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To Study Effect on Current Due to Channel Doping Concentrations Variation

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Abstract

The aim of this simulation work is to study effect of channel doping concentration. The channel lies under the oxide layer of the MOSFET. The results obtained show that as channel doping concentration decreases threshold voltage decreases and good saturation region in I-V curve is obtained and the drain current increases. So the lower channel doping concentration provides better mobility and hence, less velocity saturation.

1. Introduction

J.E Lilienfield patented the first ever field effect transistor concept, namely “Method and Apparatus for Controlling Electric Currents” nearly 80 years ago, which evolved into the modern metal oxide semiconductor field effect transistor, MOSFET. He proposed a three terminal device (Source, Drain and Gate), where the source to drain current is controlled by a field effect from the gate and is dielectrically insulated from the rest of the device [1]. The region between the two diffused islands under the oxide layer is called the channel region. The channel provides a path for the majority carriers (electrons for example, in the n-channel device) to flow between the source and the drain. The channel is covered by a thin insulating layer of silicon dioxide (SiO_2). The gate electrode, made of polycrystalline silicon (polysilicon or poly in short) stands over this oxide. As the oxide layer is an insulator, the DC current from the gate to the channel is zero. The source and the drain regions are indistinguishable due to the physical symmetry of the structure. The current carriers enter the device through the source terminal while they leave the device by the drain [2]. The transconductance of the MOSFET decides its gain and is proportional to hole or electron mobility (depending on device type), at least for low drain voltages. As MOSFET size is reduced, the fields in the channel increase and the dopant impurity levels increase. Both changes reduce the carrier mobility, and hence the transconductance [3]. The doping concentration is proportional to drain resistances [4].

2. Discussion

An electron traveling from the source to the drain along the channel gains kinetic energy at the cost of electrostatic potential energy in the pinch-off region, and becomes a “hot” electron. As the hot electrons travel towards the drain, they can create secondary electron-hole pairs by impact ionization. The secondary electrons are collected at the drain, and cause the drain current in saturation to increase with drain bias at high voltages, thus leading to a fall in the output impedance. The secondary holes are collected as substrate current. This effect is called impact ionization. The hot electrons can even penetrate the gate oxide, causing a gate current. This finally leads to degradation in MOSFET parameters like increase of threshold voltage and decrease of transconductance. Impact ionization can create circuit problems such as noise in mixed-signal systems, poor refresh times in dynamic memories, or latch-up in CMOS circuits. The remedy to this problem is to use a device with lightly doped drain. By reducing the doping density in the source/drain, the depletion width at the reverse-biased drain-channel junction is increase and consequently, the electric filed is reduced. Hot carrier effects do not normally present an acute problem for *p* -channel MOSFETs. This is because the channel mobility of holes is almost half that of the electrons. Thus, for the same filed, there are fewer hot holes than hot electrons. However, lower holes mobility results in lower drive currents in *p* -channel devices than in *n* -channel devices [2].

3. Simulation

We have supposed four MOSFETs with 8 micron channel lengths in the simulation. The simulated device can be described simply by three regions (figure 1), representing source and drain and a central region. The source and drain regions are doped to 1×10^{19} m^3 electron concentration with n type and substrate is doped at $1.5\text{x}10^{14}$ m^3 electron concentration with n type. While the channel region is doped at different concentration 2×10^{14}, $2\text{x}10^{13}$, $2\text{x}\ 10^{10}$ and $1\text{x}10^{14}m^3$ electron concentration with p type. The channel thickness is about 10 micron and the contacts are neutral.

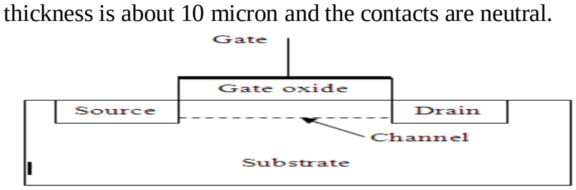

Fig: 1. MOSFET Overview.

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4. Result

The fig (2) shows the characteristics curve between gate source voltage and drain current. Table (1) shows the current value at different gate voltage for 2×10^{14}, $2x10^{13}$, $2x\ 10^{10}$ m^3 electron concentrations with p type. The drain current is decreased as the doping concentration of channel is increased. The drain current is high for channel concentration ($2x\ 10^{10}$ m^3) as compare to other channel concentration. The characteristic curve between drain source voltage and drain current for 2×10^{14}, $2x10^{13}$, $2x\ 10^{10}$ and $1x10^{14}$ m^3 electron concentrations with p type is shown in the fig-3. But as the channel concentration is decreased more i.e $1x10^{14}$ m^3 electron concentration with p type. Then the drain current is not decrease. It is same for concentration 1x105, 0.5x101 m3 electron concentrations with p type as shown in the figure-4. Table-2 shows the comparison between these electron concentrations. The characteristic curve between drain source voltage and drain current for 2×10^{14}, $2x10^{13}$ and $1x10^{14}$ m^3 electron concentration with p type is shown in the fig-5.

Table: 1, 2, 3 & 4. Comparison between MOSFETs having different channel concentrations (2×10^{15} m^3, $2\times10^{14}m^3$, 2×10^{13} m^3, 1×10^5 m^3, 0.5×10^1 m^3)

S. No	Gate Voltage	Drain Current		
		I MOSFET (2×10^{15} m^3)	**II MOSFET ($2x10^{14}$ m^3)**	**III MOSFET ($2x\ 10^{13}$ m^3)**
1	0.0V	0.0 Amp	0.0 Amp	0.0 Amp
2	2.0V	0.0 Amp	$5.5514x10^{-8}$ Amp	$1.3905x10^{-7}$ Amp
3	5.0V	$3.8557x10^{-8}$ Amp	$2.9576x10^{-7}$ Amp	$3.9862x10^{-7}$ Amp

S. No	Gate Voltage	Drain Current		
		I MOSFET (2×10^{15} m^3)	**II MOSFET ($2x10^{14}$ m^3)**	**III MOSFET ($2x\ 10^{13}$ m^3)**
1	5.0 V	0.0 Amp	0.0 Amp	0.0 Amp
2	5.0V	$1.0053x10^{-7}$ Amp	$5.8334x10^{-6}$ Amp	$1.2007x10^{-5}$ Amp

S. No	Gate Voltage	Drain Current		
		III MOSFET ($2x\ 10^{13}$ m^3)	**IV MOSFET ($1x10^5$ m^3)**	**V MOSFET ($0.5x\ 10^1$ m^3)**
1	0.0V	0.0 Amp	$3.8308x10^{-9}$ Amp	$3.8308x10^{-9}$ Amp
2	2.0V	$1.3905x10^{-7}$ Amp	$1.640x10^{-7}$ Amp	$1.640x10^{-7}$ Amp
3	5.0V	$3.9862x10^{-7}$ Amp	$4.270x10^{-7}$ Amp	$4.270x10^{-7}$ Amp

S. No	Gate Voltage	Drain Current		
		III MOSFET ($2x\ 10^{13}$ m^3)	**IV MOSFET ($1x10^5$ m^3)**	**V MOSFET ($0.5x\ 10^1$ m^3)**
1	5.0 V	0.0 Amp	0.0 Amp	0.0 Amp
2	5.0V	$1.0053x10^{-7}$ Amp	$5.8334x10^{-6}$ Amp	$1.2007x10^{-5}$ Amp

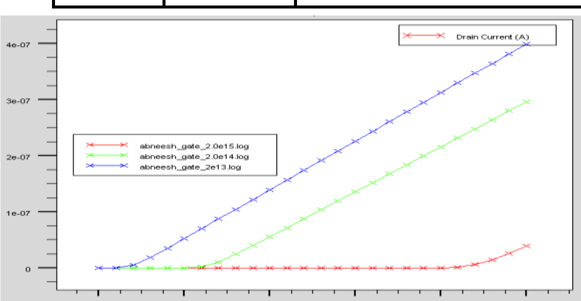

Fig: 2. Characteristics curve of Vgs Vs Id having concentrations $2x10^{15}$, $2x10^{14}$ and $2x10^{13}$

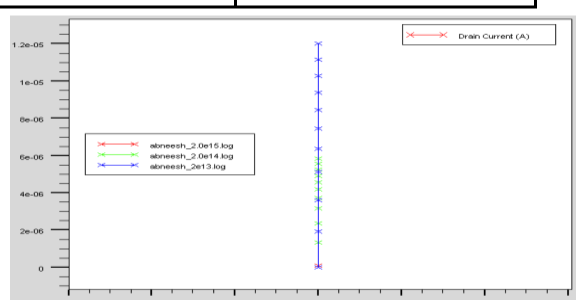

Fig: 3. Characteristics curve of V_{ds} Vs I_d having concentrations $2x10^{14}$, $2x10^{13}$ and $1x10^{14}$

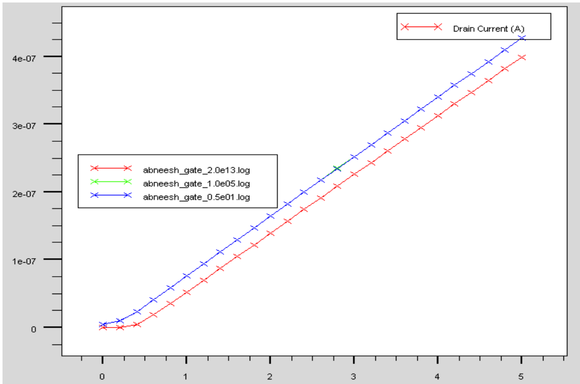

Fig: 4. Characteristics curve of Vgs Vs Id having concentrations $2x10^{13}$, $1x10^5$ and $0.5x10^1$

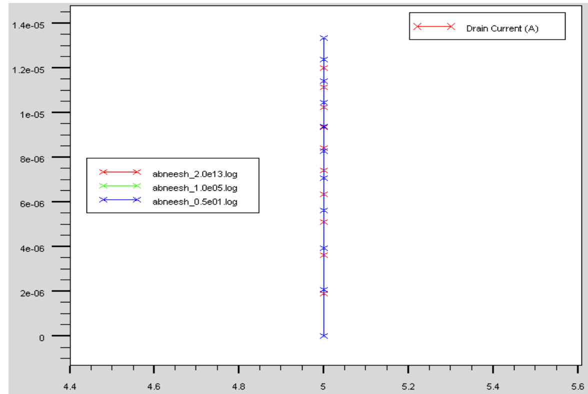

Fig: 5. Characteristics curve of V_{ds} Vs I_d having concentrations $2x10^{13}$, $1x10^5$ and $0.5x10^1$

5. Conclusion

The channel doping concentration is proportional to drain resistances. Thus, lower doping concentration gives lower drain resistances, thus more drain can flow through the junctions. If the doping concentration is high then it gives larger drain resistances and less drain current flow through the junctions. So reduction of the channel doping concentration which improves the saturation region of the I_d-V_d curves and reduces threshold voltage. Hence as the channel doping concentration decreases drain current increases.

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