CORRELATION BETWEEN SCATTERING MECHANISM OF ELECTRONS AND THE PROPERTIES OF ALGAN/GAN HEMT TYPE HETEROSTRUCTURES

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Abstract *Scattering mechanism of electrons e.g. impurities, phonons etc. in solid-state materials influenced their electrical and optical properties. In order to achieve the best quality of AlGaN/GaN HEMT type heterostructures that will influence the HEMT transistor parameters it is essential to identify the scattering mechanism that appeared in epitaxial layers. Impurities such as hydrogen, carbon, Al, Ga, Si result from the applied reagent, construction of the reactor and MOVPE (Metalorganic Vapour Phase Epitaxy) process parameters. This mechanism will reflect on the values of Johnson, Key and Baliga figures of merit the knowledge of which is important to determine the application areas of materials. (carbon, oxygen, hydrogen).*

Keywords scattering mechanism, AlGaN/GaN heterostructures, HEMT, MOVPE

1. INTRODUCTION

Many semiconductor devices are still fabricated in the most mature silicon technology even if their physical properties sometimes are not sufficient for high frequency and high power application [1]. It is essential to consistently improve the existing techniques to growth the high quality compound semiconductors that could replace the silicon technology in same applications. One of possible candidate are nitrides. Nowadays the most popular in electronic application are AlGaN/GaN HEMT (High Electron Mobility Transistor) type heterostructures. Important role in limiting the performance of devices fabricated in nitrides plays the scattering mechanisms of electrons because of they could reduce drift velocity and worsen the high frequency operations of the devices [2].

2. FIGURE OF MERIT EVALUATION

In order to get valuable information for the design of semiconductor devices based on AlGaN/GaN heterostructures the material properties of Gallium Nitride material was studied [3] in details. In 1965, Johnson [4] link the electric field at which impact ionization initiates the breakdown E_c and saturated drift velocity v_s, to introduced first figure of merit JFOM, that defines the ability of semiconductor devices for high power and high frequency operation. In 1972 Keyes [5] proposed the second figure of merit KFOM for evaluation of thermal limitation of performance of semiconductor logic devices, where: λ is thermal conductivity, ε stands for the dielectric constant and c is the speed of light. Finally in 1983 Baliga [6] proposed formula BFOM for the assessment of the conduction losses in power FET's (Field Effect Transistors) in this case E_g is the bandgap of semiconductor and μ is its electron mobility.

Table 1. Three basic figures of merit: Johnson, Keys and Baliga

JFOM	KFOM	BFOM
$\frac{E_C v_s}{2\pi}$	$\lambda\sqrt{\frac{c v_s}{4\pi\varepsilon}}$	$\varepsilon\mu E_G^3; \mu \sim v_s$

3. SCATTERING MECHANISM IN NITRIDES

In solid-state physic, the most popular Bloch model to describe motion of electrons rely on ideal periodical lattice without defects and with freeze host atoms. To describe the movement of electrons in real semiconductors devices [7], one should consider factors that could reduce the free path of electrons in real crystal lattice (Table 2). Concentration of defects and impurities have enormous impacts at movement of electrons. In addition, approximation where atoms do not move because they are much bigger then electrons are also invalid in higher temperatures where numbers of phonons will dramatically increase.

Table 2. Scattering mechanism and corresponding relaxation times with main dependences

Scattering mechanism that influenced the 2DEG concentration (n_{2DEG})	
Dislocations [8]	$\tau_{DIS} \sim \frac{\sqrt{n_{2DEG}^3}}{N_{DIS}}$
Remote ionised impurities [9]	$\tau_{RII} \sim \frac{d^3\sqrt{n_{2DEG}^3}}{N_{RII}}$
Background ionised impurities [9]	$\tau_{BII} \sim \frac{\sqrt{n_{2DEG}^3}}{N_{BII}}$
Scattering mechanism that depends on temperature T and concentration n_{2DEG}	
Acoustic phonons: deformation mode [10]	$\tau_{ADP} \sim \frac{1}{\sqrt[3]{n_{2DEG}}T}$
Acoustic phonons: piezoelectric mode [10]	$\tau_{APP} \sim \frac{1}{T\sqrt{n_{2DEG}}}$
Optic phonons [11]	$\tau_{OP} \sim \frac{n_{2DEG}^2}{T^2}$
Others scattering mechanism	
Points Defects [12]	$\tau_{DEF} \sim \frac{1}{V_o n_{DEF}}$
Alloys [13]	$\tau_{ALL} \sim \frac{1}{x(1-x)}$

Correlation between the relaxation time (time between collides of electron with each scattering mechanism) and the maximum value of drift velocity provide indirectly influence to all FOM. The drift velocity for semiconductors in low electric fields $v_d = \mu E$, and the mobility of electrons $\mu = e\tau m^{*-1}$ result in $v_d = e\tau m^{*-1}E$. Therefore, the scattering mechanism have impact at drift velocity and probably at saturated drift velocity v_s in higher electric fields to. Scattering mechanism that depend on mainly at

concentration 2DEG are: dislocations (N_{DIS} – concentration of dislocation), remote impurities (in AlGaN, N_{RII} – concentration of impurities, d – thickness of spacer), background ionized impurities (in GaN, N_{BII} – concentrations of residual atoms, usually $N_{BII} > N_{RII}$). Scattering mechanism depends mainly on temperature are: acoustic phonons in deformation mode, acoustic phonons in piezoelectric mode, optic phonons. Others scattering mechanism are alloys disorder (x – amount of aluminum fraction), points defects (n_{DEF} – concentration of each defects, V_o – volume of defect). To main scattering mechanism in MOVPE process we can involve: point defects, dislocations, remote ionized impurities, alloys and interface roughness. In order to correlate scattering mechanism with the growth process of the material it is essential to determine concentration of point's defects and dislocations in study heterostructure. For example in MOVPE process the growth is performed at H_2, it is also came from the NH_3 precursor, C atoms will be incorporated form metalorganic reagents as well as the Ga, Al and Si atoms. The hydrogen could be treated as H^0, H^- and H^+. In additional each of point defect could create a pair e.g. the donor pair of $O_i - V_{Ga}$, where V is the vacancy of gallium atom and O_i is the oxygen in the interstitial position. In AlGaN/GaN heterostructures the Ridley–Watkins–Hilsum mechanism [14] could also exist the electrons speed up by electric field could jump to neighborhood valley with higher energy state. As a result, electrons will gain higher effective mass $m_e^* \approx 15m_o$ and slow down.

4. CONCLUSION

In this paper the basic figures of merits was shown: KFOM, BFOM and JFOM. Correlation of main scattering mechanism in AlGaN/GaN HEMT heterostructures with concentration of two dimensional electron gas n_{2DEG}, temperature T, thickness of AlGaN spacer d, concentration of ionized impurities n_{II}, concentration of defects n_{DEF} and aluminum content x was discussed . Because of the complexity of point defect caused by the MOVPE process, it is essential to determine all key points defect in heterostructures e.g. using for example the Deep Level Transient Spectroscopy. To further analysis, it is essential to exam impact of two scattering mechanism: the interface roughness and carrier-carrier scattering. In addition, the Ridley-Watkins-Hilsum mechanism could also limit the saturated drift velocity. MOVPE process allow to control the aluminum content, spacer thickness, temperature and indirectly the concentration of electrons this provide a wide range of adjust of relaxation time in many scattering mechanism. From Table 2 one can deduce that the increase of the concentration of impurities, defects, and dislocations will reduce the relaxation time and that the increase of the aluminum content in AlGaN layers and temperature will reduce the relaxation time. Only the increase of the concentration of two-dimensional electrons will slightly increase relaxation time in low temperature and considerably in higher temperatures.

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