The Sapphire Regime: Realizing Si-Doped α-$(Al_xGa_{1-x})_2O_3$ Films with $E_g > 7$ eV with *S*-MBE

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Introduction

For high power devices, the superlinear dependence of $V_{Br} \propto E_g^{\sim 5.5}$ has led to research interest in ultrawide bandgap (UWBG) semiconductors ($E_g \gtrsim 3.5$ eV). One emerging candidate UWBG is α-$(Al_xGa_{1-x})_2O_3$ because it has a tunable E_g from 5.4 – 8.6 eV that is predicted to have shallow donors over the range of 5.4 – 7.5 eV, which is higher than any known semiconductor. Achieving active donors, even at the limit of $x = 0$, has proven to be extremely difficult and the first successful demonstration by MBE was only shown last year, 2024, and had very limited conductivity.[1] As we had previously used *S*-MBE to grow α-$(Al_xGa_{1-x})_2O_3$ with the best structural quality and α-Ga_2O_3 with the highest mobility and conductivity of any method, we now extend the technique to dope α-$(Al_xGa_{1-x})_2O_3$ thin films.[2]

Experimental Procedures

To grow these α-$(Al_xGa_{1-x})_2O_3$ films, an *S*-MBE Veeco Gen10 MBE system was fitted to provide 80% distilled O_3 + 20% O_2 as the oxidant gas and was loaded with three pumped, retractable effusion cells containing elemental aluminum, Ga_2O, and SiO_2 sources. The growth procedure was a three-step method where a relaxed α-$(Al_xGa_{1-x})_2O_3$ buffer layer was grown at a relatively high substrate temperature (T_{sub}) of ~725 °C, a second layer was grown at a moderate T_{sub} of ~550 °C, and the doped overlayer was grown at a relatively low T_{sub} of ~480 °C.

Results and Discussion

By altering the two-step procedure that we utilized to achieve record electrical transport properties in α-Ga_2O_3 to be a three-step procedure, as described above, we can reliably achieve conductive Si-doped α-$(Al_xGa_{1-x})_2O_3$ thin films with *S*-MBE. The technique has so far produced conductive α-$(Al_xGa_{1-x})_2O_3$ with x as high as 0.62, which corresponds to an E_g of 7.20 eV. This is the highest E_g of any semiconductor that has been successfully doped to date. For $x \geq 0.42$ ($E_g \geq 6.5$ eV), we exhibit a $10^8\times$ advantage in conductivity over the previous best results.[3]

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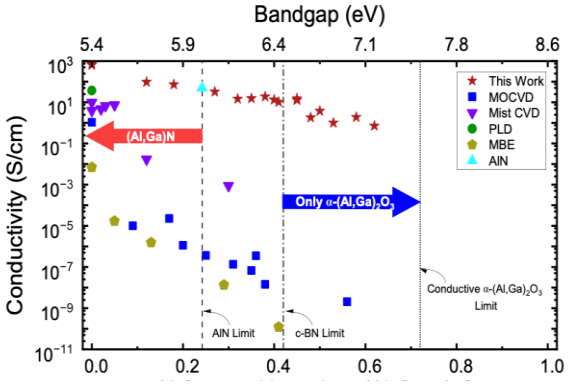

Figure 1. A plot of the conductivity in S/cm versus eV and x. The highest published conductivities for AlN and α-$(Al_xGa_{1-x})_2O_3$ films grown by MOCVD, mist CVD, PLD, and MBE are included.[1][3]-[8]

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