Epitaxial Growth of α- using Suboxide MBE

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Abstract:

α-phase has an extremely high and extremely wide bandgap. These properties make it extremely promising material to be used in high voltage and high temperature electronics. In this experiment the films were grown on sapphire substrates using suboxide MEB. Once several films had been grown spanning across the desired range, the growth rates were increased. This was done by increasing the ozone pressure and decreasing the temperature of the substate. Films were created ranging from 0 to 100% aluminum incorporation. This allows for a film to be grown with a band gap ranging from 5.3 to 8.5 eV, with growth rates of over one μ/hr.

Summary:

α-phase has a very high and ultrawide band gap ranging from 5.3 to 8.5 eV.[1] In order to be able to tune this band gap it is necessary to be able to grow α-with 0 - 100% aluminum incorporation. However, the growth rate when using traditional MBE is severely limited. This is due to the growth rate being controlled by how fast the gallium can react with the oxygen. For this reason, instead of using traditional MBE, this experiment used suboxide MBE which eliminates the time constraining reaction step and changes the growth from being a reaction controlled growth to an absorption controlled growth.[2] This drastically increases the growth rate. All films were grown on A-Plane sapphire.

To start the research several films were grown with an extremely high percentage of aluminum. This was done because α-phase is metastable and switches back to the more stable β-phase, while is stable. Starting with films that have a high percentage of aluminum incorporation insured that the growths would be successful. From there the percentage of aluminum in the films was decreased and the percentage of gallium in the films was increased. This was done by increasing the flux of the source and decreasing the flux of the source.

Once several films containing a high percentage of aluminum and a high percentage of gallium had been successfully grown, the growth rate was increased. This was done by raising the ozone pressure and decreasing the substrate temperature.

Results and discussion:

Once a sample had been grown, the location of the film peak was found using x-ray diffraction. The percentage of aluminum in the film was then calculated using Vegard's Law.[3] Growth conditions were then altered to reduce the percentage of aluminum in the film. It was found that as the substrate temperature was decreased, there was a corresponding decrease in the percentage of aluminum. This can be seen in figure one. Also, as the aluminum flux was decreased there was a corresponding decrease in the percentage of aluminum in the film and when the gallium flux was increased there was a higher percentage of gallium in the film.

Films were created ranging from 0 to 100% aluminum incorporation. This allows for a film to be grown with a band gap ranging from 5.3 to 8.5 eV, with growth rates of over one μ/hr.

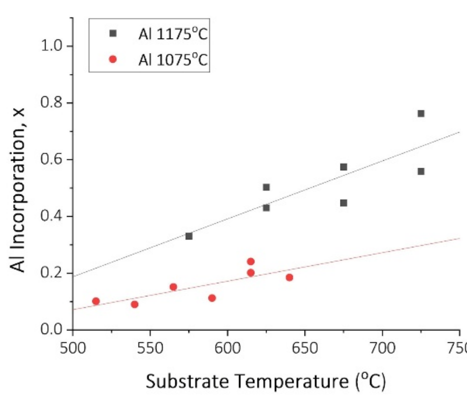

Figure one shows how decreasing the substrate temperature or decreasing the aluminum flux will lower the aluminum incorporation. At Al 1175 °C the gallium flux was 2E14 $cm^{-2}s^{-1}$ and at Al 1075 °C the gallium flux was 5E14 $cm^{-2}s^{-1}$ [4]

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References:

1. Chen, Z. et al. Epitaxial growth of (AlxGa1-x)2O3 thin films on sapphire substrates by plasma assisted pulsed laser deposition. *AIP Advances*. Advance online publication. https://DOI:10.1063/5.004623
2. Vogt, Patrick et al (2020). Adsorption-Controlled Growth of Ga2O3 by Suboxide Molecular-Beam Epitaxy.
3. R. Jinno, et al. Sci Adv. 7, eabd5891, (2021).
4. Steel, Jacob, Epitaxial Growth of
5. α-$(Al_xGa_{1-x})_2O_3$ by Suboxide Molecular Beam Epitaxy, 8/8/2022, Cornell University