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Summary of the Electrical Properties of a MOS Device on Various Semiconductors

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ABSTRACT

This is a review cum research communication in brief. A summary of the electrical properties of a metal-oxide-semiconductor (MOS) device on various semiconductors of Silicon, Silicon Carbide and Gallium Nitride is presented in the form of Table 1. The electrical properties for most of the devices in the summary have been published elsewhere and this brief mainly summarizes them so as to be able to compare the properties with one below the other in one view.

Keywords: Silicon, Silicon Carbide, Gallium Nitride, MOS device, Electron mobility.

SHORT COMMUNICATION

The electrical properties of a MOS device are: Intrinsic Fermi energy level in a semiconductor below its conduction band (CB), CB Offset at the oxide/semiconductor interface, Fowler-Nordheim (FN) electron tunneling onset electric field, oxide leakage current density at the FN onset field, electrical breakdown field for a 10^{-4} A/cm^2 oxide current density, the total interface trap density, and electron and hole mobility in the channel of the MOSFET device. The above properties have been studied for the MOS devices on Silicon, Silicon Carbide, Gallium Nitride, and Diamond [1-10]. These are presented in Table 1 to give a comparative and wholesome view.

The theoretically calculated electrical properties hinges on the determination of the intrinsic Fermi energy level below the CB of a semiconductor utilizing the universal mass-energy equivalence relation given as dE/E = dm/m [11-12]. Here, E is the energy of the semiconductor bandgap and m is the free electron mass. dE and dm are the differential energy and mass of the electron in the semiconductor or oxide materials. dE forms the intrinsic Fermi energy level below the semiconductor CB as E_i, and dm is the differential mass of the electron in the material. For example, dm for Silicon is 0.49m for one conduction valley in the [100] direction of the crystal momentum. The procedure for calculations of the electrical properties are described in the above ten references and is therefore avoided in this research brief [1-10]. The conduction band offset of the trench MOSFET on the Si-face of the 4H-SiC (0001) is crudely estimated to be 2.46 eV. Two faces of the trench are oriented on the $(11\bar{2}0)$ planes and one face is oriented in the (0001) plane. The estimated conduction band offset is thus (2 x 2.3 + 1 x 2.79) /3 =2.46 eV.

The total interface trap density at the oxide/semiconductor interface and the channel electron effective masses in the devices are inversely proportional to the electron mobility in the channel of the MOSFET [13]. This property is used to determine the electron mobility in the channel of the MOSFET using a Silicon control MOSFET with a known total interface trap density and the electron mobility in the channel [13]. The oxide/semiconductor interface has total interface trap density in the range of 5 x 10^{11}/cm^{2}eV to 5 x 10^{12}/cm^{2}eV giving the average electron mobility in the channel to be in the range of about 30 to 300cm^2/V-s [7-8].

Table 1: Comparison of Electrical Properties of a MOS device on different semiconductors.

S.No.	Material	Bandgap (eV)	Relative longitudinal electron effective mass, (dm/m)	Intrinsic Fermi energy level below CB (eV)	Conduction Band (CB) Offset at the oxide/Semi interface (eV)	FN Electron tunneling onset field in the MOS device (MV/cm)	Leakage Current density in the MOS device at FN onset field (A/cm^2)	Electric Brkdown Field in the MOS device at 10^{-4}A/cm^2 (MV/cm)
1.	Bulk Si	1.12	0.49	0.55	3.20	6.4(B=254)	2.71 x 10^{-10}	9.5
2.	1nm dia SiNW	2.5	0.47	1.175	2.575	5.15(B=183)	1.42 x 10^{-8}	6.9
3.	0.7nm dia SiNW	3.5	0.49	1.715	2.035	4.07(B=128.5)	5.8 x 10^{-7}	4.9
4.	4H-SiC (0001) MOS on Si face	3.23	0.297(0.30)	0.96	2.79 (2.785)	5.58(B=206)	1 x 10^{-9}	7.8
5.	4H-SiC (11$\bar{2}$0) MOS	3.23	0.45	1.45	2.30	4.6(B=154.4)	9 x 10^{-8}	5.9
6.	Trench MOSFET on 4H-SiC (0001) Si-face	3.23	---	---	2.46	4.92(B=170)	3 x 10^{-8}	6.4
7.	GaN Planar MOSFET on (0001) Ga-face	4.35 L-valley	0.218	0.95	2.8	5.6(B=207.4)	3.5 x 10^{-9}	7.6
8.	Thermal/Atomic Layer Deposited (ALD) SiO_2	8.93	0.42	3.75	---	---	---	9.5

Points to note:

1. B is the Fowler-Nordheim Slope constant given as B = 68.3 x $(m_{ox}/m)^{1/2}$ $\phi_b^{3/2}$ MV/cm.
2. Φ_b is the conduction band offset (CBO) at the oxide/semiconductor interface in the MOS device.
3. (m_{ox}/m) is 0.42 for thermal SiO_2.
4. The Fowler-Nordheim (FN) electron tunneling current density $J = AE_{ox}^2 \exp(-B/E_{ox})$ in A/cm^2 at 300K temperature.
5. CBO = (3.75 - E_i) eV, where 3.75 eV is the E_i in SiO_2, and E_i is the intrinsic Fermi energy level below CB given in column 5.
6. FN onset field = 2MV/(cm-eV) x CBO given in column 7. Here, 2MV/(cm-eV) is the minimum field for electron heating in the oxide and 1 eV is the energy required to generate hot electrons in vacuum.
7. As CBO increases, J decreases and E breakdown increases.
8. Electrical properties of MOS device on 1nm diameter Silicon nanowire (SiNW) in Row 2, is as good as the MOS device properties of the Trench MOSFET in Row 6. It means that if one can make a Trench MOSFET on 4H-SiC, then one can also make a MOSFET on 1nm diameter SiNW. Also, device in Row 4 is as good as the device in Row 7.
9. Diamond MOS hole device is separate, published in 2022 in IOSR-J. of Electrical and Electronics Engg.
10. The entry in Column 8 of Row 4 in Table 1 above is the observed leakage current density in the MOS device at FN onset field [3].

CONCLUSION

The comparative summary of the electrical properties of a MOS device on various semiconductors highlights the fact that 1nm diameter SiNW is similar to trench MOSFET on 4H-SiC, showing similar electrical properties. This implies that a MOS device is practical on the 1nm diameter SiNW as a trench MOSFET has already been shown to be practical by companies in Europe, USA, Japan, and Italy. Also, the planar MOSFET on 4H-SiC (0001) Si-face and GaN (0001) Ga-face have similar properties. Ga-face has GaOx problem and so N-face of GaN is also being explored.

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