HBT on LEO GaN

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Dramatic progress in GaN electronics has led to increased interest in bipolar transistors. Although there have been reports of GaN bipolars from several groups, [1,2,3,4] the development of the GaN bipolar transistor is still in its fundamental stages. In the case of GaN, the usual correlation between common base, Gummel, and common emitter characteristics does not exist due to significant collector-emitter leakage, leaving only the common emitter characteristic as a reliable measure of DC device performance. We identify the source of this leakage as threading dislocations and clarify the effect of this leakage on the DC characteristics of these transistors. Further, we conclude from various growth structures and methods of device fabrication that the lifetime of electrons in the neutral base is currently the limiting factor in the performance of GaN NPN transistors.

Typical GaN material has high threading dislocation densities, 10^7 - 10^9 cm^{-2}, due to its lattice mismatch with the substrate, typically Sapphire or SiC. Previous studies have shown that threading dislocations are a major source of leakage in pn junctions on GaN [5], and it has been shown that in optoelectronic applications, dislocated material provides a leakage path through pn junctions [6]. To study the effects of threading dislocations on GaN bipolar transistors, we have fabricated devices on material grown using the lateral epitaxial overgrowth technique, LEO. To our knowledge this is the first demonstration of GaN bipolar transistors grown on non-dislocated material. The LEO substrate allows us to compare devices grown on material with a negligible dislocation density with those grown on a standard template. We have demonstrated common emitter characteristics for an HBT structure grown by MBE on an MOCVD grown LEO substrate on sapphire. The threading dislocation density of the window, or dislocated region is approximately 10^8 cm^{-2}, while the dislocation density on the wing or non-dislocated region is negligible [7].

The LEO substrate was grown by MOCVD on sapphire. SiO_2 was patterned on an MOCVD template, and GaN was selectively regrown over and around the SiO_2 mask (Figure 1). The MOCVD growth was completed with the growth of an N^+ GaN subcollector. The remainder of the device was grown by plasma source MBE (Figure 2) to avoid junction placement variations caused by the Mg memory effect in MOCVD reactors. The devices were processed using a Cl_2 RIE etch to access the base and collector layers, and contacted using standard lift-off techniques (Figure 3). The devices had a base thickness of 100 nm, and a base doping of approximately 5 x 10^{17} cm^{-3}. The heterojunction emitter was $Al_{0.1}Ga_{0.9}N$: Si (10^{18} cm^{-3}) graded to GaN:Si for the emitter contact.

We observed a large reduction (3-4 orders of magnitude) in emitter-collector leakage for devices grown on the non-dislocated material (Figure 4). We present common emitter characteristics of the HBTs (Figure 5). We did not find a significant improvement in current gain suggesting that for these highly doped layers threading dislocations are not the limiting factor for minority carrier lifetime. A dependence of the leakage on base dopant (Mg) concentration, as well as dislocation density suggests that the dislocations are compensating a surrounding region of the base, providing low-barrier channels for emitter-collector electron flow. Preliminary simulations confirm our hypothesis.

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[5] Kozodoy et al. *Appl. Phys. Lett.*, vol.73, (no.7), AIP, 17 Aug. 1998.
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[7] Fini et al. *Appl. Phys. Lett.* 75, 1706 (1999).

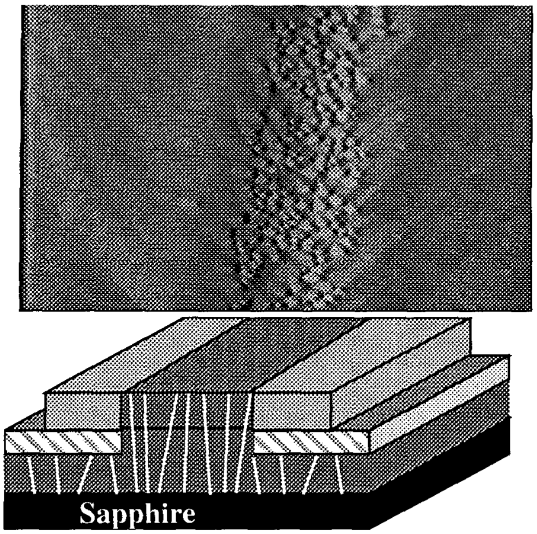

Figure 1: AFM of wing vs. window region of LEO substrate showing spiral growth of MBE around screw-type dislocations. This growth mode is not observed in wing regions

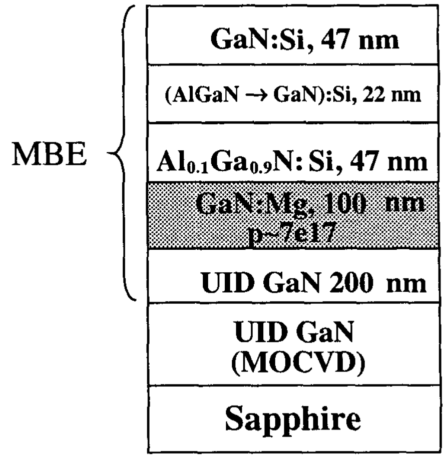

Figure 2: Growth structure of HBT on LEO GaN

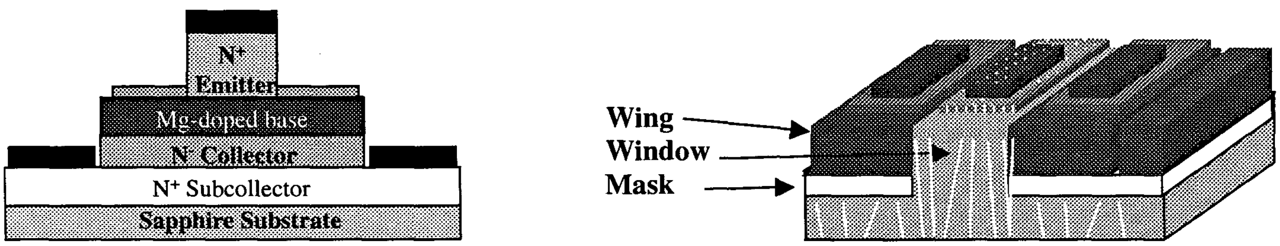

Figure 3: Processed structure schematic (left) and placement (right) on LEO wing and window regions. Dislocatio propagate through window regions, but are blocked by SiO2 under wing regions.

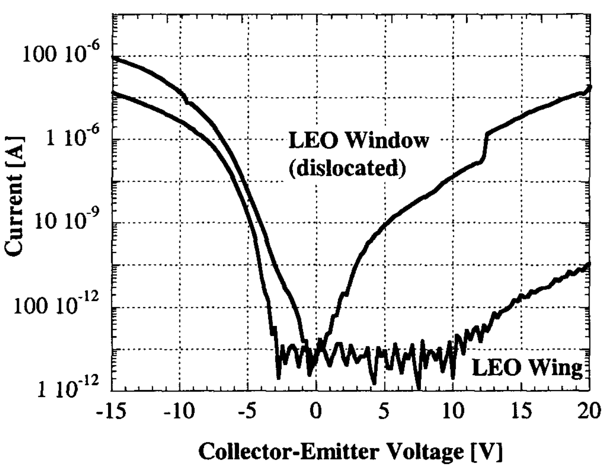

Figure 4: Common emitter characteristics of AlGaN/GaN HBT on LEO substrate. The device shows gain of ~2.5 with operation to 20V.

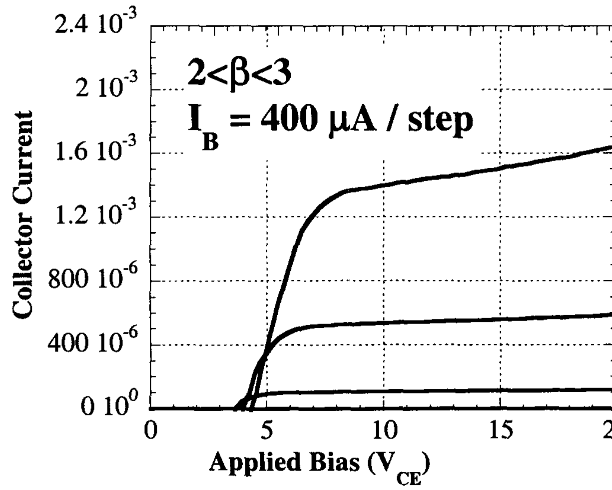

Figure 5: Emitter-collector leakage of adjacent HBTs on LEO window (dislocated) and wing regions. Log plot shows reduction of leakage by several orders of magnitude