* **Use MathCAD 4.0 or 5 only. No other version would open using university MathCAD.**

**NOTE:** Use the physical constants that you need from the tables and graphs shown after the Exam problems. Use only the constants you need.

Problem 1

Design a 3C-SiC p+-n-p transistor. The structure is similar to the figure below. The base doping is 1.0x1017 cm-3 and the collector doping is 1x1016 cm-3. The data sheet of the 3C-SiC material indicates that the material has a bulk recombination center of 1.0x1015 centers/cm3 and a capture cross-sections of 2x10-15 cm2 for both the electrons and holes.

1. What would be the metallurgical base width, WB, that gives a common base gain β=500, if Emitter-Base voltage of 2.2V and a Collector-Base voltage of ̶ 10V are applied.
2. If the device area Ar=100µm2, calculate the terminal currents IE, IC, and IB and the Common Emitter gain α.



Problem 2:

You are asked to build a 4H-SiC n-channel MOSFET with a substrate doping of 1x1016 acceptor atoms/cm3. The device has a Chromium (Cr) Gate metal. The gate oxide is a Silicon Nitride (Si3N4) layer with a thickness of 200 Aº. The total oxide charge Qox =5x1010 qC/cm2.

If the gate length is L=1 um and the gate width is Z=20 μm, find Wmax, VFB, VT, the current at VD=2V and VG=5V, and the saturation current for the device at VG=5V.

NA is p-doped

n+

n+

n-MOSFET

Problem 3

Complementary CMOS technology uses n-MOSFET and p-MOSFET devices on the same chip to build integrated circuits. Here, the n-MOSFET is the one you designed in problem 2. Now you need to design the 4H-SiC p-MOSFET. The figure shown below shows a CMOS inverter.

The way the inverter built is to start with a p-4H-SiC substrate with the same doping as the substrate of Problem 2. Since the p-MOSFET requires n-type region, such region is created by implantation to produce net donor doping of 1x1015 donors/ cm-3. Then you dope the n+ and the p+ regions as shown below.

Because the devices are built on the same chip, both devices have the same gate metal, same gate oxide material, same oxide thickness, and same oxide charge density, as the device of Problem 2.

1. What donor concentration you should implant to obtain a net doping of ND = 1x1015 donors/cm3, for the n-type layer under the p-type gate, as shown below?
2. Calculate VT.
3. It is required for the p-MOSFET to have saturation current IDSS = -10 mA at VG =-5V, what is the gate width Z, if the gate length, L= 1 μm?

n-type

p-type

n-MOSFET

p-MOSFET

p+

p+

n+

n+

**Properties of cubic Si, Ge, 3C-SiC, GaAs, and GaN at 300K**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name of parameter** | **Si** | **Ge** | **GaAs** | **SiC (3C)** | **GaN** |
| Energy gaps, Eg | 1.12 eV | 0.67 eV | 1.42 eV | 2.36 eV | 3.2 eV |
| Electron affinity | 4.05 V | 4 V | 4.07 | 3.8 V | 4.1 eV |
| Effective conduction band density of states, NC | 2.86x1019 cm-3 | 1.04x1019 cm-3 | 4.7x1017 cm-3 | 1.689x1019 cm-3 | 1.2 x 1018 cm-3 |
| Effective valence band density of states, NV | 2.66x1019 cm-3 | 6x1018 cm-3 | 7x1018 cm-3 | 1.159x1019 cm-3 | 4.1 x 1019 cm-3 |
| Effective mass for electrons | 0.26 | 0.082 | 0.063 | 0.68 | 0.13 m0 |
| Effective mass for holes | 0.69 | 0.28 | 0.57 | 0.6 | 1.4 m0 |
| Dielectric constant | 11.9 | 16 | 12.4 | 9.72 | 9.7 |

 **The Basic Properties of SiO2 and Si3N4**

|  |  |  |
| --- | --- | --- |
| **Insulator**:  | **SiO2**  | **Si3N4**  |
| Structure  | Amorphous  | Amorphous  |
| Melting Point (°C)  | ~1600  | -  |
| Density (g/cm3)  | 2.2  | 3.1  |
| Refractive index  | 1.46  | 2.05  |
| Dielectric constant  | 3.9  | 7.5  |
| Dielectric strength (V/cm)  | 107  | 107  |
| Infrared absorption band (μm)  | 9.3  | 11.5 – 12.0  |
| Energy gap  | 9  | ~5.0  |
| Thermal Expansion coefficient (°C-1)  | 5 x10-7  | -  |
| Thermal conductivity (W/cm-K)  | 0.014  | -  |
| dc resistivity (Ω-cm) at 25 °C at 500 °C  | 10141016  -  | ~1014 ~2 x 1013  |

**Work Functions for Metals**

|  |
| --- |
| **Work function of elements, in units of**[**electron volt**](https://en.wikipedia.org/wiki/Electron_volt)**(eV).** |
| [Ag](https://en.wikipedia.org/wiki/Silver) | 4.26 – 4.74 | [Al](https://en.wikipedia.org/wiki/Aluminium) | 4.06 – 4.26 | [As](https://en.wikipedia.org/wiki/Arsenic) | 3.75 |
| [Au](https://en.wikipedia.org/wiki/Gold) | 5.1 – 5.47 | [B](https://en.wikipedia.org/wiki/Boron) | ~4.45 | [Ba](https://en.wikipedia.org/wiki/Barium) | 2.52 – 2.7 |
| [Be](https://en.wikipedia.org/wiki/Beryllium) | 4.98 | [Bi](https://en.wikipedia.org/wiki/Bismuth) | 4.31 | [C](https://en.wikipedia.org/wiki/Carbon) | ~5 |
| [Ca](https://en.wikipedia.org/wiki/Calcium) | 2.87 | [Cd](https://en.wikipedia.org/wiki/Cadmium) | 4.08 | [Ce](https://en.wikipedia.org/wiki/Cerium) | 2.9 |
| [Co](https://en.wikipedia.org/wiki/Cobalt) | 5 | [Cr](https://en.wikipedia.org/wiki/Chromium) | 4.5 | [Cs](https://en.wikipedia.org/wiki/Caesium) | 2.1 |
| [Cu](https://en.wikipedia.org/wiki/Copper) | 4.53 – 5.10 | [Eu](https://en.wikipedia.org/wiki/Europium) | 2.5 | [Fe](https://en.wikipedia.org/wiki/Iron): | 4.67 – 4.81 |
| [Ga](https://en.wikipedia.org/wiki/Gallium) | 4.32 | [Gd](https://en.wikipedia.org/wiki/Gadolinium) | 2.90 | [Hf](https://en.wikipedia.org/wiki/Hafnium) | 3.9 |
| [Hg](https://en.wikipedia.org/wiki/Mercury_%28element%29) | 4.475 | [In](https://en.wikipedia.org/wiki/Indium) | 4.09 | [Ir](https://en.wikipedia.org/wiki/Iridium) | 5.00 – 5.67 |
| [K](https://en.wikipedia.org/wiki/Potassium) | 2.29 | [La](https://en.wikipedia.org/wiki/Lanthanum) | 3.5 | [Li](https://en.wikipedia.org/wiki/Lithium) | 2.9 |
| [Lu](https://en.wikipedia.org/wiki/Lutetium) | ~3.3 | [Mg](https://en.wikipedia.org/wiki/Magnesium) | 3.66 | [Mn](https://en.wikipedia.org/wiki/Manganese) | 4.1 |
| [Mo](https://en.wikipedia.org/wiki/Molybdenum) | 4.36 – 4.95 | [Na](https://en.wikipedia.org/wiki/Sodium) | 2.36 | [Nb](https://en.wikipedia.org/wiki/Niobium) | 3.95 – 4.87 |
| [Nd](https://en.wikipedia.org/wiki/Neodymium) | 3.2 | [Ni](https://en.wikipedia.org/wiki/Nickel) | 5.04 – 5.35 | [Os](https://en.wikipedia.org/wiki/Osmium) | 5.93 |
| [Pb](https://en.wikipedia.org/wiki/Lead) | 4.25 | [Pd](https://en.wikipedia.org/wiki/Palladium) | 5.22 – 5.6 | [Pt](https://en.wikipedia.org/wiki/Platinum) | 5.12 – 5.93 |
| [Rb](https://en.wikipedia.org/wiki/Rubidium) | 2.261 | [Re](https://en.wikipedia.org/wiki/Rhenium) | 4.72 | [Rh](https://en.wikipedia.org/wiki/Rhodium) | 4.98 |
| [Ru](https://en.wikipedia.org/wiki/Ruthenium) | 4.71 | [Sb](https://en.wikipedia.org/wiki/Antimony) | 4.55 – 4.7 | [Sc](https://en.wikipedia.org/wiki/Scandium) | 3.5 |
| [Se](https://en.wikipedia.org/wiki/Selenium) | 5.9 | [Si](https://en.wikipedia.org/wiki/Silicon) | 4.60 – 4.85 | [Sm](https://en.wikipedia.org/wiki/Samarium) | 2.7 |
| [Sn](https://en.wikipedia.org/wiki/Tin) | 4.42 | [Sr](https://en.wikipedia.org/wiki/Strontium) | ~2.59 | [Ta](https://en.wikipedia.org/wiki/Tantalum) | 4.00 – 4.80 |
| [Tb](https://en.wikipedia.org/wiki/Terbium) | 3.00 | [Te](https://en.wikipedia.org/wiki/Tellurium) | 4.95 | [Th](https://en.wikipedia.org/wiki/Thorium) | 3.4 |
| [Ti](https://en.wikipedia.org/wiki/Titanium) | 4.33 | [Tl](https://en.wikipedia.org/wiki/Thallium) | ~3.84 | [U](https://en.wikipedia.org/wiki/Uranium) | 3.63 – 3.90 |
| [V](https://en.wikipedia.org/wiki/Vanadium) | 4.3 | [W](https://en.wikipedia.org/wiki/Tungsten) | 4.32 – 5.22 | [Y](https://en.wikipedia.org/wiki/Yttrium) | 3.1 |
| [Yb](https://en.wikipedia.org/wiki/Ytterbium) | 2.60 [[13]](https://en.wikipedia.org/wiki/Work_function#cite_note-13) | [Zn](https://en.wikipedia.org/wiki/Zinc) | 3.63 – 4.9 | [Zr](https://en.wikipedia.org/wiki/Zirconium) | 4.05 |

**4H-SiC constants**

|  |  |  |
| --- | --- | --- |
|  Parameter | *Value* | *Remarks* |
| Energy Gap | 3.23 eV | 300K |
| Dielectric constant  | 9.7 | 300 K |
| Effective electron mass  *me* | 0.29 *m*o | 300 K |
| Effective hole masses *mp* | 0.98*mo* | 300 K |
| Electron affinity | 3.1 eV | 300 K |
| Lattice constant, a | 3.073 A | 300 K |
| Lattice constant, c | 10.053 A | 300 K |
| Breakdown Field (intrinsic) | 4x106 V/cm | 300K |
|  |  |  |
|  |  |  |
|  |  |  |

**Electron Mobility**

**For 3C-SiC**

**Hole Mobility**

**For 3C-SiC**

Electron and Hole mobility for 3C-SiC

Electron



Electron Mobility for 4H-SiC and 6H-Sic

Hole



Hole Mobility for 4H-SiC and 6H-Sic



**Electron Mobility of GaN vs. doping Concentration**



**Hole Mobility of GaN vs. doping Concentration**