MASK DESIGN, FABRICATION AND TEST NMOS TRANSISTOR

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PERPUSTAKAAN TUNKU TUN AMINAH

For My Mother Iswati Binti Khamis,

My Father Sahdan Bin Saikon,

And My Fiancé Azrini Binti Idris

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ABSTRACT

Dalam proses fabrikasi MOSFET, satu set topeng digunakan bagi tujuan menutup atau membuka sesuatu kawasan pada *silicon wafer*. Set topeng yang digunakan dalam fabrikasi piawai adalah sangat tinggi kosnya dan tidak praktikal untuk tujuan pendidikan. Satu set topeng yang ekonomik adalah penyelesaiannya dengan menggunakan filem *transparency* yang mempunyai panjang saluran daripada 250um hingga maksimum 20um telah dihasilkan. Sebanyak 4 empat topeng telah direkabentuk dalam perisian AutoCAD 2002 *drawing tools* dan telah dicetak ke atas filem *transparency*. Kaedah *contact printing* digunakan untuk memindahkan bentangan topeng ke atas *silicon wafer* 4 inci menggunakan teknik *standard photolithography* untuk memastikan keseragaman lapisan. Proses fabrikasi MOSFET dilakukan selepas kesemua parameter dioptimumkan.Selepas MOSFET selesai dihasilkan, *probe station* dan MOSFET *characterization analyzer software* digunakan untuk menganalisa ciri-ciri MOSFET. Set topeng yang digunakan dalam projek ini adalah praktikal untuk tujuan pendidikan dan MOSFET yang dihasilkan juga berfungsi seperti yang dikehendaki.

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ABSTRACT

In MOSFET fabrication, mask set was used to define certain region on a silicon wafer. The mask sets that used in standard fabrication are very expensive and not practical for education purposes. An economical solution of masks using transparency films with various channel length from 250um to 20 um was produced. Four mask set of MOSFET were designed using AutoCAD 2002 drawing tools and then printed on the transparency film. Contact printing method was utilized to transfer the mask layouts on a 4-inch silicon wafer using standard photolithography technique to check the line uniformity. The MOSFET fabrication process was done after optimizing the parameters. Probe station and MOSFET characterization analyzer software was used to characterize the fabricated MOSFET. The mask used in this project was practical for education purpose and the MOSFET was successfully fabricated.

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PERPUSTAKAAN TUNKU TUN AMINAH

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF FIGURES	x
	LIST OF TABLES	xii
	GLOSSARY OF ABBREVIATIONS	xiii
	LIST OF APPENDIX	xv
CHAPTER I	INTRODUCTION	1
	1.1 Background	1
	1.2 Problem Statement	3
	1.3 Project Objectives	3
	1.4 Scope of Work	4

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER II **LITERATURE REVIEW** **5**

2.1 Background 5
2.2 The Geometric Parameter of NMOS 5
2.3 The gate capacitance 7
2.4 Transistor parameter 7
2.5 Current-Voltage relationship 8
2.6 MOSFET Mask 10
2.7 MOSFET Fabrication Process 11
2.7.1 Deionized (DI) water 11
2.7.2 Oxidation 12
2.7.3 Photolithography 16
2.7.4 Etching 17
2.7.5 Diffusion 20
2.7.6 Physical Vapor Deposition (PVD) 24
2.7.7 Characterization 27

CHAPTER III **METHODOLOGY** **29**

3.1 Background 29
3.2 Computer Aided Design (CAD) tool 31
3.3 Experimentation 34
3.3.1 Oxidation Process 34
3.3.2 Photolithography 34
3.3.3 Diffusion 35
3.3.4 Etching 35
3.3.5 Metallization 36
3.4 Testing MOSFET 36

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER IV	**EQUIPMENT AND CONSUMABLE**		**37**
	4.1	Background	37
	4.2	KUKUM Microfabrication Cleanroom	37
	4.3	Process Equipment	39
	4.4	Consumable	45
CHAPTER V	**RESULTS AND DISCUSSION**		**46**
	5.1	Background	46
	5.2	Mask Design and Fabrication	46
	5.3	Fabrication Process	49
	5.4	MOSFET Testing	52
CHAPTER VI	**CONCLUSION AND RECOMMENDATIONS**		**55**
	5.1	Conclusion	55
	5.2	Recommendations	56
	REFERENCES		57
	APPENDIX A		59
	APPENDIX B		60
	APPENDIX C		61

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF FIGURE

FIGURE NO.	TITLE	PAGE
1.1	Common symbol of NMOS transistor	2
2.1	Basic geometric parameter of NMOS transistor	6
2.2	Alignment mark design	10
2.3	NMOS Transistor characteristic	28
3.1	Flow chart of project implementation	30
3.2	Planar and cross section of various steps creating NMOS transistor	32
4.1	A view at Microfabrication Cleanroom, KUKUM	36
4.2	The Oxidation Furnace	39
4.3	The Diffusion Furnace	40
4.4	The Physical Vapor Deposition (PVD) furnace	41
4.5	The Ambios XP1	41
4.6	The Spinner	42
4.7	The Hot Plate	42
4.8	The Mask Aligner Module	43
4.9	The Filmetrics	43
4.10	The 4 Point Probe	44
5.1	Mask drawing steps in AutoCAD 2002	47
5.2	Mask sets on transparency films	48
5.3	Photoresist patterning using standard chemical and lithography process	50
5.4	Process development after etching	51
5.5	Process development after striping	52

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

5.6	Characteristic of NMOS transistor using Probe Station	53
5.7	The Transfer Characteristic of NMOS transistor	53
5.8	Output Parameter of NMOS transistor	54

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF TABLE

TABLE NO.	TITLE	PAGE
2.1	The DC relationship of NMOS transistor	9
2.2	Linear and parabolic growth rate pre-exponentials and activation energies	14
3.1	Steps in designing mask sets using AutoCAD 2002	33
4.1	Consumable used in NMOS Fabrication	45

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

GLOSSARY OF ABBREVIATIONS

V_{GS}	-	Voltage gate to source (V)
V_{DS}	-	Voltage drain to source (V)
V_{TH}	-	Threshold Voltage (V)
i_D	-	Drain current (mA)
IV	-	Current (mV) versus Voltage (V)
C_{ox}	-	oxide capacitance (F)
Si	-	Silicon
IC	-	Integrated Circuit
CVD	-	Chemical Vapor Deposition
R_s	-	Sheet Resistance (Ohm)
t_{ox}	-	Oxide thickness (um)

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PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF APPENDIX

APPENDIX	TITLE	PAGE
A	Paper Published in PERFIK Conference	59
B	Poster Published in PERFIK Conference	69
C	Process Flow of Fabrication Process	70

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PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER I

INTRODUCTION

1.1 Background

The microelectronic history start in December 1947 when three scientists Bardeen, Walter Brattain and William Shockley from Bell Laboratory of United State, invented the first semiconductor device, called transistor [1]. It was the component that gave birth to the solid state electronic era with all its famous progeny. Since that year, the semiconductor industry has seen the continuous development of new and improved processes.

The improvement of the process has in turn led to the more highly-integrated and reliable circuits that have fuelled the continuing electronics revolution [2]. This improvement falls into two broad categories; process and structure. Process improvements are those that allow the fabrication of the device and circuits in smaller dimension, higher density, quantity and reliability. The structure improvements are the

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invention of new device designs allowing greater circuit performance, power control and reliability.

In the process development, semiconductor is the materials that are used to fabricate ICs. Semiconductors are useful in electronics because their electronic properties can be greatly altered in a controllable way by adding small amounts of impurities. These impurities, called dopants, add extra electrons or holes. A semiconductor with extra electrons is called an n-type semiconductor, while a semiconductor with extra holes is called a p-type semiconductor.

In IC fabrications, there are two type of semiconductor used, which are Silicon (Si) and Gallium (GaAs). The two main classes of transistor types are bi–polar and uni-polar. Bi-polar devices are normally used in high speed semiconductor and low noise application. The main type of uni-polar is MOSFET (Metal Oxide Semiconductor Field Effect Transistor).

MOSFET device is a digital device and it can either be n-channel (NMOS transistor) or p-channel (PMOS transistor). This project will study the NMOS transistor only and will not be considering the PMOS transistor. Figure 1 below will show the common symbol for NMOS transistor.

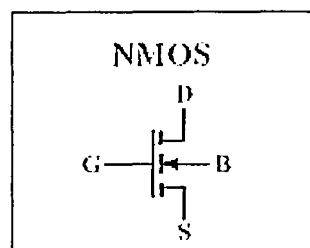

Figure 1.1: Common symbol of NMOS transistor

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1.2 Problem Statement

In IC fabrication, mask sets are needed to transfer the designed pattern onto a wafer. The mask set produced by company in the market is very expensive and not practical for education purpose. In fabrication process, the most important thing is to get the correct recipe to fabricate transistor. This correct recipe will determine the performance of NMOS transistor that will give the best characteristic. This project was done experimentally to design a low cost mask set and to fabricate NMOS transistor using optimized parameters that would give the best characteristic.

1.3 Project Objective

There were four main objectives to be achieved in this project. The objectives are as follows;

i. To design a low cost mask set using transparency films.
ii. Optimize and characterize the process parameters and process flow of the transistor.
iii. Fabricate NMOS transistor using spin-on dopant technique.
iv. Test NMOS transistor to get the characteristics of the device.

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1.4 Scopes

This project will be done by limiting the scopes into five. These scopes of the project are as follows;

i. To establish process module, process parameter, process flow and process run card.
ii. To design and produce a set of mask for MOSFET fabrication process.
iii. To optimize and characterize process module.
iv. To integrate the process module and start fabricates process of NMOS transistor.
v. To analyze and test the product.

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CHAPTER II

LITERATURE REVIEW

2.1 Background

Before doing this project, the first thing that was done was studying the characteristic of NMOS transistor. This chapter will explain the important part that must be known before implementing this project.

2.2 The Geometric Parameter of NMOS

A 3-D structure in Figure 2.1 below illustrate the component of NMOS transistor source (S), drain (D) and gate (G). The gate of the NMOS transistor is usually made of polysilicon, which is formed from polycrystalline silicon and relatively good conductance. The gate is insulated by the layer of the silicon dioxide, SiO_2, from a

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conducting channel existing between two diffusion areas which form the drain and the source of the transistor.

Diffusion areas (source and drain) are created inside a substrate (also known in some technological context as the well) of the opposite type, e.g. n+ diffusion inside the p substrate, where 'n+' indicates silicon highly doped with donors.

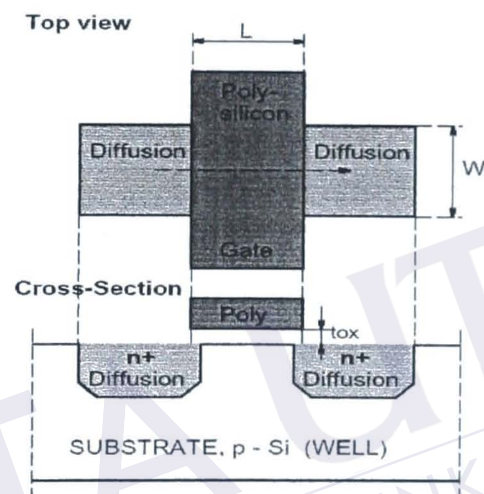

Figure 2.1: Basic geometric parameter of NMOS transistor

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From the top and cross-sectional views of the MOS transistor presented in Figure 2.1 we found that three basic geometrical parameters of the transistor are the following;

i. L and W – the length and width of the conducting channel between the source and drain.
ii. t_{ox} — thickness of the oxide layer between the gate and the diffusion/substrate areas.

2.3 The gate capacitance

The gate-oxide-channel structure forms a **capacitor**. The gate-oxide capacitance per unit area can be approximately calculated as:

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} \tag{2.1}$$

Where t_{ox}= 0.351 pF/cm is the permittivity (a dielectric constant) of SiO_2. Note that the capacitance is inversely proportional to the thickness of the silicon dioxide layer.

2.4 Transistor parameter

In this section we will discuss the relationship between constant (DC) voltages at the transistor terminals and the resulting drain current I_D. Apart from the voltages, the I_D current is also a function of;

i. The process parameters: the threshold voltages and a process transconductance, k_c defined as follows;

$$k_c = \mu_c . C_{ox} \tag{2.2}$$

Where μ_c is the effective mobility of the carrier and C_{ox} is the gate capacitance per unit area.

ii. The width, W, and length, L, of the channel between the source and the drain (Figure 2.1).

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The parameter which links the process transconductance, k_c, with the transistor dimension is called the (non-linear) transistor transconductance parameter, g_c, and is defined by:

$$g_c = \frac{\mu_c . C_{ox}}{2} \frac{W}{L} \tag{2.3}$$

The gate voltage relative to the threshold voltage is defined as;

$$V_\Delta = V_G - V_T \tag{2.4}$$

The parameters K_c, g_c, μ_c can be referred to k_n, g_n, μ_n due to NMOS transistor.

2.5 Current-Voltage relationship

With the above parameters, the relationships between the DC I_D current and relevant voltages can be summarized as in Table 2.1.

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Table 2.1: The DC relationship of NMOS transistor

nMOS
Cut-off region: $V_{GS} < V_{Tn}$ $I_D = 0$
Linear region: $V_{GS} \geq V_{Tn}, V_{DS} < V_{\Delta_n}$ $I_D = g_c \cdot (2V_\Delta - V_{DS})V_{DS}$
Saturation region: $V_{GS} \geq V_{Tn}, V_{DS} \geq V_{\Delta_n}$ $I_D = g_c \cdot V_\Delta^2$

The drain current I_D is proportional to the ratio W/L of the transistor channel size. For given process parameters and voltages;

i. The wider the transistor channel, W, the larger ID current and,
ii. The longer the transistor channel, L, the smaller ID current.

The saturation occurs when

$$V_{DS} = V_{GS} - V_T$$

At the saturation point the current expressions for the linear and saturation regions are identical and can be derived by:

$$I_{sat} = g_c(2V_\Delta V_\Delta - V_\Delta^2) = g_c V_\Delta^2 \quad (2.5)$$

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2.6 MOSFET Mask

Based on Christopher T. Timmons [3], MOSFET mask design is based on four level mask steps. The mask design started with designing an alignment mark in the first mask level that was used as a reference for later levels. The mark was isolated for better alignment. Alignment was accomplished using alternating solid and outlined crosses as shown in Figure 2.2. The cross in the centre is used to align X and Y position while the outer cross is used for rotational alignment.

The alignment mark shown in Figure 2.2(a) is the design for the first mask. The dark field would leave cross island on the wafer after lithography process. This island would act as an indicator for the following masks in the alignment process. Figure 2.2(b) shows the mark design for mask 2, mask 3 and mask 4. The cross was light field, while the outer of the cross was made dark. The purpose was to make the alignment process easier by aligning the cross island through the window.

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Figure 2.2: Alignment mark design. (a) Alignment mark for mask 1; (b) alignment mark for mask 2, mask 3 and mask 4.

2.7 MOSFET Fabrication Process

There are many steps in MOSFET fabrication process. Information about fabrication process involved are clarified in this section.

2.7.1 Deionized (DI) water

Deionized (DI) water is water that has no ions and it is one of the wet cleaning technologies and is a centrifugal spray cleaning technique. This process can reduce the volume of fresh chemical and is faster than immersion. The spin-drying process requires anti-static protection to prevent static-induced particle deposition on the wafers. There are two loops for DI water installation;

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i. The make-up loop
   It is the process of removing particles and colloids, total organic carbons, microorganisms, ionic impurities and total dissolved solids from raw water. In other words, it has pretreatment section for removal of gross particles of sizes larger than 1 um and purifier section for removal ionic impurities, bacteria and dissolved gases.

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