

# Enhanced Thermal Oxidation of 4H-SiC Using $\text{SrTi}_{1-x}\text{Mg}_x\text{O}_{3-\delta}$ Catalyst

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## Abstract

**Low temperature oxidation of 4H-SiC using  $\text{SrTi}_{1-x}\text{Mg}_x\text{O}_{3-\delta}$  catalyst is demonstrated. The linear rate constant of the oxidation model for 4H-SiC(0001) Si-face at 800°C is enhanced by two orders of magnitude from that of the conventional dry oxidation. Capacitance-voltage measurement of a MOS diode prepared by the catalytic oxidation shows similar interface state density to the conventional dry oxidation at 1100°C.**

## 1. Introduction

The higher breakdown field of the 4H-SiC leads to smaller on-state resistance of a power MOSFET than that of Si [1]. However, the low channel-carrier mobility of the 4H-SiC MOSFET still remains to be solved [2]. The electron mobility is significantly degraded by electron traps generated at and near the 4H-SiC/SiO<sub>2</sub> interface [2] during thermal oxidation to form the SiO<sub>2</sub>. It has been reported that interface states ( $D_{it}$ ) in a thermally grown SiO<sub>2</sub> at 1250°C can be reduced by 60% as compared to that at 1080°C [3]. On the other hand, it has been also shown that lowering the oxidation temperature results in reduced  $D_{it}$  [4]. Besides, it has been reported that low-temperature heat treatment in oxygen ambient applied to high-temperature oxidized 4H-SiC is effective to reduce  $D_{it}$  [5].

However, most of previous studies of oxidation including MOSFET characterization have employed oxidation at temperatures higher than 1100°C. The reason for this is that the surface of 4H-SiC is hard to be oxidized at temperatures below 1000°C [6]. In this paper, we report a new oxidation method which is able to significantly enhance the thermal oxidation rate of 4H-SiC. Oxide growth at 800°C up to 34 nm in thickness on the 4H-SiC(0001) Si-face surface is presented. Impact of the low temperature oxidation on interface property is also investigated.

## 2. Experimental details

Fig. 1 shows the unit cell of  $\text{SrTi}_{1-x}\text{Mg}_x\text{O}_{3-\delta}$ . An oxygen vacancy is produced by replacing  $\text{Ti}^{4+}$  with  $\text{Mg}^{2+}$  in the  $\text{SrTiO}_3$  lattice of the basic  $\text{ABO}_3$  perovskite structure. When  $\text{O}_2$  molecules are introduced, an oxygen atom occupies the oxygen vacancy as an  $\text{O}^-$  ion. The  $\text{O}^-$  ion is a metastable state, so that it is desorbed from the material as an oxygen radical ( $\text{O}^*$ ) to form an oxygen vacancy ( $\text{V}_\text{O}$ ). The emission of  $\text{O}^*$  occurs at temperatures above 400°C. Preliminary results of oxidation enhancement of Si by using the  $\text{SrTi}_{1-x}\text{Mg}_x\text{O}_{3-\delta}$  is reported elsewhere [7].

To evaluate enhancement in oxidation of 4H-SiC using the catalyst material, oxidation experiment was conducted using the setup shown in Fig. 2.  $\text{SrTi}_{1-x}\text{Mg}_x\text{O}_{3-\delta}$  catalyst powder was placed in a rectangular quartz dish and covered with a 1 mm-thick quartz plate in which a 7×7 mm<sup>2</sup> window

was fabricated. A 4H-SiC wafer was set face-down on the quartz plate. Oxidation was performed at 800~900°C under atmospheric pressure with an  $\text{O}_2$  flow rate of 1 L/min. The 4H-SiC wafer used was (0001)-oriented Si-face n-type with a 6.6 μm-thick epitaxial-layer. The thickness of the SiO<sub>2</sub> layer after oxidation was measured using spectroscopic ellipsometry (Horiba AutoSE).

## 2. Results and discussion

Fig. 3 shows the thickness distribution of SiO<sub>2</sub> on 4H-SiC formed by oxidation at 800°C for 10 h with the  $\text{SrTi}_{0.4}\text{Mg}_{0.6}\text{O}_{3-\delta}$  catalyst. A 34 nm-thick SiO<sub>2</sub> layer was formed in the region where the 4H-SiC surface was exposed through the opening in the quartz plate. Impact of the composition of the catalyst was investigated by using Si. Fig. 4 shows change in oxidation characteristic of with composition  $x$  of  $\text{SrTi}_{1-x}\text{Mg}_x\text{O}_{3-\delta}$ . We can clearly see that the growth rate increases with increasing  $x$ , i.e., increasing density of oxygen vacancy.

Fig. 5 shows the SiO<sub>2</sub> thickness as a function of oxidation time at 800~900°C. Results obtained from oxidation performed with  $\text{SrTiO}_3$  and without catalyst were also plotted. The results clearly indicate that the oxidation rate is significantly increased by using the  $\text{SrTi}_{0.4}\text{Mg}_{0.6}\text{O}_{3-\delta}$  catalyst. Also, the growth rate appears as the linear region of the Deal-Grove model [8] under the experimental conditions, suggesting that reaction at the oxide/SiC interface limits the growth rate. Since the oxidation temperature in this study is lower than the previous studies, the reaction limited growth may become predominant. In addition, diffusion of oxidation species through the oxide layer can be enhanced by the presence of  $\text{O}^*$  in the ambient. In fact, investigation carried out by using Si indicated that the parabolic rate constant is also enhanced by using the catalyst.

Assuming that the reaction rate determines the growth rate, the linear rate constant  $B/A$  of the Deal-Grove model was extracted and plotted in Fig. 6. Results reported by Goto et al [9], who intensively investigated and precisely measured the growth rate of dry oxidation, were also plotted in the figure. The results obtained in this study indicate a lower activation energy than the dry oxidation, which suggests that enhanced oxidation is a result of enhanced reaction owing to  $\text{O}^*$  generated in the oxidation ambient by the  $\text{SrTi}_{1-x}\text{Mg}_x\text{O}_{3-\delta}$  catalyst.

The interface state density  $D_{it}$  was measured by using the High-Low method. For comparison, samples prepared by conventional dry oxidation at 1100°C followed by post oxidation annealing (POA) in  $\text{O}_2$  at 800°C were also measured. Fig. 7 shows  $D_{it}$  of these samples. The catalytic oxidation sample indicates slightly less  $D_{it}$  than the dry oxidation sample in the energy level of 0.3~0.63eV.

#### 4. Summary

By using oxidation catalyst  $\text{SrTi}_{1-x}\text{Mg}_x\text{O}_{3-\delta}$ , growth rate of  $\text{SiO}_2$  is enhanced by about two orders of magnitude compared with the conventional dry oxidation in the temperature range  $800^\circ\text{C}\sim 900^\circ\text{C}$ . As a result, an  $\text{SiO}_2$  film having a few tens nm can be grown on 4H-SiC Si-face at  $800^\circ\text{C}$  within realistic oxidation time. The reduced activation energy for the reaction limited growth strongly suggests that oxygen radicals produced by the catalyst enhances the oxidation rate. The interface state density of the  $800^\circ\text{C}$  catalytic oxide is similar to that of oxide grown at  $1100^\circ\text{C}$ , which suggests that the proposed method will be useful for low temperature passivation of the surface.

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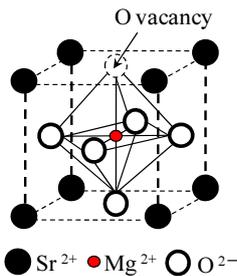


Fig. 1. Unit cell structure of  $\text{SrTiMgO}_3$ .

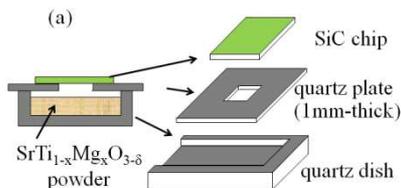


Fig. 2. Experimental setup of the catalytic oxidation.

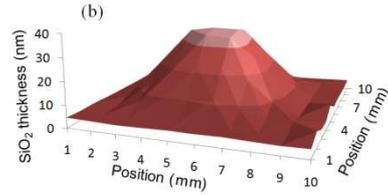


Fig. 3. Thickness distribution of the  $\text{SiO}_2$  by the catalytic oxidation.

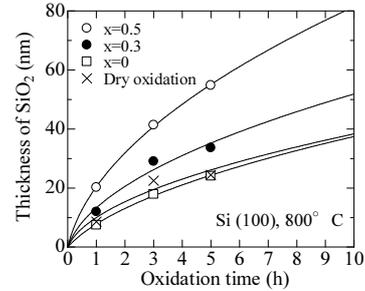


Fig. 4. Effects of change in composition  $x$  of  $\text{SrTi}_{1-x}\text{Mg}_x\text{O}_{3-\delta}$  on thermal oxidation rate investigated by using Si(100) crystal.

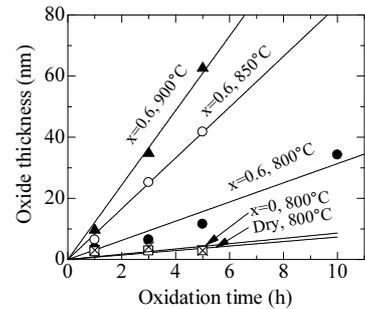


Fig. 5. Time evolution of the  $\text{SiO}_2$  thickness.

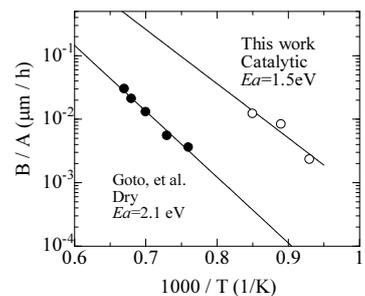


Fig. 6. Linear rate constants ( $B/A$ ) of the oxidations.

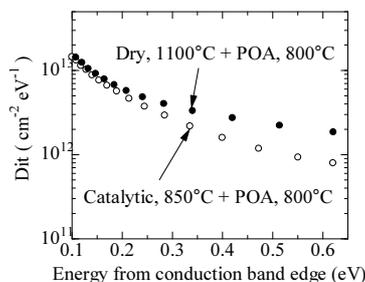


Fig. 7.  $D_{it}$  measured by using the High-Low method.