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Transport in Metal-Oxide-Semiconductor Structures

Mobile Ions Effects on the Oxide Properties

Springer

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Preface

The present work deals with the study of the mobile ions in the silicon dioxide insulator, which has great importance because their presences affect significantly on the MOS structure characteristic. The subject is introduced with the necessary background concepts of MOS structure dealing with various aspects of the oxides and their charges. Besides, theoretical approaches to determine the density of mobile ions as well as their density-distribution along the oxide thickness are developed. In fact, three attempts have been discussed each makes use of different approaches. In the first attempt, the density of the mobile ions has been determined from experimental measurements using different techniques such as the Charge Pumping (CP) technique associated with the Bias Thermal Stress (BTS) method. In the second attempt, the theoretical approaches using empirical models or numerical approach for the mobile ions density distribution are described. In the last attempt, an analytical model of the mobile ions density distribution, which is based on physical concepts at equilibrium state and ionic current-voltage characteristic of MOS structure, is presented.

The whole book is divided into 7 chapters. After introducing the subject in the first chapter, Chap. 2 deals with the background studies of the MOS structure ideal and non-ideal case. Chapter 3 presents methods typically used to grow oxide such as thermal oxidation, chemical oxidation (anodic oxidation) and Rapid Thermal Oxidation (RTO) as well as oxide-charges and different effects of these charges on the device performance. A complete review of transport Mechanism in thin oxides of MOS devices is discussed in Chap. 4. The studies carried out on mobile ionic charge in thermally oxidized silicon system were primarily aimed at determining its total density. Accordingly, several experimental techniques such as Charge Pumping (CP) technique associated with the BTS method have been developed for measuring the mobile ion concentration in oxides of MOS structures that are described in Chap. 5. Nevertheless, none of these techniques so developed has been used to obtain the density distribution of mobile ions. However, a few theoretical attempts have also been made in this direction, which are reviewed in Chap. 6. In the present work, certain new attempts have been investigated towards the determination of the mobile ionic density-distribution. In the first attempt, methods have been developed to determine the density-distribution of mobile ionic charge in explicit form simply from the knowledge of the measured values of flat band voltage under three different conditions, namely, before contamination/activation, after contamination/activation, and finally after ion-drift. In other method, a numerical modelling has been used to obtain the mobile ion profile not only at equilibrium state but also its profile evolution when BTS is applied. These methods are presented in Chap. 6. However, the density-distribution of mobile ions in the oxide has been obtained analytically which is based on the argument that these ions must attain an equilibrium density-distribution under the influence of various internal and external forces which are acting upon them. This analytical model of the density-distribution of mobile ions is described in Chap. 7. In the other attempt, a new approach of determining dynamic ionic current-voltage characteristic that is due to ion transport phenomenon in the oxide is presented in Chap. 7. In that approach, the formulation of I-V characteristics of MOS device can be achieved using the theoretical model of mobile ion distribution in oxides.

This work can be used by device physicists, characterisation engineers, or any researches interested in the studies of the MOS device properties.

Boumerdes, August 2010 Hamid Bentarzi

Contents

List of Symbols, Abbreviations and Physical Constants

A	Area
A_{G}	Area of the channel
C	Capacitance
C_{D}	Depletion capacitance
C_{HF}	High frequency capacitance
C_{it}	Interface trap state capacitance
C_{LF}	Low frequency capacitance
C_{OX}	Oxide capacitance
C_{Si}	Silicon capacitance
C_{MOS}	MOS capacitance
D	Diffusion coefficient
D_{it}	Interface trapped charge density
E	Energy
E_{A}	Activation energy
E_{c}	Conduction band energy
E_{F}	Fermi energy
E_{g}	Energy bandgap
E_{ae}	Activation energy of electrons
E_{d}	The trap energy
E_{v}	Valence band energy
E_{o}	Activation energy at the interface
F	Flux, force
f	Frequency
G	Conductance
G_{MOS}	Leakage conductance through MOS structure
h	Planck constant
J	Current density
J_{DT}	Current density in direct tunneling
J_{FN}	Current density in fowler–nordheim tunneling

k	Boltzmann coefficient
L_D	Debye length
m	Mass
m_o	Free mass of electron
m^*	Effective electron mass
m_{Si}	Effective electron mass in the silicon
m_{ox}	Effective electron mass in the oxide
n	Charge density
N_c	Density of states in the oxide conduction band
n_i	Intrinsic carrier concentration
n_s	Electron density at the silicon/silicon dioxide interface
n_A	Density of ionized acceptors
n_D	Density of ionized donors
N_t	Trap density
N_m	Mobile ions density
N_{ox}	Oxide charge density
N_s	Silicon/Silicon dioxide interface charge density
P	Hole density
q	Unit charge
Q	Charge
Q_{it}	Interface trapped charge
Q_f	Fixed oxide charge
Q_{ot}	Oxide trapped charge
Q_m	Mobile ionic charge
Q_{tot}	Total charge
R	Resistance
t	Time
t_{ox}	Oxide thickness
T	Temperature in kelvin
V	Voltage
V_A	Applied voltage
V_F	Effective gate voltage
V_{FB}	Flat band voltage
ΔV_{FB}	Flat band voltage shift
V_G	Gate voltage
V_{ox}	Voltage across the oxide
V_{Th}	Threshold voltage
W_{ms}	Work function difference between the metal and S_i
x	Distance from metal–oxide interface
X	Centroid of the charge distribution
ε_o	Permittivity of the free space
ε_{si}	Relative permittivity of the silicon
ε_{ox}	Relative permittivity of the oxide
ϕ	Potential
ϕ_B	Bulk potential

ϕ_M	Barrier height at metal/oxide interface
ϕ_S	Surface potential
ϕ_{Si}	Barrier height at silicon/oxide interface
$\psi(x)$	Band bending
ψ_S	Total band bending
ζ	Electric field
ζ_s	Electric field at the silicon/silicon dioxide interface
ζ_{ox}	Electric field in the silicon dioxide
μ	Mobility
μ_e	Mobility of electron
μ_{ion}	Mobility of ion
ρ	Charge density

BTS	Bias thermal stress
CP	Charge pumping
CV	Capacitance voltage
CVD	Chemical vapor deposition
FET	Field effect transistor
FN	Fowler nordheim
HF	High frequency
IC	Integrated circuit
LF	Low Frequency
LPCVD	Low pressure CVD
MOS	Metal oxide semiconductor
MOSFET	Metal oxide semiconductor field effect transistor
NMOS	N-Channel MOS
PECVD	Plasma enhanced CVD
PMOS	P-Channel MOS
RF	Radio frequency
RTD	Resonance tunneling diode
RTA	Rapid thermal annealing
RTO	Rapid thermal oxidation
SCL	Space charge layer
TSIC	Thermally stimulated ionic current

ε_o	8.85×10^{-12} F/m
ε_{ox}	4.1
ε_{si}	11.8
μe	1400 $cm^2/(Vs)$, in Si
k	1.4×10^{-23} J/K
h	$6.62606896 \times 10^{-34}$Js
q	$1.6{\times}10^{-19}$ Coulomb