1. Introduction
The oxidation is one of the most important processes in semiconductor device fabrication. Silicon (Si) has been described by the Deal-Grove model [1]. Germanium (Ge) has similar characteristics as Si in various aspects [2]. However, oxidation kinetics of Ge has been proved quite different from that of Si experimentally [3]. Therefore, a kinetic model is needed to better understand the mechanism of Ge oxidation.

In this work, we propose a possible kinetic model for Ge oxidation by considering two oxidant diffusion processes and two reactions.

2. Experiment
Both SiO$_2$/Ge and GeO$_2$/SiO$_2$/Ge stacks as shown in Fig. 1(a) were prepared. All oxide layers were deposited by radio-frequency (rf) sputtering followed by post-deposition annealing (PDA) in N$_2$ at 550°C. Then these stacks were thermally treated in 1-atm O$_2$ ambient at 550°C, and GeO$_2$ layer generated at Ge/SiO$_2$ interface was estimated after removing the top GeO$_2$ layer by the grazing incidence X-ray reflectivity (GIXR) measurement.

3. Results and discussions
Fig. 1 (b) shows the thickness change of the GeO$_2$ layer generated at SiO$_2$/Ge interface with different GeO$_2$ top layer thicknesses. The SiO$_2$/Ge stack (50 nm SiO$_2$) yields the highest interfacial GeO$_2$ growing rate, implying a fast O$_2$ diffusion through the SiO$_2$ cap layer, while the interfacial GeO$_2$ growing rate on Ge is sharply reduced with the increase of top-GeO$_2$ cap layer thickness. It suggests that O$_2$ diffusion in the top-GeO$_2$ layer is significantly suppressed comparing with that in SiO$_2$.

It was already reported that oxygen vacancy (V$_0$) was formed through the GeO$_2$/Ge interfacial reaction [4]. This fact can be regarded as the oxidation of Ge by GeO$_2$. In Fig. 2, we propose a possible kinetic model for the Ge oxidation by considering two oxidant diffusion processes: One is the O$_2$ diffusion from oxide surface, and the other is V$_0$ diffusion from the interface on Ge substrate. A hypothetical boundary at which O$_2$ molecule may react with V$_0$ (O$_2$ molecule decomposes into O) is located at $\xi$ in Fig. 2. An analytical model for the Ge oxidation rate will be shown in this work. For limiting cases (thin and thick oxide cases), Ge oxidation follows approximately the linear-parabolic law, but the reaction kinetics is quite different from the Deal-Grove model for Si.

4. Conclusions
We have proposed a new kinetic model for thermal oxidation of Ge, based on two kinds of oxidant diffusions and two reactions. It is totally different from the Deal-Grove model. It can help to deeply understand the thermal oxidation kinetics of Ge, as well as achieving well-controlled gate stacks on Ge.

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Reference

Fig. 1 (a) Schematic of SiO$_2$/Ge and GeO$_2$/SiO$_2$/Ge stacks structure. (b) Thickness change of the interfacial GeO$_2$ at Ge/SiO$_2$ interface in these stacks.

Fig. 2 Schematic illustration of Ge oxidation model.