IONIZING RADIATION EFFECT OF GAMMA RAY AND NEUTRON FLUX ON n-ZnO/p-$CuGaO_2$ HETEROJUNCTION DIODE FOR FLEXIBLE SPACE ELECTRONICS APPLICATION

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I hereby declare that the material in this thesis is my own except for quotations, excerpts, equations and summaries, which have been acknowledged.

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ABSTRACT

Space electronics based on invisible circuitry requires both transparent n-type and p-type oxide-based semiconductor materials as active channel layers to make circuit design more flexible. However, in space, semiconductor devices are vulnerable to various effect of high energy level of radiation causing single event upsets (SEU), damaging or altering the lattice structure. In this work, n-ZnO/p-$CuGaO_2$ was selected due to its relatively wide bandgap and a visibility transmittance up to 75%, has wide bandgap of II-VI semiconductor group (~3.3-3.4 eV), a high electron mobility, easily fabricated under low temperature, an efficient photon emission and high conductivity. P-$CuGaO_2$ and n-ZnO thin films were deposited by using radio frequency (RF) powered sputtering method on indium tin Oxide (ITO) with a base pressure of $9x10^{-3}$ Torr, at 300 ^{0}C deposition temperature, an Argon gas flow of 10 sccm, a radio frequency power of 100 Watt and deposition time of 30 minutes. Once the deposition of the active and confining layer has been fabricated, a silver (Ag) paste was applied as the contacting layer. Structural morphology, optical and electrical properties of both n-ZnO/p-$CuGaO_2$ thin film and heterojunction diode were investigated before and after irradiation. Fabricated samples were then irradiated at SINAGAMA and NUR II facility. The samples were irradiated using Cobalt-60, gamma-ray with a dose ranging from 10 kGy to 200 kGy and separately a neutron flux of $2x10^{14}$ n/cm^2, 9.5 $x10^{14}$ n/cm^2 and $6.5x10^{15}$ n/cm^2. The structural properties reveal that p-$CuGaO_2$ and n-ZnO films, shows the degradation of grain size after irradiation and has a lower diffraction peak with an increase in the Full width half maximum (FWHM). The optical properties of deposited p-$CuGaO_2$ thin film and n-ZnO, exhibits approximately 75% and 80% respectively in the invisible region at pre-irradiation and post-irradiation due to gamma shows a decrease of optical transmittance up to 55% and 70% at 200 kGy. A decrease in band gap was also tabulated from the transmittance and shows a decrease from 3.85 eV to 3.62 eV for $CuGaO_2$ and 3.50 eV to 3.28 eV for ZnO after exposure towards gamma irradiation. However, exposure towards neutron flux of $6.5x10^{15}$ n/cm^2 only shows small significant changes with transmittance increasing to 85% and 80% for p-$CuGaO_2$ and n-ZnO, with a band gap of 3.84 eV and 3.50 eV.

As the samples were irradiated with gamma ray, the high energy particle loses its energy in small steps through the interaction with electrons in the materials causing nuclear Collison. This will then in turn create defects in the material such as the formation of color centers (*Farbe center*) that absorbs the signal photons which results to the degradation of the light transmission efficiency of the thin film. On the I-V properties, the decrease in the turn-on voltage of the diode varies with increasing radiation dose for both gamma and neutron flux exposure. The maximum, turn-on-voltage of the prepared diode was shown to be 1.5 V. Exposure towards gamma, shows that the turn-on-voltage has a higher turn-on-voltage of 4.7 V at 200 kGy. However, the effect of neutron flux at $6.5x10^{15}$ n/cm^2 shows a small significant difference of 1.7 V. Results shows moderate mitigation towards irradiation, indicating that n-ZnO/p-$CuGaO_2$ thin film is capable of withstanding harsh radiation environment while still retaining its semiconductor as the changes in band gap ranges between 3 eV to 4 eV after post-irradiation

ABSTRAK

KESAN SINARAN PENGIONAN SINAR GAMMA DAN FLUKS NEUTRON TERHADAP DIOD SIMPANG HETERO n-ZnO/p-$CuGaO_2$ UNTUK APLIKASI ELEKTRONIK FLEKSIBEL DI ANGKASA LEPAS

Teknologi elektronik di angkasa lepas berasaskan litar lutsinar memerlukan kedua-dua semikonduktor logam oksida jenis n dan p sebagai lapisan saluran aktif untuk membentuk litar elektronik yang fleksibel. Namun begitu, di angkasa lepas, diod semikonduktor terdedah dengan pelbagai kesan tenaga radiasi bertenaga tinggi yang menyebabkan "single event upsets" *(SEU), kemerosotan atau kecacatan kekisi. Dalam kajian ini, n-ZnO/p-$CuGaO_2$ telah dipilih kerana sampel ini mempunyai jurang tenaga optik yang luas, kehantaran sifat optik yang tinggi iaitu sebanyak 75%, kumpulan jurang tenaga yang luas dalam semikonduktor II-VI (~3.3-3.4 eV), mobiliti elektron yang tinggi, suhu fabrikasi yang rendah, pancaran foton yang cekap dan konduksi yang tinggi. Filem nipis p-$CuGaO_2$ dan n-ZnO telah difabrikasikan menggunakan teknik pemercikan Magnetron Frekuensi Radio di atas substrat indium tin oxide (ITO) dengan tekanan $9x10^{-3}$ Torr pada suhu 300 °C berserta aliran gas Argon pada kadar 10 sccm, tenaga RF 100 Watt dan pemendapan selama 30 minit. Setelah pemendapan disiapkan, adunan konduktif perak disalut sebagai saluran aktif diod. Struktur morfologi, sifat optik dan sifat elektrik diod simpang-hetero dan filem nipis n-ZnO/p-$CuGaO_2$ dikaji sebelum dan selepas didedahkan kepada sinaran. Sampel telah didedahkan kepada sinaran di SINAGAMA dan NUR II untuk proses radiasi. Pendedahan ini melingkungi sinaran Cobalt-60, serakan gamma dengan dos 10 kGy hingga 200 kGy dan serakan neutron dengan fluks sebanyak $2x10^{14}$ n/cm^2, 9.5 $x10^{14}$ n/cm^2 and $6.5x10^{15}$ n/cm^2. Struktur mofologi yang dikaji menunjukkan bahawa sampel mengalami kemerosotan pada saiz butir selepas pengionan dan serakan oleh sinar gamma dan mempunyai puncak belauan yang rendah dalam lebar lengkap separa maksimum (FWHM). Sifat optik filem nipis p-$CuGaO_2$ dan n-ZnO masing-masing mempunyai ketelusan sebanyak 75% dan 80% sebelum disininari dan serakan radiasi menunjukkan penurunan dalam kepancaran optik sebanyak 55% dan 70% pada 200 kGy. Data juga menunjukkan penurunan pada jurang tenaga optik dari 3.85 eV ke 3.62 eV bagi $CuGaO_2$ dan 3.50 eV hingga ke 3.28 eV untuk ZnO selepas serakan*

gamma. Walau bagaimanapun, serakan neutron dengan fluks 6.5x10^{15} n/cm^{2} hanya menunjukkan perubahan yang kecil dengan penurunan kepancaran sifat optik sebanyak 72% dan 75% untuk p-$CuGaO_2$ dan n-ZnO dengan jurang lebar 3.84 eV dan 3.50 eV. Penurunan dalam kepancaran sifat optik adalah disebabkan pembentukan "Farbe center" pada filem nipis yang telah disinari oleh gamma. Untuk sifat kelektrikan, penurunan dalam voltan putaran diod adalah dihubungkan dengan dos radiasi untuk serakan gamma dan neutron. Voltan putaran maksima untuk diod yang disediakan adalah sebanyak 1.5 V. Serakan gamma terhadap diod menunjukkan peningkatan dalam voltan putaran. Tetapi, serakan neutron dengan fluks 6.5x10^{15} n/cm^{2} menunjukkan perubahan kecil sebanyak 1.7 V sahaja. Keputusan menunjukkan mitgasi yang sederhana terhadap serakan radiasi, bahawa n-ZnO/p-$CuGaO_2$ mampu menangani keadaan radiasi yang tinggi dan mengekalkan sifat semikonduktor dengan rangkaian jurang tenaga optik, 3 eV hingga ke 4 eV selepas serakan radiasi.

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LIST OF ABBREVIATIONS

AC	-	alternating current
ALICE	-	A large Hadron Collider Experiment
ATLAS	-	A Toroidal LHC Apparatus
BJT	-	Bipolar Junction Transistor
CERN	-	European Organization for Nuclear Research
CME	-	Coronal Mass Ejections
CMS	-	Compact Muon Solenoid
$CuGaO_2$	-	Cupper Gallium Oxide
DC	-	Direct Current
Fet	-	Field Effect Transistor
FWHM	-	Full Width Half Maximum
GCR	-	Galactic Cosmic Rays
GeV	-	Gigaelectron Volt
HOMO	-	Highest occupied molecular orbital
IMF	-	Intraplanetry Magnetic Field
I-V	-	Current -Voltage
IZO	-	Indium Zinc Oxide
KeV	-	Kiloelectron Volt
Km/hr	-	Kilometer per Hour
LHC	-	Large Hadron Collider
MIS	-	metal-insulator -semiconductor

MOCVD	-	Metal organic chemical vapor deposition
NASA	-	National Aeronautics and Space Administrations
PLD	-	Pulse Laser Deposition
Rad	-	Radiation Absorbed Dose
SAA	-	South Atlantic Anomaly
SEE	-	Single Event Effects
SEU	-	Single event Upsets
Si	-	Silicon
Si:H	-	Hydrogenated Silicon
SPE	-	Solar particle events
SRIM	-	Stopping range of ion matter
TFT	-	Thin film transistor
TNT	-	Trinitrotoluene
TOTEM	-	Total Cross Section, Elastic Scattering and diffraction Dissociation
TRIM	-	Transport range of ion matter
UV-Vis	-	Ultraviolet Visible spectroscopy
XRD	-	X-Ray Diffraction

LIST OF SYMBOLS

%	-	Percent
°	-	Degree
℃	-	Celsius
A	-	Ampere
Å	-	Angstrom
C	-	Capacitance
d	-	Average Grain Size
e	-	Electron with electronic charge of 1.6×10^{-19} C
E_d	-	Average surface binding Energy
E_b	-	Average surface binding Energy before collision
E_f	-	Final Energy
FF	-	Fill Factor
E_i	-	Initial Energy
eV	-	electron volt
Fm	-	Femtometre
γ	-	Gamma
I_o	-	Initial Beam
I	-	Intensity of Emitted Radiation
J_{sc}	-	Current density
K	-	Kelvin
M	-	Mega

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