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Formation of Si Epi./$MgO \cdot Al_2O_3$ Epi./SiO_2/Si and Its Epitaxial Film Quality

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A new type silicon-on-insulator with Si/$MgO \cdot Al_2O_3$/SiO_2/Si structure has been developed. $MgO \cdot Al_2O_3$ (spinel) epitaxial film is grown on (100) Si Substrate by chemical vapor deposition. Amorphous SiO_2 is formed by thermal oxidizing Si substrate through spinel film. Si epitaxial film is grown on $MgO \cdot Al_2O_3$/SiO_2/Si by SiH_4 pyrolysis. Strain-free Si epitaxial film is attained. Si film Crystalline quality evaluated by X-ray rocking curve is equivalent to that in SOS.

1. Introduction

Many silicon on insulator (SOI) crystal growth techniques, including silicon on sapphire (SOS) and laser beam annealing Si film recrystallization on amorphous insulator, are under development for the fabricating more densely integrated and higher speed MOS devices, high-voltage integrated circuits and so on.

Of these techniques, double-heteroepitaxial SOI with epitaxial-Si / epitaxial-insulator/Si substrate structure has a marked advantage, in that a large area SOI is easily attained by growing insulator and Si epitaxial films on the whole surface of Si substrate. Several insulators, such as $MgO \cdot Al_2O_3$ (spinel) and CaF_2 have been investigated in this technique (1)~(6). Spinel is noticable material, because it results in better Si device properties, compared with SOS, due to smaller lattice constant mismatch with Si and less impurity contamination (7, 8).

Using spinel epitaxy, Si thermal oxidization and Si epitaxy, we have developed a new type SOI having Si/spinel/SiO_2/Si structure, in which Si epitaxial film is strain-free. Thermal oxidized SiO_2 is a high quality insulator with low dielectric constant. Therefore, this SOI is expected to be more useful for device application than Si/spinel/Si. In this work, spinel hetero-epitaxial growth and Si/spinel/SiO_2/Si formation techniques are presented.

2. $MgO \cdot Al_2O_3$ Epitaxial Growth

Insulator hetero-epitaxy on Si substrate is a key technique for achieving double hetero-epitaxial SOI. In our case, spinel epitaxial growth was carried out by chemical vapor deposition (CVD). Fig. 1 shows a CVD reactor and the interrelation between gas species transported. The reactor was improved over the reactor which had been developed for $Y_3Fe_5O_{12}$ epitaxial growth (9). $MgCl_2$-Al-HCl-CO_2-H_2-N_2 gas system was used in which N_2 gas was the carrier gas. Al is transported as $AlCl_3$, which is formed by the reaction between Al and HCl. Both $MgCl_2$-$AlCl_3$ and CO_2-H_2, which are independently transported with N_2 gas, are mixed in the growth chamber. The epitaxial growth occurs on the (100) Si substrate due to the following reaction.

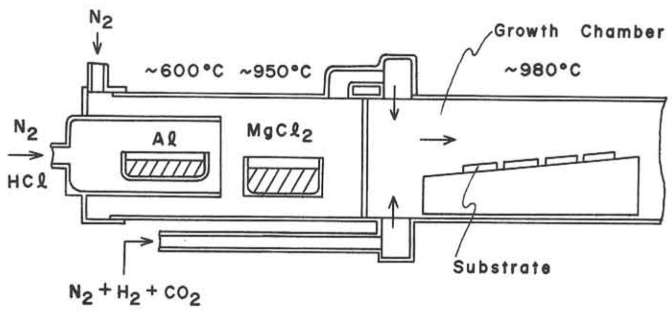

Fig. 1 CVD reactor for $MgO \cdot Al_2O_3$ epitaxial film growth.

$$MgCl_2 + 2AlCl_3 + 4CO_2 + 4H_2 \rightarrow MgO{\cdot}Al_2O_3 + 4CO + 8HCl$$

Table 1 shows the epitaxial growth conditions.

Table 1 $MgO{\cdot}Al_2O_3$ epitaxial growth conditions.

Al	transport rate	0.3~0.8	g/hr
$MgCl_2$	transport rate	6.0~11.0	g/hr
CO_2	flow rate	100~500	CC/min
H_2	flow rate	20	l/min
N_2	flow rate	56	l/min
Growth temperature		850~1050	°C
Substrate		Si (100)	

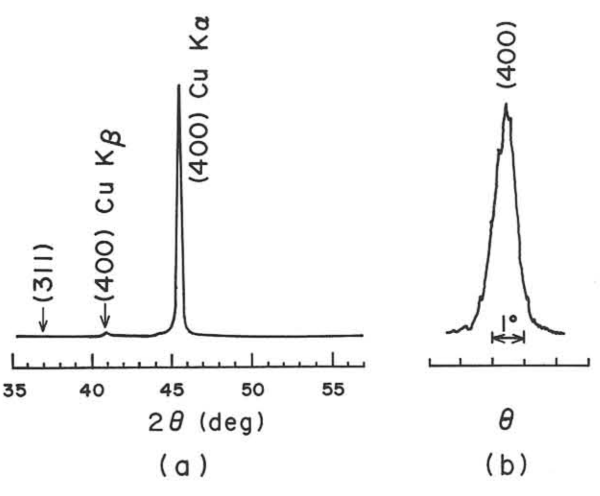

Fig. 2 $MgO{\cdot}Al_2O_3$ X-ray diffraction pattern for 0.4 μm thick epitaxial film. (a) θ-2θ mode chart (b) (400) X-ray rocking curve.

In order to evaluate the epitaxial film crystalline quality, θ-2θ mode X-ray charts and double-crystal X-ray rocking curves (XRC) were obtained as shown in Fig. 2. Only the (400) diffraction peak was observed with strong intensity in θ-2θ mode. Half value widths (HVW) of (400) XRC were from 0.75 to 1.0 degrees for 0.4 μm thick epitaxial films grown under the optimum growth conditions. The film crystalline quality became inferior as the thickness decreased because HVW increased. HVW was about 1.8 degrees for 0.1 μm thick films.

From a practical production view-point, it is necessary that film thickness and quality uniformities are achieved in the large growth area. For films grown on four 3-inch substrates in the same run, the film thickness distributiion was within ±3% and the (400) XRC HVW was almost the same. The growth rate is limited to the surface reaction, whose activation energy is 1.0 ev.

3. $Si/MgO{\cdot}Al_2O_3/SiO_2/Si$ Formation

A thicker insulator is desirable in the Si/Insulator/Si for the fabricating completely isolated and higher speed devices. However, there are problems inherent in growing thick spinel. One problem is the low growth rate, which is about 0.5 μm/hr. The other inevitable problem is crack formation in the thick spinel film due to the difference in thermal expansion coefficient between spinel and Si. Fig. 3 shows a crack which was induced in the 0.8 μm thick film grown at 980 °C. <100> crack lines indicate that the spinel film is single crystal.

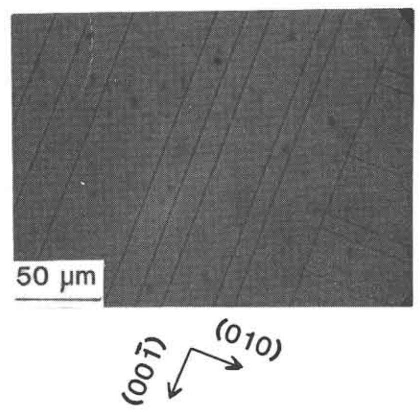

Fig. 3 Crack lines induced in $MgO{\cdot}Al_2O_3$ epitaxial film.

In order to solve the above problems, a new SOI having a $Si/spinel/SiO_2/Si$ structure has been developed. Fig. 4 shows the formation process. After spinel epitaxial growth, SiO_2 is formed between spinel film and Si substrate by thermal oxidizing the Si substrate through spinel film. Finally, Si epitaxial film is grown on spinel epitaxial film by SiH_4 pyrolysis in H_2 at 1030 °C, using a vertical reactor.

Thermal oxidization for SiO_2 formation was performed in a wet O_2 ambient. Film thickness and refractive index were measured by optical interference method and ellipsometry. About 0.5 μm-thick amorphous SiO_2 was formed by 1.5 hours thermal oxidization at 1100 °C in wet O_2 ambient. Refractive index was 1.45 which is in accord with the wellknown value of SiO_2. Fig. 5 shows a cross section view of Si/spinel/SiO_2 in which SiO_2 is observed as a black layer

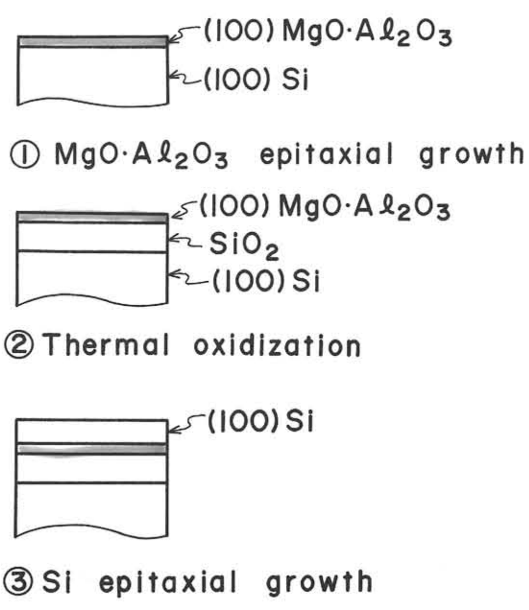

Fig. 4 Formation process of Si/MgO·Al_2O_3/SiO_2/Si.

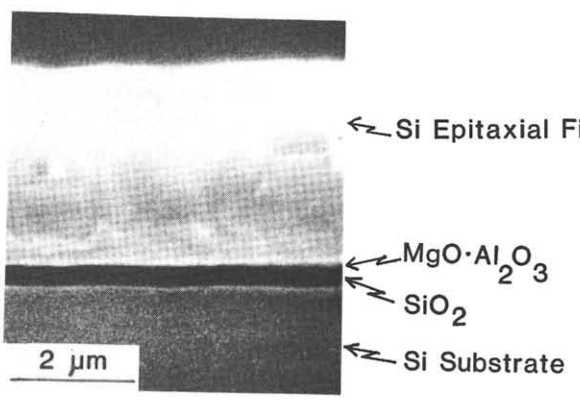

Fig. 5 Cross section view of Si/MgO·Al_2O_3/SiO_2/Si by SEM.

Fig. 6 shows XRC of spinel symmetric (400) and Si asymmetric (422) diffractions.
Fig. 6-(a) and (b) are spinel (400) XRC, which were observed in the stages of spinel/Si and Si/spinel/SiO_2/Si, respectively. Spinel epitaxial film quality was improved in the thermal oxidization process, in which HVW was reduced from 1.8 to 1.3 degrees. Fig. 6-(c) shows Si (422) XRC for Si/spinel/SiO_2/Si having 0.1 µm thick spinel and 0.5 µm thick SiO_2. It consists of a sharp top and broad skirt parts which correspond to diffractions from Si substrate and Si epitaxial film, respectively. The Si epitaxial film crystalline quality, therefore, can be evaluated from HVW of the broad skirt part. HVW of 3.0 µm thick Si epitaxial film was 0.35 degrees, while it was 0.2 degrees in Si/spinel/Si having the same Si and spinel film thicknesses.

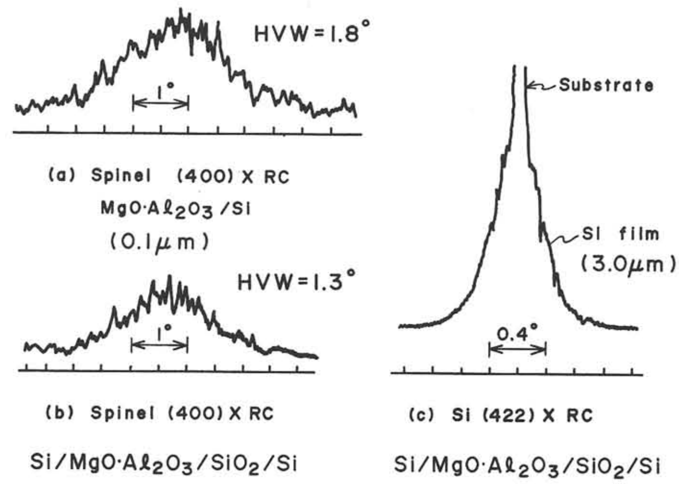

Fig. 6 X-ray rocking curve of MgO·Al_2O_3 (400) and Si asymmetric (422) diffractions forMgO·Al_2O_3/Si and Si/MgO·Al_2O_3/SiO_2/Si in the case of 0.1 µm thick spinel and 0.5 µm thick SiO_2.

The Si epitaxial film thickness dependence of Si (422) XRC HVW was investigated for Si/spinel/SiO_2/Si and Si/spinel/Si in the range of Si film thickness of 0.6 ~ 3.0 µm as shown in Fig. 7. HVW were level equivalent to SOS. However, it became larger in Si/spinel/SiO_2/Si than in Si/spinel/Si in spite of the spinel crystalline quality being improved in the former structure as mentioned above. This indicated that, in addition to spinel epitaxial crystalline quality, there are several factors to dominate the crystalline quality of Si epitaxial film (6). The slight Si epitaxial film quality inferiority in Si/spinel/SiO_2/Si may be improved by some techniques, such as Si epitaxial growth optimizations. Si/spinel/SiO_2/Si is expected to be rather more useful for device applications than Si/spinel/Si because the thermal oxidized SiO_2 is a high quality insulator with low dielectric constant.

800 Å — 10 min

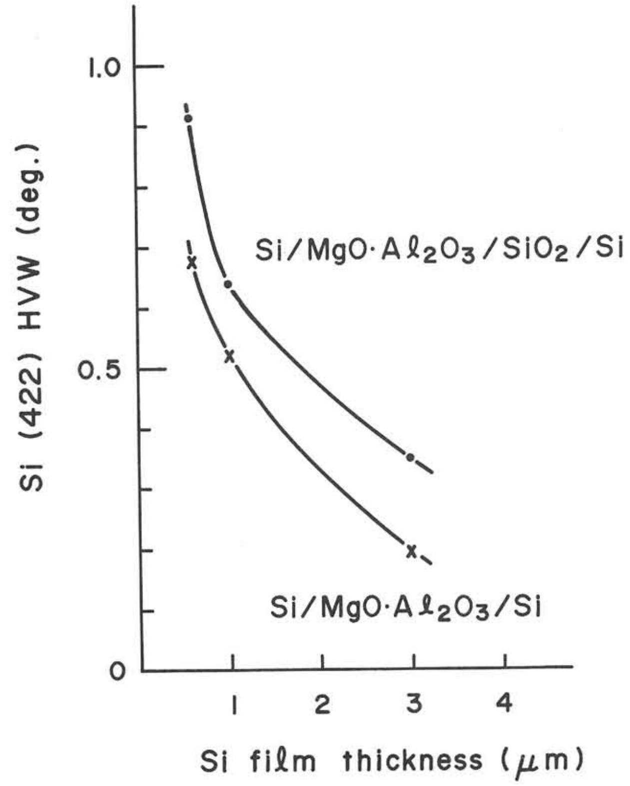

Fig. 7 Si epitaxial film thickness dependence of Si(422) X-ray rocking curve half value width for $Si/MgO{\cdot}Al_2O_3/SiO_2/Si$ and $Si/MgO{\cdot}Al_2O_3/Si$ in the case of 0.1 μm thick spinel and 0.5 μm thick SiO_2.

Insulator hetero-epitaxial SOI is expected to attain strain-free Si epitaxial film because there is no difference in thermal expansion coefficient between Si epitaxial film and substrate. The strain induced in Si epitaxial film should shift the film diffraction peak from that for the substrate in Si XRC.

Both the substrate and film diffraction peaks of Si (422) XRC shown in Fig. 6-(c) were overlapped at the same diffraction angle. This indicates that Si epitaxial film grown on spinel/SiO_2/Si substrate is strain-free. The strain-free epitaxial film was also ascertained by Raman spectroscopy. The Raman shift spectrum which appears at 521 cm^{-1} for bulk Si was observed at the same position for the Si/spinel/SiO_2/Si.

For Si/spinel/Si, the same results were obtained for 0.1 μm thick spinel. However, for 0.4 μm thick spinel, the slight compressive strain of about $4x10^{-4}$, which is one tenth that for SOS, was observed in both XRC and Raman spectroscopy.

4. Conclusion

A new type SOI having Si/spinel/SiO_2/Si structure has been developed. Spinel epitaxial films were grown on (100) Si substrate by CVD, using newly-designed horizontal reactor and $MgCl_2$-Al-HCl-Co_2-N_2 gas system. Excellent uniformities of film thickness and crystalline quality were obtained. SiO_2 was formed by thermal oxidizing Si substrate through spinel film after growing spinel film. This SOI has solved the problem regarding strain induced in the Si epitaxial film, which was inevitable when using other SOI techniques. No strain was observed by either XRC or Raman spectroscopy.

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References

1. M. Ihara, Y. Arimoto, T. Yamaoka, and K. Kurokawa, ISSCC Digest of Technical Papers (1981) 210
2. M. Ihara, Y. Arimoto, M. Jifuku, T. Kimura, S. Kodama, H. Yamawaki and T. Yamaoka, J. Electrochem. Soc. Solid-State and Technology 129 (1982) 2569
3. K. Egami, M. Mikami, T. Igarashi and H. Tsuya, Autumn Japan Applied Physics Conference Digest (1982) 542
4. H. Ishiwara and T. Asano, Appl. Phys. Lett. 40 (1982) 66
5. M. Mikami and T. Igarashi, Spring Japan Applied Physics Conference Digest (1983) 517
6. K. Egami, M. Mikami and H. Tsuya, to be published in Appl. Phys. Lett.
7. H. Schlotter, Solid State Elect. 11 (1968) 107
8. G.W. Cullen, J. Crystal Growth 9 (1971) 118
9. M. Mikami and K. Matsumi, J. Crystal Growth 37 (1981) 1