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# Intrinsic and Pinned Fermi Energy Levels in 2H-GaN and 4H-SiC

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***ABSTRACT:*** *This paper highlights the physic behind the calculations of the intrinsic and pinned Fermi energy levels in the bandgap of the semiconductors 2H-GaN and 4H-SiC. These are the future semiconductors for high power and high voltage devices like HEMT and MOSFET. The Schottky diodes are also manufactured with different metals as contact material having pinned energy levels due to high density of surface states on the semiconductor surfaces. The universal mass-energy equivalence relation in the differential form is used to calculate the energy levels in the semiconductor bandgaphaving the same high-field conductivity electron effective masses at velocity saturation for one conduction valley. The calculation results are presented and the application of the physical principle is established as the calculated pinned energy levels of 1.0 eV below the semiconductor conduction band match the observed experimental Schottky barriers on both materials.*
***KEYWORDS–****Fermi Energy Levels, Semiconductors, SiC and GaN, Mass-energy equivalence relation.*

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## I.INTRODUCTION

Energy at the intrinsic Fermi level and at the Fermi level pinning in the bandgap of a semiconductor has been determined recently using the physics of the universal mass-energy relation in the differential form [1-3]. Examples of Si[100], Ge[100], GaAs[100] and thermal $SiO_2$ are used for the above determinations [2-3]. Two future semiconductor materials are 4H-SiC and 2H-wurtzite GaN on which high power devices are being considered and built. The 4H-SiC is being used for making a lateral or trench power MOSFET and GaN is considered for the high electron mobility transistor (HEMT). The Schottky diodes on these semiconductors are also being manufactured in USA and Europe. The high density of surface states in the metal-semiconductor Schottky diodes pin the Fermi energy level to a high value of 1.0 eV below their respective conduction bands, as will be shown below. These surface states at the semiconductor surfaces can be passivated well in 4H-SiC MOS device by NO annealing reducing their density tenfold at about 0.2eV below the conduction band. This passivation is not good in GaN because of the hetero interface of Ga or N and $SiO_2$ and Fermi energy level remains pinned to about 1.0 eV below the conduction band in GaN. It therefore requires higher voltage to form the inverted channel in the MOS device because more electrons are trapped at the high density of surface states upon application of the gate voltage. This being one of the main reasons, a MOSFET on GaN is slower and less efficient than a MOSFET on 4H-SiC. Therefore a HEMT device is considered on GaN.

## II.THEORY

The intrinsic Fermi energy level and the energy at the Fermi level pinning in a semiconductor is calculated using the physics of the universal mass-energy equivalence relation in the differential form for a particle like electron, given as:

$$\frac{dE}{E} = \frac{dm}{m} \qquad (1).$$

Here, dE represents ΔE as the change in energy level relative to the conduction band in the semiconductor, dm/m represents the relative conductivity electron effective mass at high electric fields and at velocity saturation for one conduction valleyin the semiconductors, and Ecan represents two things. One E can represent the energy level up to which the surface states extend to in a semiconductor at high fields for finding the energy of the Fermi level pinning relative to the conduction band. Two, E can represent the bandgap of the semiconductor to find the intrinsic Fermi energy level relative to the conduction band as ΔE.

## III.CALCULATION RESULTS OF THE ENERGY LEVELS

The dm/m for the 4H-SiC semiconductor in the M direction is 0.30 and for 2H-GaN is 0.2. The 4H-SiC has a satellite valley about 0.1 eV above the minimum in the M-conduction valley of 3.23 eV. So, at high fields, the surface states on 4H-SiC will extend up to 3.23 + 0.1 = 3.33 eV. With the relative electron effective mass stated above as 0.3, the ΔEcomes out to be 3.33 x 0.30 = 1.0 eVas the energy at the Fermi level pinning below the conduction band of 4H-SiC[0001]. The same value is observed experimentally in Schottky barrier diodes on n-4H-SiC with different metals such as Ta, Ti, W, Mo and others [4]. Similarly, for n-2H-GaN semiconductor, the ΔE comes out to be 5.0 x 0.2 =1.0 eV below the GaN conduction band. Here, at high fields in GaN[0001], the surface states extend up to 5.0 eV. The same pinning energy value is observed in the manufactured lateral AlGaN/GaN hetero Schottky Barrier diodes [5]. Since the bandgap of GaN is 3.4 eV, the intrinsic Fermi energy level can be calculated to be 3.4 x 0.2 = 0.68 eV below the conduction band of the GaN.

## IV.CONCLUSION

In both the future semiconductor materials of 4H-SiC and 2H-GaN, the energy at the Fermi level pinning is calculated to be 1.0 eV below their respective conduction band. This matches with the observed pinning energies in the Schottkybarrier diodes made from different metals on n-4H-SiC and lateral n-GaN and AlGaN/GaNheterojunctions. The physics of the universal mass-energy equivalence relation in the differential form given above dictates the value of the barrier heights to be 1.0 eV below the conduction band. The physics has already been found to be applicable on Si, Ge, GaAsin the [100] direction, and $SiO_2$ from the author's previous research study. This new physics can possibly be found to be applicable on all parabolic semiconductors. The intrinsic Fermi energylevels below the conduction band of the semiconductors are also found similarly,where the high-field electron masses atvelocity saturation for one conduction valley remains the same, but the energy E changes to bandgap energy.

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