Innovative substrate solutions for GaN applications: the Smart-Cut® approach

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Introduction

Wide Band Gap (WBG) materials such as SiC and GaN are today the most attractive materials for out of silicon world applications such as high power, high frequency, high temperature and short wavelength optoelectronic applications. These applications are today pushing bulk material developments required to trigger their use at an industrial level. In this article, we propose new innovative substrates solutions using the Smart-Cut process, dedicated to above listed Wide Band Gap applications with a special focus on GaN. The Smart-Cut® technology is now recognized as a technology of choice for the development and manufacturing of thin film substrates whose interest relies on the gain of performance they can add to the applications compared to bulk approaches. The most popular example is SOI substrates (Silicon On Insulator) which are now used by most IC manufacturers who see in SOI substrates the opportunity to develop new high performance devices [1]. SOI substrates are also the first example of future thin film composite substrates that will bring even higher performance enhancements in the devices of the future. For non-silicon applications and in particular, for wide band gap materials, bulk substrate issues are still far from being completely solved for SiC applications as well as for GaN devices. In this article, we particularly focus on innovative substrate solutions for GaN growth.

Substrate solutions for GaN applications

Today, the GaN industry mainly relies on SiC and sapphire substrates for development and industrial production of blue, green and white high brightness LEDs for lighting as well as blue, and violet laser diodes for DVD applications. The reasons of the use of these two substrates have been already extensively discussed [2]. Nevertheless, even if these solutions are today pushed to propose products on the market, substrate issues are not solved and today limit device performance. The first big issue is epitaxial layer quality. Whatever GaN is grown on SiC or sapphire, blanket epilayers exhibit around 10^8 –10^9 dislocations / cm² due to lattice and CTE mismatches. This high level of crystalline defects may rapidly be seen as an obstacle as device performances need to be improved. This limitation has already been identified for more stringent application than LEDs such as high lifetime laser diodes. Expensive ELOG or pendeo-epitaxy growth techniques have enable to partially solve this issue but less defective substrates obtained do not exhibit homogeneous defect density.

Moreover, besides epilayer quality, bulk substrate properties are far from being optimal from a device performance point of view. In the case of SiC, the main advantage relies on the possibility to have a vertical packaging which simplify the manufacturing technology and allows the overall cost of the LED to be competitive with sapphire based LEDs. Moreover, the vertical conductive structure make these LEDs very well adapted to ESD sensitive applications. Main drawback of the SiC substrate is its bulk photon trapping property due to large refractive index. This feature has led to substrate shaping to enhance the external quantum efficiency of the LED through better light extraction. Finally, the still low crystalline quality and high price of SiC substrates are limitations. In the case of sapphire substrates that represent today around 75% of the substrate market, the transparency of the substrate is clearly one advantage that advanced packaging, such as flip-chip, aims to derive benefits from, allowing light to escape from the back substrate side. On the other hand, substrate hardness during backside thinning steps performed in the manufacturing process, make dicing step more difficult, and increase LED overall cost. The low thermal conductivity of sapphire can also be a limitation during high power operation. From a packaging point of view, the electrical insulating behavior of sapphire makes packaging more complex. Apart these two main substrates, technological developments performed mainly on silicon have not exhibited yet satisfactory performance to compete with SiC and sapphire solutions.

For electronic applications such as power RF transistors, substrate issues are the same than for optoelectronics even if focus is done on electrical insulating and thermal conductive substrate properties.

Smart-Cut® substrate solutions for GaN epitaxy and related applications

Innovative substrates developed using the Smart-Cut technology must be seen as composite substrates comprising a single crystal layer bonded onto a supporting wafer. The possible combination of different materials due to wafer bonding flexibility allows thinking of new substrate solutions for new or already existing devices solutions. Among the different possible combinations, SiC single crystal on Si substrates obtained with the Smart-Cut® process [3] is today one example of development. In this article, we will describe some material solutions such as bonded composite substrates obtained with the Smart-Cut® process and involving SiC, Si, sapphire materials as well as GaN substrates today available as epiwafers or as free standing substrates. Wafer bonding and layer transfer results of WBG materials will be presented as well as their application to GaN material growth.

References

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