Phys. Status Solidi C **8**, No. 5, 1625–1628 (2011) / **DOI** 10.1002/pssc.201000594

physica status solidi c
www.pss-c.com
current topics in solid state physics

Determination of the in-plane effective mass and quantum lifetime of 2D electrons in AlGaN/GaN based HEMTs

Ozlem Celik[1], Engin Tiras[*, 1], Sukru Ardali[1], Sefer Bora Lisesivdin[2], and Ekmel Ozbay[3]

[1] Department of Physics, Faculty of Science, Anadolu University, Yunus Emre Campus, 26470 Eskisehir, Turkey

[2] Department of Physics, Faculty of Science and Arts, Gazi University, Teknikokullar, 06500 Ankara, Turkey

[3] Nanotechnology Research Center, Department of Physics, and Department of Electrical and Electronics Engineering,
Bilkent University, Ankara, Turkey

Received 30 June 2010, revised 17 December 2010, accepted 30 December 2010

Keywords Shubnikov de Haas, effective mass, quantum lifetime, AlGaN

---

* Corresponding author: e-mail etiras@anadolu.edu.tr

Magnetoresistance and Hall resistance measurements have been used to investigate the electronic transport properties of AlGaN/GaN based HEMTs. The Shubnikov–de Haas (SdH) oscillations from magnetoresistance, is obtained by fitting the nonoscillatory component to a polynomial of second degree, and then subtracting it from the raw experimental data. It is shown that only first subband is occupied with electrons. The two-dimensional (2D) carrier density and the Fermi energy with respect to subband energy (E_F–E_1) have been determined from the periods of the SdH oscillations. The in-plane effective mass (m*) and the quantum lifetime (τ_q) of electrons have been obtained from the temperature and magnetic field dependencies of the SdH amplitude, respectively. The in-plane effective mass of 2D electrons is in the range between 0.19 m_0 and 0.22 m_0. Our results for in-plane effective mass are in good agreement with those reported in the literature.

1 Introduction The GaN and AlN are ideal materials for the construction of blue/green light-emitting devices (LEDs and lasers) and transistors intended to operate at high power and high temperatures because of their wide band gap structure [1].

There are three main techniques used in the evaluation of the transport properties of GaN/AlGaN heterostructures, namely, magnetotransport, cyclotron resonance absorption under high magnetic field and Raman spectroscopy [2]. The wide band gap energy, high electron mobility, high saturation drift velocity, high breakdown voltage and good thermal conductivity in GaN/AlGaN heterosutructure open new areas in their usage for wide range high- temperature, high frequency and high power applications [3,4].

Despite the progress in the development of devices, many fundamental materials parameters of GaN/AlGaN still remain to be fully understood. The sound knowledge on these parameters, such as effective mass, is important for the exploration and optimization of this material system in device applications.

In this work we report the results of effective mass, quantum lifetime, Dingle temperature of the 2DEG in AlGaN/GaN based HEMTs which are determined from the orthodox SdH measurements.

2 Experiment Van der Pauw samples were used in the experiments and the measurements were carried out in darkness. The resistance (R_{xx}) along the applied current was measured as a function of temperature at fixed magnetic field. Applied voltage was kept low enough to ensure ohmic conditions, hence to avoid carrier heating. The measurements were performed in a four terminal configuration in a cryogen-free superconducting magnet system (Croyogenics Ltd.). The conventional DC technique was used in combination with a constant current–voltage source Keithley 2400, a switch system Keithley 7100, a nanovoltmeter Keithley 182A, and a temperature controller Lakeshore 340. The current flow was in the plane of the samples and magnetic field was perpendicular to both the current and the sample plane.

3 Results and discussions A typical example for the temperature dependence of magnetoresistance is shown in Fig. 1. Here the data sets measured at three different temperatures only are presented for clarity. The oscillation amplitude of the magnetoresistance reduces with increasing temperature in accordance with the usual thermal damping factor It is also evident that the oscillatory effect is superimposed on a monotonically increasing component, which occurs as a result of positive magnetoresistance probably in the barriers [5]. This may affect the accuracy of the determination of oscillation amplitude, particularly at elevated temperatures. A widely used method to exclude the effects of the background magnetoresistance (R_b) and to extract the SdH oscillations is obtained by fitting the nonoscillatory component to a polynomial of second degree, and then subtracting it from the raw experimental data [4]. This technique does not change either the peak position or the period of the oscillations. Figure 2 shows the SdH oscillations at $T = 1.8$ K for AlGaN/GaN sample. The oscillations are sinusoidal with well-defined envelopes and are almost symmetrical about a horizontal line.

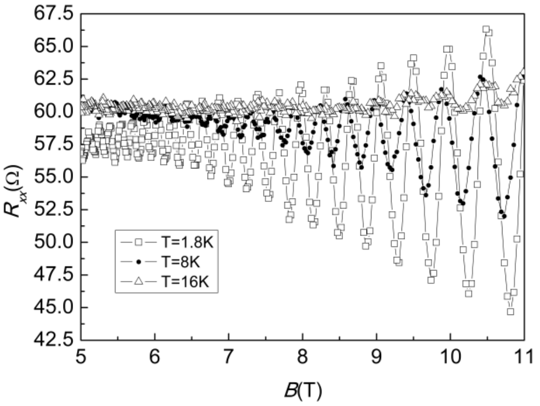

Figure 1 The magnetoresistance (R_{xx}) as a function of magnetic field for the AlGaN/GaN sample measured at three different temperatures.

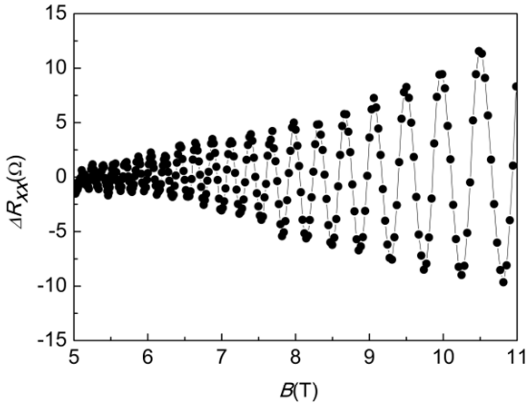

Figure 2 Oscillating components of the magnetoresistance (ΔR_{xx}) obtained by subtracting the nonoscillating components from the raw experimental data given in Fig. 1.

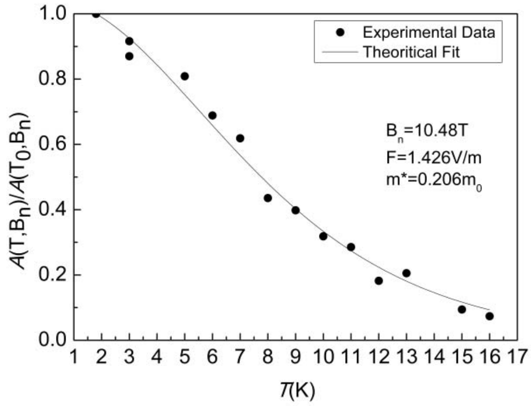

Figure 3 Temperature dependence of the normalized amplitude of the oscillation peak at a fixed magnetic field of B_n measured for AlGaN/GaN. The data points are represented by the full circles. The curve is the best fit of Eq. (1) to the experimental data.

Figure 3 shows the determination of effective electron mass graph of AlGaN/GaN at a steady current $I = 250$ μA ($F = 1.426$ V/m) and a magnetic field $B_n = 10.48$ T. The in-plane effective mass m^* can be extracted from the temperature dependence of the SdH amplitude at constant magnetic field using [5-7]

$$\frac{A(T,B_n)}{A(T_0,B_n)}=\frac{T.\sinh\left(\dfrac{2\pi^2 k_B m^* T_0}{\hbar e B_n}\right)}{T_0.\sinh\left(\dfrac{2\pi^2 k_B m^* T}{\hbar e B_n}\right)} \tag{1}$$

where $A(T,B_n)$ and $A(T_o,B_n)$ are the amplitudes of the oscillation peaks observed at a magnetic field B_n and at temperatures T and T_o, respectively. The in-plane effective mass of 2D electrons are then determined by fitting the experimental data for the temperature dependence of $A(T,B_n)/A(T_o,B_n)$ to Eq. (1). The effective electron mass for AlGaN/GaN is $m_e^*= 0.206m_0$. Our result for m^* of 2D electrons in AlGaN/GaN is in good agreement with the bulk effective mass in GaN [3, 10, 11]. Therefore, this indicates that both the nonparabolicity of the conduction band of GaN and the wavefunction penetration into the AlGaN barrier layer have no significant effect on m^* of 2D electrons. Our experimental datas are also consistent of theoretical results by other research groups [3, 10, 11].

The quantum lifetime (τ_q) can be determined from the magnetic-field dependence of the amplitude of the SdH oscillations (i.e. Dingle plots) at a constant temperature provided that the electron effective mass is known [5, 7, 9]. Figure 4 shows an example of Dingle plot for AlGaN/GaN. There is a good agreement between the experimental data and the straight line described by [7, 9]

$$ln\left[\frac{A(T,B_n).B_n^{-1/2}.\sinh\chi}{\chi}\right]=C-\frac{\pi m^*}{e\tau_q}\frac{1}{B_n} \qquad (2)$$

where $\chi = 2\pi^2 k_B T/(\hbar\omega_c)$, $\omega_C(=eB_n/m^*)$ is the cyclotron frequency and C is a constant. The quantum lifetime, obtained from the slope of the Dingle plot using Eq. (2) together with the measured values of m^*, is τ_q=0.109 ps.

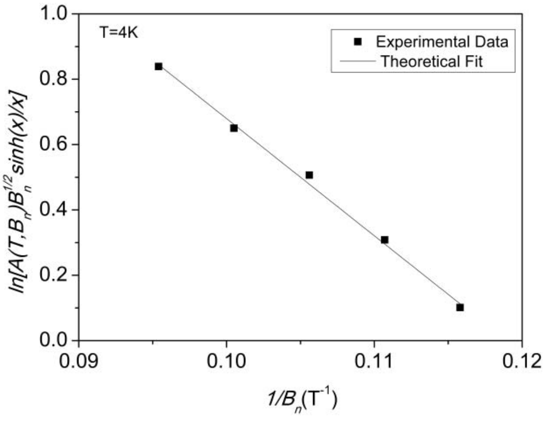

Figure 4 Determination of the quantum lifetime for AlGaN/GaN. The data points are represented by the full squares. The straight line is the least-squares fit of Eq. (2) to each set of the experimental data.

2D electron density, Fermi energy and the separation of the subbands can be found from SdH oscillations period. To measure SdH oscillation's period two different methods are used. For the first method, in experimental $R_{xx}(B)$ data SdH oscillation peaks are numbered than the magnetic field (B_n) value for the peaks are determined. The period of the SdH oscillations has been obtained from the plots of the reciprocal magnetic field ($1/B_n$), at which the nth peak occurs, against the peak number (n). If the electrons in only one subband participate in the SdH oscillations, the graph of $1/B_n$ versus n gives a straight line, the slope of which yields the oscillation period, $\Delta(1/B)$ (the figure inside Fig. 5). For the second method, Fourier transform is applied on experimental $R_{xx}(B)$ data. The peak number in Fourier transform is equal to number of full subbands. Each peak corresponds a different oscillation period. Oscillation period can be calculated from

$$\Delta\left[\frac{1}{B}\right]=\frac{N(\Delta t)}{m-1}=\frac{e}{\pi\hbar N_{2D}}=\frac{e\hbar}{m^*(E_F-E_1)} \qquad (3)$$

where $N=2^n$ is number of data, $\Delta t=(1/B_{min}-1/B_{max})/N)$ (T^{-1}), m is the number read from the horizontal axis that the peak occurs on FFT power spectra. The Fourier analysis of the SdH oscillations confirms that, for the sample studied; only the first subband is populated [4]. Figure 5 shows clearly that there is no evidence for the population of higher subbands or for any contribution from higher harmonics. The 2D carrier density and Fermi energy for the sample obtained from the oscillation period using Eq. (3) together with the in-plane effective mass m* of 2D carriers are: $N_{2D} = 9.67x10^{16}$ m^{-2} and $E_F-E_1 = 115.7$ meV.

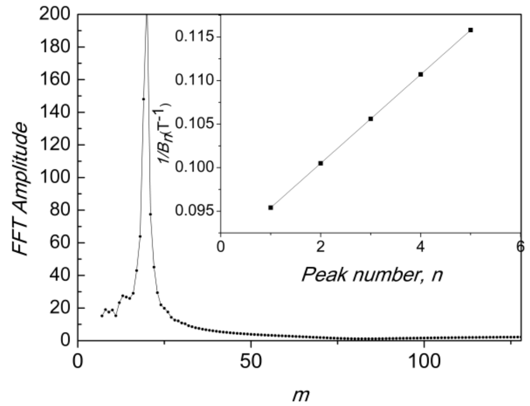

Figure 5 Obtaining SdH oscillation period for AlGaN/GaN heterostructures. The full circles correspond to the data determinated from fast Fourier spectrum of the oscillations given in Fig. 2. The insert shows the data obtained from SdH oscillation amplitude and the straight line is the least-squares fit to the experimental data.

4 Conclusion

The in-plane effective mass of AlGaN/GaN heterosutructures is obtained using temperature dependence of the SdH amplitude at constant magnetic field. The effective electron mass for AlGaN/GaN is obtained from the measurements as $m_e^* = 0.206m_0$. The quantum lifetime (τ_q) is obtained using magnetic field dependence of the SdH amplitude together with the measured value of m^*, is $\tau_q = 0.109$ ps The 2D carrier density is obtained from the SdH oscillation period as $N_{2D} = 9.67x10^{16}$ m^{-2}.

References

[1] R. de Paiva, J.L.A. Alves, R.A. Nogueira, C. de Oliveira, H.W.L Alves, L.M.R Scolfaro, and J.R. Leite, Mater. Sci. Eng. B **93**, 2-5 (2002). S. Nakamura and G. Fasol, The Blue Laser Diode (Springer, 1997). Y. Wu, B.P. Keller, S. Keller, D. Kapolnek, P. Kosodoy, S.P. Denbaars, and J.K. Mishra, Appl. Phys. Lett. **69**, 1438 (1996).

[2] S. Contreras, M. Goiran, W. Knap, F. Yang, H. Rakoto, R. Barbaste, J.L. Robert, J. Leotin, S. Askenazy, Q. Chen, and M. Asif Khan, Physica B **246/247**, 274-277 (1998).

[3]A. M. Kurakin, S. A. Vitusevich, S. V. Danylyuk, H. Hardtdegen, N. Klein, Z. Bougrioua, A. V. Naumov, and A. E. Belyaev, J. Appl. Phys. **105**, 073703 (2009).

[4] H. Çelik, M. Cankurtaran, A. Bayrakli, E. Tiras, and N. Balkan, Semicond. Sci. Technol. **12**, 389-395 (1997).

[5] S.B. Lisesivdin, N. Balkan, O. Makarovsky, A. Patane, A. Yildiz, M.D. Caliskan, M. Kasap, S. Ozcelik, and E. Ozbay J. Appl. Phys. **105**, 093701 (2009).

[6] D.G. Seiler and A.E. Stephens, Landau Level Spectroscopy, Vol. 2, edited by G. Landwehr and E. I. Rashba (North-Holland, Amsterdam, 1991), p. 1031.

[7] E. Tiras, M. Cankurtaran, H. Çelik, A. Boland Thoms, and N. Balkan, Superlattices Microstruct. **29,** 147-167 (2001).

[8] N. Balkan, H. Celik, A.J. Vickers, and M. Cankurtaran, Phys. Rev. B **52**, 210 (1995).

[9] H. Çelik, M. Cankurtaran, A. Bayrakli, E. Tiras, and N. Balkan, Semicond. Sci. Technol. **12**, 389 (1997).

[10]A. Kasic, M. Schubert, B. Rheinländer, V. Riede, S. Einfeldt, D. Hommel, B. Kuhn, J. Off, and F. Scholz, Mater. Sci. Eng. B **82**, 74-76 (2001).

[11] Z. Yarar, Solid State Commun. **147**, 98-102 (2008). Y.C. Yeo, T.C. Chong, and M.F. Li, J. Appl. Phys. **83**, 1429 (1998).