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Growth of Ga_2O_3 thin films on Si(100) substrates using a trimethylgallium and oxygen mixture

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Gallium oxide (Ga_2O_3) has attracted interest as a promising material for applications in a gas sensor [1, 2], transparent conductor [3], and solar cells [4, 5]. In addition, β-Ga_2O_3 and amorphous Ga_2O_3 have attracted much attention as new phosphor host materials for thin film electroluminescence devices [6]. The Ga_2O_3 thin films have been produced by various synthetic methods such as evaporation [7], sol–gel process [8], sputtering [9, 10], molecular beam epitaxy [11], and metal organic chemical vapor deposition (MOCVD). The MOCVD method has the advantage of producing uniform, pure, reproducible, adherent films with good step coverage and accordingly various deposition techniques using the precursors of $Ga(hfac)_3$ with O_2 [12], $Ga[OCH(CF_3)_2]_3{\cdot}HNMe_2$ with H_2O [13], and $[Ga(u\text{-}O\text{-}t\text{-}Bu)(O\text{-}t\text{-}Bu)_2]_2$ with O_2 [14] have been developed.

Although numerous materials, such as Al_2O_3 [8, 15], GaAs [16], CoGa(100) [17], GaN [18], and Ni(100) [19], have been studied as substrates for the Ga_2O_3 growth, there are few reports on the growth onto a silicon (Si) substrate [10], which will pave the way for integration of future devices with developed Si integrated circuit technology.

In this paper, we demonstrate the first growing of Ga_2O_3 films on Si using a simple reaction of a trimethylgallium (TMGa) and oxygen (O_2) mixture at a temperature of 650 °C and investigate the structure of the Ga_2O_3 thin films.

The p-type Si substrate with (100) orientation was cleaned with organic solvents and dried before loading into the system. A schematic diagram of the MOCVD reactor used in our experiments was previously provided [20]. The Ga_2O_3 film was synthesized by supplying O_2 and Ar carrier gases with the flow rates of 30 sccm at a temperature of 500–650 °C. High-purity Ar (99.999% purity) passed through the TMGa bubbler, which was maintained at a temperature of −5 °C, and delivered TMGa vapor to the reactor. A scanning electron microscope (SEM) (Hitachi S-4200, 30 kV) and an X-ray diffractometer (XRD) (Philips, CM20T, 200 kV, Cu K_{al} $\lambda = 1.5405$ Å) were used to characterize the structural quality of the films. An atomic force microscope (AFM) (Nanoscope III, Digital Instruments) was used to evaluate the surface roughness of the films.

Fig. 1 shows the XRD patterns of deposits on Si substrates at a growth temperature of 650 °C. The Θ–2Θ scan data of deposits exhibit a strong 2Θ peak at 69.13°, corresponding to the (400) peak of Si. Although we suppose that the deposits are close to the amorphous phase due to the absence of a strong Ga_2O_3 diffraction peak, close examination of the diffractogram reveals that the line observed at 44.87° corresponds to the $(\bar{1}06)$ peak of β-Ga_2O_3 (JCPDS 11-370). The β-Ga_2O_3 is a thermodynamically stable form of gallia and has a monoclinic structure [19]. The existence of the Ga_2O_3 peak indicates the production of Ga_2O_3 deposits on Si substrates. We infer from the XRD data that the deposits are crystallographically amorphous but contain very small crystallites. Fig. 2 shows the cross-sectional SEM images of Ga_2O_3 deposits at a growth temperature of 650 °C. We are not able to observe grain boundaries, and therefore we surmise that the Ga_2O_3 films are amorphous, agreeing with the XRD data.

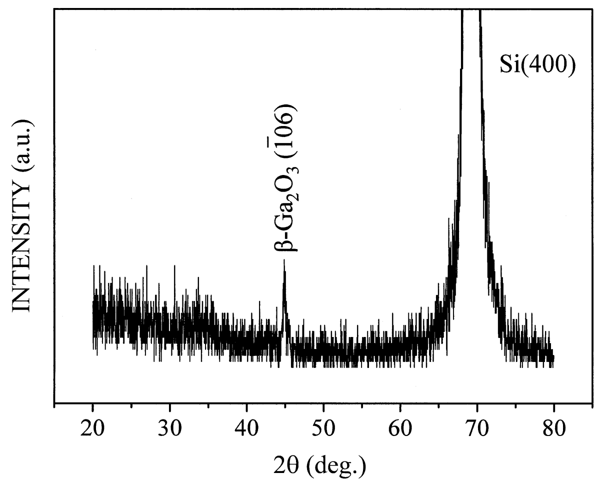

Figure 1 XRD patterns recorded from Ga_2O_3 deposits at 650 °C. Indexing of weak diffraction peak corresponds to a monoclinic structure of β-Ga_2O_3.

Fig. 3 shows the AFM image of Ga_2O_3 thin films. The AFM images indicate that small crystallites appear on top of the Ga_2O_3 thin film grown at the temperature of 650 °C, in contrast to the thin film deposited at 500 °C, which is relatively smooth and flat. Previous researchers reported that the crystallinity of Ga_2O_3 thin films was enhanced by increasing the substrate temperature [12], and we surmise that the crystallization from the amorphous phase can be initiated at higher temperatures. A more systematic study is needed in

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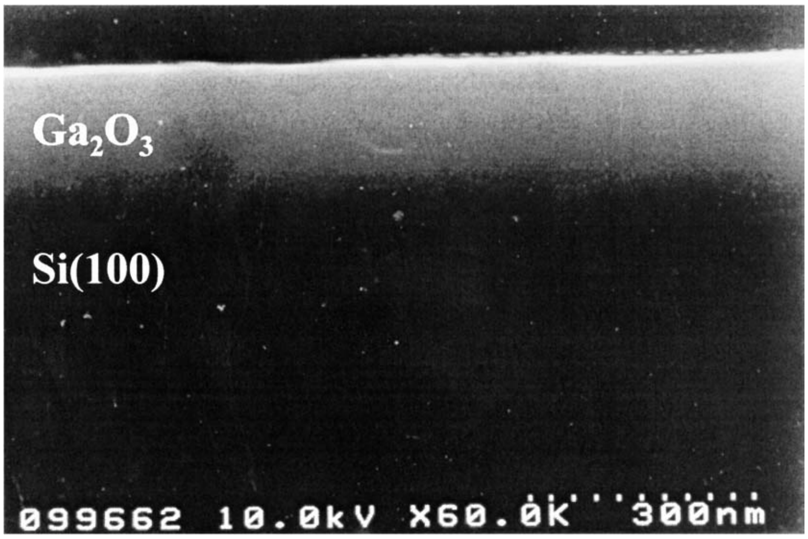
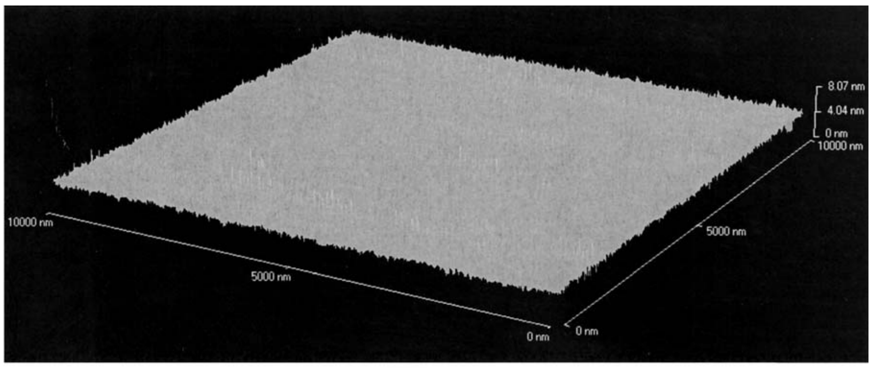
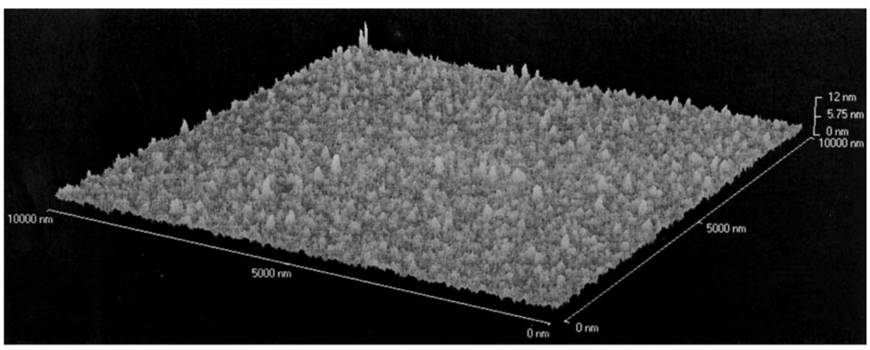


Figure 2 Cross-sectional SEM images of Ga_2O_3 films grown at a temperature of 650 °C.



(a)



(b)

Figure 3 AFM images of Ga_2O_3 films on Si substrate grown at a temperature of: (a) 500 °C and (b) 650 °C.

order to reveal the temperature effect on the initiation of crystallization in the Ga_2O_3 thin film. The root mean square (RMS) roughness values of the surface of Ga_2O_3 film deposited at 500 °C and 650 °C, respectively, are 0.38 and 0.82 nm, revealing that the surface becomes rougher at higher growth temperatures.

In summary, we have demonstrated the deposition of Ga_2O_3 thin films on Si substrates by MOCVD using the TMGa as a precursor in the presence of oxygen. We found that amorphous Ga_2O_3 films with very small crystallites are deposited on Si substrats at the deposition temperature of 650 °C. The AFM analysis indicates an RMS roughness value of 0.82 nm for the Ga_2O_3 films deposited at 650 °C. The production of Ga_2O_3 thin films on Si using the conventional source is a step forwards in terms of potential applications for Ga_2O_3 films.

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References
1. M. FLEISCHER, W. HANRIEDER and H. MEIXNER, *Thin Solid Films* **190** (1990) 93.
2. M. FLEISCHER and H. MEIXNER, *Sensors Actuators* B **5** (1991) 115.

3. *Idem.*, *Appl. Phys.* A **54** (1992) 560.
4. M. PASSLACK, E. F. SCHUBERT, W. S. HOBSON, M. HONG, N. MORIYA, S. N. CHU, K. KONSTADINIS, J. P. MANNAERTS, M. L. SCHNOES and G. J. ZYDZIK, *J. Appl. Phys.* **77** (1995) 686.
5. I. HAMBERF and C. G. GRANQVIST, *ibid.* **60** (1986) R123.
6. T. MIYATA, T. NAKATANI and T. MINAMI, *J. Lumin.* **87–89** (2000) 1183.
7. M. FLEISCHER and H. MEIXNER, *J. Vac. Sci. Technol.* A **17** (1999) 1866.
8. Y. LI, A. TRINCHI, W. WLODARSKI, K. GALATSIS and K. KALANTARZADEH, *Sensors Actuators* B **93** (2003) 431.
9. P. P. MACRI, S. ENZO, G. SBERVEGLIERI, S. GROPPELLI and C. PEREGO, *Appl. Surf. Sci.* **65/66** (1993) 277.
10. M. OGITA, K. HIGO, Y. NAKANISHI and Y. HATANAKA, *ibid.* **175/176** (2000) 721.
11. M. PASSLACK, M. HONG and J. P. MANNAERTS, *Appl. Phys. Lett.* **68** (1996) 1099.
12. G. A. BATTISTON, R. GERBASI, M. PORCHIA, R. BERTONCELLO and F. CACCAVALE, *Thin Solid Films* **279** (1996) 115.
13. L. MIINEA, S. SUH, S. G. BOTT, J.-R. LIU, W.-K. CHU and D. M. HOFFMAN, *J. Mater. Chem.* **9** (1999) 929.
14. M. VALET and D. M. HOFFMAN, *Chem. Mater.* **13** (2001) 2135.
15. M. ORITA, H. HIRAMATSU, H. OHTA, M. HIRANO and H. HOSONO, *Thin Solid Films* **411** (2002) 134.
16. C. HUANG, A. LUDVIKSSON and R. M. MARTIN, *Surf. Sci.* **265** (1992) 314.
17. R. FRANCHY, M. EUMANN and G. SCHMITZ, *ibid.* **470** (2001) 337.
18. P. CHEN, R. ZHANG, X. F. XU, Y. G. ZHOU, Z. Z. CHEN, S. Y. XIE, W. P. LI and Y. D. ZHANG, *Appl. Phys.* A **71** (2000) 191.
19. Y. JELIAZOVA and R. FRANCHY, *Surf. Sci.* **527** (2003) 57.
20. H. W. KIM, K. S. KIM and C. LEE, *J. Mater. Sci. Lett.* **22** (2003) 1117.

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