

A New Planarization Technique for LSI Utilizing Si-Ge Film Oxidation

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A new planarization technique in the LSI process utilizing Si-Ge film oxidation is proposed. The Si-Ge film is deposited by thermal decomposition of SiH_4 and GeH_4 . The oxide growth rate is more than one order of magnitude higher than that in crystalline Si. The oxide thickness decreases with increases in Ge content and oxidation temperature. Large fluidity appears above 750°C only in the progress of oxidation. This planarization is related to Ge evaporation. Electrical properties of the Si-Ge oxide film are good enough for an insulating layer. The Si-Ge film oxide does not react with an underlying SiO_2 or Si_3N_4 layer.

1. Introduction

The planarization technique in LSI fabrication is becoming increasingly important. A buried oxide isolation technique has recently been developed in place of LOCOS (local oxidation of silicon) to reduce the isolation area.¹⁻⁵⁾ In this process, however, it has been difficult to insert an insulating material with a flat surface into various shaped grooves. For a smoothing process for metallization, phosphosilicate glass flow is widely used.⁶⁻⁸⁾ This technique needs an annealing at about 1000°C . Since such a high temperature process influences the impurity profile, the reduction of planarization temperature is desired.

In this paper, we propose a new planarization technique utilizing Si-Ge film oxidation. The important features are a high oxidation rate, small volume change in oxidation and large fluidity during oxidation below 800°C . This planarization involves a new mechanism related to Ge evaporation. The technique is applicable to a buried oxide isolation process as well as a smoothing process in advance of metallization.

2. Experimental

Si-Ge films were deposited by thermal decomposition of a SiH_4 - GeH_4 mixture diluted with helium gas. The deposition temperature, the

total flow rate and the gas pressure in the furnace were 450°C , 300 cc/min and 0.2 Torr, respectively. The Ge content in the film was controlled by the gas flow-rate ratio, $\text{GeH}_4/\text{SiH}_4$. The deposition rate was about 3 nm/min for $\text{GeH}_4/\text{SiH}_4=0.3 - 0.6$. Most Si-Ge films were doped with B as required for detailed comparison of oxidation characteristics with a control Si film, because deposition and oxidation rates of non-doped Si film are very low. For measurement of film thickness change due to oxidation or due to heat treatment after oxidation, sapphire substrates were used. A substrate used for the oxide profile observation is schematically shown in Fig. 1. The Si-Ge films were oxidized at 750 - 900°C in a wet O_2 ambient provided through a 90°C water bubbler. The boundary abruptness between the Si-Ge oxide layer and an underlying SiO_2 or Si_3N_4 layer was examined by AES.

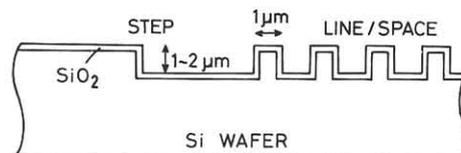


Fig. 1. Substrate used for the oxide profile observation.

3. Results

3.1 General features of Si-Ge film oxidation

The deposited Si-Ge film is a polycrystal-

line solid solution of Si and Ge; phase separation does not occur. The Si and Ge contents estimated by XFA and chemical analysis are listed in Table I.

Table I. Composition of the Si-Ge films.

Gas flow rate ratio ($\text{GeH}_4/\text{SiH}_4$)	Composition (Ge/Si)	
	XFA	Chemical analysis
0.3	2.7	2.7
0.6	4.6	5.3

The Si-Ge oxide growth rates for oxidation at 800°C in a wet O_2 ambient are shown in Fig. 2. The broken line indicates the oxidation rate for crystalline Si. The oxide growth rate in Si-Ge film is more than one order of magnitude higher than that in crystalline Si. The high oxidation rate is a desirable feature for application to the LSI process because the Si-Ge film should be selectively oxidized so that active areas are not oxidized. The oxide film is a $\text{SiO}_2\text{-GeO}_2$ mixture. In the infrared absorption spectra, two peaks due to vibration modes in the Ge-O bond^{9,10} are observed at 880 cm^{-1} and 580 cm^{-1} .

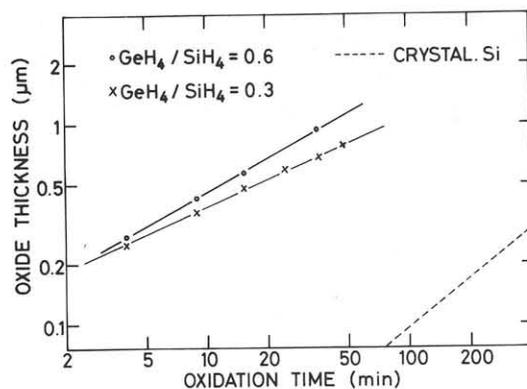


Fig. 2. Si-Ge oxide growth rate.

The oxide thickness, d_{ox} , normalized with the Si-Ge film thickness, d_{sem} , before oxidation, is depicted in Fig. 3. As $\text{GeH}_4/\text{SiH}_4$ increases, $d_{\text{ox}}/d_{\text{sem}}$ decreases. This suggests that part of the Ge evaporates during oxidation. When a film deposited for $\text{GeH}_4/\text{SiH}_4=0.6$ is oxidized at 850°C , the volume change due to oxidation becomes zero. The ir transmittance spectra of the oxide grown at different tempera-

tures appears in Fig. 4. The absorption intensity for Si-O vibration is independent of oxidation temperature, whereas that for Ge-O vibration at 900 cm^{-1} decreases with an increase in oxidation temperature. Also, the film thickness is no longer decreased by heat treatment even at temperatures higher than the oxidation temperature. These results indicate that the Ge evaporates only during the progress of oxidation.

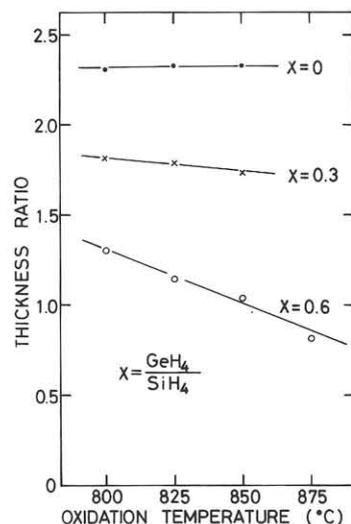


Fig. 3. Film thickness change in oxidation.

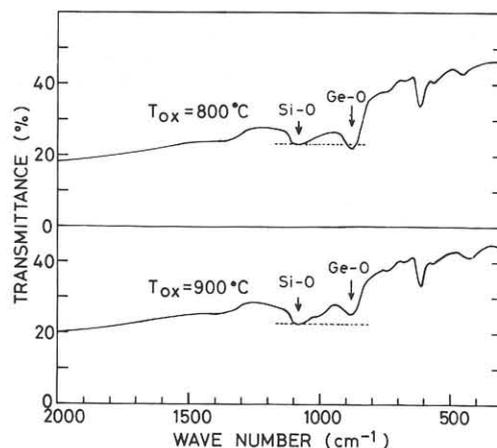


Fig. 4. Infrared transmittance spectra of the oxide grown at different temperatures.

Electrical properties of Si-Ge oxide films grown at 800°C are summarized in Table II. They have satisfactory characteristics for use as insulating films in semiconductor devices.

3.2 Planarization during oxidation

Figure 5 and 6 show SEM photographs of the

Si-Ge film profiles before oxidation (a) and the oxide profiles formed at 800°C (b). In Fig. 5, a 1 μm height step is gently covered with a Si-Ge oxide film. In Fig. 6, a 1 μm line/space pattern with a 1 μm height is covered with an oxide film with a completely flat surface. When oxidation is stopped before the whole Si-Ge film is oxidized, Si-Ge films remain only in the grooves. In Fig. 6(b), thin Si-Ge films with a flat surface are observed in the grooves. Since the conductivity of the Si-Ge film doped with B is about $10^3 \text{ S}\cdot\text{cm}^{-1}$,¹¹⁾ the residual film can be used as an electrode. A similar oxide profile is also obtained for oxidation at 750°C. The present process temperature is more than 200°C lower than the temperature needed for phosphosilicate glass flow.

Figure 7 (a) shows an oxide profile over a 2 μm - height step formed by oxidation at 750°C. Figure 7 (b) shows a profile of the same sample after heat treatment at 875°C for 1 hour. No obvious change is caused by heat treatment at the temperature higher than the oxidation temperature. This result indicates that the Si-Ge oxide film itself has little fluidity

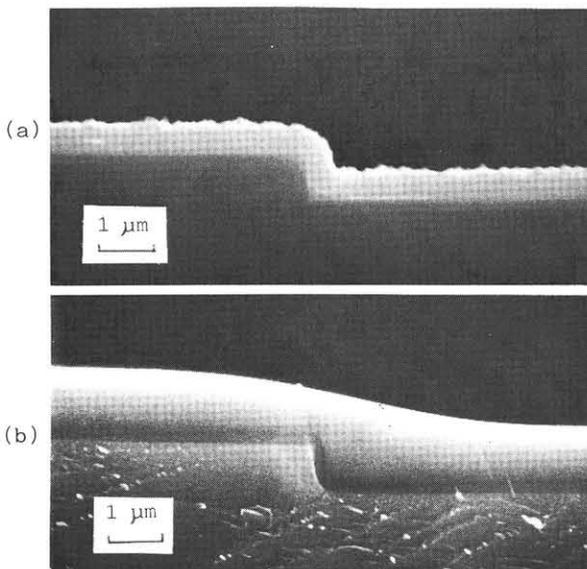


Fig. 5. Profiles over a 1 μm height step before oxidation (a) and after oxidation (b).

and that fluidity appears only in the progress of oxidation.

3.3 Boundary abruptness

When the flow phenomena during Si-Ge oxidation is applied to the LSI process, the Si-Ge oxide film will be put on a SiO_2 or Si_3N_4 layer, or sandwiched between them. Therefore,

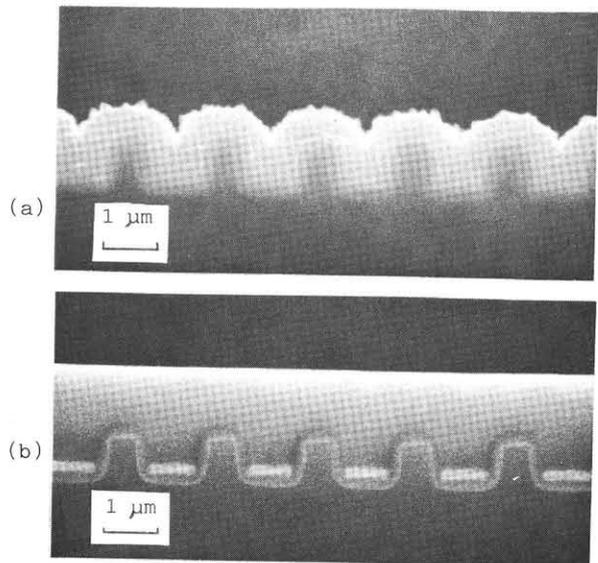


Fig. 6. Profiles over a 1 μm line/space pattern before oxidation (a) and after oxidation (b).

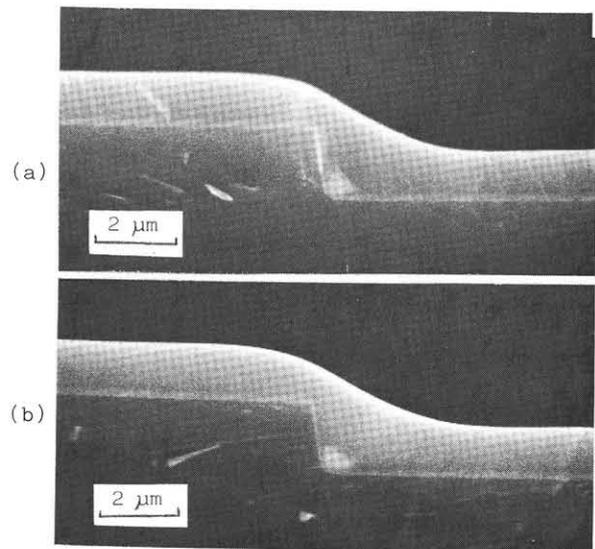


Fig. 7. Profiles over a 2 μm height step after oxidation at 750°C (a) and after 875°C heat treatment (b).

Table II. Electrical properties of Si-Ge oxide films.

$\text{GeH}_4/\text{SiH}_4$	Dielectric constant	dielectric strength (V/cm)	resistivity ($\Omega\cdot\text{cm}$)	$\tan\delta$ (100kHz)
0.3	4.41	7×10^6	$> 10^{15}$	4.1×10^{-3}
0.6	4.62	8×10^6	$> 10^{14}$	1.6×10^{-3}

it is desirable that the Si-Ge oxide film does not react with the SiO_2 or Si_3N_4 layer. Figure 8 (a) shows an AES depth profile of a 150 nm oxide film on a 110 nm- SiO_2/Si -substrate formed at 800°C . Figure 8 (b) shows a profile after 950°C heat treatment for the same sample as that shown in Fig. 8 (a). In both profiles, boundary abruptness between the Si-Ge oxide and the underlying SiO_2 layer is almost equal to that between the SiO_2 layer and the Si substrate. In the Si-Ge oxide film on a $\text{Si}_3\text{N}_4/\text{Si}$ substrate, similar depth profiles are obtained for the same experimental procedure.

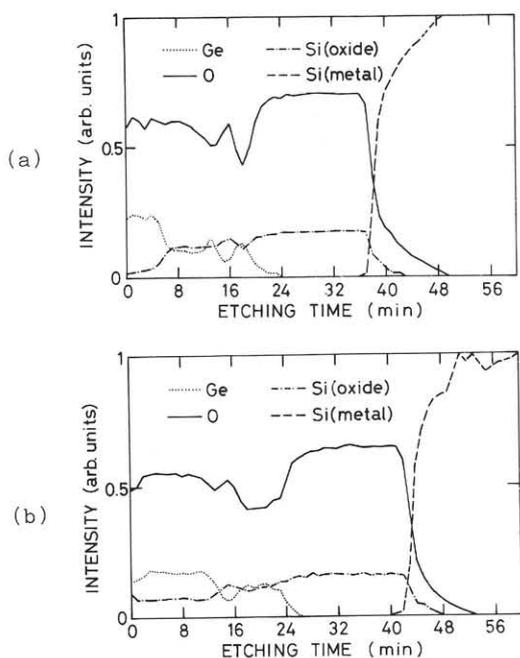


Fig. 8. AES depth profiles after oxidation at 800°C (a) and after 950°C heat treatment (b).

4. Discussion

The planarization mechanism is generally divided into viscous flow, evaporation-condensation, volume diffusion and surface diffusion.^{12,13} In the experimental results, the oxide profile was not changed by heat treatment at the temperature higher than the oxidation temperature. Since viscosity and diffusion constant depend strongly on temperature, these are not the existing planarization mechanism. Evaporation-condensation planarization is improbable because the present system is not a closed system in equilibrium. As a result of the above discussion, the existing planarization is not explained by a known mechanism.

Both Ge evaporation and planarization occur only during the progress of oxidation. This suggests that the present planarization mechanism is related to Ge evaporation. A GeO molecule produced at the oxide - Si-Ge film interface is diffused in the oxide and sublimated or converted to GeO_2 at the surface. In this process, it is probable that GeO diffusion is accompanied with breaking of the Ge-O or Si-O bond which forms the oxide network. Exchange of an O atom between the GeO molecule and the $\text{SiO}_2\text{-GeO}_2$ network is also likely. We believe that planarization in Si-Ge film oxidation is attributed to bond breaking associated with the GeO diffusion.

5. Concluding remarks

The planarization technique proposed in this paper is achieved below 800°C ; this is much lower than the temperature needed for phosphosilicate glass flow. Moreover, the low-pressure CVD and the thermal oxidation utilized in this work are processes with high uniformity and a high throughput. Therefore, the present technique is promising for low temperature planarization in the LSI process.

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