DESIGN AND CHARACTERIZATION OF SELF-SWITCHING DIODE AND PLANAR BARRIER DIODE AS HIGH-FREQUENCY RECTIFIERS

by

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LIST OF ABBREVIATIONS

1D	One-dimensional
2 DEG	Two-dimension electron gas
3D	Three-dimensional
AC	Alternating Current
Al_2O_3	Aluminium Oxide
AlGaN	Aluminium Gallium Nitride
AlGaSb	Aluminium Gallium Antimony
AUG	Auger recombination model
BJT	Bipolar Junction Transistor
BUD	Bulk Unipolar Diode
CONSRH	Concentration dependent lifetimes SRH
DC	Direct Current
EHF	Extremely High Frequency
EMF	Electromagnetic Field
ERCs	Explosives and Related Compounds
ETRAP	Specifies the trap energy of SRH recombination
FET	Field-effect Transistor
FLDMOB	Parallel electric field dependent
GaAs	Gallium Arsenide
GD	Geometric Diode
GaN	Gallium Nitride
GNRs	Graphene Nanoribbons
GPS	Global Positioning System
HBT	Heterojunction Bipolar Transistor
HF	High-Frequency
InAlAs	Indium Aluminium Arsenide
InAs	Indium Arsenide
InGaAS	Indium Gallium Arsenide
InP	Indium Phosphide
IR	Infrared
ITRS	International Technology Roadmap for Semiconductor
I-V	Current-Voltage
LAN	Local Area Network

LED	Light Emitting Diode
MC	Morte Carlo
MISFET	Metal Insulator Semiconductor Field Effect Transistor
MOS	Metal Oxide Semiconductor
MPU	Microprocessor Unit
PBD	Planar Barrier Diode
PDA	Personal Digital Assistant
PDBD	Planar-doped Barrier Diode
RF	Radio Frequency
RFID	RF Identification
SHF	Super High Frequency
Si	Silicon
SiC	Silicon Carbide
SiGe	Silicon Germanium
SiO_2	Silicon Dioxide
SLG	Single Layer Graphene
SRH	Shockley-Read-Hall
SSD	Self-switching Diode
TAUN0	Specifies SRH lifetime for electron
TAUP0	Specifies SRH lifetime for hole
TB	Triangular shape
TCAD	Technology Computer Aided Design
TSS	Tangential Signal Sensitivity
UHF	Ultra High Frequency
VHF	Very High Frequency
WiFi	Wireless Fidelity
ZnO	Zinc Oxide

LIST OF SYMBOLS

Δi	Identical to the first bracket term on the right-hand side
ψ	Electrostatic potential
θ	Angle
γ	Curvature coeficient
$Ø_{BL}$	Potential barrier height for the carrier to move from left
$Ø_{BR}$	potential barrier height for the carrier to move from right
A^*	Effective Richardson constant for electron
Å	Amstrong
C	Capacitance
C_{jo}	Junction capacitance at zero bias
C_p	Parasitic capacitance
$\mathcal{E}_0$	Permittivity of free space
$\mathcal{E}_g$	Bandgap
$\mathcal{E}_r$	Dielectric permittivity
E	Electric field
eV	Electron volt
f	Frequency
f_{max}	Frequency maximum
f_t	Cuttoff frequency
$f^{(N)}$	N^{th} order derivative of $f(V)$
GHz	Gigahertz
H	Potential energy inside the channel
Hz	Hertz
I_s	Total current density
J	Reverse saturation current
K	Kelvin
k	Boltzman constant
kHz	KiloHertz
L	Channel length
MHz	Megahertz
MUN	Electron mobilities
N	Carrier density
nm	Nanometer

ρ	Local space charge density
q	Magnitude of electrical charge of an electron
$\mathrm{R_D}$	Differential resistance
$\mathrm{R_s}$	Series resistance
t	Timeline
μ	Electron mobility
μ_{no}	Low field electron mobility
τ_n	Electron lifetime
τ_p	Hole lifetime
T	Terahertz
$\mathrm{T_L}$	Lattice tempertaure
THz	Absolute temperature
µm	Micrometer
µA	Micro ampere
V	Voltage across the diode
$\mathrm{V_{bias}}$	Applied bias voltage
$\mathrm{V_D}$	Applied voltage
$\mathrm{V_o}$	Applied DC bias
$\mathrm{V_{sat}}$	Electron saturation velocity
$\mathrm{V_{TH}}$	Threshold voltage
v_{RF}	Frequency signal voltage
ω	Angular frequency
W	Channel width
$\mathrm{W_t}$	Trench width
$\mathrm{W_V}$	SOI thickness
$\mathrm{X_C}$	Capacitive reactance

REKABENTUK DAN PENCIRIAN STRUKTUR DIOD PENSUISAN-SENDIRI DAN DIOD SAWAR SATAH SEBAGAI PENERUS BERKELAJUAN TINGGI

ABSTRAK

Pembangunan peranti penerus berkelajuan tinggi telah menjadi salah satu bidang penyelidikan utama yang boleh digunakan dalam banyak aplikasi, termasuk frekuensi radio (RF) dan sistem pengesanan. Contoh-contoh peranti ini ialah diod Schottky dan diod sawar terdop-satah. Walau bagaimanapun, semua peranti yang sangat cemerlang ini memerlukan proses fabrikasi yang sangat mencabar disebabkan oleh struktur-strukturnya yang kompleks dan kepekatan pengedopan yang tepat untuk setiap lapisan kritikal yang mana kosnya adalah agak tinggi. Prospek menggunakan peranti-peranti elektronik dengan struktur satah telah menjadi semakin mempunyai harapan. Peranti-peranti planar ini memberi kelebihan tambahan bukan hanya mudah malah boleh juga beroperasi pada frekuensi tinggi. Oleh demikian, dalam kerja penyelidikan ini, kemungkinan penggunaan dua buah peranti nano satah berasaskan diod pensuisan-sendiri (SSD) dan diod sawar satah (PBD) untuk gelombang mikro dan penerusan terahertz telah ditunjukkan menggunakan penyelakuan. SSD telah ditunjukkan sebagai penerus suhu bilik yang beroperasi pada frekuensi terahertz. Dalam kerja penyelidikan ini, prestasi penerus SSD dinilai menggunakan parameter yang dikenali sebagai pekali kelengkungan, yang diperolehi daripada ciri-ciri arus-voltan *(I-V)* peranti tersebut. Kesan mengubah struktur geometri dan dielektrik penebat nisbah kebertelusan (dari 1 - 9.3) sesuatu SSD keatas pekali kelengkungan peranti tersebut dikaji dan dianalisa dengan menggunakan alat penyelakuan dua dimensi. Penyelakuan juga dilakukan di bawah julat suhu 250 - 500 K. Hasilnya menunjukkan bahawa frekuensi potong tertinggi yang dicapai dalam kerja penyelidikan ini adalah menghampiri 19 GHz, beroperasi pada keadaan yang tidak terpincang. Dengan melaksanakan penyelakuan serupa yang digunakan dalam menunjukkan SSD berasaskan silikon, satu diod-nano satah ekakutub baharu sebagai satu penerus telah diperkenalkan dan dibangunan dalam kerja penyelidikan ini. Peranti baru ini dirujuk sebagai PBD yang mempunyai satu saluran geometri bentuk corong yang membolehkan arus mengalir merentasi peranti. Pada pincang sifar, kawasan susutan yang tidak seragam, telah terjadi pada bahagian leher saluran bentuk corong disebabkan oleh cas permukaan pada antara muka semikonduktor/ penebat, diramalkan untuk mencipta sawar tenaga di sepanjang saluran dengan profil yang tidak simetri. Voltan luaran yang digunakan merentasi satu PBD dijangka akan menghasilkan ketinggian yang berbeza sawar tenaga bergantung sama ada voltan yang diberikan adalah positif atau negatif. Hasilnya, ciri-ciri *I-V* tak lelurus direalisasikan yang mana boleh digunakan dalam penerusan isyarat. Prinsip operasi PBD ini telah ditunjukkan dan disahkan dalam penyelakuan kerja penyelidikan ini. Ia juga telah diterangkan dengan menggunakan teori pemancaran ion haba yang boleh mengawal aliran arus merentas peranti. Serupa dengan SSD, prestasi penerusan PBD telah dicirikan dan dinilai berdasarkan pekali kelengkungan dan frekuensi potong peranti tersebut. Dengan mengubah rekabentuk geometri dan nisbah dielektrik penebat kebertelusan (dari 1-9.3) PBD, pekali kelengkungan peranti boleh dioptimumkan untuk meningkatkan prestasi penerus. Frekuensi potong tertinggi yang diperolehi dalam

penyelakuan kerja penyelidikan ini adalah menghampiri 0.8 THz. Kedua-dua peranti SSD dan PBD ini mempunyai senibina sawar yang seterusnya boleh direalisasikan dengan satu langkah litografi yang akan menjadikan keseluruhan proses fabrikasi peranti lebih mudah, lebih cepat dan lebih murah jika dibandingkan dengan peranti elektronik konvensional yang lain.

DESIGN AND CHARACTERIZATION OF SELF-SWITCHING DIODE AND PLANAR BARRIER DIODE AS HIGH-FREQUENCY RECTIFIERS

ABSTRACT

The development of high-speed rectifying devices has become one of major research areas which can be utilized in many applications, including radio-frequency (RF) and detection systems. Examples of these devices are Schottky diode and planar-doped barrier diode. However, all these excellent devices require a very challenging in fabrication process due to their complex structures and a precise doping concentration for each critical layers which are relatively high cost. The prospects of using electronic devices with planar structure are therefore become increasingly promising. These planar devices provide additional advantages of being not only simple but also able to operate at high frequencies. As such, in this research work, the feasibility of utilizing two silicon-based planar nanodevices of self-switching diode (SSD) and planar barrier diode (PBD) for microwave and terahertz rectification has been demonstrated using simulations. SSD has recently been demonstrated as room-temperature rectifiers operating at terahertz frequencies. In this research work, the rectifying performance of SSD is evaluated using a parameter known as the curvature coefficient, derived from the current-voltage *(I-V)* characteristic of the device. The effects of varying the geometrical structure and the insulator dielectric relative permittivity (from 1 – 9.3) of SSD on the curvature coefficient of the device are studied and analyzed by means of a two-dimensional device simulator. The simulations are also performed under temperature range of 250 – 500 K. The results show that the highest cut-off frequency attained in this research work is approximately 19 GHz, operating at unbiased condition. By implementing similar simulation settings used in demonstrating silicon-based SSDs, a new unipolar planar nanodiode as a rectifier is introduced and developed in this research work. This new device is referred as PBD which has a funnel-shaped geometrical channel that allows current to flow across the device. At zero bias, the nonuniform depletion region, developed at the neck of the funnel-shape channel due to surface charges at semiconductor/insulator interface, is predicted to create an energy barrier along the channel with asymmetrical profile. An external voltage applied across a PBD is expected to produce different height of the energy barrier depending either the voltage given is positive or negative. As a result, a nonlinear *I-V* characteristic is realized which can be utilized in signal rectification. This operating principle of PBD has been demonstrated and validated in the simulations of this research work. It has also been described using thermionic emission theory which may govern the flow of current across the device. Similar to SSD, the rectification performance of PBD is characterized and evaluated based on the curvature coefficient and cut-off frequency of the device. By varying the geometrical design and insulator dielectric relative permittivity (from 1-9.3) of PBD, curvature coefficient of the device can be optimized in order to improve the rectification performance. The highest cut-off frequency obtained in the simulation of this work is approximately 0.8 THz. Both SSD and PBD have a planar architecture that can therefore be realized in a single lithography step which makes the whole fabrication process of the devices simpler, faster and at lower cost when compared with other conventional electronic devices.