

# Activation energy of thermal oxidation germanium oxide on germanium substrates

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**Abstract**— The activation energy of GeO<sub>2</sub> was studied by determining the oxide thickness versus temperature from lower to higher oxidation temperature in the range between 450°C and 600°C. It was found that a linear relationship can be obtained between oxidation time and oxide thickness for the oxidation temperature between 450 and 575°C while for the 600°C oxidation, a linear relationship can be obtained for the shorter oxidation time. The rate of oxidation increased until 0.55 and abruptly decreased after increasing oxidation temperature to 600°C which implies that the oxygen intermixing occurs during higher oxidation (600°C) rather than diffusion mechanism that leads to the lower activation energy.

**Keywords**—activation energy, Ge oxidation, GeO<sub>2</sub>, GeO desorption

## I. INTRODUCTION

Over the past 40 years, impressive progress has been made in Silicon (Si) technology by continual scaling of devices to smaller size. This action limits the performance, power consumption, current and short-channel effects which have the trade-off relationship with each other. Therefore, device structures and materials with high carrier mobility without associated leakage current in gate capacitance are needed. Germanium (Ge) is a promising candidate and become a great current research interest that has higher electron and hole mobility to than Si. [1-2]. The lower melting point of Ge (938°C) compared to Si (1414°C) gives an advantage to Ge metal-oxide-semiconductor (MOS) field effect transistors (FETs) with much lower thermal budget processes [3]. However, with the problem of inferior properties of Ge compared to Si annihilate it in semiconductor foundry [13-16]. Faster oxidation just after cleaning compared to Si oxidation reflects a

difficulty in integrating novel materials as a metal gate electrode and high-k dielectric [4]. Another big issue in implementing Ge as a metal gate electrode and high-k dielectric into advanced transistor is volatilization of Ge monoxide (GeO) during thermal process, which can degrade the performance of MOSFETs. However, previous study shown that the combination of Aluminium Oxide (Al<sub>2</sub>O<sub>3</sub>) and Ge formed Ge oxide (GeO<sub>x</sub>) after post anneal deposition lower the interface trap density [5]. From this finding, the GeO<sub>x</sub> can be a potential interfacial layer between high-k and Ge. Recent study shows that the surface cleaning of Ge and anneal temperature influences the growth of interfacial layer between GeO<sub>x</sub> and Al<sub>2</sub>O<sub>3</sub> that cause the intermixing between GeO<sub>x</sub> and Al<sub>2</sub>O<sub>3</sub> [6]. In addition, theoretical study on the GeO<sub>2</sub>/Ge interface has been performed based on the calculations of SiO<sub>2</sub>/Si interfaces, but the reaction mechanism of Ge oxidation remains unsolved [7]. Therefore, fundamental understanding of the mechanism of Ge oxidation is essential to form a good quality of oxide on Ge surface. Hypothetically, the change of activation energy of Ge oxide growth also can influence the mechanism of Ge oxidation. From the activation energy, the reaction between Ge-O can be discussed in detail. In this work, the thickness of Ge oxide is evaluated with temperature dependence. The activation energy is calculated based on the Arrhenius plot. The value of activation energy will be compared with the reported diffusivity of oxygen in GeO<sub>2</sub>. From experimental data, the mechanism of Ge oxide growth will be discussed in detail

## II. EXPERIMENTAL PROCEDURES