Comparison of MOSFET and MESFET using Visual TCAD tool

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ABSTRACT: *This paper, talks about implementation and presents a comparison of mosfet and mesfet constructed with various semiconductor materials. The materials considered in the study include both traditional semiconductors viz. silicon(si), germanium,and materials from recent research silicon carbide (SiC) and silicon-germanium(SiGe) . The technology node used in this research is 10nm .*

KEYWORDS - *MOSFET, MESFET, TCAD, 10nm, NMOS, device characteristics*

I. INTRODUCTION

MOS devices are a crucial part of an electronic circuit. They gained importance after the integrated and portable devices gained popularity in consumer electronics. Now, there is no device on the market that cannot have these. For many years NMOS only logic was mostly used as they were faster than pmos and cmos logic, as mobility of electrons is higher than mobility of holes [1] and also it was easy to implement unlike cmos circuit where both transistors must be implemented. However, in NMOS logic, static power dissipation occurs which means dc current is necessary to flow along the logic gate even when output is in steady state [1]. This problem was overcome as cmos logic as they low static power dissipation and higher speed of operations, hence CMOS replaced NMOS.

Currently CMOS technology widely used is a combination of P-type and N-type mosfets connected in complementary and symmetrical pairs. Due to the combination of pmos and nmos, pmos creates a low resistance path between its source and drain when a low gate voltage is applied unlike nmos where there is a high resistance path even for a low gate voltage and therefore static power dissipation is low in CMOS logic. CMOS logic also provides high noise immunity but has problems of tunneling leakage current (when mosfet is scaled) and short channel effects occur.

Mesfet(metal-semiconductor field effect transistor) can be considered as a solution as its name suggests it is similar to fet but in this the metal is directly deposited on to a semiconductor without any insulator(oxide) and therefore, creates a Schottky junction. As the oxide layer is absent, tunneling issue is resolved. It is very similar to JFET(junction field effect transistor) as both of them doesn't have insulator between gate and semiconductor and hence mesfet should be biased such that it has reverse biased depletion zone controlling the channel [1] and hence gate voltage should confine in reverse biased and cannot surpass certain voltage of forward bias. The other good thing about MESFET is that it has high carrier mobility due to absence of oxide layer and hence, high current density.

II. LITERATURE REVIEW

1) Chenming Hu et al, "A Comparative Study of Advanced MOSFET Concepts", IEEE Transactions on Electron Devices, November 1996. :- This project compares various advanced device structures of mosfet such as Threshold voltage control and subthreshold swing, short channel effect, mobility and saturation current and capacitance and relative gate delay. Various devices included in this study are * MOSFET with uniformly doped substrate (UD), Delta-doped MOSFET (DD), Pocket-implanted MOSFET (PI), Partially-depleted SO1 MOSFET (PDSOI), Fully-depleted SO1 MOSFET (FDSOI), Dynamic-threshold MOSFET (DT), and Double-gate MOSFET (DG) [2]. It concludes that MOSFET with uniform channel doping has lower Ioff than delta-doped MOSFET. Ideal delta doping profile can improve Lmin by 20% [2]. Fully-depleted SO1 MOSFET is difficult to be scaled down below 0.15 pm with satisfactory short-channel effect. Partially-depleted SO1 MOSFET has the same potential for scaling as bulk MOSFET, but can improve speed by 15-40%, depending on load capacitance, channel doping profile, etc.

2) Rakesh Vaid et al, "Comparative study of power MOSFET device structures", Indian Journal of Pure & Applied Physics Vol. 43, December 2005, pp. 980-988:- Power mosfet is very widely used device as it is used in many applications such as audio amplification, music and in rf amplification due to its high input impedance and safe operating area. This work compares six types of power mosfets which are as follows, 1) Vmos transistor (v grove):- It has a v formation, such formation has advantage of accurate control of its channel length but its mobility is lower than vdmos (virtually diffused mos). 2) virtually diffused mos(Vdmos):- Its structure begins with a heavily doped n type substrate then two successive diffusions are made in which p-zone appropriately biased will generate a channel and a high quality gate oxide is grown[3]. Its die size and on resistance are inversely proportional as its die size increases, on-resistance reduces but it generates larger parasitic capacitance and hence switching performance is poor. 3) Trench mosfet:- It is similar to vmos although its groove is made perpendicular to the surface such that the channel gets formed on the plane. However, its sharp edges influence its breakdown and hence it is mostly used for low voltage, high current applications. 4) (Silicon Semiconductor Corp. FET) Sscfet and jsbfet:- A basic power mosfet is revised by implementing a sliced gate stack to lower internal gate resistance, this device is known as sscfet. In sscfet, it augments its power mosfet performance due to gate width and transition region doping profile is optimized. Jsbfet is a new structure that subsumes schottky diodes into power mosfets. Due to this schottky barrier lowering phenomenon reduces and channel length reduction is also obtained.

The below table gives details of the materials that are going to be used for research:

Properties	Si	Ge	SiC	SiGe
Effective density of states (conduction, N_c T=300 K) [cm^{-3}]	2.8×10^{19}	1.04×10^{19}	1.7×10^{19}	
Effective density of states (valence, N_v T=300 K) [cm^{-3}]	1.04×10^{19}	6.0×10^{18}	2.5×10^{19}	
Energy Gap E_g at 300 K (Minimum Indirect Energy Gap at 300 K) [ev]	1.12	0.66	3.2	0.804

Mobility electrons[cm^2 / (V x s)]	1400	≤ 3900	900	3300
Mobility holes [cm^2 / (V x s)]	450	≤ 1900	100	1537.5
Diffusion coefficient electrons [cm^2/s]	36	≤ 100		
Diffusion coefficient holes [cm^2/s]	12	≤ 50		

Table 1: Material Properties

III. METHODOLOGY

3.1 Introduction to Visual TCAD:-

To develop and manufacture any semiconductor device is a costly and complicated process, hence in order to eliminate any losses and increase device yield this process simulation software's are produced. To simulate or develop any semiconductor material or device in any software, its characteristics should be modelled. Technology Computer-Aided Design (TCAD) is used to model operation of various semiconductor devices [5].
Visual TCAD is a graphical user interface for device simulator Genius [4]. There are many other TCAD software's available in the market but most of them require scripting. However visual TCAD doesn't require coding, and yet provides all the features and functions of tcad. Thus, it is good for even a tyro to implement/develop semiconductor devices.

Visual TCAD provides a graphical user interface to construct the structure of the device. Both 2D and 3D structures can be created. It also offers various types of dopants and the doping area and the doping profile can be selected by the programmer. The depletion area created at the junction is also visible in the structure constructed which is quite useful while doing the analysis.The device is divided into small sections; with smaller portions at the junction and then analysis is carried out

3.2 About dimensions of device: -

We have implemented MOSFET at 10nm technology with channel length(L)=10nm, it has pwell of area of 0.255, It has drain of area of 0.0075, It has metal area of 0.05, It has source of 0.0065, It has bulk of 0.0255. We have also implemented mesfet with channel length(L)=10nm, it has pwell of area OF 0.255, It has drain of area of 0.0075, It has metal area of 0.05, It has source of 0.0065, It has bulk of 0.0255.

3.3 Simulation:-

Different device structures were constructed for channel length of 10nm and the output characteristics of the devices were analyzed. All the devices constructed were NMOS devices. Doping concentration of P-substrate was 10^{16} and the source and drain regions had a doping concentration of 10^{18} cm^{-3}. The doping profile was considered to be gaussian and a spread of the N+ regions can be seen around the device.
The device structure are as shown below:

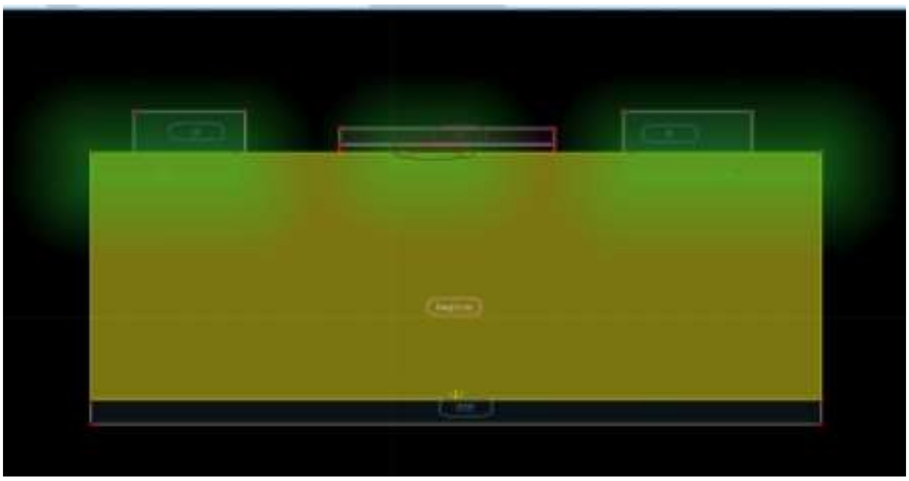

Figure 1: Constructional view of Si MOSFET

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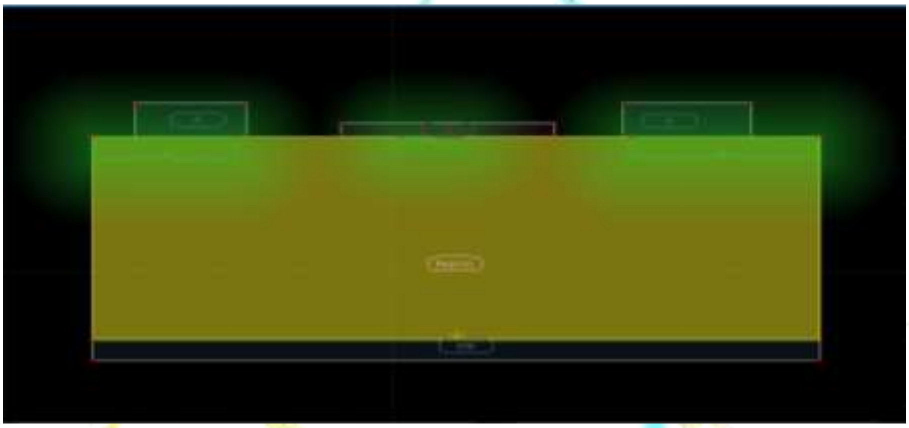

Figure 2: Constructional view of Si MESFET

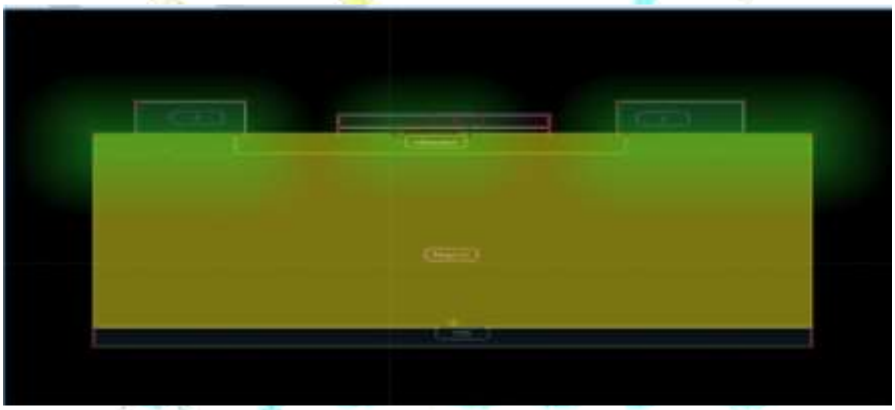

Figure 3: Constructional view of Gei MOSFET

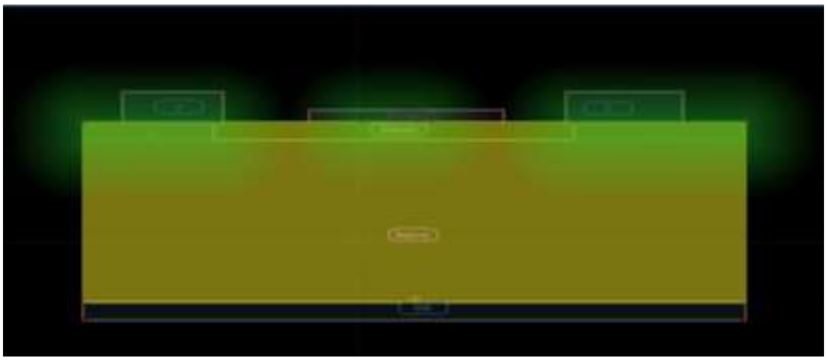

Figure 4: Constructional view of Ge MESFET

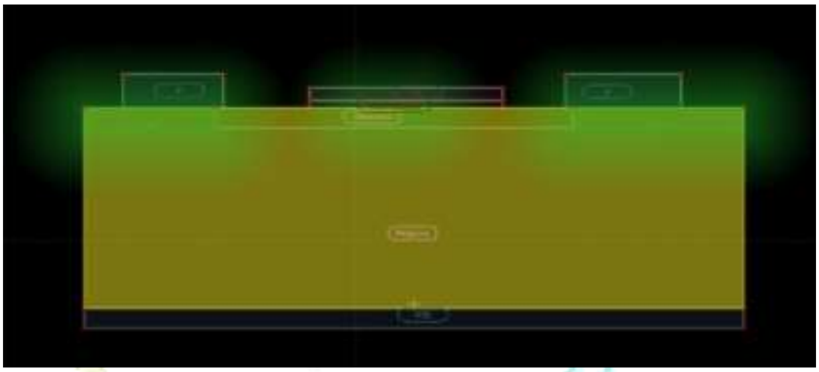

Figure 5: Constructional view of SiC MOSFET

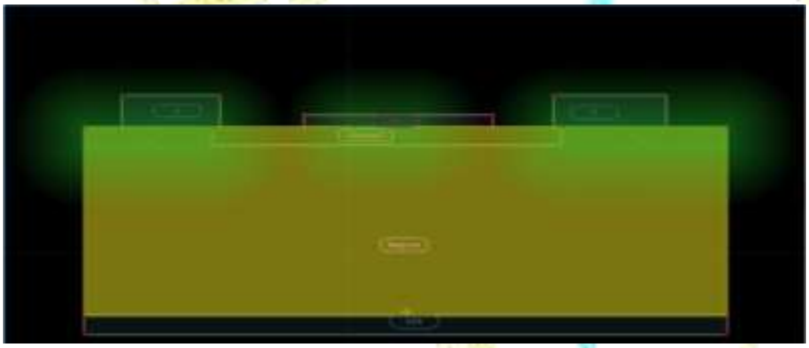

Figure 6: Constructional view of SiC MESFET

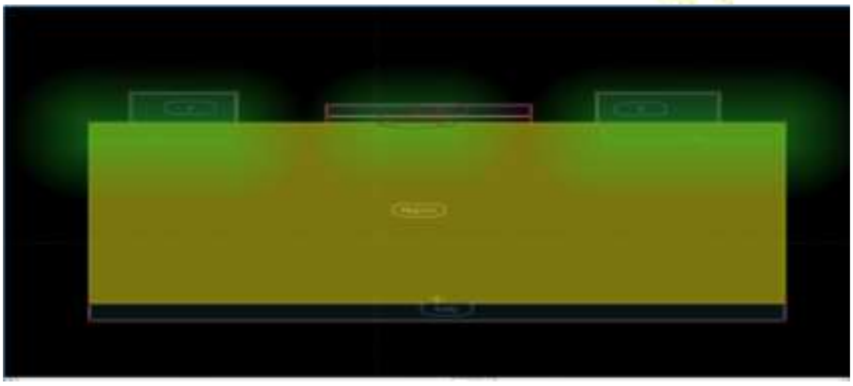

Figure 7: Constructional view of SiGe MOSFET

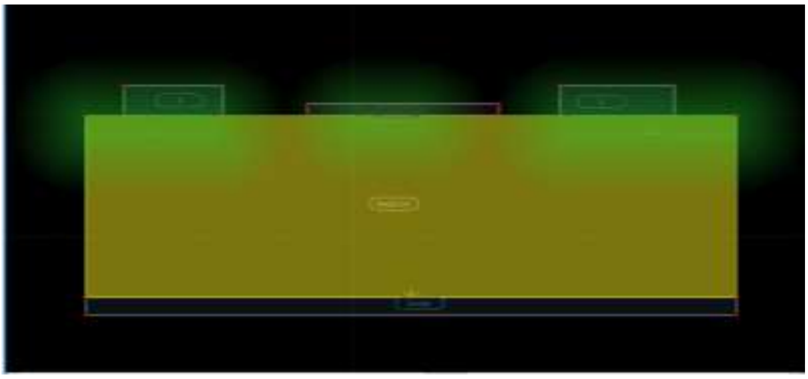

Figure 8: Constructional view of SiGe MESFET

IV. RESULTS

The NMOS devices constructed were simulated and output characteristics were observed and analysed.

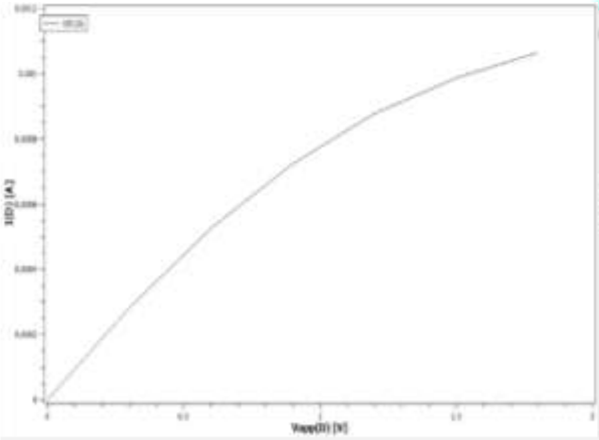

Figure 9: Si MOSFET output

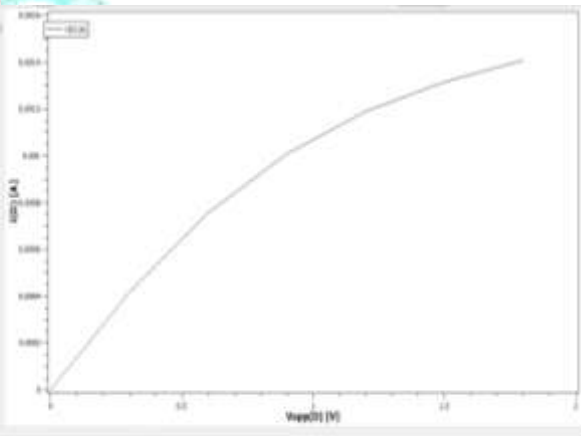

Figure 10: Si MESFET output

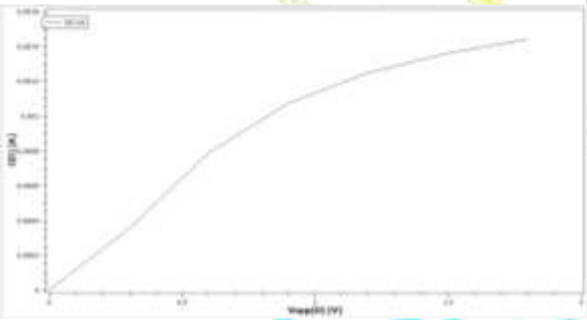

Figure 11: Ge MOSFET output

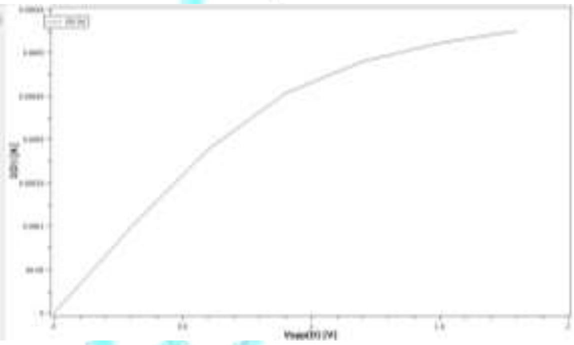

Figure 12: Ge MESFET output

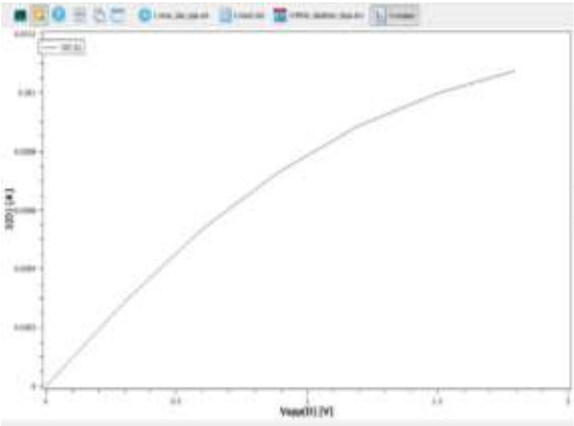

Figure13: SiC MOSFET output

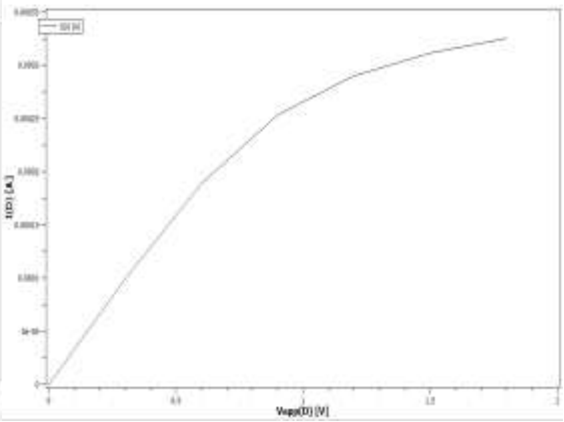

Figure14: SIC MESFET OUTPUT

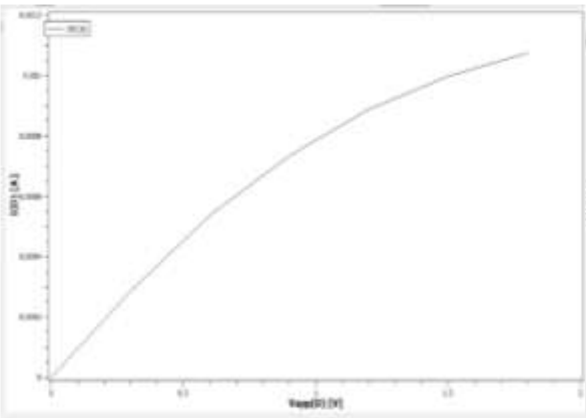

Figure15: SiGe MOSFET output

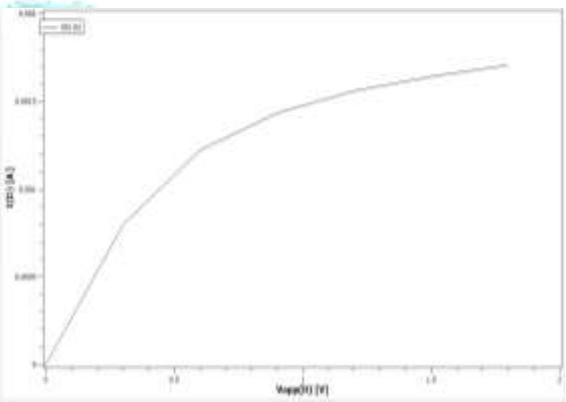

Figure16: SiGe MESFET output

The table below shows the value of the current ID at saturation for different materials.

	Si		Ge		SiC		SiGe	
V(D)	I(D) [nmos]	I(D) [mesfet]	I(D) [nmos]	I(D) [mesfet]	I(D) [nmos]	I(D) [mesfet]	I(D) [nmos]	I(D) [mesfet]
0	-4.10572e-18	1.34605e-18	2.20649e-06	2.28066e-06	-3.74631e-10	-7.5786e-12	3.10472e-18	-3.89107e-18
0.3	0.000279971	0.000417277	0.000227702	0.000354762	4.47383e-05	9.94465e-05	0.00028744	0.00079816
0.6	0.00052366	0.000756305	0.000437769	0.000790166	8.60112e-05	0.000188898	0.00053543	0.00121938
0.9	0.000719733	0.0010081	0.000624234	0.00107535	0.000119737	0.000253533	0.000734921	0.00143347

1.2	0.000869766	0.00118867	0.000781326	0.00124831	0.000139933	0.000289946	0.000887084	0.00155701
1.5	0.00097861	0.0013164	0.000906288	0.00136096	0.000149736	0.000311438	0.000997704	0.00164095
1.8	0.0010555	0.00140816	0.00100006	0.00144071	0.000154198	0.000325215	0.00107593	0.00170557

Table 2: Saturation current ID for all devices simulated

For Si & Ge, In mosfet, current increases quickly for VD greater than 0 and less than equal to 0.9 than later values of VD. Similarly, In mesfet too current increases quickly for vd greater than 0 and less than 0.9 than later values of VD. However, in MESFET for VD greater than 0.9 and less than equal to 1.8 current values of MESFET gets saturated but in mosfet for VD greater than 0.9 and less than equal to 1.8 current still has a little slope.

For SiC, In mosfet, current increases quickly for VD greater than 0 and less than equal to 0.9 than later values of VD. Similarly, In mesfet too current increases quickly for vd greater than 0 and less than 0.9 than later values of VD. However, in mosfet for vd greater than 0.9 and less than equal to 1.8 current values of mesfet gets saturated but in mesfet for vd greater than 0.9 and less than equal to 1.8 current still increases slowly.

For **SiGe,**In mosfet, current increases quickly for vd greater than 0 and less than equal to 0.9 than later values of vd. Similarly, In mesfet too current increases quickly for vd greater than 0 and less than 0.9 than later values of vd. However, in mosfet as well as mesfet for vd greater than 0.9 and less than equal to 1.8 current increases slowly..

V. CONCLUSION

The paper provides a contrast of output characteristics of MOSFET and MESFET on the basis of different materials used. The Silicon carbide and silicon Germanium provides lower over drive voltage and the device enters into saturation much earlier as compared to the elemental semiconductors like Silicon and Germanium for the same dimensions. Thus, they can be used for low voltage applications.

REFERENCE

[1]. Chenming Hu et al, "A Comparative Study of Advanced MOSFET Concepts", IEEE Transactions on Electron Devices, November 1996

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