Carrier density in the high mobility channel from SdH-analysis of V_D. The illumination is by a red, 635 nm, LED*

means that the sample has been exposed to the red LED illumination for a total of 1.16 ms. The vertical scale only apply to the 0.66 curve; the other curves are each shifted a bit upwards in order that they can be seen separately. The level of V_D in between the peaks is the same for all four curves, and it stayed the same during the subsequent measurements where the integrated illumination time was increased to 33 ms.

The gradual way in which the SdH pattern in fig. 3 evolves as the illumination time increases, strongly indicates that the photo excited electrons have arrived into the high mobility channel. When the integrated illumination time is increased beyond 13 ms the peaks develop low-field shoulders, and the SdH pattern of V_D becomes unreliable for the determination of the channel carrier density.

In fig. 4 we show the carrier densities obtained from SdH-analysis of V_D. The density increases gradually by roughly 10% before the analysis is stopped due to the appearance of the low-field shoulders. For larger illumination times (up to 33 ms) the shift of the V_D-peak positions is considerably slower. This behavior is in qualitative accordance with the recently reported one [4] on Hall-bar samples with contacts, in which a slow-down in the density increase happens after 20%.

5. Conclusion

In a sample with no contacts it is possible to generate a persistent, accumulative increase of the carrier density in the high mobility channel by photoexcitation using 1.95 eV photons.

Considering the two mechanisms for the persistent photoconductivity suggested by Kastalsky and Hwang (see fig. 4 in [2]): (i) DX center ionization in the AlGaAs layer and subsequent penetration into the channel through contacts, and (ii) electron-hole generation in bulk GaAs followed by charge separation at the heterojunction, the contactless Corbino technique excludes (i). Thus, this technique offers a possibility to test the Kastalsky-Hwang suggestions by the use of photon energies less than the energy gap of GaAs.

References

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