© 2018 IJSRST | Volume 4 | Issue 7 | Print ISSN: 2395-6011 | Online ISSN: 2395-602X
Themed Section: Science and Technology

Study of Theoretical development on Semiconductor Heterostructure

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ABSTRACT

In this paper, we studied the most commonly used heterostructure for two—dimensional transport is composed of the two semiconductors. GaAs and AlxGa1-xAs, which has nearly the same lattice parameter. In the latter material, a fraction (commonly x-0.3) of the Ga atoms in the GaAs lattice is replaced by AI atoms, thus keeping III-v ration the same. For x<0.45 the semiconductor AlxGa1-xAs has a direct band gap, arger than that of GaAs, being approximately proportional to the AI content; a widely used expression, due to Casey and Panish 16 (1978) is E gap-1.424 +1.247 xeV at room temperature, although slightly different values have been reported by other workers.

Keywords : Heterostructure, Semiconductors, Lattice Constant, Band Gap, Doping Level.

I. INTRODUCTION

In the last thirty years or so, there has been a dramatic increase of interest in the physics and application of structure (mainly realized in the semiconducting materials) which can be described as 'low-dimensional'. In the case of electronic transport , this term refers to a system in which the mobile charge carriers are constrained by potential barriers so that they lose one or more degrees of freedom for motion; the system becomes two, one or even zero dimensional, depending on whether the potential barriers confine in one, two or three dimensions, respectively. It is important to realize that the dimensionality is not an absolute property, but is related to the length scales which determine the physical properties under study. Some length scale that can be important for transport are sample dimensions, de Broglie wavelength, magnetic length, effective Bohr radius, elastic scattering length, inelastic scattering length and phase coherence length. By changing the carrier concentration, the magnetic field or the sample dimensions one can, in certain cases, change the effective dimensionality of a system, this enables the influence of the dimensionality and the effects of a dimensional crossover to be studied directly Berggren, 1987).

II. MATHEMATICAL FORMATION USED IN THE EVALUATION

Magnetotransport measurements in homogeneous samples, characterized by a resistivity tensor, are established experiments with a sound theoretical basis which has been discussed, for instance, by Beer (1963) and Seeger (1985). Most theories have been derived for the three dimensional case,but we will present their two

dimensional equivalent here. The standard geometry for a so-called Hall bar,(the geometry of a two dimensional system is sketched). It is essential a rectangularly shaped sample with current contacts (1 and 5) at the two ends and potential probes(2,3,4,6,7 and 8) at the sides. Experimentally, the shape is usually defined by etching, and electrical contacts to the two dimensional electron gas in GaAs and $Al_xGa_{1-x}As$ heterostructure are made by alloying a metal (e.g. In or Aug ENi alloy) into the contact regions; this gives low resistance ohmic contacts,although the process is rather critical (Murakamiet al 1986, Tlwarl et al 1987, Kamada et al 1987). Only the component of the magnetic field perpendicular to the two dimensional system influences the electrical transport directly. The parallel component mainly influences the energy of quantization of the motion in the third dimension (Ando 1975),whereas the spin splitting (Zeeman splitting) is influenced by the total magnetic field.

The 2D resistivity tensor ρ describes the electrical transport in a material by a generalization of Ohm's law. As in three dimensions, it related the local electric fielf F to the local current density J by F= ρ J. The inverse of ρ is the conductivity tensor, σ , which is given explicity in equation (4). The components of σ are related to those of ρ by the tensor relations $\sigma_{xx} = \rho_{xx}/ (\rho^2_{xx} + \rho^2_{xy})$, where use has been made of the relationships ρxx = ρxy and ρxy =-ρyx appropriate for an isotropic material. We define the components of σ ,ρ and J with reference to the x and y axes of the Hall bar. Ix, the total current flowing sample in the x direction, is given by Ix = ∫Jx(x,y) by and is independent of x because of cuurent conservation. The distribution of J over the width of the sample is defined by Kirchhoffs laws, i.e. it is determined by current conservation and continuity of the electric field. The magnetotransport coefficients are resistances defined as the ratio of the transeverse or longitudinal voltages to the surrent ix; thus the hall resistance,Rxy, is Vy/Ix, where Vy = V8,2 or V7,3, for example , an the magneto resitance, Rxx is Vx/Ix, where, for example, Vy=V4.2 (It is important to realize that the word magnetiresistance is used in the literature with two different meaning : the first, used in this thesis, is defined as the resistance in a magnetic field, Rzz(B), and the second is defined by the additional resistance due to the magnetic field, Rxx(B)-Rxx(0) in our notation). These coefficients are determined by integrals over the local resistivity tensor; we thus have

$$R_{xy} = \left|\frac{V_y}{I_x}\right| = \frac{1}{I_x}\int F_y(x,y)dy \qquad (1)$$

$$R_{xx} = \left|\frac{V_x}{I_y}\right| = \frac{1}{I_x}\int F_y(x,y)dy \qquad (2)$$

$$= \frac{1}{I_x}\int \rho_{xx}(x,y)J_x(x,y) + \rho_{xy}(x,y)J_x(x,y)dy$$

When the resistivity tensor is homogeneous (ρ independent of x and y) over the sample, equation (1) and (2) reduce to

$$R_{xy} = \rho_{xy}\left(1 - \cot\theta_H \frac{\int J_x(x,y)dy}{\int J_x(x,y)dy}\right) \qquad (3)$$

$$R_{xx} = \rho_{xx}\left(\frac{\int J_x(x,y)dx + \tan\theta_H \int J_x(x,y)dx}{\int J_x(x,y)dy}\right) \quad (4)$$

Where θH = tan-1 (ρxy/ρxx) is the Hall angle (the angle between the electric field and the current and the parts in large parentheses contain the geometrical factors calculated by Wick (1954)and by Lippmann and Kuhrt (1958).Far from the ends of a long Hall bar we obviously have a homogeneous current flow with Jy(x,y) = 0, resulting in Rxy = ρ xy and R xy = (d2.4/d7.3) ρ xx, (di.j is the sample dimesion between contact I and j).
A long Hall bar geometry can be used to determine the 2D electron density, ns,by (Seegar 1985)

$$\rho_{xy} = \frac{r_H B}{n_s e} \quad (5,a)$$

(here e is the electronic charge and the Hall factor, rH, is – 1-2, depending on the scattering process present in the material, the Fermi energy and the strength of the magnetic field). Similarly, the Hall mobility, μH is given by

$$\rho_{xx} = \frac{\rho_{xy}}{\mu_H B} \quad (5,b)$$

And is thus realted to the drift mobility, maelectrons μ, by μH = rHμ. These equations are only useful for material characterization at low, non-quantising magnetic fields; the effects of higher magnetic fields will be considered.We give two examples of the potential distribution over a Hall bar geometry in a homogeneous material, as calculated by Wakabayashi and Kawaji (1978). No electric field can current from crossing a metal semiconductor interface over its full length, because then the Hall Voltage in the semiconductor would be short circuited. This effect ρxy/ρxx =σxy/σxx → . In a strong magnetic field, most of the current will therefore enter a sample in one corner of the contact, and leave it in the diagonally opposite corner of the other current contact, thus avoiding the short circuiting effect. Changing the direction of the magnetic field (and thus the sign of θH) makes no difference in this respect. Because voltages are only generated where a current flows, the Hall voltage will be built up in two corners (where the equipotential lines converge). At the bottom of the discussion we see that the Hall voltage is indeed built up only on one side of the Hal bar with respect to a current contact. Changing the direction of the magnetic field also changes the side where the Hall voltage appears.
A geometry that has quite different properties, because the Hall voltage is short-circuited, is the Corbino disc. It is essentially a circular geometry, as sketched in the discussion . A current I flows between the inner and outer contacts of the ring of semiconductor, and the voltage between these contacts is measured. In a homogeneous material with the geometry, the electric field can only be built up in the radial direction (because of rotational

symmetry). The current will flow at the Hall angle with respect to the electric field, as shown by the broken lines in the figure. The resistance R10 between the inner and the outer contact is defined by

$$R_{io} = \frac{1}{I}\int_{r_i}^{r_0} F(r)dr = \frac{1}{I}\int_{r_i}^{r_0} \frac{1}{2\pi r\sigma_{xx}}dr = \frac{In(r_i)}{2\pi\sigma_{xx}} \tag{6}$$

Here ri and r0 are the inner radius and the outer radius, respectively, and the radial electric field F(r) is determined by current concervation; Σxx is the diagonal component of the cobductivity tensor, σ . In a Corbino disc, it is difficult to determine the off-diagonal terms of σ directly, thus making this geometry less useful for material characterization.

III. DISUSSION AND RESULTS

A simple geometry often used for material characterization is square with a small contact in each corner, numbered clockwise)1,….4), say. The magnetic field is applied perpendicular to the sample. Theresistivity is calculated from

$$\rho_{xy} = \frac{\pi f}{1\ln 2}\left(\frac{V_{1.2}}{I_{3.4}} + \frac{V_{2.3}}{I_{4.1}}\right) \tag{7}$$

Where f depends on the relative magnitude of the two terms in brackets above. This method, including evaluation of the correction factor f and consideration of a more suitable clover leaf geometry, was first described by van der Pauw(1961), Seeger (1985).For thwe Hall resistance, two sets of measurements are performed, each with without the magnetic field. In the first one, 1 and 3 are the current contact and the Hall voltage is measured between contacts 2 and 4; to eliminate geometrical factors, the role of contact pairs, 1,3 and 2,4 is then interchanged. For isotropic material, the Hall resistance is then given by the average of these measurements:

$$R_{xy} = \frac{1}{2}\left(\frac{(V_{2.4}(B) - V_{2.4}(0))}{I_{1.3}} + \frac{(V_{1.3}(B) - V_{1.3}(0))}{I_{2.4}}\right) \tag{8}$$

Alternatively, measurements may be made with forward and recersed magnetic fiels, and the difference halved to give tha Hall resistance. Thus the electron density and the mobility can be obtained by the van der Pauw method as well as in the Hall geometry. Material characterization using both methods often gives results differing by a few percent. Both techniques essentially rely on the homogeneity of the material to calculate ns and μ from the measured quantities. Inhomogeneities may be one of the reasons for the different results; a test for the homogeneity of the resistivity over a sample is the six probe method proposed by van Haarent et al (1988).

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