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Investigation of magnetoresistance measurements in the evaluation of transferred electron device

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Abstract
Material manufactured with the calculation of moved electron gadgets can be portrayed utilizing the mathematical magnetoresistance method, GMR. It is indicated how the method can be utilized to contemplate the portability of GaAs moved electron and to relate these versatility estimations to balance clamor in Gunn oscillators. The impact on non-ohmic contacts on the interpretation of GMR results is additionally investigated with specific reference to contacts on InP material. A basic identical circuit is introduced to empower the genuine portability to be extricated from the test brings about the instance of Ag, Ag/Sn, and Sn contacts.

Keywords: magnetoresistance measurements and electron device

Introduction

The technique of geometric magnetoresistance (GMR) has been used to determine niagnetoresistance mobility (μ_m) of thin epitaxial layers of many semiconducting materials. An important feature of this technique is the ability to determine μ_m for encapsulated devices of the geometry (aspect ratio) used for transferred electron oscillators. This is valuable since it removes the need to extrapolate the results obtained from special samples to those of working devices made from the same semiconducting slices. Thus it is possible to characterize the mobility of actual devices to be used for specific microwave measurements. The magnetoresistance mobility is related to the Hall mobility (μ_H) by the equation $\mu_m = \mu_H\xi$, where E is the scattering factor which generally has a value approximately equal to unity [1]. It is because $\xi \approx 1$ (i.e. $\mu_H = \mu_E$) that the magnetoresistance technique can be used to investigate the field and temperature dependence of the mobility of the two III-V compounds GaAs and InP which are commonly used for microwave oscillator structures. In this paper we will also show that the mobility data on transferred electron material can be used to predict the noise performance of transferred electron oscillators.

Tests of n-type Ge, Si, and GaAs have been examined utilizing the magnetoresistance and Hall estimation procedures. For the Hall tests, tests with a viewpoint proportion of 2.0 were utilized. Similar examples were then diminished utilizing a rotational lapping machine and the last surface completion acquired utilizing a vibratory polisher followed by compound scratching. Appropriate low-opposition contacts were made to the material by utilizing techniques portrayed in the writing [2]. Gadgets showing a contact opposition > S%, of the mass semiconductor obstruction (as decided from mass opposition estimations utilizing the versatility as acquired from the Hall explore) were not viewed as satisfactory, in this way evading the requirement for a huge 'contact remedy'. The adjustment elements of the last gadgets were 2% because of the limited viewpoint proportion and 1% because of the contact opposition (this accepts the contact obstruction is invariant with attractive field). Magnetoresistance tests were then performed at low fields on every one of the gadgets.

An examination of the Hall versatility and magnetoresistance portability (Table 1) shows close concurrence with the perceptions of past laborers. The dispersing factor, decided from the portability information, is appeared in Table 1 and is in close concurrence with the consequences of Blood and Tree [3].

Table 1: Comparison between magnetoresistance and Hall mobilities genmanium– ND = $10^{15}/cm^3$

	I	II	III	IV	V
Hall mobility μ_H (m^2/V s)	0.372	0.372	0.395	0.321	
magnetoresistance mobility μ_m (m^2/Vs)	0.375	0.362	0.405	0.340	
μ_m/μ_H	1.008	1.026	1.026	1.060	
silicon — $N_D = 2 \times 10^{15}/cm^3$					
Hall mobility μ_H (m^2/V s)	0.145	0.172	1.165	0.162	0.157
magnetoresistance mobility μ_m (m^2/Vs)	0.150	0.173	0.172	0.164	0.162
μ_m/μ_H	1.033	1.006	1.041	1.013	1.032
GaAs — $N_D = 2 \times 10^{16}/cm^3$					
Hall mobility μ_H (m^2/V s)	0.565	0.450	0.403		
magnetoresistance mobility μ_m (m^2/Vs)	0.565	0.465	0.424		
μ_m/μ_H	1.00	1.035	1.052		

The Field and Temperature dependence of Electron mobility in Gaas devices

To confirm that the geometrical magnetoresistance technique may be used for the determination of electron mobility in our samples, the magnetoresistance mobility was measured as a function of temperature (100 to 500 K) and electric field strength for thirty GaAs devices and six InP devices. Measurements were taken for fields up to the threshold field, as determined by a terminal current drop, under pulsed voltage conditions.

Calculation of the field below threshold was made on the basis of the simple equation $E = U = U_A/L$ where U_A is the applied voltage and L is the length of the device. The procedure involves two assumptions: firstly, it assumes negligible distortion of the electric field in the device, and secondly it ignores the barrier resistance associated with the contact-semiconductor interface. Although the first assumption is difficult to justify, minimal influence on the measurement due to the contact may be assumed if the selection procedure outlined in the previous section is carried out and if the devices yield symmetrical results for either bias polarity for all temperatures. All the GaAs devices satisfied these conditions, but an anomalous behaviour was observed with some InP devices. This contact anomaly will be discussed later in this paper.

The GaAs samples were fabricated from n-type epitaxial layers (L = 7.5 pm, $N_D = 2 \times 10^{15}$ cm^{-3}) grown on n^+ substrates. The contacts consisted of the n^+ region and a 60 pm diameter Au-Ge circular dot on the free surface. The devices were fabricated from five different slices where each slice produced devices of similar room-temperature magnetoresistance mobility, but variations were observed for different slices. The InP devices were of a similar structure with an epitaxial layer thickness of 10 pm and a carrier concentration equal to 5×10^{15} cm^{-3}.

All devices were mounted in 54 microwave packages with top hats purposely omitted [4]. As interest was centred on the contact properties, devices were made from the same slice, but three types of contact were used:

Table 2: Ag, Sn and Sn dot ohmic contact

contacts		alloying	mounting	
layer (n)	substrate (n^+)	temp. (°C)	solder	temp. (°C)
Ag	Ag/Sn	430	Ag	180
Ag/Sn	Ag/Sn	430	Ag	180
Sn dot	Sn	340	on heater strip	

These are in order of the observed rectifying properties, only the Sn dot being a good approximation to an ohmic contact.

Measurements were made with the devices under dc bias conditions ($U_A \approx 50$ mV, I = 5 mA) in a standard temperature-controlled vacuum chamber. Details of the procedure for determining μ_m from the change in device resistance with applied magnetic field B and the precautions necessary to ensure the linearity of the R-B^2 relationship have been outlined elsewhere. The dependence of μ_m on temperature for five devices from the same slice is shown in Fig. 1.

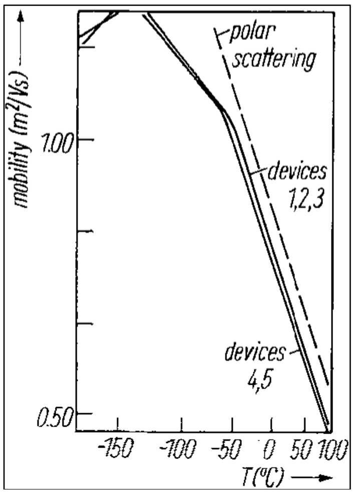

Fig 1: Magnetoresistance mobility versus temperature for five GaAs devices made on the same slice. A comparison with theoretical calculations involving polar mode scattering and ionized impurity scattering is also shown

We consequently presume that the room-temperature magnetoresistance versatility is characteristic of the complete ionized debasement thickness in these examples. We currently look at the test field reliance of versatility with the hypothetical expectations of Ruch and Fawcett [5] and the microwave warming analyses of T'Lam and Acket [6]. For these trials the gadgets were worked under heartbeat inclination conditions (100 pps; 0.5 μs), and the portability was resolved at steady temperature for fields up to the precariousness edge field. The outcomes are appeared in Fig. 2

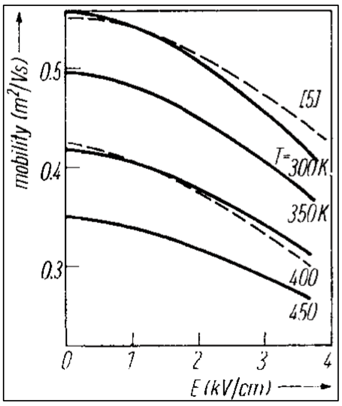

Fig 2: Mobility variation with electric field for a GaAs sample at various temperatures. Comparison, where possible, has been made with the results of Ruch and Fawcett [5] (Monte Carlo) and T'Lam and Acket [8] (microwave heating)

Along with the predicted variations extracted from the theoretical results of Fawcett and the experimental results of T'Lam and Acket. The measured values of mobility are seen to be in good agreement with those extracted from the curves of T'Lam and Acket for all values of field up to the threshold value.

Magnetoresistance studies on InP Devices

Indium phosphide has gotten extensive consideration in the previous barely any years because of its likely application in strong state inicrowave oscillators. Despite the fact that the methods of wavering of these gadgets are not satisfactory and the idea of the electron move instrument not certain, viable gadgets have been appeared to display a wide area of negative obstruction and the capability of higher yield power than GaAs moved electron (TE) gadgets.

Hypothetical methodologies (see, for instance, Hilsum and Itees [7]) propose that the chance of higher yield powers is basically because of the more prominent top to-valley proportion anticipated from InP. In any case, odd contact impacts have been seen on InP TE gadgets, and the proposal is that the contact properties are a main consideration in deciding the microwave transformation effectiveness [8, 9]. Subsequently we have explored the utilization of the GMK, method to decide in finished gadgets the obvious versatility as an element of inclination at different temperatures. The inclination of this strategy in this setting has just been worried by Jervis and Johnson [4].

Effect of a Contact resistance on GMR Measurements

Ideally GMR should be a pure bulk effect, i.e., any change in resistance due to an applied magnetic field should not be influenced by contact effects and the true mobility will be measured. Consider a device whose current-voltage characteristics are symmetrical even at low temperatures. The variation of mobility with pulsed bias for such a device is shown in Fig. 3.

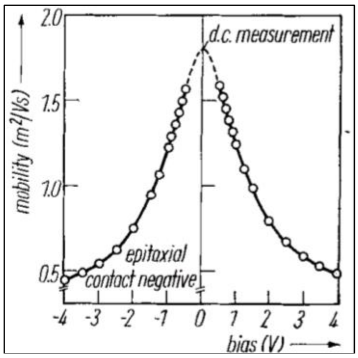

Fig 3: Mobility variation with bias for an InP sample at 163 K. The solid curve is taken under pulsed conditions (1μs pulse, 80pps) and the dashed curve is the extrapolation to the dc measured value of 1.8 m^2 V^{-1}s^{-1}

A symmetrical bell-shaped curve is obtained with a peak value of 1.8 m^2 V^{-1}S^{-1} as measured by dc methods. For a device of this kind we as Evaluation some that the electric field E (for the low bias range considered here) is uniform throughout the device active layer and is simply the bias divided by the active length.

A contact resistance, however, will always degrade the relative change in terminal resistance and hence a lower (apparent) mobility will be measured. For a contact resistance R_C, in series with a bulk resistance R_B, the ratio of apparent to true mobilities will be given by

$$\frac{\mu_A}{\mu_T} = \sqrt{\frac{R_B}{R_B + R_c}} \qquad (1)$$

Note that in this equation, $R_B + R_C$ is the dc terminal resistance.

In practice the problem is complicated by the following problems:

a) In the case of a device with asymmetrical current-voltage characteristics, the contact resistance as defined here is voltage-dependent.
b) The mobility in InP, especially at low temperatures, is a function of field and hence RB is also voltage-dependent.
c) These problems have been overcome with diminishing success in the order Sn dot devices, Ag/Sn devices, and Ag devices.

Tin dot devices approach nearest to the ideal conditions previously discussed, with their current-voltage characteristics as shown in Fig. 4

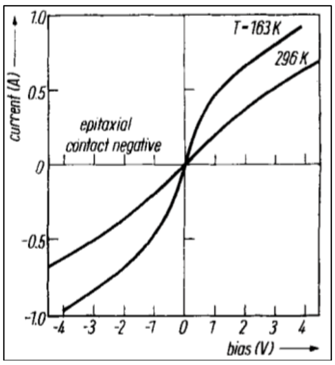

Fig 4: The current-voltage characteristic of a Sn dot device at room temperature and at 163 K

Being symmetrical even at the lower temperatures. A typical low-field mobility variation with temperature is shown in Fig. 5

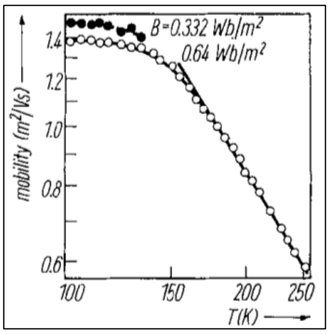

Fig 5: Mobility variation with temperature of an InP device with Sn dot contacts (1/2) and a bias of 50 mV. Results taken for two values of magnetic field B are shown to illustrate the extent of the error induced by using too large a value of B (slope - 1.6)

Where the results for two values of magnetic field are shown in order to highlight the compromise in the value of B chosen to give sufficient change in resistance for reasonable accuracy. The slope of the straight-line portion of the log μ_m: log T plot suggests that polar mode vibrations are the mobility-determining mechanism in this temperature range with a temperature dependence $\approx T^{-1.6}$. The saturation value at the high temperature suggests a large contribution from ionized impurity scattering. Lower temperatures have not been examined. The apparent mobility versus applied bias as shown in Fig. 6

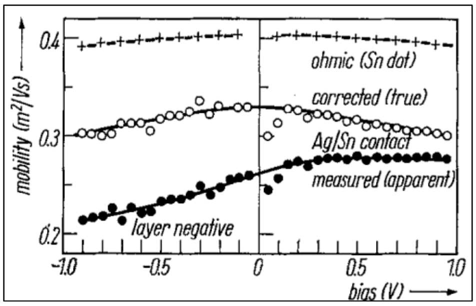

Fig 6: The mobility variation with bias for an Ag/Sn contact device (T = 296 K). The corrected curve is obtained from it as explained in the text. Also shown for comparison is the same measurement for an Sn contact device on the same slice

is symmetrical although the peak value is lower than expected from measurements on similar slices (0.4 instead of $0.46 m^2 V^{-1} s^{-1}$). In Fig. 6 the measured and corrected mobilities of an Ag/Sn contact device are also shown. The current-voltage characteristic of this device is shown in Fig. 7.

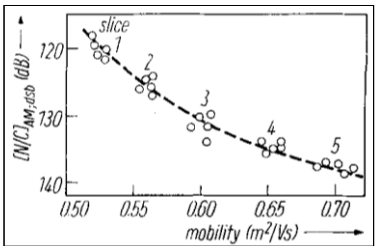

Fig 7: Monotonic relation between the room-temperature low-field magnetoresistance mobility and the AM noise in a 1 Hz wide band, 1 kHz away from the carrier frequency of 9 GHz

It was decided that because of the high reverse current flowing, a model involving a low Schottky barrier in series with the n-layer resistance [10] would not suffice. This is in conflict with the idea of a large (200 mA) reverse saturation current, and an alternative current path, R_p was included in the equivalent circuit. In this circuit I_s and U_0 are the parameters characterizing the diode in the equation

$$I_d = I_s\left[\exp\left(\frac{U_d}{U_0}\right)-1\right] \tag{2}$$

This equivalent circuit was fitted to the measured I-U by minimizing the expression with respect to R_B, R_p I_s, U_0.

$$\delta = \sum_{U=first}^{U=last}[I_{calc}(U_{meas}) - I_{meas}(U_{meas})]^2 \tag{3}$$

Correlation of The Modulation noise of Gunn oscillators with Carrier

It has been suggested by a number of authors that the frequency modulation noise close to the carrier ($\lesssim$ 10 kHz) is due to local density fluctuations in carrier concentration within the bulk of the material and at the outside of the dynamic locale of the M-GaAs-M structure. It is proposed that these changes offer ascent to an adjustment of the area capacitance and hence up-changed over PM commotion. Notwithstanding, if so, at that point in many microwave oscillator circuits FM to AM transformation will be watched and the AM clamor will likewise have its inceptions in nearby transporter changes. It is likely that such changes are firmly identified with the pollution substance of the mass GaAs, and accordingly it may be normal that, since the room-temperature low-field portability is influenced by the all out contamination focus (as we have appeared over), the tweak commotion attributes of Gunn oscillators ought to be firmly corresponded with the versatility. To test this theory the AM commotion estimated in a 1 Hz wide band, 1 kHz from the transporter recurrence (9 GHz), was resolved for thirty Gunn diodes (recently portrayed as far as their versatility) mounted in a tunable waveguide cavity. The kind of microwave oscillator structure was, for example, to limit the circuit impacts on tweak clamor and in this manner highlight potential contrasts because of the diodes themselves. The aftereffects of these analyses are appeared in Fig. 7.

Two significant allowances might be produced using these outcomes:

a) The AM clamor is around the equivalent for gadgets taken from a similar cut and with comparative room-temperature mobilities.
b) The AM commotion falls monotonically with expanding versatility and shows a 20 dB decline in AM clamor over the portability range 0.50 to 0.75 m^2Z/Vs. Doubtlessly, consequently, that before advanced circuit methods are utilized to limit balance commotion in Gunn oscillators, the beginning stage ought to be to pick a diode with the most elevated room-temperature portability. Right now this must be accomplished utilizing the mathematical magnetoresistance strategy.

Conclusions

In this paper we have demonstrated how the methods of mathematical magnetoresistance and Hall impact can be utilized to describe the versatility of GaAs moved electron gadgets. The method is especially important since it empowers the versatility of complete bundled gadgets to be estimated preceding their inclusion into appropriate oscillator circuits. Utilizing these outcomes we have demonstrated that there is a solid relationship between's the versatility and the adjustment commotion of the gadgets. InP gadgets have likewise been considered utilizing GMR with specific reference to contact conduct. The lower obvious mobilities saw in gadgets whose contacts contain Sn are credited (like the situation of GaAs) to the presence of a locale under the contact exceptionally doped, firmly redressed, and consequently of low portability. Sn speck gadgets actually show a bigger obvious versatility than Ag/Sn gadgets on the grounds that their alloying temperature is lower. The portability in Ag contact gadgets is a lot bigger on the grounds that either a regrown district is absent or its impact is negligible.

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