Si and Mg ion implantation for doping of GaN grown on silicon

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Because of its large bandgap and high breakdown voltage, Gallium nitride (GaN) is a good candidate for high power device applications, as well as Radio Frequency (RF). Moreover, the ability of growing GaN layers on large (200 mm) Si wafers is a key point for its integration in microelectronic lines with reduced costs. Most of the expected applications require n-type and p-type doping of GaN layers. Although, in-situ doping is commonly used during epitaxy growth, ion implantation offers an interesting alternative to enable localized doping for advanced devices. However, the difference in lattice parameters and Coefficient of Thermal Extension (CTE) in the GaN on Si makes the material even more sensitive to the high thermal budgets required to activate dopants after ion implantation.

In the present work, we investigated p-type and n-type GaN doping by ion implantation. GaN layers were grown by MetalOrganic Chemical Vapor Deposition (MOCVD) on 200 mm silicon (111) wafers. To prevent GaN layer surface damaging during high temperature activation anneal, they were capped with an $Al_xGa_{1-x}N$ (or AlN) / SiN_x stack [1].

Silicon is one of the most favorable species for n type doping of GaN. First of all, we showed that the activation efficiency increases with the Si implanted dose (up to $3x10^{15}$ at.cm^{-2}) and that Si does not diffuse significantly at high temperature (1100°C) in GaN. Then, we implanted through a typical heterostructure (AlGaN/GaN) used for High-Electron-Mobility Transistor (HEMT). As shown on Fig.1, we revealed that at high dose ($1x10^{15}$ at.cm^{-2}), the sheet resistance can be reduced in relation to the 2DEG using traditional soak (up to 1100°C) and/or Rapid Thermal Annealing (RTA) (up to 1300°C) which makes the process relevant to improve contact resistance in these devices.

Electrical activation of implanted Mg is still a very challenging subject and, as far as we know, has not yet been demonstrated for GaN grown on Si. The difficulties originate from compensation effects linked to ion implantation induced defects. To understand this phenomenon, we studied the “healing” kinetics of these defects using various physicochemical techniques. Among them, Photoluminescence (PL) measurements were performed to study optical activation of Mg, i.e emission attributed to substitutional Mg in Ga site of the GaN lattice ($Mg_{(Ga)}$). It was revealed that maximizing thermal budgets combining soak anneal (up to 1100°C) and RTA (up to 1400°C) have a beneficial effect on optical activation (Fig.2). PL measurements also showed that Mg implantation leads to the formation of nitrogen vacancies ($V_{(N)}$), which may have a donor behavior. We showed that Mg/N co-implantation reduces $V_{(N)}$ vacancies related emission (Fig.2). Optimization and / or combination of these approaches are then a promising way to obtain electrical activation of Mg implanted in GaN grown on Si.

References

1. A. Lardeau-Falcy et al., Phys. Status Solidi A 214, No. 4 (2017)

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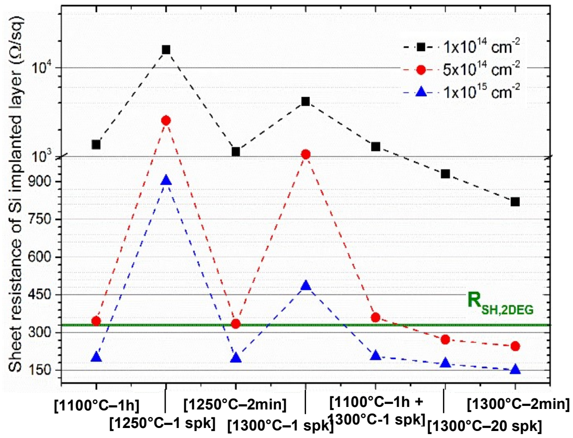

Fig. 1: Sheet resistance as a function of annealing (traditional and/or RTA) for three doses

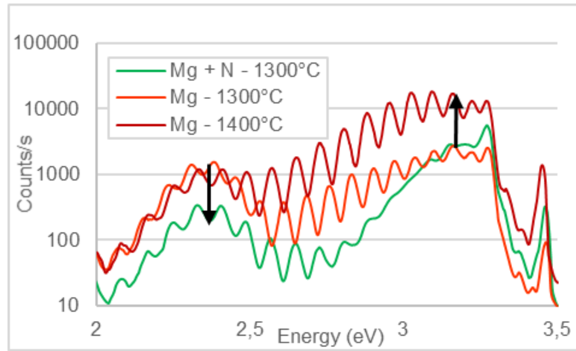

Fig. 2: PL spectra of implanted Mg and Mg+N GaN and annealed with soak + RTA