EMISSION OF ACOUSTIC PHONONS BY HOT CARRIERS IN WURTZITE GaN EPILAYERS

Mustafa EROL
Dokuz Eylul University, Education Faculty of Buz, Physics Department,
Buz, 35150, Izmir, TURKEY.

Abstract.- In this paper, we report a study of acoustic phonon emission by hot carriers in wurtzite GaN epilayers, using heat pulse technique. In this technique, the carriers were heated up by means of a short (~10 ns) voltage pulse and emitted phonons were detected by generally super conducting Al bolometers biased on their super conducting transition edge. Obtained phonon signals indicates that the optic phonon emission threshold has not been reached and longitudinal acoustic (LA) and transverse acoustic (TA) modes can clearly be resolved. This paper specifically concentrates on the power per electron dependence of the emission signals.

1. INTRODUCTION

The energy relaxation processes by hot carriers are of fundamental significance to the operation of semiconductor devices. Direct studies of emission of phonons by hot carriers allow more detailed information regarding the energy relaxation processes and phonon scattering. In particular, heat pulse experiments, in which the carriers are excited with a pulse short compared to the phonon time of flight across the substrate, make possible the temporal resolution of different phonon modes owing to their different velocities [1]. Over the last few years, there has been a growing interest in GaN, a wide bandgap (3.20eV in wurtzite form and 3.45eV in zincblende form) compound semiconductor. Following the breakthrough in 1992 [2], the ability to grow the p-n junctions of GaN, as well as heterojunctions of AlGaN/GaN/InGaN systems has opened the way for the development of blue light emitting diodes. In addition, the wide bandgap and high melting point of GaN make it a promising material for high power and high temperature operating electronic devices. The elastic constants and related properties of tetrahedrally bonded (zincblende) GaN are theoretically determined by Kim et al [3]. The nonequilibrium electron distributions and phonon dynamics in wurtzite GaN are studied experimentally by Tseng et al [4], by using subpicosecond time resolved Raman Spectroscopy. The LA phonon lifetime and possible decay route for LO phonons in GaN are estimated by Ridley [5]. Valance band splittings and band offsets of GaN have been studied by Wei and Zunger [6]. Zone boundary phonons in wurtzite and zincblende GaN structures have been studied experimentally by Siegle et al [7], and their measurements revealed the energies of acoustic zone boundary phonons in hexagonal GaN epilayers. Anisotropic hole scattering in hexagonal GaN has been theoretically worked out by Lee et al [8]. The elastic moduli of wurtzite phase GaN have been measured by resonant ultrasound method by Schwartz et al [9].

2. EXPERIMENTAL DETAILS

The samples employed in these experiments were that of wurtzite GaN grown by MBE on a 0.3mm thick Al2O3 substrates. The actual samples were O-ring shaped with a thickness, diameter and width of 1μm, 1.5mm and 100μm, respectively. The other side of the substrate was polished and superconducting Al bolometers were deposited by classical vacuum evaporation technique. The bolometers were defined photolithographically and infrared front to back alignment used to position them relative to the device on the opposite side of the wafer. The samples were mounted in a He cryostat and cooled down to superconducting transition temperature of the bolometers, Tc=1.5K. In addition to the measurements of phonon emission, some transport measurements have been carried out to determine the device resistance which was later used to determine the actual electron

The experimental part of the work was carried out in the Physics Department of Nottingham University.
temperature dependence of the power dissipation. Determination of the power dissipated in the device active area was achieved by observing the amplitude of the forward and reflected pulses on the 50 Ω transmission line between the pulse generator and the actual device.

<table>
<thead>
<tr>
<th>Sample No</th>
<th>Growth Temperature(°C)</th>
<th>Thickness(μm)</th>
<th>ρ(Ω·cm)</th>
<th>μ( cm²V⁻¹·s⁻¹)</th>
<th>n( cm⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG386</td>
<td>750</td>
<td>1 undoped</td>
<td>36</td>
<td>400</td>
<td>4.98×10¹⁷</td>
</tr>
<tr>
<td>MG411</td>
<td>750</td>
<td>0.52undoped</td>
<td>76</td>
<td>65</td>
<td>1.34×10¹⁷</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+1.56 Si doped</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MG413</td>
<td>750</td>
<td>0.52undoped</td>
<td>30</td>
<td>35</td>
<td>6.5×10¹⁷</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+1.56 Si doped</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Room temperature transport parameters of the samples employed in this work.

According to the transmission line theory, the power dissipated in any system is given by:

\[ P_d = \frac{V_f^2 - V_r^2}{50} \]  

where \( V_f \) is the amplitude of the forward pulse, and \( V_r \) is the amplitude of the reflected pulse, both corrected for the cable attenuation. Following the method, defined by Hawker et al [10], measurement of the overall energy loss rates were achieved by simply using the active channel resistance itself as a thermometer. With short pulses applied to avoid lattice heating effects, the resistance of the device was measured as a function of the power delivered in the pulse. The power was measured by using the pulse reflectance method as described above and the corresponding actual device resistance is given by:

\[ R_d = \frac{50(V_f + V_r)^2}{V_f^2 - V_r^2} \]  

A calibration of the device resistance as a function of ambient temperature was made under equilibrium conditions, using a small current to avoid carrier heating effects. Comparison of the two sets of measurements enabled us to determine the carrier temperature, \( T_n \), as a function of the power dissipated in the device. The pulse reflectance measurements become inaccurate when the device resistance more than ten times the characteristic impedance of the transmission line, 50Ω, where upon the forward and reflected pulses have nearly the same amplitude.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 1 shows the heat pulse signals detected on a bolometer directly opposite the actual device.

![Figure 1: Heat pulse signals with input power of 14.2 pW/electron](image)

From the time of flight measurements, the testing longitudinal acoustic (LA), fast transverse phonons travelling ballistically. The small heating pulse from the figure 1, time 83.11ns for the first and slow transverse, indicating that we do not see any long delayed relative to the ballistic pulses of heat pulse signal at high power, falling off.

![Figure 2: Power per electron dissipated](image)

Power per electron plotted versus between the signal height and the power dependence is almost obeyed experiment.

![Figure 3: Power per electron versus electron temperature](image)

The electron temperature dependence in the range where acoustic phonon or electron temperatures the power dep
The electron configuration depends on the power dependence of the electron relaxation. The electron configuration is the dominant factor in the relaxation process. A lower electron configuration results in a greater power dependence.

![Graph 1: Power vs. Electron Configuration](image1)

**Figure 1:** Power vs. Electron Configuration within the Effective Configuration Range

The electron configuration depends on the power dependence of the electron relaxation. The electron configuration is the dominant factor in the relaxation process. A lower electron configuration results in a greater power dependence.

![Graph 2: Power vs. Electron Configuration](image2)

**Figure 2:** Power vs. Electron Configuration within the Effective Configuration Range
to be obeying to the power law of $P_e \propto T_e^3$. A brief comparison with the theory by Jasukiewicz and Karpus [11] indicates with that in the Bloch-Grüneisen’s regime, the piezoelectric coupling dominates the electron-acoustic phonon scattering mechanism, which estimates a relation of $P_e \propto \alpha(T_e^3 - T^3)$. At very low electron temperatures (≤2K) the temperature dependence of the energy loss rate does not trend to increase the power law, which indicates that the screening does not play any significant role in this mechanism.

In figure 4, power per electron plotted against the electron temperature at high temperature end, equipartition regime. Also shown is the power law dependence curve, that is $P_e \propto T_e^3$. A brief comparison of the theory and the curve indicates that within the equipartition regime both piezoelectric and deformation potential coupling mechanisms could be playing an important role. A good agreement between the theory [11] and the experimental data has been shown in the figure 3. We do not see any deviation from the theory as the temperature goes up which would show up if we reached to the optic phonon emission threshold.

![Figure 4: Power per electron versus electron temperature, within the equipartition regime.](image)

**Acknowledgements** - We would like to acknowledge the support of TÜBITAK of Turkey and Royal Society of U.K. for this work. We also thank Dr. A. J. Kent and Dr. P. Hawker for discussions and Dr. T. S. Cheng and Dr. C. T. Foxon for the preparation of the samples.

**REFERENCES**


**Abstract** - We present low temperature (~2K) electron in wurtzite GaN epitaxial layer study specifically concentrates on the mobility which are considered to be transferred from conduction bands [1]. The measurements were performed using a Hall technique. The interpretation of the data is as follows: 

1. **INTRODUCTION**

Gallium Nitride (GaN) has received a great deal of attention for its potential for especially opto-electronic devices and also for devices operating at high temperatures. The technological achievements of the last few decades concerning the basic physical, electrical, and mechanical properties of GaN have been reviewed in various reports in the literature [9,10] dealing with GaN in the same two band model has been employed. The independent mobility, carrier concentration, and wurtzite GaN epilayers obtained by employing the ensemble Monte Carlo method with the electric field range of 1-1000 V/nm.

2. **SAMPLE AND EXPERIMENTAL DETAILS**

The sample employed in this work is a GaN epilayer on sapphire. The room temperature parameter of the epilayer were measured with a Hall effect and Van der Pauw technique. The contacts on the GaN layers. The measured Hall effect parameter of the fixed magnetic field of 1T and fixed temperature of 100 µA and kept constant by a high precision current source. The current is starting from 1 Vm" up to 1000 Vm", and the experimental part of the work is carried out.