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GaN BASED POWER SEMICONDUCTOR DEVICES

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Introduction

The newly emerging semiconductor material GaN has great potential for high voltage power electronics and high-temperature applications because of its attractive material properties such as wide bandgap energy (~ 3.44 eV), high electric breakdown field strength (~ 3.5 MV/cm), and high thermal conductivity (~1.3 W/cm.K). A detailed comparison of the material properties of GaN with other existing semiconductor materials can be found in [1-4]. The material, (4H)SiC has almost similar properties like that of GaN, but the former has carrier life time in the order of µs whereas the latter has in the order of ns and hence, the switching performance of the semiconductor device is far better for GaN material. Also, GaN is a direct bandgap material and very much optically efficient. One of the issues in the field of power electronics is the noise due to the presence of electro-magnetic interferences (EMI) which interfere the link between controlling switch and high voltage power stage and hence significantly affect the efficiency of the power converters. Thus, if the controlling switch is triggered by optical means, EMI immunity between the controller and the high voltage power stage is realized and also a complete electrical isolation is ensured. GaN material has very high optical absorption coefficient [1-4] and is very much optically efficient in comparison to other materials. So, if the switches in the power converters are made of GaN material and are controlled by optical means, EMI's presence would be negligible.

In the present work, the author compiles some of the proposed GaN-based semiconductor device structures for high power electronics applications. The simulation results for the high voltage blocking capacity and transient response characteristics are provided in the results and discussion section. ATLAS/Mixedmode module of the semiconductor device simulator from Silvaco Inc. [5] is used for the simulation purpose.

Power semiconductor device structures and Description

Fig. 1 shows a GaN-AlN-(4H)SiC optically triggered vertical NPN power device. A layer of AlN is introduced to avoid the lattice mismatch of ~3.4% between GaN and (4H)SiC. The on- and off-state of the device is controlled by exciting the P-base GaN region using the 350 nm UV short-pulse of 15 W/cm^2 with a switching frequency of 200 KHz

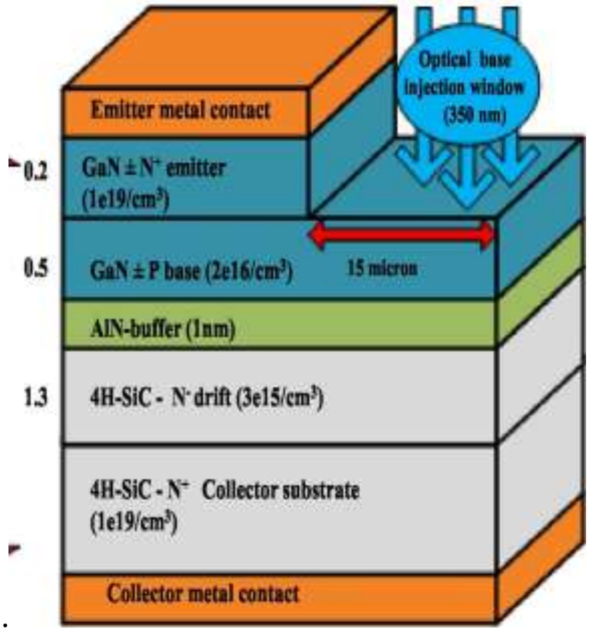

Fig. 1: Structure for GaN-AlN-(4H)SiC optically triggered vertical NPN power device.

Fig. 2. shows an optically triggered latch-free GaN Thyristor. The structure contains two active devices.: 1) controlling power NPN device, and 2) main Thyristor device. An optical pulse of wavelength 350 nm and 50 W/cm^2 with a switching frequency of 200 KHz , controls the vertical NPN device and triggers the Thyristor as well.

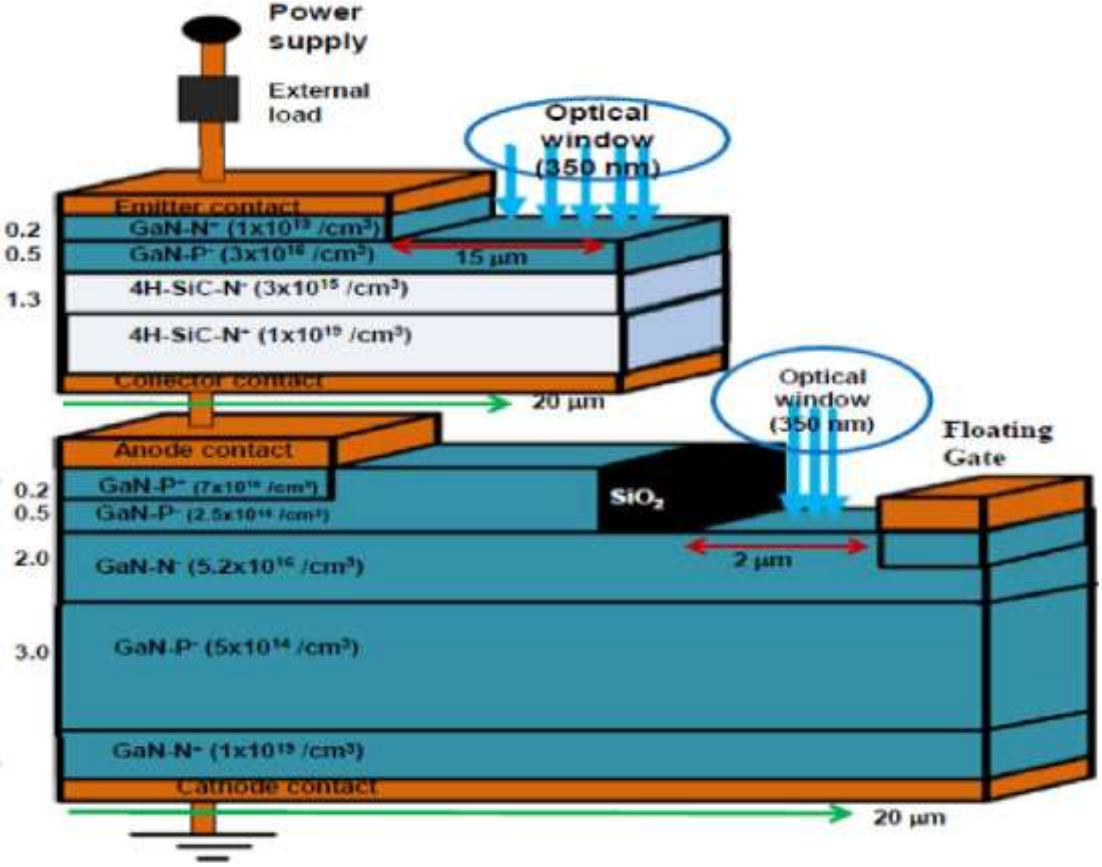

Fig. 2: Structure for optically triggered GaN power Thyristor.

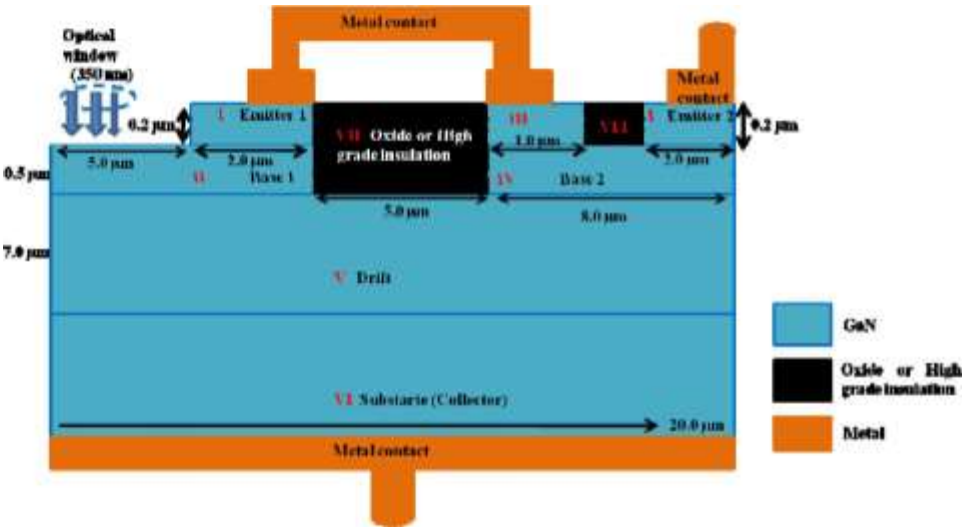

Fig. 3: Structure for optically triggered GaN Darlington power transistor.

Fig. 3 shows a GaN Darlington power transistor structure. The switching action of the device is controlled by exciting the base of the first transistor (Base 1) with UV light source of 350 nm wavelength and light intensity of 5 W/cm^2 with a switching frequency of 200 KHz.

Fig. 4 shows a lateral power device structure where a layer of AlN is placed over Si and then the GaN layers are placed over AlN making it thermally robust. An optical pulse of wavelength 350 nm and 50 W/cm^2 with a switching frequency of 200 KHz , controls the switching action of the device.

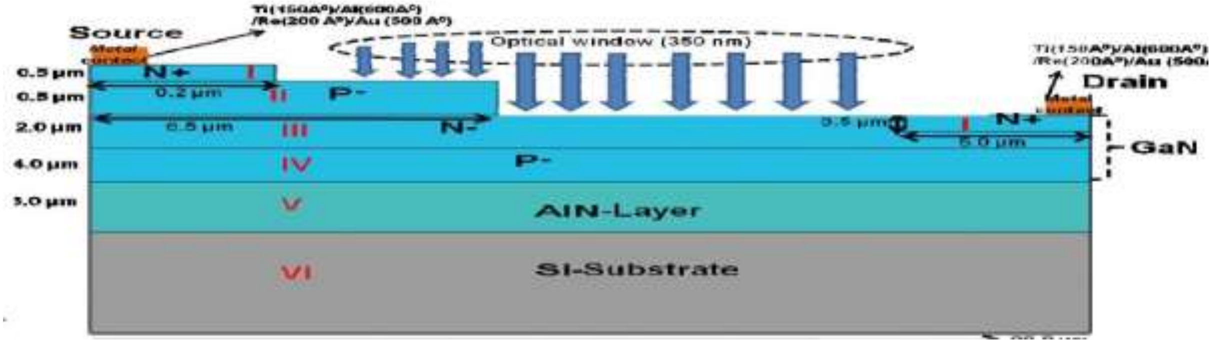

Fig. 4: Structure for optically triggered GaN lateral power device.

All the above device structures (Figs. 1-4) follow the principle of photoconductivity [6], thereby creating the photogenerated carriers (as because GaN is a direct bandgap semiconductor material). The structural dimensions and doping densities shown in the structures are for the optimized performance.

Simulation Results and Discussions

Fig. 5(a) shows the high-voltage blocking capacity of the power device shown in Fig. 1. We can see that the device can block more than 1200 V. The rise and fall times for the device are 0.04 µs and 0.2 µs, respectively and is shown in Fig. 5(b) which depicts the transient response. The device generates a current up to ~1 A.

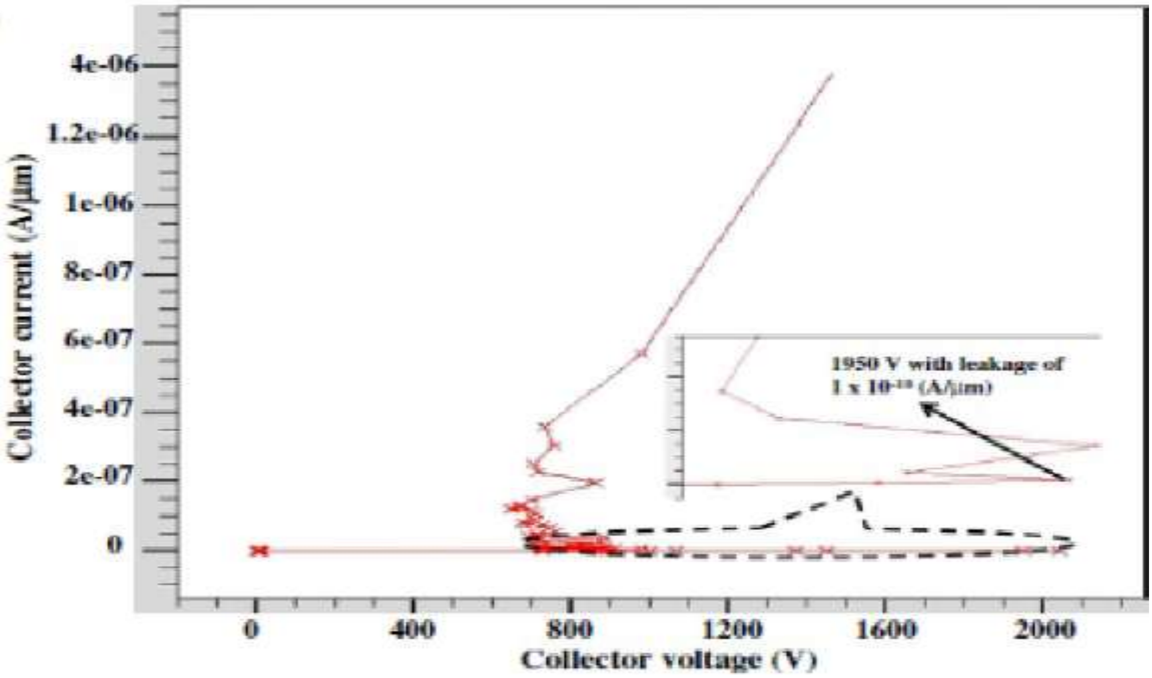

Fig. 5(a): Break-down voltage characteristics for the device shown in Fig. 1.

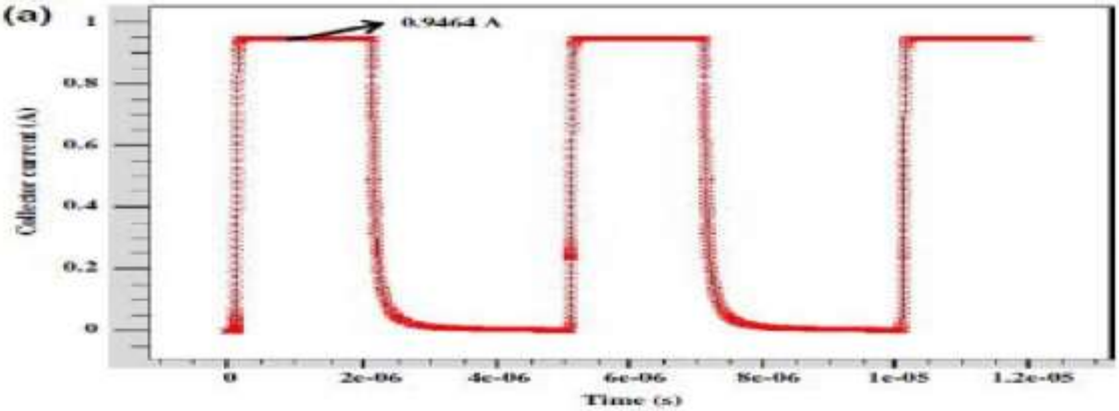

Fig. 5(b): Transient response for the device shown in Fig. 1.

Fig. 6(a) shows the high-voltage blocking capacity of the power Thyristor device shown in Fig. 2. We can see the device can block more than 500 V. The transient response for the integrated device is shown in Fig. 6(b). The turn-on delay and the rise times for the device are 0.025 µs and 0.043 µs, respectively. The device generates a current more than —1 A.

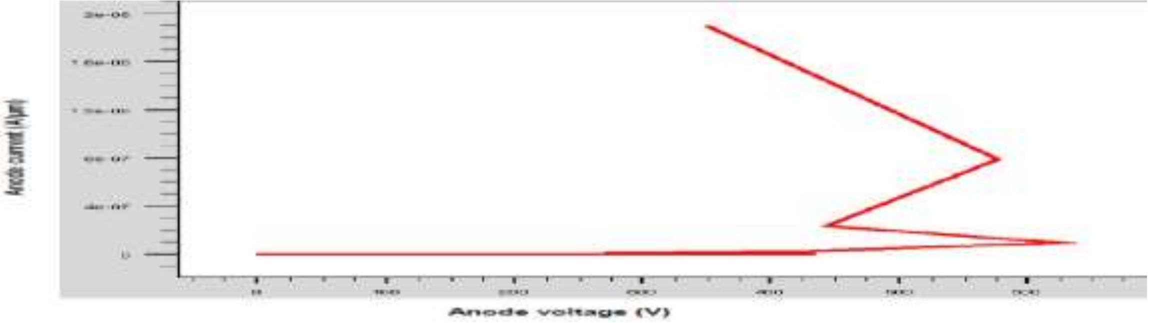

Fig. 6(a): Break-down voltage characteristics for the Thyristor shown in Fig. 2.

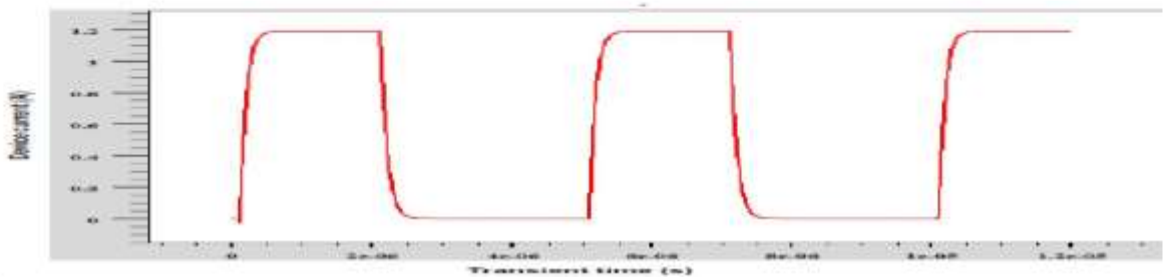

Fig. 6(b): Transient response for the integrated power device shown in Fig. 2.

Fig. 7(a) shows the high-voltage blocking capacity of the power Darlington transistor device shown in Fig. 3. We can see the device can block more than 5000 V. The transient response for the device is shown in Fig. 7(b). The device generates a current more than —10 A.

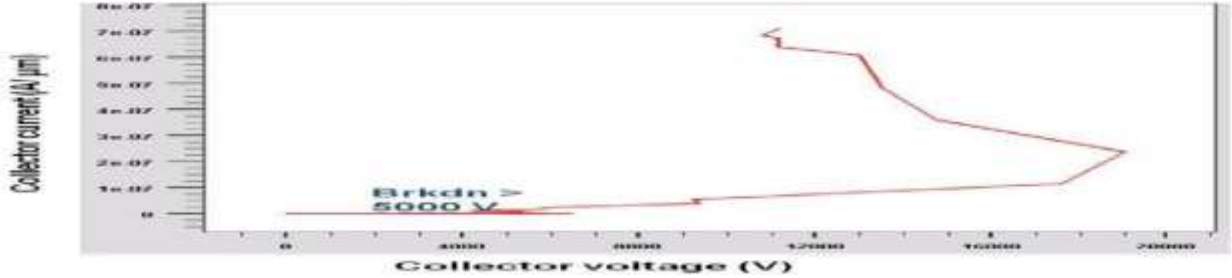

Fig. 7(a): Break-down voltage characteristics for the power device shown in Fig. 3.

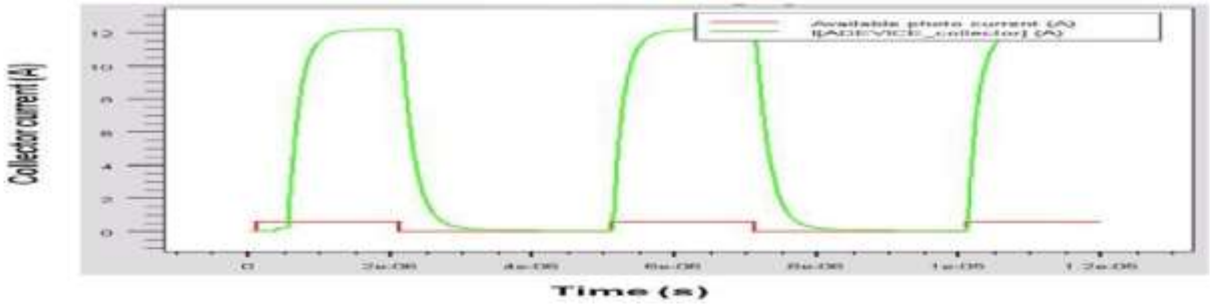

Fig. 7(b): Transient response for the power device shown in Fig. 3.

Fig. 8(a) shows the high-voltage blocking capacity of the lateral power device shown in Fig. 4. We can see that the device can block more than 1500 V. The transient response for the device is shown in Fig. 8(b). The device generates a current more than ~15 A.

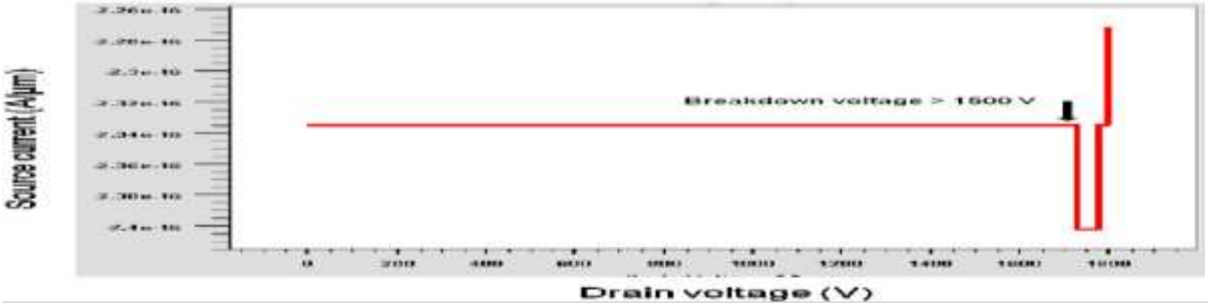

Fig. 8(a): Break-down voltage characteristics for the lateral power device shown in Fig. 4.

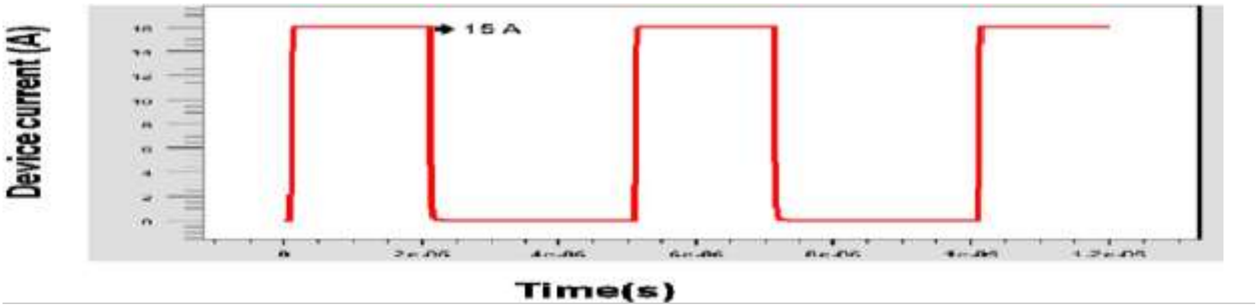

Fig. 8(b): Transient response for the lateral power device shown in Fig. 4.

Summary

From the simulation results, it can be said that GaN material is the most optimized semiconductor material which can be used for fabricating the devices not only for low-voltage electronics applications but also for high-power/high-voltage power electronics applications as switches in various converter topologies, due to meritorious material properties like shorter carrier life time, high critical electric field strength, and good optical absorption coefficient (very good for optically controlling the devices, to have no electromagnetic interferences).

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