GROWTH AND PROPERTIES OF ZINC OXIDE FILMS FROM CONVERSION OF EVAPORATED ZINC SELENIDE FOR APPLICATION TO MIS DEVICES

by

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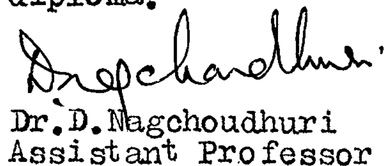
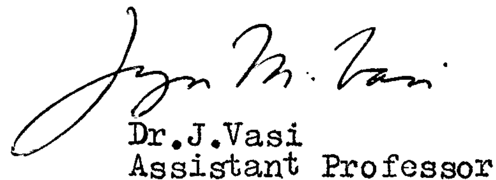
CERTIFICATE

This is to certify that the dissertation entitled, 'Growth and Properties of Zinc Oxide Films from conversion of Evaporated Zinc Selenide for Application to MIS Devices' which is being submitted by Ms. Sarita Ahuja 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 her under our guidance and supervision.

In our 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 full, to any other University or Institute for the award of any degree or diploma.





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ABSTRACT

This dissertation deals with the fabrication and characterization of piezoelectric zinc oxide thin films, using a simple evaporation technique, for the realization of strain transducers having MIS structures. The chief aspects studied were (a) the growth of zinc oxide and its physical characterization (b) an optimization of the films growth parameters to obtain device quality films using the C-V technique, (c) the conduction mechanism through the zinc oxide film in an MIS test structure (capacitor) and (d) the realization of the strain transducers.

The growth technique adopted was that of the conversion of evaporated zinc selenide films to zinc oxide by oxidation. The technique not having been reported in detail before, the process parameters were varied and standardized to obtain high purity, polycrystalline ZnO films having a preferential orientation of the c-axis perpendicular to the silicon substrate. These physical properties were determined using some standard physical characterization techniques. Lithium doping, a technique by which resistivity of ZnO films is enhanced was also tried for our grown films. This did increase the low field d.c resistivity from 10^9 ohm-cm to 10^{11}-10^{12} ohm-cm but produced instabilities in the electrical characteristics of

the MIS capacitor thus fabricated.

Oxidation and inert-ambient annealing parameters were standardised to obtain C-V characteristics which were free of hysteresis, had low threshold voltages and sharp depletion region characteristics. This was done keeping in view the performance of the MIS capacitor as a strain transducer. A tentative model was proposed to explain the oxidation mechanism. In particular, hysteresis was attributed to electron injection from the silicon into zinc oxide due to excess zinc ions near the ZnO/Si interface in films not completely oxidised. Annealing in nitrogen at 600°C for one hour before the oxidation was found to give the sharpest depletion region characteristics resulting in a low threshold voltage as well. This was also explained on the basis of the model proposed for oxidation.

Current-voltage characteristics were studied in detail for the MIS capacitor structure, in particular for the aluminium-ZnO-n-Si device for both kinds of bias polarities on the gate. Models for both biases were proposed. Schottky emmission of electrons from the aluminium gate into zinc oxide seemed to be the governing conduction mechanism when the gate was biased negatively. From the characteristics a Schottky barrier of about 0.6 eV was calculated. When the gate was biased positively space-charge-limited-currents flowed through

the structure. A trap level at about 0.44 eV below the conduction band was located having a trap density of about $10^{17}/cm^3$. Saturation effects attributed to velocity saturation at high fields were also observed in this case. Large currents observed in this bias polarity were attributed to surface inhomogenities at the ZnO/Si interface.

Finally, the MIS capacitor and a MIS field effect transistor were fabricated and demonstrated as strain transducers. A simple set up was designed to apply strains of suitable magnitudes to the MIS capacitor and transistor. Shifts in the C-V characteristics of the capacitor on strain application were recorded. A linear relation between the shifts in the flat-band voltage with strain was established. A sensitivity factor was plotted to show the region on the C-V plot most sensitive to strain. A rough estimate was made of the coupling coefficient for the ZnO films and found to be considerable lower (about an order) than the single crystal value. Crudeness of the measurement technique and limitations of the film fabrication technique were suggested as the reasons for this difference. The I_D-V_{DS} characteristics of the MIS-FET showed shifts proportional to the strain applied in both the linear and saturation regions as expected. The

piezoelectric nature of the ZnO films was established by verifying the dependance of some of the strain sensitive parameters. Gauge-factor for the transistor was calculated to be $\sim 1.1 \times 10^5$ from the experimental data observed.

NOMENCLATURE

a	constant, $q\varphi / kT$
A	area of metal electrode (cm^2)
A^*	Richardson Dushman constant (120 $amp/cm^2/^oK$)
b	constant, $q^{3/2}/\varepsilon_i^{1/2}\ kT$ ($(cm\ volt^{-1})^{1/2}$)
B	half-width of the reflection line (radians)
c	constant, A^*T^2 ($amp \times {}^oK/cm^2$)
C	measured capacitance (farads)
C_i	accumulation or insulator capacitance (farads)
C_d	depletion capacitance (farads)
C_1	constant ($ohm^{-1}\ cm^{-1}$)
C_{min}	minimum or the inversion capacitance (farads)
$C_{d_{min}}$	depletion capacitance for maximum depletion width (farads)
C_{ij}	Stiffness elastic constant for a constant electric field ($Newton/cm^2$)
d	thickness of the film (cm)
d_1	centroid of trapped charge from the metal electrode (cm).
d_x	scale factor
d_{ij}	piezoelectric stress coefficients (Coulombs/Newtons)

D	grain diameter (Å)
D	displacement vector (Coulomb/cm^2)
D_n	normal component of the displacement vector (Coulomb/cm^2)
e	piezoelectric strain coefficient (Coulomb/cm^2)
E	electric field (Volt/cm)
E_c	conduction band-edge (eV)
E_f	fermi level (eV)
E_g	band-gap (eV)
E_i	component of the electric field (Volt/cm)
E_t	trap level (eV)
E_v	valence band edge (eV)
$E_{s(o)}$	field at the Si-Zno interface at time t = 0 Secs. (Volt/cm)
$E_{s(t)}$	field at the Si-Zno interface at time t Secs (Volt/cm)
f	resonance frequency (Sec^{-1})
g	degeneracy factor
g_m	channel transconductance (mhos)
g_{ds}	drain to source transconductance (mhos)
G.F.	gauge factor
h	Planck's constant (6.62×10^{-34} J Sec)
(hkl)	Miller's indices
I	current (amps)

I_D	quiescent drain current of the MISFET transistor (amps)
I_o	constant (amps)
I_x	peak amplitude at the peak for element x.
$I_{D,sat}$	Saturation drain current (amps)
ΔI_D	$(I_{D,strained} - I_{D,quiescent})$, (amps)
J	current density (amps/cm^2)
J_1	initial current density (amps/cm^2)
J(t)	current density crossing the interface at time t (amps/cm^2)
k	Boltzmann's constant(8.62x10^{-5} eV/deg.K)
k	Imaginary part of the refractive index
k^2	electromechanical or the piezoelectric coupling coefficient
K	constant of magnitude near unity
K	constant (cm/sec)
K_1	constant (ohm^{-1})
K_2	constant
K_3	constant (Sec^{-1})
K_4	constant
K_5	constant (amp/cm^2)
l	distance from point of application of stress to point of strain sensing (cm)

L wavelength of the X-ray (Å)

m constant $(0 < m < 1)$

m constant $(1 < m' < 2)$

n real part of the refractive index

n free electron concentration (cm^{-3})

n constant (greater than 1)

$[n]$ unit normal

n_t trapped electron concentration (cm^{-3})

N_c effective density of states (cm^{-3})

N_D silicon substrate doping (cm^{-3})

N_T concentration of traps at E_t (cm^{-3})

$P_{t,o}$ concentration of traps not occupied by electrons in equilibrium (cm^{-3})

P Polarization density $(coul/cm^2)$

q electronic charge (Coulombs)

Q_{ss} interface state charge $(coul/cm^2)$

$Q'(t)$ total charge per unit area crossing the interface at time t $(coul/cm^2)$

r % age intensity of the reflected beam

S elastic strain matrix

S_j components of the strain matrix

S_x relative sensitivity

S_{1A} sensitivity of the parameter A

t % age intensity of the transmitted beam

t	time (secs)
T	Temperature (^{o}K)
T	Stress (Newton/cm^2)
V, V_G	gate voltage (Volts)
V_i	voltage drop across the insulator (Volts)
V_p	piezoelectric polarization voltage (Volts)
V_T	threshold voltage (Volts)
V_1	voltage where $C/C_i = 0.9$ (Volts)
V_2	voltage where $C/C_i = 0.1$ (Volts)
V_{DS}	drain to source voltage (Volts)
V_{FB}	flat-band voltage (Volts)
V_{GS}	gate to source voltage (Volts)
V_{Si}	voltage drop across the silicon (Volts)
V_{TO}	threshold voltage of an unstrained capacitor (Volts)
V_{TS}	threshold voltage of a strained capacitor (Volts)
V_{FBO}	flatband voltage of an unstrained capacitor (Volts)
V_{FBS}	flatband voltage of a strained capacitor (Volts)
V_{TFL}	traps-filled-limit voltage (Volts)
V_{SiO_2}	voltage drop across SiO_2 (Volts)
V_{FB}	$(V_{FBS}-V_{FBO})$ (Volts)
X_d	depletion width (cm)
$x_{d_{max}}$	maximum depletion width (cm)

y	deflection of cantilever (cm)
W/L	width to length ratio of the channel of the MISFET transistor
α	absorption coefficient(cm^{-1})
Δ	$(V_1 - V_2)$, (Volts)
λ	Wave length (cm)
ε_i	dielectric constant of insulator (farad/cm)
ε_{Si}	dielectric constant of Si (farad/cm)
φ	barrier height (eV)
φ_s	surface potential in silicon (eV)
φ_B	bulk potential in silicon (eV)
φ_{MS}	metal to semiconductor work function (eV)
Θ	n/n_t, ratio of free to trapped electron concentration
θ	half-angle between the incident and reflected beam (radians)
μ	mobility (cm^2 $Volt^{-1}$ sec^{-1})
ν	frequency (Sec^{-1})

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