PROPERTIES OF RF PLASMA GROWN Al_2O_3 AND ALN INSULATORS ON SILICON AND EFFECT OF PLASMA ANNEALING ON THERMALLY GROWN SiO_2 FILMS

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CERTIFICATE

This is to certify that the dissertation entitled, "Properties of RF Plasma Grown Al_2O_3 and AlN Insulators on Silicon and Effect of Plasma Annealing on Thermally Grown SiO_2 Films", which is being submitted by Mr. Sudhir Chandra to the Indian Institute of Technology, Delhi, for the award of the degree of Doctor of Philosophy, is a record of bonafide research work carried out by him under my guidance and supervision.

In my opinion, this dissertation has reached the standard fulfilling the requirements of the regulations relating to the degree. The results contained in it have not been submitted, in part or in full, to any other university or institute for the award of any degree or diploma.

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ABSTRACT

Thin insulating films are an integral part of today's semiconductor devices and integrated circuits. In a large number of applications, these are required to be grown at relatively low temperatures. In the present work, the growth and characteristics of low-temperature RF plasma enhanced chemical vapour deposited (PECVD) aluminum nitride (AlN) and aluminum oxide (Al_2O_3) films on silicon are examined. Some studies were also made on the effect of exposing thermally grown Si-SiO_2 structures to RF plasmas.

Aluminum nitride films grown by PECVD technique were found to be amorphous. Some of the physical and dielectric properties of AlN films were studied. The capacitance-voltage (C-V) characteristics of Al-AlN-SiO_2-Si structures were investigated at 1 MHz. AlN films were also evaluated for surface passivation applications.

The as-grown Al_2O_3 films were found to be amorphous; those annealed at 720^{o}C or more showed a polycrystalline structure. The physical and dielectric properties of these films were examined. Extensive studies were made on the charge trapping behavior of Al_2O_3 films using a simple Al -Al_2O_3-SiO_2-Si (MAOS) structure. The mobility of minority carriers in the silicon close to the Si-SiO_2 interface was studied using the MAOS transistor.

Silicon-silicon dioxide structures exposed to plasma show marked changes in their C-V characteristics. The flat-band voltage changes to more negative values due to hole trapping in the oxide. In addition, surface-states are also believed to be generated at the Si-SiO_2 interface. Plasma annealing conditions have a profound effect on hole trapping and generation of surface states. The original characteristics of Si-SiO_2 structures could be completely restored by a subsequent low temperature thermal annealing. Some studies were also made on electron trapping effects in plasma exposed Si-SiO_2 structures.

NOMENCLATURE

Å	Angstrom unit
ac	alternating current
Al	aluminum
$AlCl_3$	aluminum trichloride
AlN	aluminum nitride
Al_2O_3	aluminum oxide
BN	boron nitride
B_2O_3	boron oxide
B-T	bias-temperature
C	capacitance
C_b	blocking capacitor
C_I	insulator (s) capacitance per unit area
C_{max}	maximum value of the capacitance in high-frequency C-V curve
C_{min}	minimum value of the capacitance in high-frequency C-V curve
C_{MIS}	metal-insulator(s)-semiconductor capacitor
C_{ox}	silicon dioxide capacitance per unit area
cm	centimeter
C-V	capacitance versus voltage

dc	direct current
d_n	normalised thickness of the double insulator
d_1	charge centroid from the metal-Al_2O_3 interface in an MAOS structure
E	electric field
E_a	electric field at the SiO_2-Al_2O_3 interface
E_c	conduction band edge in Si
E_m	electric field at the metal-Al_2O_3 interface
E_F	silicon fermi level
E_{FM}	metal fermi level
E_i	intrinsic fermi level in silicon
eV	electron volt
E_v	valance band edge in silicon
FET	field effect transistor
g_m	transconductance
h_{FE}	current gain of bipolar transistor
HCl	hydrochloric acid
HF	hydrofluoric acid
HNO_3	nitric acid
i	current flowing through an MIS capacitor in response to a voltage sweep
I	current through an MIS capacitor, steay state

i_C	conduction current in an MIS capacitor in response to a voltage sweep
I_D	drain current of an IGFET
IGFET	insulated gate field effect transistor
IR	infra red
I-V	current versus voltage
J	current density
K	ramp constant (dv/dt)
k	Boltzmann constant
k_a	relative dielectric constant of Al_2O_3
L	channel length of IGFET
L_1, L_2	inductances (electron injection circuit)
lpm	litre per minute
M	metal
MAOS	metal-Al_2O_3-SiO_2-Si
MA_nOS	metal-AlN-SiO_2-Si
MIS	metal-insulator(s)-semiconductor
mm	millimeter
MOS	metal-SiO_2-Si
mV	milli volt

N_A	density of ionized acceptor atoms in Si.
N_2	nitrogen
N_+	total charge per unit area due to hole trapping
N_{ss}	fast surface-state density at the $Si-SiO_2$ interface ($cm^{-2}\ eV^{-1}$)
O_2	oxygen
pF	pico farad
ppm	parts per million
q	elementary charge
Q	"Q" of the inductance
Q_{ii}	charge at the $SiO_2-Al_2O_3$ interface, per unit area
Q_{ox}	fixed charge at the $Si-SiO_2$ interface per unit area
$\bar{Q}_{ss}$	charge in surface states at the $Si-SiO_2$ interface under flat-band conditions per unit area
$Q_T(t)$	trapped charge in Al_2O_3 at time 't', per unit area
$Q(t)$	total charge at time 't'
R_b	biasing resistance (C-V plotter)
R_M	measuring resistance (C-V plotter)
R_L	load resistance (C-V plotter)
R_1	a resistance (electron injection circuit)
Q_{ss}	charge in surface states at the $Si-SiO_2$ interface per unit area

RF, rf	radio frequency
rpm	rounds per minutes
S_1,S_2	switches
S_i	silicon
SiO_2	silicon dioxide
T_e	electron temperature
T_g	gas temperature
t_S	stressing time of MIS capacitor
TCE	trichloroethylene
TMA	trimethyl aluminum
uv	ultraviolet
v	input voltage in C-V plotter across R_L
v_m	voltage across R_M (C-V plotter)
V_G	gate voltage (dc)
V_{DS}	drain to source voltage in an IGFET
V_{FB}	flat-band voltage of an MIS structure
V_{FBO}	initial flat band voltage
$V_{FB}(x_o)$	flat-band voltage of an MOS capacitor for x_o thickness of SiO_2
$V'_{FB}(x_o)$	flat-band voltage of an MOS capacitor for x_o thickness of SiO_2 in the absence of hole trapping
V_{max}	maximum voltage applied during I-V measurement of an MAOS capacitor

V_S	stressing voltage across MAOS capacitor
vs	versus
V_T	threshold voltage of an IGFET
ΔV_{FB}	change in V_{FB}
$\Delta \overline{V}_{FB}$	change in V_{FB} after applying V_{max}
ΔV_H	change in V_{FB} due to hole trapping in SiO_2
W	channel width of an IGFET
x_a	aluminum oxide thickness
x_o	silicon dioxide thickness
x_{oo}	SiO_2 thickness before etch-off begins.
x_c	charge centroid measured from: (a) the Si-SiO_2 interface in an MOS structure and (b) the Al_2O_3-SiO_2 interface in an MAOS structure
ω	angular frequency
D	Debye length
μ_{eff}	effective surface mobility
ϵ	permittivity of free space
ϵ_o	dielectric constant of SiO_2
ϵ_a	dielectric constant of Al_2O_3
ϕ_{MS}	metal-semiconductor work function difference

ϕ_B	potential for electrons at the $Si-SiO_2$ interface
$\rho(x), \rho(Y)$	trapped charge distribution due to hole trapping, per unit volume
ϕ_{ii}	potential at the $SiO_2-Al_2O_3$ interface
ψ_f	silicon surface potential

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