Mobility of Charge Carriers in N-channel MOSFET and Temperature Dependence

Electronic Devices Lab : Experiment 11

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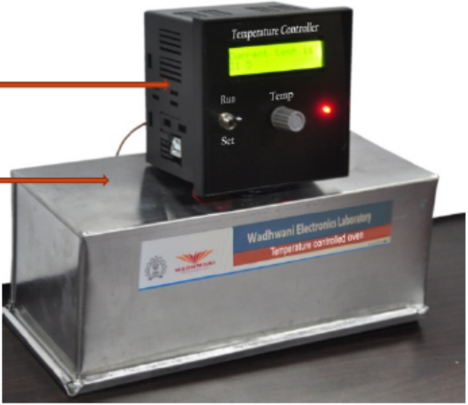
Think it. Make it. Prove it.

Experiment set-up

Temperature Indicator and Controller

Temperature Controlled Oven

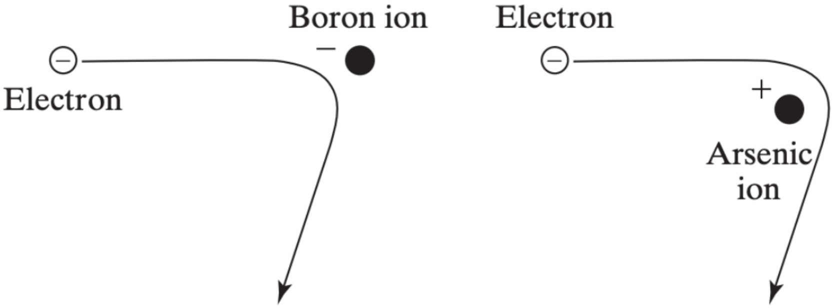


Experiment set-up

The MOSFET terminals are marked on the oven.

COULOMB SCATTERING

This type of scattering is associated with the presence of electrostatic centers affecting the motion of channel carriers. The scatterers are mainly impurity ions, interface states, charges in the oxide and the gate material.
The mobility due to Coulomb scattering varies with temperature as $T^{3/2}$.



PHONON SCATTERING

The atoms in a semiconductor crystal have a certain amount of thermal energy at temperatures above absolute zero that causes the atoms to randomly vibrate about their lattice position within the crystal. The lattice vibrations cause a disruption in the perfect periodic potential function. A perfect periodic potential in a solid allows electrons to move unimpeded, or with no scattering, through the crystal.

But the thermal vibrations cause a disruption of the potential function, resulting in an interaction between the electrons or holes and the vibrating lattice atoms. This lattice scattering is also referred to as phonon scattering.

The mobility due to Phonon scattering varies with temperature as $T^{-3/2}$.

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Background Theory

- At lower electric fields, the dominating scattering mechanism is Coulomb scattering. Here, the mobility increases with increase in electric field.
- At higher electric fields, the dominating scattering mechanism is Phonon scattering (and eventually surface roughness). Here, the mobility decreases gradually with increase in electric field.

Before You Start...

* Make the connections of the binding post terminals (screws) of temperature controller and oven. Connect the heating element to 230 V mains. **HIGH VOLTAGE WARNING : BE CAREFUL WHILE CONNECTING TO THE MAINS.**
* **Make sure that SET/RUN switch is in SET position every-time you power ON the controller. If the switch is in RUN position before power ON, the SET register may take any garbage value and heater may remain continuously ON!**
* Set the desired temperature by controlling the 'Temp' knob. If the set temperature is more than the current temperature, the heater will turn ON and is indicated by the LED on the front panel of the controller. In RUN mode you will see current temperature being displayed while the heater is getting heated.

Part 1 : Characterizing the NMOS

Before going into the temperature dependence, the discrete NMOS (2N7000) needs to be characterized at room temperature.

- Measure I_D by increasing V_{GS} from 0 to $2V$ with a constant V_{DS} of $3V$.
- Note down when the NMOS starts conducting. This will give the threshold voltage V_T of the NMOS.

You will notice that the NMOS was operating in saturation region during this part of the experiment.

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- The data obtained can also be used to calculate the value of $\beta = \mu_n C_{ox} \frac{W}{L}$ of the NMOS.
- Plot $\sqrt{I_D}$ vs V_{GS}. The slope of this curve will be useful to obtain β.

$$\sqrt{I_D} = \sqrt{\frac{\beta}{2}}(V_{GS} - V_T)$$

$$slope = \frac{\sqrt{I_D}}{V_{GS}} = \sqrt{\frac{\beta}{2}} \qquad \implies \beta = 2 * (slope^2)$$

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Part 2 : Mobility Extraction

- Set the temperature to $30^o C$ using the temperature controller.
- Fix $V_{DS} = 0.6V$ for this part, since the measurements for this part will be done in linear region. Use the 0-32V variable supply to directly give V_{DS}.
- Vary V_{GS} from $0.6 + V_T$ (V_T is obtained from the characterization) to around $10V$ and tabulate I_D. Use the $12V$ supply and a potentiometer to vary V_{GS}. Make sure you take readings at $V_{GS} = 1.8V$ and $V_{GS} = 8V$.

Important points to note:

1. More data points are needed at low V_{GS}. Hence vary V_{GS} in steps of $0.2V$ till $4V$. Then you can increase the step to $1V$.
2. To get accurate readings, DON'T change the multi-meter range in the middle of the experiment. Select 2 A and keep it at that.

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Circuit Diagram

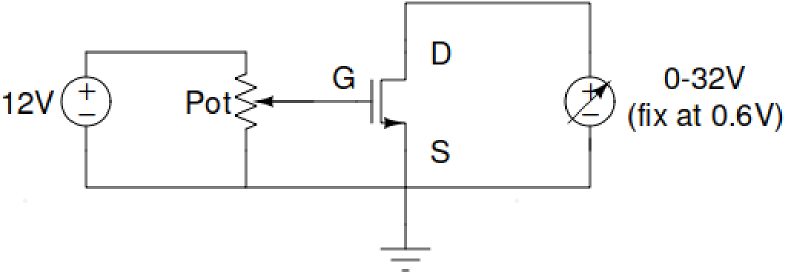

Figure: Circuit for reference

Part 2 : Mobility Extraction

Once you have all the data, the only task left is to interpret them.

- The current equation through the NMOS in linear region is known. β can be estimated from it.

$$\beta = \mu_n C_{ox} \frac{W}{L} = \frac{I_D}{V_{DS}(V_{GS} - V_T - 0.5V_{DS})}$$

- Obtain β for each of your readings from the above formulae.
- Plot β vs V_{GS}. Notice the trend and relate it to the theory explained earlier.

Part 2 : Temperature Dependence

- Perform the same mobility extraction procedure for higher temperatures $50^o C$ and $70^o C$.
- Plot β vs V_{GS} for all 3 temperatures in the **SAME PLOT**.
- C_{ox}, W and L don't change with temperature and hence the only contributing quantity is the mobility μ_n.
- Notice the trends in the β vs V_{GS} plot with respect to different temperatures. How is the trend changing at low V_{GS} and high V_{GS}?

Part 2 : Temperature Dependence

To quantify the temperature dependence, you can plot β vs T for low V_{GS} (of $1.8V$) and high V_{GS} (of $8V$)

- $V_{GS} = 1.8V$:

$T\ (^oC)$	$\beta\ (mA/V^2)$
30	
50	
70	

- $V_{GS} = 8V$

$T\ (^oC)$	$\beta\ (mA/V^2)$
30	
50	
70	

Can you explain the reason behind the observed trends?

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