

# GERMANIUM OXIDATION



## Theoretical and Experimental Analysis



S i t i   K u d n i e   S a h a r i

# **GERMANIUM OXIDATION**

**Theoretical and Experimental Analysis**

**Siti Kudnie Sahari**

**Universiti Malaysia Sarawak  
Kota Samarahan**

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# Contents

|                        |     |
|------------------------|-----|
| <b>Preface</b>         | vii |
| <b>Acknowledgement</b> | ix  |
| <b>Introduction</b>    | 1   |

## Chapter 1 **Native Oxidation on Ge Surface**

|                                                                                                     |    |
|-----------------------------------------------------------------------------------------------------|----|
| Introduction                                                                                        | 11 |
| Native Oxidation in Clean Room Air with<br>Different Chemical Treatments                            | 12 |
| Effect of Conduction Type and Crystallization<br>Orientation Dependence of Native Oxidation<br>Rate | 16 |
| The Growth of Native Oxidation in Dry<br>Oxygen Ambience                                            | 21 |
| Summary                                                                                             | 21 |

## Chapter 2 **Metal and Semiconductor Oxidation**

|                             |    |
|-----------------------------|----|
| Introduction                | 25 |
| Theory of Oxide Film Growth | 26 |
| Theory of Si Oxidation      | 32 |
| Overview of Ge Oxidation    | 48 |
| Summary                     | 56 |

# Preface

Scaling down of the planar bulk silicon (Si) metal-oxide-semiconductor (MOS) field effect transistors (FETs) has been confronted its fundamental limit associated with performance, on current, power consumption, and short-channel effects which have the trade-off relationship with each other. Therefore, device structures and materials with high carrier mobility are needed for further continues enhancement in device performance. Recently, germanium (Ge) channel has attracted much of the attention for the development of MOSFETs due to the higher carriers' mobility than Si. However, the precise control of the Ge surface and oxide/Ge interface is the most critical issues for the development of Ge-channel MOSFETs. The quality at the interface between the Ge channel and gate dielectric degrades with increasing native oxide thickness. Understanding the native oxidation is required to provide a good passivation on Ge surfaces.  $\text{GeO}_2$  can be useful; however, the basic understanding of Ge thermal oxidation is needed.

Because of the rapid progress of Germanium fabrication, the first edition of Germanium oxidation clearly needed as a revision. From the native oxidation to the thermal oxidation, the reader is presented with all the series of experiment results. In addition, many broader topics such as overview of Germanium oxidation since 1950s are presented. The chapter's introduction provides a general discussion of the topics and subsequent section presents the detail of native and thermal oxidation of Germanium.

The book is intended as revision for the postgraduates and engineers in oxidation process of Germanium; it assumes that the reader has already acquired an introductory understanding the physics and technology of semiconductor devices.

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# Introduction

## Limitation of Silicon

Silicon (Si) is a chemical element in periodic table that has atomic number 14. The Si-based Metal of Semiconductor Field Effect Transistor (MOSFET) was first invented by Mohamed Atalla and Dawon Kahng in 1959 [1-2]. Since the first invention of the Si-based Metal of Semiconductor Field Effect Transistor (MOSFET), there has been a tremendous evolution in semiconductor industry. An astounding progress has been made in Si technology over 40 years by shrinking down the size of transistor to accommodate the large number of transistor per chip in accordance with Moore's Law proposed in the 1970s [3-4]. According to Moore's law, the number of transistors is double in one or two years as shown in figure 1.1. Figure 1.2 shows the scaling trend of MOSFETs [5]. From figure 1.2, the feature size of MOSFET becomes smaller and smaller to accommodate the increment of the transistors count in Central Processor Unit (brain of the computers). The reduction of the dimension of transistor leads to the higher performance device reliability and cost reduction of MOSFETs.

# Chapter 1

## Native Oxidation on Ge Surface

### Introduction

Because Ge has higher mobility carriers than Si, it has recently, been considered as a promising channel material to replace Si for higher performance CMOS technology [1]. It is well known that the primary difference between Si and Ge is their surface chemistries and that the Hydrogen-terminated Si surface is fairly stable against native oxidation. Therefore, understanding the mechanism and controlling native oxidation on the Ge surface is of great importance in obtaining a good quality at the interface between the channel and the gate dielectric [2-3]. In addition, the passivation and surface cleaning of Ge is still a matter of research. Several different chemical passivation methods for Ge have previously been explored, including Ammonium hydroxide ( $\text{NH}_4\text{OH}$ ) [4-5], Ammonium sulfide ( $\text{NH}_4)_2\text{S}$  [6-7], Hydrobromic (HBr) [8], Hydrochloric HCl [9], and Hydrofluoric (HF) [10-11]. In terms of Si wafers, hydrogen passivation after HF cleaning makes the surface stable against oxidation in the air [12-14]. In contrast, hydrogen passivation on Ge after HF cleaning leads to faster oxidation [10-11] and no oxygen free surface can be obtained, presumably due to the lower thermal and chemical stability of Ge hydrides compared to Si hydrides [15]. It is also well known that the oxidation of Si (100) and (111) surfaces proceeds in a layer-by-layer fashion, creating a very flat  $\text{SiO}_2/\text{Si}$  interface that is compositionally abrupt in an atomic scale. The origin of



the layer-by-layer oxidation is often thought to relate to a structural strain at the  $\text{SiO}_2/\text{Si}$  interface [16-17]. Despite much less strain at the  $\text{GeO}_2/\text{Ge}$  (100) interface than the  $\text{SiO}_2/\text{Si}$  interface, it was recently reported that the native oxidation on an HF-last Ge (100) surface is likely to occur in a layer-by-layer fashion after exposure to clean room air [10].

In this chapter, the growth of native oxidation is discussed in order to provide a foundation for the understanding of oxidation mechanism and interface properties of Germanium. Section 1.2 examines the growth of native oxide on Ge after different cleaning. It also describes the effects of crystallographic orientation and conduction type dependence on the growth rate of native oxidation.

## **Native Oxidation in Clean Room Air with Different Chemical Treatments**

Experiments have indicated that the different chemical cleaning on Ge surface influenced the kinetics of native oxide. Sahari and co-workers investigated the oxidation kinetics between the samples treated with diluted 30% HCl and 50% HF solution and found that the native oxidation of the HF- last Ge surface is likely to proceed slowly (except in very early stages) compared to the HCl- last surface [18]. The native oxidation of the HF- last Ge surface is likely to proceed slowly (except in very early stages) compared to the HCl- last surface. The native oxide growth for both the HF- and HCl- last samples shows stepwise trend with increases of about 0.2 - 0.3 nm, which is similar to the Ge-O bond length of 0.2 nm for the growth after early stage of oxidation as shown in figure 1.1 [19]. It is confirmed that the layer-by-layer growth of native oxide on Ge surface is similar with native oxide trend on the silicon wafer [19].



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Germanium (Ge) has received much attention in recent years for the development of Metal Oxide Semiconductors Field Effect Transistors (MOSFETs) due to its high carriers mobility than Silicon (Si). Understanding the native Ge oxidation is required to provide a good passivation on Ge surfaces. Ge Oxide ( $\text{GeO}_2$ ) can be useful; however the basic understanding of Ge thermal oxidation is needed. The suppression of Ge oxide desorption is thought to be a key to obtaining a high FET performance. Therefore, understanding the mechanism of native and thermal oxidation on the Ge surface is necessary in obtaining a good quality at the interface between the channel and the gate dielectric. In this book, the reader is presented with all the series of experimental results of Ge native and thermal oxidation. In addition, many broader topics such as overview of Ge oxidation since 1950s are presented. The chapter's introduction provides a general discussion of the topics and subsequent section presents the detail of native and thermal oxidation of Germanium.

### The Author



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