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DC Characteristics and RF performance comparison between field-plated and non field-plated devices under different bias conditions

Tanmaya Kumar Das, Meryleen Mohapatra and A.K. Panda

***Abstract*—This paper is mainly showing the comparison between Field Plated and Non Field Plated AlGaN/GaN High Electron Mobility Transistor (HEMT) under different biasing conditions. It also shows the effect of the field plate structure on the RF performance of the HEMT device. The field plate structure increases the breakdown voltage of the device at high frequencies by the local modulation of the electric field. Because of the field plate there is introduction of additional feedback capacitance from drain to gate. This type of capacitor also has effect on the RF performance of the device, mainly at high frequency values. So here the investigation on the above along with the comparison with field plated and non field plated HEMT device is presented systematically.**

***Keywords*— Field Plate, HEMT, AlGaN/GaN, RF performance, local modulation, feedback capacitance**

I. Introduction

The introduction of wide band gap devices such as gallium nitride (GaN) enhances the scope of semiconductor devices by including the application possibility for high power and high frequency operation.[1, 2] A new generation of high speed-high frequency devices is required to meet current and future needs.[2] The Gallium Nitride High Electron Mobility Transistor (HEMT) is showing great promise and considered as the enabling technology in the development of military radar systems, electronic surveillance systems, communications systems and high voltage power systems.[1] Gallium nitride and its related alloys are widely acknowledged as prime candidates for high-power microwave applications due to their high breakdown field (~3 MV/cm) which is 3 times of that in Si or GaAs [3], high electron saturation velocity ($2.5X10^7$ cm/s), and high operating temperature.[4]

Tanmaya Kumar Das
Trident Academy of Technology, Bhubaneswar
Odisha, India
tanmaykumar.das@gmail.com

Meryleen Mohapatra
Institute of Technical Education and Research,
Siksha O Anusandhan University, Bhubaneswar, Odisha, India
meryleen2001@yahoo.com

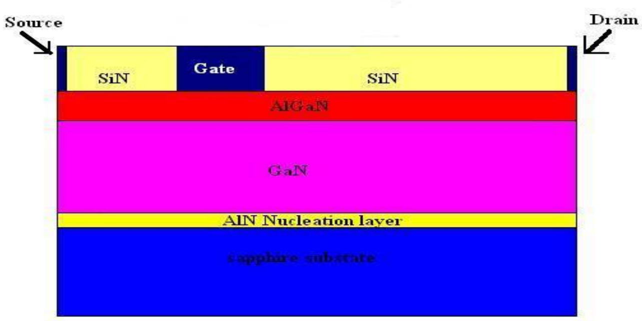
A.K.Panda
National Institute of Science and Technology, Berhampur
Odisha India
akpanda@nist.edu

The associated AlGaN/GaN heterostructure system, enhanced by the spontaneous and piezoelectric polarization present in the heterostructure [5,6], yields two-dimensional electron gases (2DEGs) with high sheet charge concentration (in excess of 10^{13}cm^{-2}) and electron mobility (up to 2000cm^2/V.s).[3,4] In previous works, the use of SiN film was mostly for surface passivation, as it reduces response of the surface traps and in turn suppresses the effect of current collapse. But collapse-free devices using SiN passivation, however, exhibited significant decrease in the gate–drain breakdown voltage [6]. This tradeoff relation between current collapse and breakdown characteristics has been known to be a main difficulty for realizing high-voltage high power operation with a GaN-based FET. [7] Significant improvement in breakdown voltage of an AlGaN/GaN HEMT is possible by employing a field plate (FP) connected to the gate and placed in the gate to drain separation, over a uniform insulator. [3,8] It also suppresses the surface trap effect which markedly affects the power performance of the device [9]. The extension gate of the field plate increases the gate capacitance (Cgd) and results in reduction in transconductance (Gm) and gain characteristics. Considering the circuit analysis, the field plate behaves as a drain-to-gate feedback capacitor which provides additional modulation on the signals at the input and output of the device. Under such circumstances, impact on the RF performance is expected especially at high frequencies due to the additional phase variations provided through the feedback path. [10]

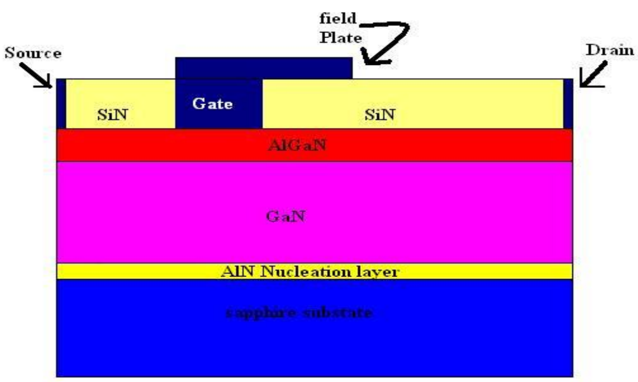
Thus, this study focuses on the systematic comparisons of the RF performance between field-plated and non field-plated devices under different bias conditions.

II. Device Fabrication

In this paper, AlGaN/GaN HEMT structure was grown on sapphire. The structure included 20 nm AlN nucleation layer, 3-µm-thick GaN buffer and 30-nm-thick $Al_{0.25}Ga_{0.75}N$ layers. To observe the spontaneous and piezoelectric polarization effect thin layers (5 nm thickness) of n type and p type doping was done in both GaN and AlGaN region. The schematic cross section of the non field-plated and field-plated AlGaN/GaN HEMT is shown in fig-1(a) and fig-1 (b) respectively. The spacing between source and drain was 7 µm. The ohmic contact resistance was $3 \times 10^{-6}\ \Omega\ cm^2$. Ni/Au gate (Lg = 1 µm) was deposited and subsequently the device was passivated with a 100-nm-thick SiNx layer. Finally, Ti/Au was deposited as the field plate structure (LFP = 1 µm), which was connected to the gate electrode.



(a)



(b)

Fig. 1. (a)The schematic cross section of the non field-plated AlGaN/GaN HEMT device, (b) The schematic cross section of the field-plated AlGaN/GaN HEMT device

Here, both FP and non-FP (nFP) AlGaN/GaN HEMTs were fabricated to observe the effect of the field plate structure on the DC and RF characteristics at microwave frequencies.

III. Result and Analysis

A. *Simulated Structure*

The AlGaN/GaN HEMT structure without Filed Plate and with Field Plate was made according to the specification by the Silvaco software. The fig-2 shows Non Field Plated Structure and fig-3 shows the Field Plated Structure of AlGaN/GaN HEMT.

The energy band diagram for AlGaN/GaN HEMT is shown in fig-4 with the cutline from gate contact to GaN Layer. The left column is the gate contact with 0 eV band gap, the center column is for AlGaN layer with band gap 3.94 eV and the right column is the GaN layer which has a 3.42 eV band gap (As expected value for intrinsic GaN). The energy band diagram was obtained by the Silvaco software.

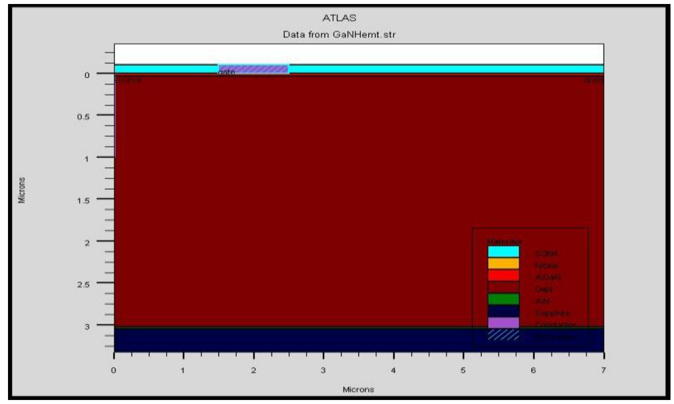


Fig. 2. Non Field Plated AlGaN/GaN HEMT Structure

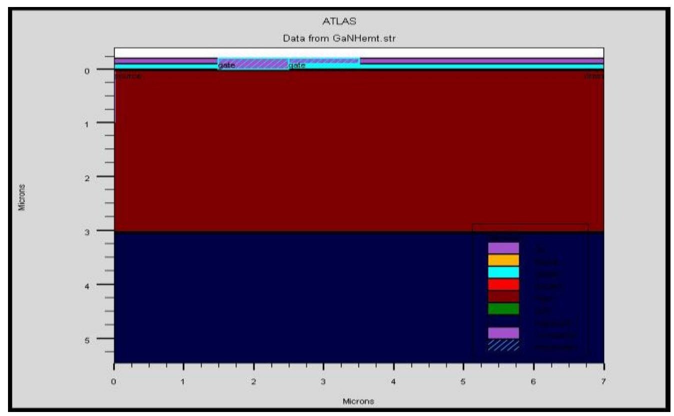


Fig. 3. Field Plated AlGaN/GaN HEMT Structure

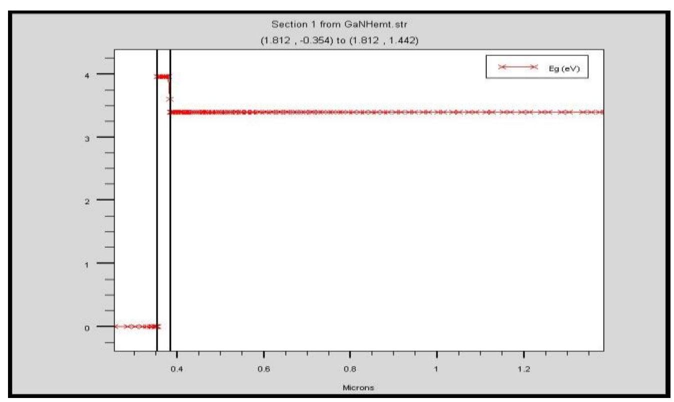


Fig. 4. Energy Band Diagram for AlGaN/GaN HEMT

B. *DC Characteristics*

Fig. 5 shows the DC I-V curves of the FP and nFP HEMT devices. From the graph it is observed that the maximum drain

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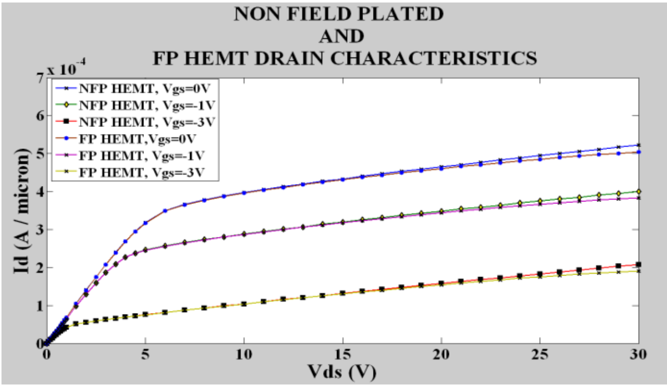


Fig. 5. DC I-V curves of the FP and nFP HEMT devices

current at V_{GS} = 0 V was 522 mA/mm for the nFP HEMT , compared to 503.862 mA/mm for the FP HEMT.

Fig. 6 compares the G_m as a function of gate biases for both Field plated and non Field Plated devices respectively. As observed, the maximum transconductance was 85.3 mS/mm for the nFP HEMT, compared to 85.1 mS/mm for the FP HEMT.

Fig. 7(a,b)compares the Drain current as a function of gate biases for both Field plated and non Field Plated devices respectively. Fig. 7 (a) shows the comparison of drain current variation with respect to Gate voltage for FP and NFP devices. Fig- 7 (b) shows the enlarged version of Fig 7 (a). It represents that the drain current reduces for FP device in comparison to non Field Plated one.

As it is observed from the characteristics in fig. 5, clearly a 3.47% reduction of saturation drain current in the FP-HEMT is

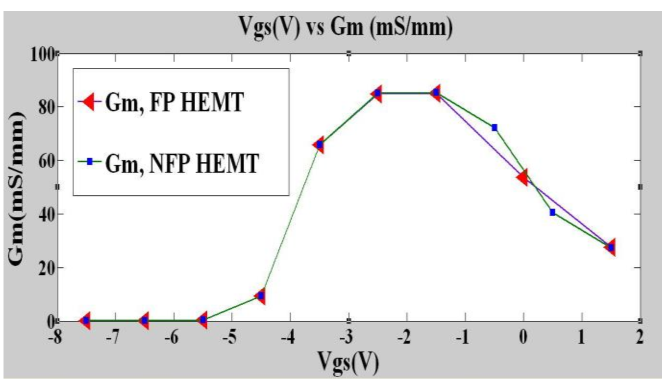
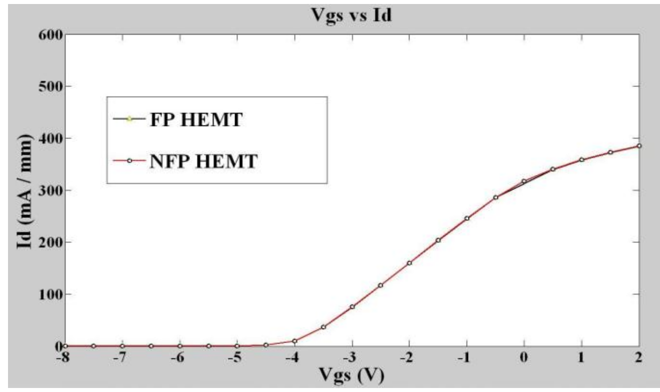
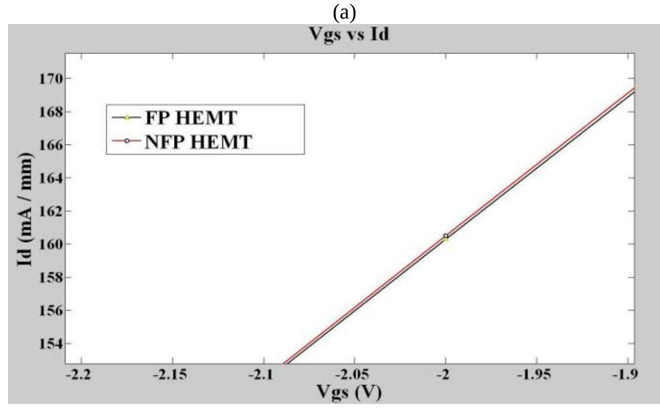


Fig. 6. Comparison of Gm as a function of gate voltage for Field-plated and non field-plated structure

seen which is mainly due to the gate extension from the field plate structure. Such extension together with the thin SiNx passivation layer yields a larger effective gate length causing degradation in the drain saturation current.



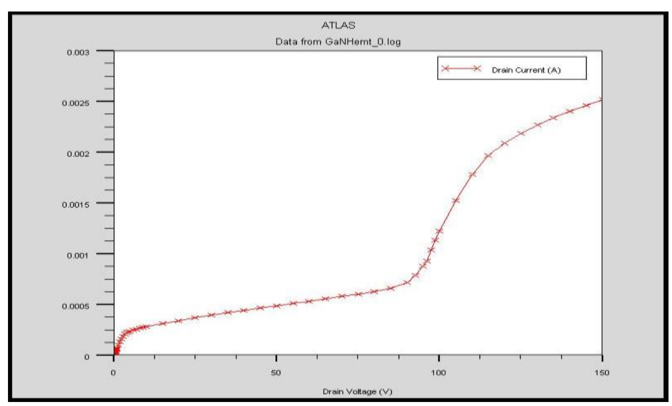
(a)



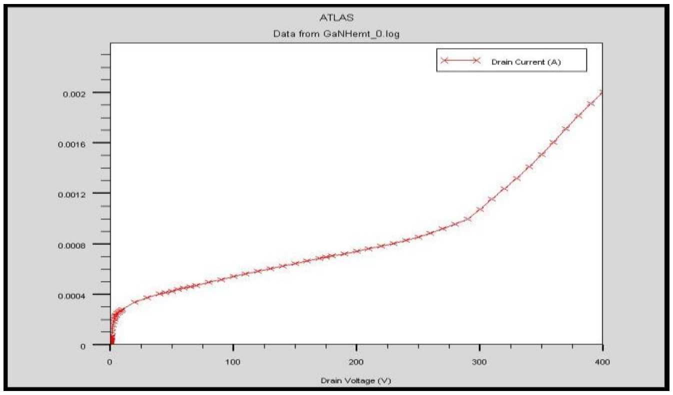
(b)

Fig 7. (a)Comparison of Drain current as a function of gate voltage for Field-plated and non field-plated structure ,(b) Enlarged version of fig. 7. (a)

Despite the degradation in saturation current, the FP-HEMT exhibited an improved breakdown voltage of 280 V compared with 90 V for the nFP-HEMT. The improvement in breakdown voltage makes higher drain bias possible leading to better power and linearity performance with good reliability. The breakdown voltage improvement is as shown in fig. 8



(a)



(b)

Fig 8. Comparison of breakdown voltage for both field-plated and non filed-plated structure (a) non Field-Plated Structure, (b) Field-Plated Structure

C. *Small Signal RF Performance*

S-parameters of the FP and nFP-HEMT devices were extracted for 1 to 200 GHz using Silvaco Software. Fig. 9 shows the extracted Gm and Fig. 10 shows drain-to-gate capacitance (Cgd) as functions of the drain bias for the FP and nFP devices respectively. As it was observed from the graph that Gm for field plated device is less as compared to non Field Plated one because of the feedback capacitance and Gm variation is less for both the devices due to Drain voltage variation. Now Cgd that is the gate to drain capacitance is the feedback capacitance between the input and the output. In FP device the value of Cgd is more and it was obvious because of the presence of Field Plate between Gate and Drain.

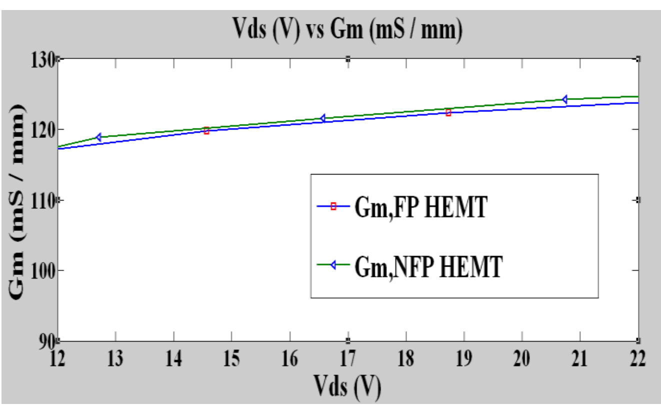


Fig. 9. Dependence of G_m on drain bias for FP and NFP device

Fig. 11 correspondingly shows the extracted gate-to-source capacitance (Cgs) as a function of the drain bias. The dependence of the cutoff frequency (f_T) on the drain biases for the FP and nFP devices is included in Fig. 12. In order to have a fair comparison, the gate biases for generating the three figures were chosen at the peak DC transconductance to accommodate for the slight shift in the threshold voltage for device with field plate. As expected, the extracted Cgd of FP device exhibited a major increase compared with that of nFP one. Moreover, the gate-to-source capacitance showed a minor

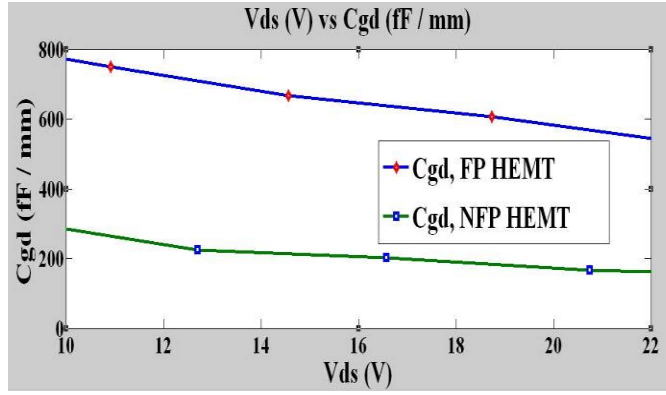


Fig. 10. Dependence of C_{gd} on drain bias for FP and NFP device

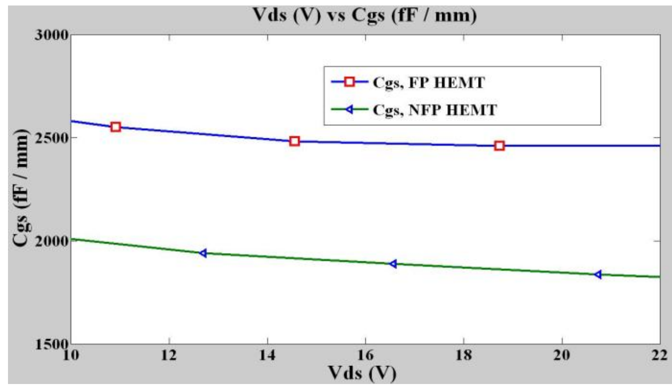


Fig. 11. Dependence of C_{gs} on drain bias for FP and NFP device

increase with increasing drain bias.

The dependence of f_T on the drain bias for FP and nFP devices along with the comparison was shown in fig 12. Here for different values of Vds i.e. 10V, 20V and 30V f_T was calculated and plotted. Clearly, the FP devices showed a lower f_T due to the major increase in Cgd compared to the nFP devices. The dependence of f_{max} is also represented for both the structures with different values of Vds. Fig. 13 shows the dependence of f_{max} on the drain bais for FP and nFP devices.

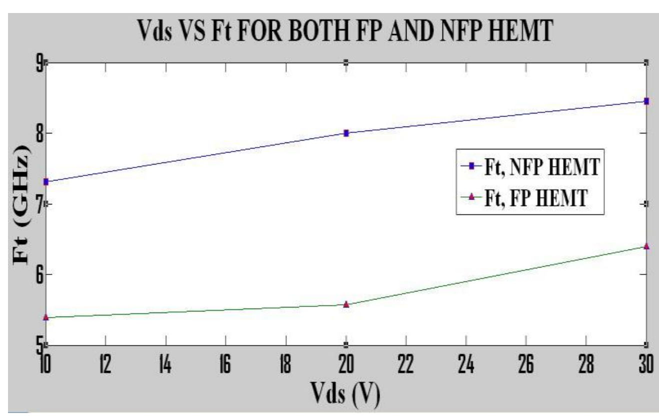


Fig. 12. Dependence of f_T on drain bias for FP and NFP device

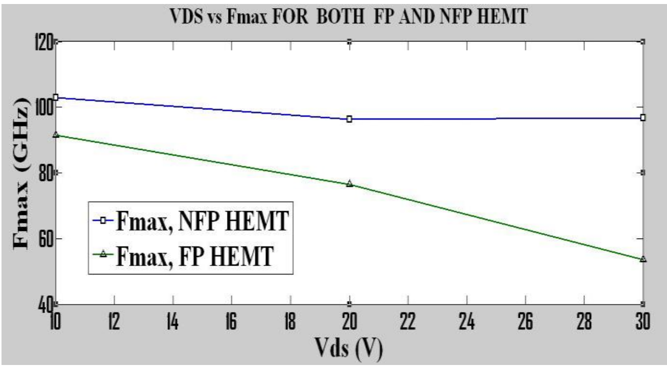


Fig. 13. Dependence of f_{max} on drain bias for FP and NFP device

IV. Conclusion

In this paper a non field-plated and a field-plated AlGaN/GaN HEMT device has been made with Silvaco software and characterized. To improve the tradeoff between current collapse and breakdown characteristics field plate structure was applied. The major impact of the field plate on the device performance was the degradation in the cutoff frequency which is mainly due to the increase in the gate-to-drain capacitance or the feedback capacitance. The characterization shows the improvement in breakdown voltage from 90 to 280 V. The above results show that FP AlGaN/GaN HEMT is a promising high voltage operation device for high power applications.

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Tanmaya Kumar Das obtained his B.Tech in the field of Electronics and Telecommunication Engg. from Institute of Technical Education and Research, BBSR, Odisha in 2008 and continuing his M.Tech in Institute of Technical Education and Research, Bhubaneswar .He is a life member of ISTE and currently working as a Teaching Faculty in Department of Electronics and Telecommunication Engineering at Trident Academy of Technology, Bhubaneswar

Meryleen Mohapatra obtained her M.Tech degree in 2005 in the field of Electronics and Communication Engg. from Biju Patnaik University of Technology, Rourkela and is working now as an Asst. Professor in Institute of Technical Education and Research which is under Siksha O Anusandhan University. She is a life member of ISTE and a member of IEEE. Her research interest includes modeling of homo/hetero structure semiconductor devices to operate at high frequency, VLSI circuits and FPGA.

A K Panda obtained his Ph. D. degree in 1996 in the field of Microelectronics from Sambalpur University and is working now as a Professor in National Institute of Science and Technology. He was a BOYSCAST fellow of Government of India to Department of Electrical Engineering and Computer Science of University of Michigan in the year 1999-2000. He is a Regular Associate of Microprocessor laboratory of ICTP, Trieste, Italy. He is a life member of IETE, ISTE, member of VLSI Society of India and IEEE. He has published more than 30 papers in the Journals of repute and has presented his work in more than 60 National/International Conference. He is handling the DST-FIST program of NIST with a grant of 1 Crore. He is also recently assigned as the TIFAC CORE Coordinator for the Center of Excellence in "3G/4G Communication Technologies" at NIST, Berhampur. His research interest includes modeling of homo/hetero structure semiconductor devices to operate at high frequency, VLSI circuits and FPGA implementation for Communication, DSP and Electrical engineering applications.