The growth of γ-LiAlO$_2$ layer with a highly-preferred orientation on (0001) sapphire

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Abstract Using vapor transport equilibration (VTE) technique we succeeded in the fabrication of single-phase γ-LiAlO$_2$ layer on (0001) sapphire substrate. X-ray diffraction indicated that the as-fabricated layer was highly textured with [100] orientation at proper VTE treatment temperature range from 1050°C to 1100°C. The main factors affecting the quality of the γ-LiAlO$_2$ layer were investigated by SEM and transmission spectra. These results reveal the possibility of fabricating γ-LiAlO$_2$ (100)// sapphire (0001) composite substrate for GaN-based epitaxial film by VTE.

Keywords: γ-LiAlO$_2$, composite substrate, vapor transport equilibration.

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GaN together with its alloys is receiving a great deal of attention lately due to its excellent physical and chemical properties. It is widely used in photoelectronic devices, high temperature and power electronic devices and high frequency microwave devices[1]. The large size GaN single crystal is difficult to grow because of its high melting-point and saturated vapor pressure, and the growth cost of the crystal is high[2]. GaN thin films deposited on foreign substrates were used instead of its single crystal in many fields, and sapphire is known as the most commonly used substrate for its merits of low cost, easy-growth technique and steady chemical and physical properties[3]. However, due to large mismatch in the lattice constants (~14%) and thermal expansion coefficient between GaN and sapphire substrate, devices show high defect densities which affect electrical and optical properties of the devices. Though the high defect densities can be decreased with some new techniques, they increased the cost of GaN films. Recently, LiAlO$_2$ has attracted more attention for its small mismatch (1.4%) in the lattice constant between [001] LiAlO$_2$ and [1 1 2 0] GaN, and M-plane GaN with nonpolar structures can be successfully grown on (100) γ-LiAlO$_2$. However, the high quality single crystal of LiAlO$_2$ is very difficult to grow due to the non-chemical-stoichiometric vaporization of Li[4,5]. It is very attractive to combine the merits of LiAlO$_2$ and Al$_2$O$_3$ to form a new-type substrate for GaN device manufacture. Many studies were focused on utilizing vapor
transport equilibration (VTE) technique to improve the crystal quality by using the activity of lithium\textsuperscript{[6–9]}. In this paper, the capabilities of the VTE method to produce high quality thin films on the sapphire substrate were investigated\textsuperscript{[10]}, and the $\gamma$-LiAlO$_2$ layer with a highly-preferred orientation of [100] on (0001) sapphire substrate was fabricated by VTE.

1 Experiment

In this experiment, we used Al$_2$O$_3$ crucible instead of platinum crucible which is usually used in VTE. Li$_2$O would react with Al$_2$O$_3$ at high temperature and form $\gamma$-LiAlO$_2$ protection layers on the inner wall of the crucible. These protection layers are stable and anticorrosive in lithium-rich atmosphere and the samples of VTE would not be contaminated. Small amount of Li$_2$CO$_3$ powder was put into Al$_2$O$_3$ crucible and sintered at 800—1000$^\circ$C for 72—100 h, then the $\gamma$-LiAlO$_2$ protection layer was formed on the inner wall of the crucible. Li$_2$CO$_3$ powder was loaded into the crucible. Several one-side well-polished (0001) sapphires were suspended above the surface of the powder to avoid direct contact with a platinum thread. The crucible was covered with an Al$_2$O$_3$ plate. This crucible was slightly buried in another bigger crucible with the powder of a mixture of Li$_2$O and LiAlO$_2$. VTE processing was carried out at 1000$^\circ$C, 1050$^\circ$C and 1100$^\circ$C for 72 h, respectively, the samples were treated at lithium-rich atmosphere, and then the furnace was cooled to room temperature. X-ray diffraction (XRD) analyses were performed using a MXP18AHF X-ray diffractometer for composition and preferred orientation of the new thin film. The SEM micrographs were obtained using a JSM-6360LA microscope of JEOL. The transmission spectra were measured by a UV/VLS spectrophotometer (Model-570 JASCO) at room temperature.

2 Results and discussion

Fig. 1 shows the XRD diffraction patterns of the surface of (0001) sapphire treated by VTE at 1000$^\circ$C, 1050$^\circ$C and 1100$^\circ$C, respectively. The results show that surface layer on sapphire treated by VTE at 1000$^\circ$C showed some diffraction peaks that were the peaks of $\gamma$-LiAlO$_2$ in Miller indices and no impurity phase was detected in the XRD patterns of layers on sapphire. The polycrystalline layers fabricated on the sapphire by VTE are pure phase of $\gamma$-LiAlO$_2$. As seen in fig. 1, the XRD patterns exhibited only one extremely strong peak compared with other peaks. This means that the layer is a $\gamma$-LiAlO$_2$ layer with a more highly-preferred orientation by VTE at 1050$^\circ$C and 1100$^\circ$C, and at the same time the other peaks were weakened or even disappeared. The results at different VTE temperature are different showing that growth of the $\gamma$-LiAlO$_2$ layers was based on the structure of sapphire crystal lattice in lithium-rich ambient and the orientation of $\gamma$-LiAlO$_2$ grains depended on the VTE temperature. In this experiment, it is clearly shown that the $\gamma$-LiAlO$_2$ layers by VTE at 1050$^\circ$C and 1100$^\circ$C have better highly-preferred orientation on [100] than at other temperatures, so a proper temperature range of $\gamma$-LiAlO$_2$ layer by VTE may be 1050—1100$^\circ$C.