Excimer laser annealing of Mg-implanted GaN films

NAIST [1], Kyushu University[2] °Juan Paolo Bermundo[1], Yuki Tada[1], Hiroshi Ikenoue[2],
Mutsunori Uenuma[1], Yasuaki Ishikawa[1], and Yukiharu Uraoka[1]
E-mail: b-soria@ms.naist.jp

GaN is a very attractive material with extensive application in short wavelength light-emitting diodes and next-generation high power devices due to its outstanding properties such as large breakdown field, high-speed switching, minimal on-resistance, and wide bandgap. For better turn on voltage control, performance, and prevention of current collapse, p-type GaN has been used in various configurations. A great challenge with p-type GaN especially those obtained through Mg implantation is the difficulty to activate Mg substituted at the Ga site (Mg_{Ga}) to reliably obtain p-type conductivity. Other defects introduced during ion implantation such as N vacancies and Ga vacancies have also been shown to inhibit p-type conductivity and decrease Photoluminescence (PL) intensity [1]. Thus, high temperature annealing (>500 °C) is typically required to activate dopants and recover defects introduced by implantation [2].

In this study, we employed excimer laser annealing (ELA) to irradiate and anneal a 500 nm Mg-implanted GaN layer on a GaN substrate. Samples were irradiated with either 1 shot at a fluence (F) of 600 mJ/cm^2 or 10 shots at F = 375 mJ/cm^2 in a vacuum or Ar (Table 1) by a KrF excimer laser (λ = 248 nm, pulsewidth = 9 ns). We analyzed the ELA's effect on the optical, physical, and chemical properties of GaN by performing Ellipsometry, PL, simulation, and X-ray photoelectron spectroscopy (XPS) measurements.

Fig. 2 is the laser-induced temperature at the Mg-implanted GaN surface estimated by COMSOL Simulation. Large induced temperatures of 1200 K in ~100 ns imply that ELA can be a rapid activation annealing alternative to typical lengthy activation methods. Ellipsometry analysis show that prior to ELA, Mg-implanted GaN had a bandgap (E_g) of 3.34 eV. After ELA, only GaN-1 showed a large E_g reduction to 3.16 eV. Furthermore, PL measurements reveal higher PL intensity at ~3.38 eV after ELA in Ar. Ga 3d XPS spectra (Fig. 3) of ELA samples are broader and shift to lower binding energy compared with bare GaN (no implantation and no ELA) suggesting lower Ga-N and higher metallic Ga (Ga-Ga) concentrations for ELA samples. The results and analysis herein are crucial in developing rapid activation annealing of p-type GaN.

Sample	F (mJ/cm^2)	Shots	Environment
GaN-1	375	10	Vacuum
GaN-2	600	1	Vacuum
GaN-3	375	10	Ar
GaN-4	600	1	Ar

Table 1. KrF ELA irradiation conditions

[1] K. Kojima *et al.* Appl. Phys. Express **10**, 061002 (2017)
[2] T. Niwa *et al.* Appl. Phys. Express **10**, 091002 (2017)

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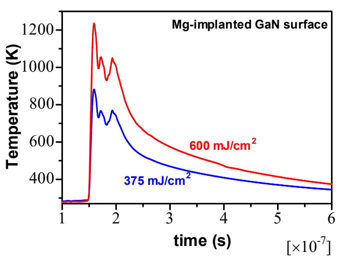

Fig 2. Temperature induced by laser heating at the Mg-implanted GaN surface

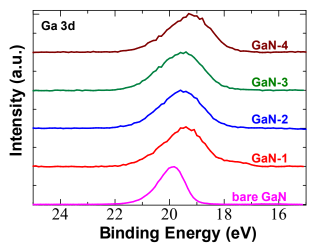

Fig 3. Ga 3d core level XPS spectra of ELA and bare GaN samples

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