MBE Selective Area Growth of N-polar GaN Nanowires

CNF Project Number: 2470-16
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Primary CNF Tools Used: JEOL 6300, Oxford 81 RIE, CVC SC4500 e-gun evaporation system

Abstract:
In this work, the impact of various growth parameters, and titanium (Ti) mask preparation on the selective area growth (SAG) of GaN nanowires by plasma-assisted molecular beam epitaxy (PAMBE) is discussed. By varying the substrate temperature, highly selective nanowire growth was found to occur for substrate temperatures near 915°C. Adjusting the V/III ratio provided control over the lateral growth rate of the nanowires, with the smallest rate being 1 nm/hr for a V/III ratio of six. Changing the N$_2$ flow rate gave control over the vertical growth rate. The highest rate of 94 nm/hr was achieved using a flow rate of 2.5 sccm. Finally, improper Ti etch conditions lead to the formation of fluoropolymers that prevent SAG.

Summary of Research:
The growth of gallium nitride (GaN) nanowires has historically been achieved through a self-aligned process using silicon (Si) as a substrate [1]. Since then, growth has moved to a multitude of substrates including SiO$_x$ [2] and Ti [3]. However, there is no direct control over the uniformity and diameter of the grown wires. SAG solves this by using a mask to limit the growth of wires to pre-defined regions giving complete control over all aspects of the nanowires.

Patterning of the mask began with evaporation of 7 nm of Ti onto bulk N-polar GaN substrates via the CVC evaporator. Following metal deposition, a mask consisting of holes and lines (for wires and fins, respectively) is defined using electron beam lithography. Use of the JEOL 6300 enabled holes of diameters down to 20 nm to be made. Lastly, the Ti was etched using CF$_4$ chemistry in the Oxford 81 RIE system. Figure 1 shows a hole that is formed in the Ti.

PAMBE growth of the nanowires was done in a Veeco Gen Xplor system. Ga atoms were provided by an effusion cell, while atomic nitrogen was supplied from a remote RF plasma source. Prior to growth, samples were nitridated at 400°C for 10 minutes. Growth proceeded at temperatures ranging from 880-925°C, under nominally nitrogen rich conditions. In this work, the V/III ratio is defined as the impinging active N flux divided by the impinging Ga flux, both measured as partial pressure. Plasma power was held constant at 400 W for all growths.

For substrate temperatures below 900°C, all selectivity in the growth was lost as the Ga adatoms not involved in the nanowire growth do not have sufficient energy to desorb before nucleating on the Ti mask. Increasing T$_{sub}$ past 900°C enabled selective growth. At, 925°C or higher, the nanowires experience incomplete growth.

Figure 1: SEM of hole in Ti mask post RIE etch. Oblong shape is owed to slight charging during e-beam exposure.
as the GaN decomposition rate exceeds the growth rate. Ideal growth conditions were found to occur at 915°C, shown in Figure 2. It can be seen that the growth is limited to only those locations where there is a hole in the Ti, with the mask itself seeing little to no parasitic growth.

Increasing the V/III ratio from 6 to 12 led in a decrease in the wire lateral growth rate from 15 nm/hr to 1 nm/hr. Changing the N₂ flow rate directly affects the vertical growth rate. A flow of 1 sccm resulted in a rate of 50 nm/hr, and increasing the flow to 2.5 sccm increased the rate to 94 nm/hr. As higher N₂ flow rates create larger growth chamber pressures, $1.8 \times 10^{-5}$ torr at 1 sccm vs $2.3 \times 10^{-5}$ at 2.5 sccm, the desorption of Ga is suppressed, increasing its diffusion length on the Ti, which translates to higher Ga incorporating into the wire.

During the RIE etching of the mask, if the etch conditions are not ideal, fluoropolymers will form at the etch edge, leading to a local increase in the surface roughness, shown in Figure 3. This local roughening severely limits the adsorption of Ga into the etched hole, causing Ga to pool at the edge instead. During growth, this accumulation of Ga serves as a nucleation site, leading to the ring like shape that is shown in Figure 4. At this point SAG cannot be recovered.

In conclusion, PAMBE SAG of GaN nanowires was achieved using a 7 nm Ti mask. By fine tuning the growth conditions, a vertical growth rate of 94 nm/hr was obtained while lateral growth rates were suppressed to 1 nm/hr resulting in ~ 200 nm tall wires that are 74 nm in diameter. These thin wires will enable strong electrostatic control in FETs while enabling high quality tunneling based devices due to their intrinsic high material quality.

References: