

The Simulation of Wide Band Gap Semiconductor Materials for Use in High Temperature and Other Applications

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Introduction

The performance of wide band gap semiconductors such as Diamond, Silicon Carbide and the III-V Nitrides has been the source of some research over recent years. This is primarily due to some of the excellent performance characteristics in terms of high temperature, radiation hardness and high power operation.

As the material and technology aspects of these semiconductors has become more mature, there has become a greater need for the simulation of such materials. This article describes the application of the ATLAS device simulation software to the simulation of the wide band gap semiconductors Gallium Nitride ($E_g=3.45\text{eV}$) and Aluminum Gallium Nitride ($E_g= 3.82\text{eV}$)

Simulation Issues

Several physical and numerical issues must be considered for the simulation of the wide band gap semiconductor devices. As an example, three of these areas are illustrated:

- (1) A complete description of carrier statistics must be included (i.e. Fermi Dirac as opposed to the more commonly used Boltzmann Approximation), in order to fully describe the potentially low levels of carriers present in room temperature simulations of wide band gap materials.
- (2) The use of non - isothermal simulation techniques (in which the heat flow equation is solved within the device domain) may be required if device is to be used in high power applications.
- (3) Some materials (particularly III-Vs) have non standard carrier velocity-field characteristics and may also exhibit velocity overshoot. This requires the careful selection of models to be used in the device simulation.

GaN	electron mobility	$1000\text{ cm}^2\text{V}^{-1}\text{s}^{-1}$
GaN	electron saturation velocity	$1.5 \times 10^7\text{ cms}^{-1}$
GaN / AlGaN	Band Offset	50%
GaN	Schottky Barrier Height	1.2eV
GaN	Energy Band Gap	3.45eV
AlGaN	Energy Band Gap	3.82eV

Table 1: Material parameter data for GaN / AlGaN heterostructure device

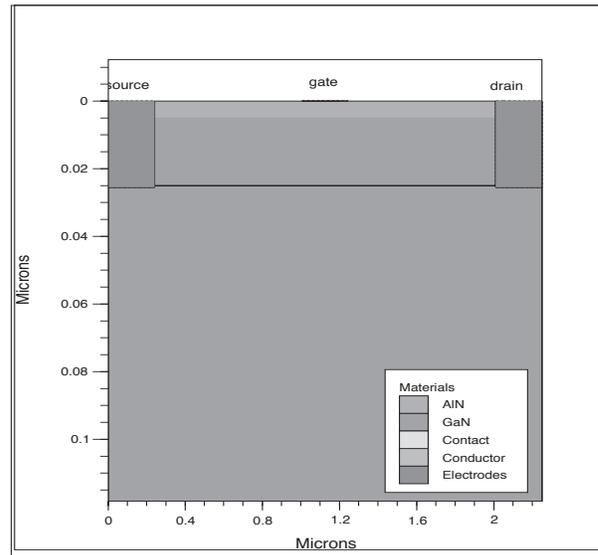


Figure 1. This figure illustrates a schematic diagram of the device structure. Note the source/drain contacts are sunk into the GaN layer.

Material Issues

The most significant issue in the simulation of wide band gap materials is, however, the low level of material parameters and characterized data available. Even with the most extensive literature search, it may not be possible to obtain all of the material data required, leading to a certain level of interpolation. Additionally, many wide band gap semiconductors contain high levels of defects due to the early level of technology maturity in these materials. In order to accurately simulate the performance of these materials it is necessary to include or account for these defects.

GaN / AlGaN Heterojunction Device Simulation

A 0.25 micron channel length $\text{Al}_{0.13}\text{Ga}_{0.87}\text{N} / \text{GaN}$ heterostructure device was simulated as illustrated in Figure 1 using ATLAS /BLAZE. This device was based on a recently published experimental structure (by Kahn et al [1]), in order to provide for a comparison between experimental and simulated data. The AlGaN surface layer was 250Å thick. The source and drain metal was sunk through to the 0.6 micron deep GaN active layer in order to provide a good ohmic contact. The substrate was sapphire. The GaN layer was unin-

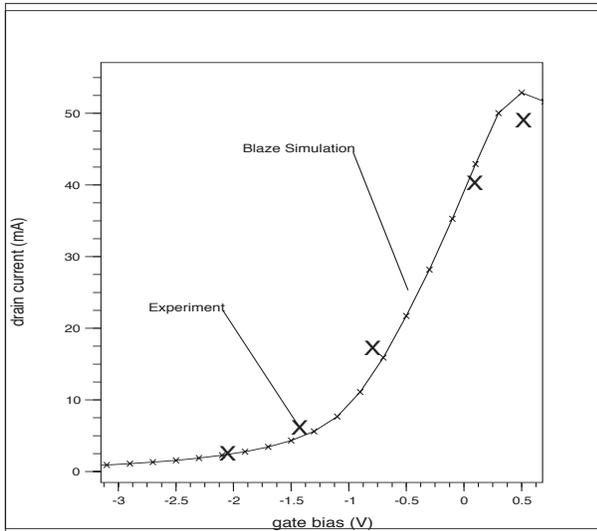


Figure 2: This figure compares the experimental and simulated I_d / V_g curves for the device. These show close agreement.

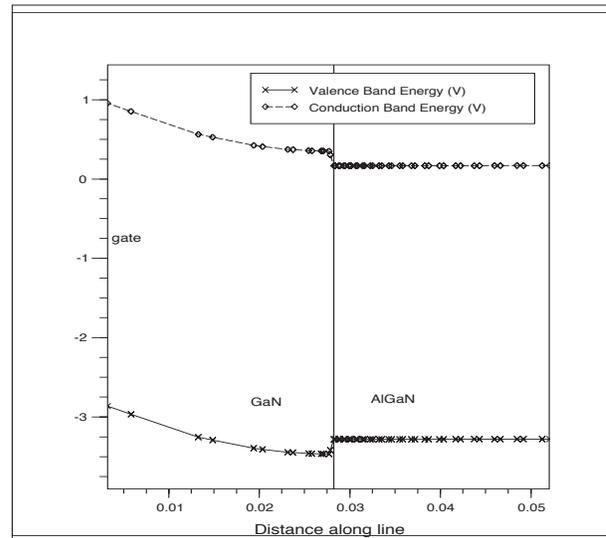


Figure 3: This figure shows a cross section of the valence and conduction bands through the gate, illustrating the heterostructure formation.

tentionally doped, but has a natural n-type doping of $1 \times 10^{17} \text{cm}^{-3}$. The AlGaN layer was grown with a donor concentration of approximately $4 \times 10^{18} \text{cm}^{-3}$. For this simulation, major material parameter values for electrical performance are given in Figure 1. A band diagram of the structure through the gate is also given in Figure 2, this illustrates not only the heterojunction step, but clearly shows the wide band gap level of this device.

Figure 3 shows an I_d / V_g curve for this device comparing both simulation and experimental device results. Note the reasonable agreement that BLAZE has produced. Also of importance to this type of non dielectrically insulated gate structure is the modeling of the drain current down turn as the Schottky barrier at the gate becomes forward bias leading to increased conduction of current.

Conclusion

To some extent this type of modeling can be regarded as calibration of BLAZE for the wide band gap III - V nitrides, which can then be applied to variations on this device and material. This was demonstrated at ESSDERC '95 where BLAZE was used to simulate an advanced type of heterojunction field effect transistor using Gallium Nitride as a wide band gap gate insulating region [2].

References

- [1] M. Asif Kahn, J.N. Kuznia, D.T. Olson, W.J. Schaff, J.W. Burm and M.S. Shur, "Microwave performance of a 0.25micron gate AlGaIn GaN heterostructure field effect transistor," Appl. Phys. Lett, pp. 1121, vol 65, 1994.
- [2] C.D. Wilson and A.G. O'Neill, "GaN Based Heterostructure Field Effect Transistors for Temperature Resistant Device Operation," ESSDERC 1995.