Technical Note

High breakdown M–I–M structures on bulk AlN

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Abstract

The breakdown characteristics of metal-AlN-metal structures are reported as a function of contact diameter. The bulk AlN was grown by a HVPE method, resulting in a resistivity of $4 \times 10^8$ $\Omega$cm. Front-side contact diameters of 175–600 $\mu$m were fabricated, displaying breakdown voltages up to $\sim 6300$ V at 25 $^\circ$C. Breakdown appeared to initiate at internal surfaces related to grain boundaries or cracks in the material. The results indicate the great promise of the Al(Ga)N system for high power rectifiers. © 2002 Published by Elsevier Science Ltd.

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There is a strong interest in developing wide band gap power devices for use in the electric power industry [1–4]. As this industry continues to be de-regulated, there are increasing numbers of transactions on the power grid in the US. A major problem in the current grid is momentary voltage sags, which affect motor drives, computers and digital controls. A system for eliminating power sags and switching transients would dramatically improve power quality. Some desirable attributes of next generation, wide gap power electronics include the ability to withstand current in excess of 5 kA and voltages in excess of 25 kV, provide rapid switching, maintain good thermal stability while operating at temperature above 250 $^\circ$C without bulky heat-dissipating systems. In particular, the absence of Si devices capable of application to 13.8 kV distribution lines (a common primary distribution mode) opens a major opportunity for wide gap electronics. The AlGaN materials system is attractive from the viewpoint of fabricating unipolar power devices such as rectifiers because of its large band gap and relatively high electron mobility. A number of groups have reported excellent high breakdown performance from both lateral and vertical geometry GaN and AlGaN Schottky and p-i-n rectifiers, both for epilayers grown on sapphire substrates and for free-standing GaN quasi-substrates [4–12]. While lateral rectifiers on epi-AlGaN have shown reverse breakdown voltages up to 9.7 kV [12], the maximum breakdown in free-standing GaN is $\sim 700$ V [13].

In this letter, we report on the breakdown characteristics of free-standing AlN substrates. This data gives some idea of the voltage-handling capability of the nitride materials system at the extreme of band gap (i.e. pure AlN). Since this material is expected to be insulating we fabricated metal-insulator–metal (M–I–M) structures rather than true rectifiers.

The bulk AlN was $\sim 200$ $\mu$m thick and was grown by the hydride vapor phase epitaxy (HVPE) method [14]. E-beam deposited full-area back contacts of Ti/Al/Pt/Au were placed on the N-face, while front-side contacts were e-beam deposited Pt/Au with diameters 125–600 $\mu$m. No edge termination methods were employed around the periphery of the front-side contacts. The
current–voltage ($I$–$V$) characteristics were recorded at 25 °C using a high-voltage power supply and sensitive ammeter.

Fig. 1 shows an optical micrograph (top) and plan view transmission electron micrograph (bottom) from the as-grown AlN. A network of crystalline defects and cracks were visible in the material. The defect density was $\sim10^7$ cm$^{-2}$, as measured by TEM.

![Optical micrograph of AlN surface (top) and plan view TEM (bottom).](image1)

Fig. 1. Optical micrograph of AlN surface (top) and plan view TEM (bottom).

Fig. 2. $I$–$V$ characteristics at low bias.

The low bias $I$–$V$ characteristics measured on 225 μm diameter contact samples are shown in Fig. 2. In this region the resistance is $\sim2 \times 10^{10}$ Ω, corresponding to a resistivity of $\sim4 \times 10^8$ Ω cm assuming the sample is fully depleted. This confirms the insulator nature of the AlN, negating the possibility of passing current through the material in the forward-bias direction.

Fig. 3 shows reverse $I$–$V$ characteristics from samples with two different contact diameters. Note the very high

![Reverse $I$–$V$ characteristics from samples with different front-side contact diameters.](image2)

Fig. 3. Reverse $I$–$V$ characteristics from samples with different front-side contact diameters.
breakdown voltage. We can estimate the critical electric field for breakdown, $E_c$, from the relationship
\[ V_{PT} = E_c W_P = \frac{qNW_P^2}{2\varepsilon_S} \]

where $W_P$ is the stand-off region thickness (assumed to be 200 μm), $N$ the doping concentration (assumed to be $<10^6$ cm$^{-3}$ for an insulator) and $\varepsilon_S$ is the AlN permittivity. From this relation, we obtain $E_c \sim 3.3 \times 10^5$ V cm$^{-1}$. This is clearly dominated by breakdown at internal surfaces and therefore the effective stand-off region thickness is much less than the sample thickness and the intrinsic $E_c$ of AlN is much larger than the value found in our samples.

Fig. 4 shows the $I$–$V$ characteristics in both the forward and reverse directions. As expected there is no rectification and the sample behaves as back-to-back diodes. Fig. 5 shows the reverse breakdown voltage (defined as the voltage for a current density of 0.01 A cm$^{-2}$) as a function of contact area. The breakdown voltage actually increases with contact size before decreasing at the largest size investigated here. This is a promising sign for future AlGaN bulk rectifiers with low carrier density. The currently available GaN bulk rectifiers have relatively high background carrier concentrations and defect densities, leading to low breakdown voltages [15].

Finally, Fig. 6 shows the reverse current density at 4200 V as a function of either front-side contact diameter (top) or area (bottom). Since the current is not proportional to either the contact perimeter (surface currents) or the area (bulk current), we confirm the breakdown is dominated by the internal surfaces in the material.

In summary M–I–M structures fabricated on bulk AlN show the excellent potential of the Al(Ga)N system for power rectifiers.

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References