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NEW GALLIUM NITRIDE TRANSISTOR TECHNOLOGIES

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ABSTRACT

Gallium Nitride High Electron Mobility Transistors GaN HEMTs represent the most interesting new generation of heterojunction devices owing to their much higher power densities as compared with other competing technologies. This feature, combined with higher values of the breakdown voltage, provides significant performance improvements in many radiofrequency, microwave and power electronics applications fields, which can take advantage of the combination of higher power density, higher efficiency, wider bandwidth offered by GaN based devices as compared to GaAs and Silicon based transistors.

Keywords: GaN HEMTs; Field Plate; RF Power Transistors; Direct Bandgap; Current Collapse.

I. INTRODUCTION

The increasing level of interest in GaN power devices is due to the favorable features of this new compound semiconductor, which make it the most promising material for electronic devices.

Among all the Group III-V materials, GaN distinguishes itself for the large value of its bandgap energy (i.e. 3.4eV), which is two or three times higher than other semiconductors like silicon and GaAs [1]; moreover Gallium Nitride is characterized by a direct bandgap, as well as high electron mobility.

These favorable features can be conveniently exploited in high performance RF Power Amplifiers and very high efficiency Power Electronics applications and systems. As a consequence Gallium Nitride technology is attracting more and more the attention of the most important semiconductor brands, which envisage the possibility of managing higher energy levels in an extremely effective and efficient way, minimizing the power loss.

II. CHARACTERISTICS

GaN devices exhibit at the same time high conductivity value and extremely fast switching properties [2], so they are able to reduce both conduction loss and frequency loss.

Indeed low output capacitance and Drain to Source resistance R_{DS-ON} make GaN HEMT transistors suitable also for switching mode amplifiers and digital power supply.

The R_{DS-ON} is remarkably lower than in other semiconductor devices which exhibit comparable breakdown voltage values, as shown in Fig.1.

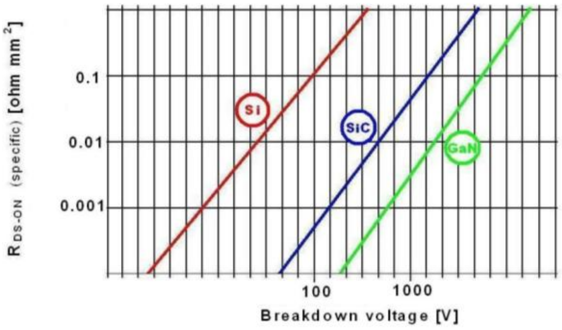

Fig.1 R_{DS-ON} Vs. breakdown voltage for different semiconductors

Besides the electrical parameters of a semiconductor material, thermal conductivity is another important feature because it represents how easily the power loss can be extracted from the component: if the material is characterized by low thermal conductivity it is not simple to cool down the device, thus

partial degradation of the devices performance can result in case of high-temperature applications; GaN based devices show a maximum junction temperature of 225°C which is much higher than 150°C, typical of silicon devices.
These characteristics allow GaN based devices to work well in hostile environments, without showing de-rating and MTTF decrease.

III. CHOICE OF THE SUBSTRATE MATERIALS

In the early days GaN crystals were grown on several substrates: diamond, silicon carbide (SiC), sapphire and different insulators have been used, thanks to their very similar cooling speed and comparable value of volume reduction coefficients. After that, many kind of substrates have been tried, also of a hybrid type, in order to find alternative materials cheaper than SiC on which GaN can be easily grown.

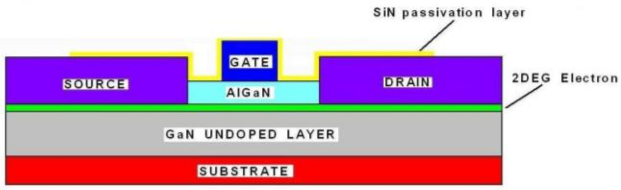

Fig.2 GaN HEMT cross section

The structure depicted in Fig.2 is replicated many times upon the substrate in order to build a power device.

Currently, GaN epitaxial growth technology, allows the production of GaN on silicon [3] to built epitaxial heterostructures, using a kind of process that is compatible with the CMOS technology: this development permits to use large diameter silicon wafer substrates, up to 12 inches.

The state of the art regarding hetero-epitaxy of GaN and AlGaN based on Metal Organic Chemical Vapor Deposition (MOCVD) allows GaN to be grown on silicon substrates [4], overcoming the mismatch due to the difference between the thermal expansion coefficients of GaN and Silicon.
Recently this issue has been conveniently solved by inserting an intermediate stress-mitigating transition layer that is grown by ammonia molecular beam epitaxy on Silicon; this solution has made possible to boost the commercial offer of GaN-on-Si products, which are now reaching a good level of competitiveness against the other semiconductors.

For instance, in the new RF devices, performance improvements are combined with the reliability, low cost and ease of use advantages of industry-standard silicon wafers.

Currently, broadband applications represent the heart of market for GaN RF power devices. The higher operating voltage and the increased power density results in significant performance advantages for the GaN devices in this field of applications.

IV. INNOVATIVE STRUCTURES

In order to improve the level of performance achievable by GaN HEMT transistors, a novel type of architecture is under development, based on the addition of a further electrode in the structure called “Field Plate” which is placed between the gate and the drain, as depicted in Fig.3.

This new electrode (FP) is able to modulate the electric field distribution profile, reshaping it across the channel of the device.

Thanks to the presence of the FP a decrease of the electric field peak value can be obtained thanks to the depletion zone that is formed under the FP electrode.
As a consequence, the value of the breakdown voltage of the devices increases.

Without Field Plate, the electric field profile exhibits a very high single peak placed nearby the drain side of the gate edge; instead, analysing the electric field distribution in devices equipped with this kind of electrode, the electric field profile shows two peaks lower if compared with the only one present in the standard devices without Field Plate: the first peak is placed in the same position (but it is quite smaller), the second one is located at the drain side of the FP edge.

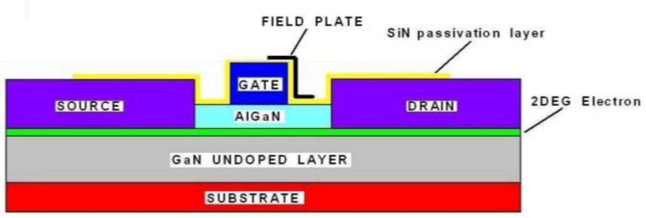

Fig.3 GaN HEMT cross section with Field Plate electrode

Thanks to the Field Plate integration, the modulation spreads the peak of the electric field obtaining a reduction of its concentration around the gate edge (at the drain side) and consequently it is possible to achieve a significant improvement in terms of electric performances. Devices with very high reliability, which can reach a MTTF of more than 20 years, can be realized.

In practice, by means of the Field Plate electrode in GaN devices, a large increase of the breakdown voltage is achieved, which allows improvements of the power density from 10W/mm to 40W/mm and even more.

Another benefit is the reduction of the surface trapping effects; this issue can limit the output power compromising performance.

Last, the FP helps to reduce the drain current collapse phenomenon. If the device is affected by this issue, the level of the drain current attainable in a RF application is lower than the level achieved in DC condition: due to this fact the output power during RF operations is reduced [5] and the performances are worse if compared to the DC value.

This kind of phenomenon happens particularly in high voltage applications; especially in this case the Field Plate plays a key role because it helps to improve the large signal RF performances.

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