COMPACT MODEL FOR DOUBLE GATE TUNNEL FIELD-EFFECT TRANSISTOR

By

Mohamed Youssef Hassan Sayed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Engineering Physics

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Key Words:

TFET; Double Gate; DG TFET; Compact model

Summary:
This thesis presents a new compact model for Double-Gate Tunnel Field-Effect Transistor (DG TFET). This physically based model accounts for the tunneling at the source channel interface as well as for the drift-diffusion in the channel region. It also accounts for the ON and the subthreshold modes of operation. This model enables the calculation of the I-V, Q-V and C-V characteristics of the device. The model is validated by comparing its results with that calculated numerically by the Sentaurus device simulator.

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Mohamed Youssef Hassan Sayed,
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χ_{ge}	germanium electron affinity (eV)
χ_{si}	silicon electron affinity (eV)
η_d	degeneracy factor in the highly doped drain region (eV)
η_s	degeneracy factor in the highly doped source region (eV)
$\hbar$	reduced Planck's constant ($J.s$)
κ	dimensionless scaling factor
λ	natural scaling length (nm)
μ	bulk mobility of electrons ($cm^2/V.s$)
μ_{eff}	effective mobility of electrons ($cm^2/V.s$)
ϕ_m	metal work function (eV)
ϕ_{si}	silicon work function (eV)
$\psi(x,y)$	potential distribution at any point x, and y (V)
$\rho(x,y)$	charge density at any point x, and y (C/m^3)
ε_o	Permittivity of free space (F/cm)
ε_{ge}	permittivity of germanium (F/cm)
ε_{ox}	permittivity of oxide (F/cm)
$\varepsilon_{r,ox}$	relative permittivity of oxide
ε_{si}	permittivity of silicon (F/cm)
$\vec{k}$	wavevector (cm^{-1})
$\vec{v}$	group velocity vector (cm/s)
ξ_x	lateral electric field component(V/cm)
ξ_y	vertical electric field component(V/cm)
ξ_{ox}	vertical component of the electric field in the gate oxide (V/cm)
ξ_{si}	vertical component of the electric field in the silicon body (V/cm)
ξ_{total}	total electric field (V/cm)
C_D	depletion layer capacitance per unit area (F/cm^2)

C_{gd}	gate to drain capacitance per unit area (F/cm^2)
C_{gs}	gate to source capacitance per unit area (F/cm^2)
C_{ox}	gate oxide capacitance per unit area (F/cm^2)
C_{si}	silicon body film capacitance per unit area (F/cm^2)
E	total energy (J)
E_g	energy bandgap (eV)
E_l	longitudinal energy (J)
E_t	transverse energy (J)
E_{cc}	channel conduction energy band edge (eV)
E_{cd}	drain conduction energy band edge (eV)
E_{fc}	quasi-Fermi energy level of electrons in the channel region (eV)
E_{fs}	Fermi energy level of holes in the source region (eV)
E_{id}	intrinsic Fermi energy level in the drain (eV)
E_{is}	intrinsic Fermi energy level in the source (eV)
E_{vs}	source valence energy band edge (eV)
g_{ds}	output-conductance ($A/V.um$)
g_m	trans-conductance ($A/V.um$)
I_{chan}	channel current per unit width (A/um)
I_{OFF}	Off-state current (A/um)
I_{ON}	On-state current (A/um)
I_{tun}	tunnel current per unit width (A/um)
$J_{c\rightarrow s}$	channel to source tunnel current density (A/cm^2)
$J_{s\rightarrow c}$	source to channel tunnel current density (A/cm^2)
J_{tun}	net tunnel current density (A/cm^2)
k_B	Boltzmann constant (J/K)
L_1	source depletion region length (nm)
L_2	length of region II in the weak lateral drain field mode (nm)
L_3	drain depletion region length in the strong lateral drain field mode (nm)

L_4	drain depletion region length in the weak lateral drain field mode (nm)
L_g	gate length (nm)
m^*	effective mass (kg)
m_o	free electron mass (kg)
n	mobile carrier concentration (cm^{-3})
$n(x,y)$	electron density at any position x and y (cm^{-3})
N_c	conduction band effective density states (cm^{-3})
N_d	drain doping concentration (cm^{-3})
n_i	intrinsic carrier concentration (cm^{-3})
N_s	source doping concentration (cm^{-3})
N_v	valence band effective density states (cm^{-3})
p	power density (W/m^2)
P_d	power dissipation (W)
Q	charge of the mobile carriers in region III (C)
q	magnitude of charge of the electron (C)
Q_D	total charge of the positive ions inside the drain depletion region (C)
Q_G	charge accumulated on the gate electrode (C)
Q_S	total charge of the negative ions inside the source depletion region (C)
Q_{III}	total charge in region III (C)
Q_{si}	total charge per unit area inside the silicon (C/cm^2)
R_{chan}	channel resistance (Ω)
R_{tun}	tunnel resistance (Ω)
T	absolute temperature in (K)
$T(E)$	tunneling probability
$T_{max}(E)$	maximum tunneling probability
t_{ox}	effective gate oxide thickness (nm)
t_{si}	silicon layer film thickness (nm)
$T_{WKB}(E)$	tunneling probability calculated using WKB approximation

V_1	quasi-Fermi potential of electrons at their entry point in the channel (V)
V_D	drain voltage (V)
V_G	gate voltage (V)
V_t	thermal voltage (V)
V_{DD}	power supply voltage (V)
V_{Dsat}	drain saturation voltage (V)
V_{DS}	drain to source voltage (V)
V_{fbc}	gate to channel flat band voltage (V)
V_{GD}	gate to drain voltage (V)
V_{GS}	gate to source voltage (V)
V_{ov}	overdrive voltage (V)
V_{ox}	voltage drop across the gate oxide (V)
V_{th}	threshold voltage in MOSFET (V)
W	width of the DG-TFET (um)
W_{min}	minimum tunneling width (nm)
$W_{tun}(E)$	tunneling barrier width (nm)
X_1	entry point position of the tunneling electron into the channel region (nm)