FABRICATION OF SILICON NANOWIRES USING SCANNING ELECRON MICROSCOPE BASED ELECTRON BEAM LITHOGRAPHY METHOD

MOHAMMAD NUZAIHAN BIN MD NOR

UNIVERSITI MALAYSIA PERLIS

MALAYSIA

2007

Fabrication of Silicon Nanowires Using Scanning Electron Microscope Based Electron Beam Lithography Method

By

MOHAMMAD NUZAIHAN BIN MD NOR

0430110011

A thesis submitted

In fulfillment of the requirements for the degree of

Master of Science (Microelectronic Engineering)

School of Microelectronic Engineering

UNIVERSITI MALAYSIA PERLIS

MALAYSIA

2007

GRADUATE SCHOOL

UNIVERSITI MALAYSIA PERLIS

PERMISSION TO USE

In presenting this thesis in fulfillment of a post graduate degree from Universiti Malaysia Perlis, I agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by my supervisor or, in their absence, by Dean of the Graduate School. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to Universiti Malaysia Perlis for any scholarly use which may be made of any material from my thesis.

Requests for permission to copy or make other use of material in whole or in part of this thesis to be addressed to:

Dean of Graduate School

Universiti Malaysia Perlis

Jalan Bukit Lagi

01000 Kangar

Perlis Indera Kayangan

Malaysia

APPROVAL AND DECLARATION SHEET

This thesis titled Fabrication of Silicon Nanowires Using Scanning Electron Microscope Based Electron Beam Lithography Method was prepared and submitted by Mohammad Nuzaihan Bin Md Nor (Matrix Number: 0430110011) and has been found satisfactory in terms of scope, quality and presentation as partial fulfillment of the requirement for the award of degree of Master of Science (Microelectronic Engineering) in Universiti Malaysia Perlis (UniMAP).

Check and Approved by

.....

(Associate Professor Dr Uda Bin Hashim)
School of Microelectronic Engineering
Universiti Malaysia Perlis

(Date :.....)

School of Microelectronic Engineering
Universiti Malaysia Perlis

2007

DEDICATION

Al- Fatihah to my mum, Allahyarhammah Jamiah Binti Hashim, may Allah S.W.T bless you. Special dedication to my dad, Md Nor Bin Awang and my siblings, thanks for all the support and understanding. May Allah S.W.T bless all of us, Amin.

Thank you!

ACKNOWLEDGEMENT

First of all my deepest thanks and humble supplication are due to Almighty Allah (SWT), the Omnipotent, the Merciful, the Compassionate, always help, support and strengthened me during my lifetime. I beg Him to continue His blessings on me forever. Alhamdulillah, finally I have fulfilled my thesis in this year, 2007. The journey towards the completion of this thesis was full of unexpected challenges and it is almost impossible to complete this thesis single-handedly, without the help and support of others. I would like to give my heartfelt thanks to everyone who has provided me with such support.

I would like to acknowledge and express the greatest gratitude to my supervisor Assoc. Prof. Dr. Uda Hashim, not only for giving me the opportunity to work in his group but also for his encouragement, supervision and guiding me throughout this whole research work. His invaluable knowledge and suggestion had develop and grown up my experience and my skills in this nanotechnology. It has been great experience in the IRPA Single Electron Transistor (SET) Group. I wish to express my gratitude for the benefits that I have gained from conversations with the other member in this group.

Many colleagues have worked closely with me on this research work. First, I would like to thank Miss S Niza for helping me to start at the lab. I am lucky to have Miss Nurhamidah, Miss Amiza and Miss Nik Hazura in pursuing the functional SEM, EBL system, AFM and Modu Lab Equipments. I do appreciate the constant help from lab technicians who always understand and their great help during the process of completing this research work. I also want to thank Mr Mohd Hafiz, Mr Mohd Sukri and Miss Suraya for helping me a lot to improve the written English.

A special thank to all staff members of the School of Microelectronic Engineering, Universiti Malaysia Perlis such as Mrs. Hasnizah, Miss Sanna, Mrs. Aznira, Mr. Khairuddin, Miss Nurjuliana and Mr. Razaidi for their technical advice and contributions either directly or indirectly. I'm also very grateful to Universiti Malaysia Perlis and the IRPA Single - Electron Transistor (SET) for their financial support throughout my postgraduate study. These special thanks also go to Miss Sharifah Husna and Miss Norzaililah for their support in managing the postgraduate and scholarship program.

Last but no least, I would like to thank my father, sisters and brothers for their love, confidence and support throughout my study. Not to forgot my housemate Mr. Amir who has always given encouragement and advise during my thesis preparation. To my friends whose names are not included here, may ALLAH bless you all.

Thanks to Almighty ALLAH.

MOHAMMAD NUZAIHAN BIN MD NOR
UNIVERSITI MALAYSIA PERLIS
m.nuzaihan@unimap.edu.my

FABRIKASI "*SILICON NANOWIRES*" MENGGUNAKAN KAEDAH MIKROSKOP IMBASAN ELEKTRON BERDASARKAN LITHOGRAFI ALUR ELEKTRON

ABSTRAK

'*Nanowires*' merupakan kelas baru dalam bahan yang telah menarik perhatian dan menjadi tumpuan penyelidikan sejak akhir-akhir ini kerana penggunaannya berpotensi di dalam nanoteknologi seperti kejuruteraan *'nanoelectronic'*, *'nanomechanical'*, *'biomedical'*. Fabrikasi *'Nanowires'* merupakan sesuatu yang sangat mencabar pada hari ini. Kaedah konvesional lithografi tidak mampu lagi untuk menghasilkan *'Nanowires'* dan walaupun dengan menggunakan lithografi nano yang maju adalah bukan mudah untuk mencapai ukuran yang kurang daripada 100 nm. Tujuan kerja penyelidikan ini adalah untuk membentuk dan menghasilkan *'Nanowires'* terkecil menggunakan kaedah fabrikasi nano *'Top-Down'* yang melibatkan Mikroskop Imbasan Elektron berdasarkan Lithografi Alur Elektron. Kaedah fabrikasi nano *'Top-Down'* berdasarkan Lithografi Alur Elektron dimulakan dengan menghasilkan Rekaan Corak *'Nanowires'* (NPD). Rekaan Corak *'Nanowires'* direka menggunakan perisian yang dipanggil *'RAITH ELPHY Quantum GDSII Editor'*. Pakej perisian ini menawarkan semua ciri-ciri yang diperlukan untuk menghasilkan struktur mikro dan nano bermula dengan reka struktur, proses selanjutnya dan kerja-kerja modifikasi. Rekaan Corak *'Nanowires'* ini direka dalam pelbagai skala daripada 100 nm dikecilkan sehingga 20 nm. Seterusnya, pembangunan proses aliran fabrikasi nano yang mengandungi parameter-parameter yang terperinci dan resepi-resepi telah dibangunkan untuk pembentukkan *'Nanowires'*. Dua (2) jenis topeng kerintangan dan tiga (3) jenis *'Nanowires'* yang terlibat dalam pembangunan proses aliran ini. Topeng kerintangan terdiri daripada Topeng Kerintangan PMMA dan Topeng Kerintangan Siri ma- N2400. Ianya digunakan sebagai bahan topeng atau topeng punaran semasa proses memunarkan lapisan oxida. Fabrikasi *'Nanowires'* merupakan fokus utama dalam kerja penyelidikan ini yang terdiri daripada *'SiO_2'*, *'Si'*, *'a-Si Nanowires'*. *'SiO_2 Nanowires'* berfungsi sebagai penebat dan topeng keras untuk punaran silica dalam usaha membentuk *'Si Nanowires'*. *'Si Nanowires'* dan *'a-Si Nanowires'* adalah sangat meluas digunakan sebagai '*Nanowires*' semikonduktor dan mempunyai nilai potensi dalam peranti *'nanoelectronic'*. Dalam usaha menghasilkan '*Nanowires*' terkecil ini, dimensi, profil pembentukkan, profil punaran dan pengecilan saiz melalui pengoksidaan secara pemanasan telah diselidik. Akhir sekali, penggabungan kaedah fabrikasi nano *'Top-Down'* dengan pengecilan saiz telah menghasilkan kejayaan pengecilan 'Si Nanowires' daripada 100 nm hinggalah menghampiri 20 nm.

FABRICATION OF SILICON NANOWIRES USING SCANNING ELECTRON MICROSCOPE BASED ELECTRON BEAM LITHOGRAPHY METHOD

ABSTRACT

Nanowires is a new class of materials that have attracted attention and great research interest in the last few years because of their potential applications in nanotechnology such as nanoelectronic, nanomechanical and biomedical engineering. Fabrication of Nanowires is one of the great challenges today. Conventional lithography methods are not capable to produce Nanowires and even with advance nanolithography sizes below 100 nm may not easily be achieved. The goal of this research work is to form and produce very small nanowires using a Top-Down Nanofabrication Method which involved Scanning Electron Microscope (SEM) based Electron Beam Lithography (EBL) method. Initially, the Top-Down Nanofabrication Method based on EBL was the design of the Nanowires Pattern Design (NPD). The NPD has been done by software called RAITH ELPHY Quantum GDSII Editor. The software package provides all the features needed to produce micro and nano scale structures starting from a structure design, post processing and design modification. The NPD is designed in various nanowires scale size from 100 nm down to 20 nm. Next, the nanofabrication process flow development which consists of the detailed parameters and recipes are developed for nanowires formation. Two (2) types of resist masks and three (3) types of nanowires are involved in the process flow development. The Resist Masks consist of PMMA Resist Mask and ma-N 2400 Series Resist Mask. It is used as a mask material or etches mask during Silicon Dioxide etching process. Fabrication of Nanowires is the main focus in this research work which consists of SiO_2, Si, a-Si Nanowires. SiO_2 Nanowires is used as insulation and hard mask for silicon etching in order to form Si Nanowires. Si Nanowires and a-Si Nanowires are widely used as semiconducting nanowires and has great potential in nanoelectronic devices. In order to produce very small nanowires, the dimensions, developments, etch profiles of nanowires and size-reduction by thermal oxidation was investigated. Finally, the combination on Top-Down Nanofabrication Method and size-reduction has resulted in successful reduction of Si Nanowires reduced from 100 nm to approximately 20 nm.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

GLOSSARY OF ABBREVIATION

SET	=	Single Electron Transistor
EBL	=	Electron Beam Lithography
AFM	=	Atomic Force Microscopy
SPM	=	Scanning Probe Microscopy
SEM	=	Scanning Electron Microscopy
STM	=	Scanning Tunneling Microscopy
CD	=	Critical Dimension
IC	=	Integrated Circuit
PMMA	=	Polymethyl Methacrylate
SiO_2	=	Silicon Dioxide
Si	=	Silicon
a-Si	=	Amorphous Silicon
VLS	=	Vapor-Liquid-Solid
OAG	=	Oxide Assisted Growth
GaN	=	Gallium Nitride
ZnO	=	Zinc Oxide
TEM	=	Transmission Electron Microscopy
FET	=	Field-Effect Transistor
CMOS	=	Complementary Metal Oxide Semiconductor
DNA	=	Deoxyribonucleic Acid
ICP-RIE	=	Inductively Coupled Plasma- Reactive Ion Etching
HPM	=	High Power Microscopy
SC	=	Standard Cleaning
BOE	=	Buffered Oxide Etch
WCM	=	Wet Cleaning Module
OFM	=	Oxidation Furnace Module
PECVD	=	Plasma Enhanced Chemical Vapor Deposition

PAC	=	photoactive Compound
MV	=	Molecular Weight
CAD	=	Computer Aided Design
GUI	=	Graphic User Interface
NPD	=	Nanowires Pattern Design
WA	=	Working Area
SPL	=	Single Pixel Line
MIBK	=	Methyl IsoBethyl Ketone
IPA	=	Isopropanol
DI	=	Deionized
DF	=	Darkfield
BF	=	Brightfield

LIST OF APPENDIXS

LIST OF PUBLICATIONS

1. **Mohammad Nuzaihan Md Nor**, S Niza Mohammad Bajuri, Uda Hashim. Pattern Design for Nanowire Formation Using Raith Elphy Quantum GDSII Editor. Proceeding of Annual Fundamental Science Seminar 2005, AFSS 2005. P. 110-116. ISBN 983-43098-0-5.

2. **Mohammad Nuzaihan Md Nor**, S Niza Mohammad Bajuri, Nur Hamidah Abdul Halim, Uda Hashim. Positive Pattern Scheme and Negative Pattern Scheme For Nanowire Formation Using Scanning Electron Microscope Based Electron Beam Lithography Technique, Journal Solid State Science & Technology Letters. Volume 12, RCSST 2005. P. 62. ISSN 0128-8393.

3. **Mohammad Nuzaihan Md Nor**, U.Hashim, N.H.A. Halim, S.N. M. Bajuri. Nanowire formation for Single Electron Transistor using SEM Based Electron Beam Lithography (EBL) Technique: Positive Tone Vs Negative Tone E-beam Resist, Technical Proceeding of NSTI Nanotech 2006, HCC Boston USA, NSTI 2006. P. 266-269. ISBN 0-9767985-8-1 Vol.3.

4. **Mohammad Nuzaihan Md Nor**, U.Hashim, N.H.A. Halim. Nanowires. Extended abstract of One-Day Seminar on Nanotechnology, Nanomig 2006, USM. P 67-70.

5. **Mohammad Nuzaihan Md Nor**, Nur Hamidah Abdul Halim, Uda Hashim, Hasnizah Aris, Sanna Taking, Zaliman Sauli , KC Phang "KUKUM Nano Fabrication Cleanroom: Efforts Towards Nanotechnology", Seminar Penyelidikan Kejuruteraan KUKUM 2006.

6. **Mohammad Nuzaihan Md Nor**, U.Hashim, Armiza Rasmi, N.H.A. Halim. Nanowire Formation Using SEM Based Electron Beam Lithography (EBL) Technique: Developments Profile of Negative Tone E-Beam Resist. The Second International Conference on Solid State Science and Technology 2006, ICSSST 2006 KUSTEM. P 282-284. ISSN 0128-839.

7. **Mohammad Nuzaihan Md Nor**, Uda Hashim, Nur Nazihah Halemi, Nur Hamidah Abdul Halim. Nanostructure Formation Using Scanning Electron Microscope (SEM) Based E-Beam Lithography (EBL) Technique: Wet Etch Profile. 15th Scientific Conference of Electron Microscopy Society of Malaysia, EMSM 2006 KUSTEM, P 43-44.

8. **Mohammad Nuzaihan Md Nor**, Uda Hashim, Nur Hamidah Abdul Halim. Top Down Approach: Fabrication of Si Nanowires Using Scanning Electron Microscope (SEM) Based E-Beam Lithography (EBL) Technique and Inductively Coupled Plasma-Reactive Ion Etching. Submitted and accepted for International Conference on Advancement of Materials and Nanotechnology 2007, ICAMN 2007 SIRIM & UITM.

9. S Niza Mohammad Bajuri, Nur Hamidah Abdul Halim, **Mohammad Nuzaihan Md Nor** and Uda Hashim. PMMA Characterization and Optimization for Nano Structure Formation. Proceeding of 1st national Conference on Electronic design (NCED) 2005. P 81-83. ISBN 983-42724-0-5

10. Armiza Rasmi, **Mohammad Nuzaihan Md Nor**, Uda Hashim. SOI Single Electron Transistors (SET) Set Design and Process Development. 1st National Conference on Electronic Design 2005, NCED2005, P 85-90. ISBN 983-42724-0-5.

11. S Niza Mohammad Bajuri, Nur Hamidah Abdul Halim, **Mohammad Nuzaihan Md Nor** and Uda Hashim. 495K & 950K PMMA Thickness Characterizations and Optimization. Proceeding of Annual Fundamental Science Seminar 2005, AFSS 2005. P.140-144. ISBN 983-43098-0-5.