UNIVERSITI PUTRA MALAYSIA

CARRIER TRANSPORT AND I-V CHARACTERIZATION OF SI, AN/SI AND AG/SI SILICIDES USING PHOTOACOUSTIC AND FOUR POINT PROBE TECHNIQUES

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By

YAP SIEW HONG

Thesis Submitted to the School of Graduated Studies, Universiti Putra Malaysia, in fulfilment of Requirement for the Degree of Master Science

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DECICATION

To my beloved parents Yap Yong Kim and Ng Yoon Kiow

For their endless love and concern……

To my beloved Goh Bee Kui

For his romantic love, support, understanding and care……

To my supervisor Prof. Dr. Wan Mahmood Mat Yunus

For his guidance, advice, understanding and endless support……

To my co-supervisors Prof. Dr. Mohd. Maarof Moksin

and Assoc. Prof. Dr. Zainal Abidin Talib

For their kindly advice and indispensable support……

To my friends and seniors (too many)

For their wonderful encouragement and support……

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Chairman : Professor W. Mahmood Mat Yunus, PhD

Faculty : Science

The Au/Si and Ag/Si systems have been studied extensively due to the importance of carrier transport and I-V characterization of metal silicide compounds in microelectronic applications. In this study, the metal thin film was deposited on the polished Si substrate and annealed in air environment. Open photoacoustic cell and four point probe techniques were applied for carrier transport and I-V characterization respectively of Si substrate, Au/Si, Ag/Si interface system at room temperature. X-ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) analysis were used to confirm the silicide formation and sample surface microstructure respectively.

The thermal diffusivity and diffusion coefficient of Si substrate were found independent of the surface condition. The surface recombination velocity values for the polished surface were in the range of 392.3 cm/s to 458.0 cm/s and the band to band recombination lifetime for polished surface ranged from 11.57 μs to 17.28 μs.

For the annealed Au(150 nm)/n-Si sample, gold silicide clusters were agglomerated out to the sample surface while gold clusters were shrunk. The silicide clusters have

caused the surface and bulk recombination process to dominate. $Au_{8.1}Si_{1.9}$ and Au_7Si (622) silicides were formed on Au/p-Si sample after annealing at temperatures of 363 °C and 800 °C respectively. The surface recombination velocity increased from 408.0 cm/s to 596.8 cm/s as the annealing temperature increased. The surface and bulk recombination process increased with the formation of Au_7Si silicide, which indicates that Au_7Si (622) silicide was present as n-conducting that in contact with the p-Si substrate to form p-n junction characterization (Schottky curve) at the annealing temperature of 800 °C.

In this investigation, we found a new approach for the Ag miscible with Si to form the silver silicide compounds for the Ag/p-Si system. In the approach, the suitable type of the Si substrate, deposited thin film thickness, annealing temperature and time were the main factors for the chemical reaction within Ag and Si. We also found a transition from 2-D to 3-D growth (Stranski-Krastanov mode) of silver and silver silicide clusters. For Ag/p-Si system, the thermal diffusivity was in the range of 0.800 cm^2/s to 0.850 cm^2/s. The increased surface and bulk recombination process was due to the formation of silver silicide on the sample surface. The I-V characteristic illustrated an ideal diode junction and Schottky curve for annealed Ag(100 nm)/p-Si and annealed Ag(150 nm)/p-Si respectively. We suggested that Ag_3Si silicide became n-conducting on the p-type Si which responsible in forming Schottky diode junction. The surface recombination velocity and band to band recombination lifetime of annealed Ag(150 nm)/n-Si sample was 428.7 cm/s and 8.86 μs respectively. Both annealed Ag/n-Si samples exhibited linear I-V relation in the range of -40 mV to 90 mV.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

CIRI-CIRI PEMBAWA AND I-V BAGI Si, SILICIDE Au/Si DAN Ag/Si DENGAN MENGGUNAKAN TEKNIK FOTOAKUSTIK DAN PENDUGA EMPAT TITIK

Oleh

YAP SIEW HONG

JUN 2005

Pengerusi : Profesor W. Mahmood bin Mat Yunus, PhD

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Sistem Au/Si dan Ag/Si telah banyak dikaji disebabkan kepentingan pencirian angkutan pembawa dan I-V bagi kompoun silicide logam dalam appikasi mikroelectronik. Dalam kajian ini, filem nipis logam telah dimendapkan di atas permukaan gilap substrat Si dan disepuh lindap dalam keadaan berudara. Teknik sel fotoakustik terbuka dan penduga empat titik telah diaplikasikan dalam pencirian angkutan pembawa dan I-V bagi substrat Si, sistem antara muka Au/Si dan Ag/Si dalam suhu bilik. Belauan Sinar–X (XRD) dan Mikroskop Pengimabasan Elektron (SEM) masing-masing digunakan untuk memastikan pembentukan silicide dan mikrostruktur permukaan sampel.

Resapan terma dan kecekapan resapan bagi substrat Si didapati tidak bergantung pada keadaan permukaannya. Nilai halaju pergabungan semula permukaan bagi permukaan gilap adalah dalam lingkungan 392.3 cm/s ke 458.0 cm/s dan masa hayat pergabungan semula jalur ke jalur melingkungi 11.57 μs ke 17.28 μs. Untuk sampel Au(150 nm)/n-Si tersepuh lindap, kelompok silicide emas telah aglomerasi keluar ke atas permukaan sampel manakala kelompok emas telah mengecut. Kelompok

silicide telah menyebabkan proses halaju pergabungan semula permukaan dan pukal menjadi dominan. Silicide $Au_{8.1}Si_{1.9}$ and Au_7Si (622) terbentuk di atas sampel Au/p-Si yang telah disepuh lindap pada kedua-dua suhu 363 °C and 800 °C. Halaju pergabungan semula permukaan telah bertambah dari 408.0 cm/s ke 596.8 cm/s akibat penningkatan suhu sepuh lindap. Proses pergabungan semula permukaan dan pukal meningkat dengan pembentukan Au_7Si silicide di mana ia menunjukan bahawa Au_7Si (622) silicide muncul sebagai pengkonduksian –n yang sentuh pada substrat p-Si untuk membentuk pencirian simpang p-n (lengkung Schottky) pada suhu sepuh lindap 800 °C.

Dalam kajian ini, kami telah menjumpai satu penemuan baru iaitu Ag boleh bercampur dengan Si untuk membentuk kompoun silicide perak bagi sistem Ag/p-Si. Dalam penemuan baru ini, kesesuaian jenis substrat Si, ketebalan filem tipis mendapan, suhu dan masa tersepuh lindap adalah faktor-faktor utama bagi tindak balas kimia antara Ag dengan Si. Kami juga mendapati satu peralihan pertumbuhan dari 2-D ke 3-D (mod Stranski-Krastanov) bagi kelompok perak dan silicide perak. Bagi sistem Ag/p-Si, resapan termanya adalah sekitar 0.800 cm^2/s ke 0.850 cm^2/s. Peningkatan proses pergabungan semula permukaan dan pukal akibat pembetukan silicide perak di atas permukaan sampel. Pencirian I-V menjadi simpang diod ideal dan lengkung Schottky bagi Ag(100 nm)/p-Si tersepuh lindap and Ag(150 nm)/p-Si tersepuh lindap masing-masing. Kami mencadangkan bahawa silicide Ag_3Si silicide menjadi pengkonduksian –n atas Si jenis –p di mana ia bertanggungjawab untuk membentuk simpang diod Schottky. Halaju pergabungan semula permukaan dan masa hayat pergabungan semula jalur ke jalur bagi sampel Ag(150 nm)/n-Si tersepuh lindap masing-masing ialah 428.7 cm/s and 8.86 μs. Kedua-dua sampel Ag/n-Si tersepuh lindap menunjukkan hubungan linear dalam lingkungan -40 mV to 90 mV.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

2-D	Two Dimensional
3-D	Three Dimensional
AFM	Atomic Force Microscopy
Ag	Silver
Ag/Si	Silver Silicon
Ar^+	Argon ion
ARPES	Angle Resolved Spectroscopy
As deposited Au(45 nm)/p-Si	45 nm Thickness of Gold Thin Film Deposited on p-type Si Substrate without Annealing Process
Au	Gold
Au/Si	Gold Silicon
B-GaSe	Gallium Arsenate doped with Boron
Br-Si	Bromine Silicon
d.c.	Direct Current
EDX	Energy Dispersion X-ray
EHP	Electron-hole pair
Eq.	Equation
Eqs.	Equations
EPMA	Electron Probe Microanalyser
He-Ne	Helium Neon
FM	Frank-Van der Merve
FTIR	Fourier Transformation Infra-red Spectroscopy
I-V	Current Voltage
InSb	Indium Antimony

non-UHV	Non Ultra High Voltage
n-Si	n-type Silicon Substrate
O_2	Gas Oxygen
OPC	Open Photoacoustic Cell
PA	Photoacoustic
PbTe	Lead Telluride
p-Si	p-type Silicon Substrate
R-G	Rosencwaig and Gersho
SEM	Scanning Electron Microscopy
Si-B	Silicon Boron Bonding
Si-Si	Silicon Silicon Bonding
Si/SiO_2	Silicon Substrate deposited with Silicon Dioxide layer at the roughened surface
SK	Stranski-Krastanov
UHV	Ultra High Voltage
ULSI	Ultra Large-Scale Integration
VLSI	Very Large-Scale Integration
VW	Volmer-Weber
XRD	X-ray Diffraction Analysis

LIST OF SYMBOLS

2θ	Scanning angle (two teta)
a_s	Thermal diffusion coefficient of the sample
a_g	Thermal diffusion coefficient in the gas
α_g	Thermal diffusivity in the gas
α_n	Thermal diffusivity of layer n
α_s	Thermal diffusivity of the sample
β	Optical absorption coefficient of the solid sample (in cm^{-1}) for the wavelength λ
c_n	Specific heat capacity of layer n
D	Carrier diffusion coefficient
D'	Excess carrier
d	Sample diameter
D_c	Diameter of photoacoustic cell
∂n	Excess electron concentration
∂p	Excess hole concentration
∂P	Pressure fluctuation in the gas region
∂V	Incremental volume
E	Photon energy
E_c	Energy of bottom of conduction band in semiconductor
E_g	Bandgap energy
E_f	Energy of top valance band in semiconductor
f	Modulation frequency
ϕ	Phase

ϕ_o	Initial phase angle
γ	Ratio of the specific heats
γ'	Carrier diffusion coefficient
$'G_n$	Generation rate of excess electrons
$'G_p$	Generation rate of excess holes
H	Heat density produced at any point x, owing to light absorbed in this point in the solid
h	Planck constant
hv	Incident photons
I	Current
I_o	Incident monochromatic light flux (W/cm^2)
I	Intensity
λ	Wavelength
L_c	Length of photoacoustic cell
l_b	The thickness of thermal conductor back surface
l_β	Optical length
l_g	Length of gas column/gas chamber
l_s	Sample thickness
κ_n	Thermal conductivity of layer **n**
κ_s	Thermal conductivity of the sample
μ_s	Thermal diffusion length
η	Efficiency at which the absorbed light at wavelength λ is converted to heat by the non-radiative deexcitation process
n	Layer of medium. **n** can take the subscripts of *s* for solid, *g* for gas and *b* for backing material