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# Recombination characteristics of the proton and neutron irradiated semi-insulating GaN structures

E. Gaubas[a,*], J. Vaitkus[a], K. Kazlauskas[a], A. Žukauskas[a], J. Grant[b], R. Bates[b], V. O'shea[b], A. Strittmatter[c], D. Bimberg[c], P. Gibart[d]

[a]*Institute of Materials Science, Vilnius University, Applied Research, Sauletekio av. 10, Lt-10223, Vilnius, Lithuania*
[b]*Department of Physics and Astronomy, University of Glasgow, UK*
[c]*Institut für Festkörperphysik, Technische Universität Berlin, Sekr. Pn 5-2, Hardenbergstr. 36, D-10623 Berlin, Germany*
[d]*Lumilog 2720, Chemin Saint Bernard Les Moulins I, F-06220 Vallauris, France*

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**Abstract**

Variations of the photoluminescence spectra and photoconductivity transients with proton and neutron fluence in the semi-insulating GaN-layered structures of different thickness are examined. It has been obtained that the intensity of the photoluminescence bands associated with grown-in defects of the semi-insulating GaN layers decreases non-linearly with irradiation of high-energy proton and neutron fluence in the range of $10^{14}$–$10^{16}\,cm^{-2}$. The recombination and trapping lifetimes also exhibit a significant decrease with fluence which is most prominent in thin epilayers. Defect parameters determined from lifetime variations with temperature and from the relative changes of the photoluminescence bands are discussed.


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## 1. Introduction

GaN appeared to be rather radiation-hard material for the fabrication of tentative particle detectors [1]. The main issues in applications of the state-of-the-art GaN epitaxial layers are related to high dislocation densities ($10^{8}$–$10^{10}\,cm^{-2}$) and limited thickness for particle detector implementations [1]. The role of dislocations in radiative and non-radiative recombination depends on the dislocations type and structure [2,3]. Various intrinsic and radiation induced point defects relative to GaN electrical and optical properties are still under debate [1,4].

In this article, carrier decay transients and photoluminescence spectra have been investigated in the initial and irradiated semi-insulating GaN epilayers grown by metal-organic chemical vapor deposition (MOCVD) on sapphire and Si substrates [5]. The GaN epilayers of different thickness, 2 and 12 μm, grown on sapphire have been examined. The simultaneous decrease of the carrier lifetime and intensity of the photoluminescence bands with increase of irradiation fluence of protons and neutrons has been revealed.

## 2. Experimental techniques and samples

A set of wafer pieces and diode structures, made either on 2 or 12 μm thick initial GaN epilayers, has been investigated. The top Schottky junction with a guard ring has been deposited by using Ti/Al metallization. The needle-type electrodes have been exploited for measurements of the contact photoconductivity and DC electrical characteristics in wafer samples. These structures were irradiated with 24 GeV/*c* protons and reactor neutrons of fluences in the range of $10^{14}$–$10^{16}\,cm^{-2}$.

Variations of photoluminence (PL) and contact photoconductivity (CPC) have been examined by comparing the irradiated and initial diode structures. To estimate or

*Corresponding author. Tel.: +370 5 2366082; fax: +370 5 2366079.
*E-mail address:* eugenijus.gaubas@ff.vu.lt (E. Gaubas).

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exclude an impact of contacts, the microwave absorption (MWA) probed photoconductivity transients [5,6] have been additionally investigated by the contactless method. Room temperature (RT) photoluminescence spectra have been measured at UV excitation by applying a continuous wave (cw) He–Cd laser, operating at 325 nm wavelength. The PL signal was dispersed by a double monochromator and detected using an UV-enhanced photomultiplier. The CPC photoresponse has been recorded under photo-excitation of the non-metallized area either between guard rings of two diodes with a gap of 3 mm width or with a 50 μm width spacing between the central and guard electrodes. The CPC transients under bias voltage of 1–10 V have been examined using the 3rd harmonic (355 nm) of pulsed (either 30 ps or 10 ns duration) YAG: $Nd^{3+}$ laser. The photocurrent relaxation in the time scale from few ns to tens of ms has been recorded by a digital oscilloscope TDS-5104.

## 3. Experimental observations

The excess carrier transients measured by either CPC or MWA technique exhibit a non-exponential decay for the initial GaN epitaxially grown material. Although these transients are similar when analyzing the generalized features, the decay shape and timescale depends on the growth technology as shown in Fig. 1a. Also, different PL spectra have been observed in the starting material grown over sapphire and Si substrates as well as for different thickness of epitaxial layers, Fig. 1b.

Significant transformations of carrier decay transients appear under varied irradiation fluence. Evolution of the CPC transients in 2 μm thick GaN epilayers irradiated with protons of different fluence is illustrated in Fig. 2. An initial fast decay component is determined by non-radiative recombination and carrier capture processes, and the role of fast component increases with irradiation fluence. The longtail component is shortened most significantly with irradiation fluence, as can be deduced from Fig. 2. The longtail component is ascribed to the excess carrier trapping processes at dislocations that comprise a disordered network within the epilayer. Photoluminescence spectra obtained at room temperature for the as-grown and irradiated samples, both for protons and neutrons, contain three bands, Figs. 3, 4. The peaks of these bands can be ascribed to excitonic recombination at 3.43 eV for the ultraviolet band (UV) together with the bands peaked at 2.85 eV of the blue band PL (BB) and 2.18 eV of the yellow PL band (YB) [3], respectively.

The most significant decrease of the PL intensity with irradiation fluence is observed for YB luminescence, and this band disappears in the samples irradiated with the highest fluences. The structure of a PL spectrum featuring the B band is inherent for GaN material containing a high density of dislocations [3], that form a wide band of half-filled acceptor states at 0.3 eV above the valence band, and these defect states are linked with the PL band at about

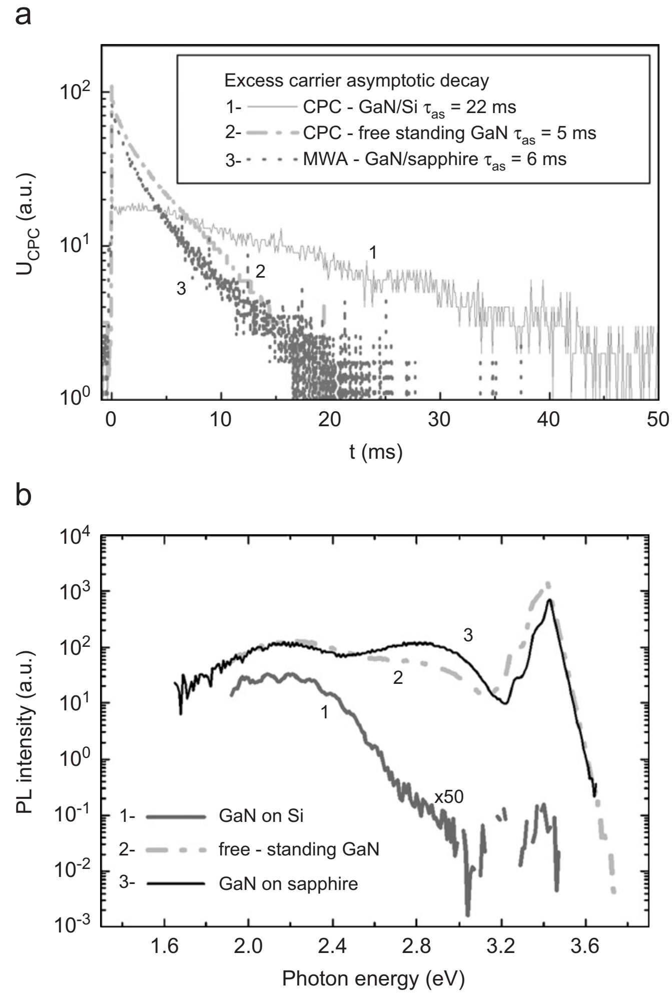


Fig. 1. (a) CPC transients for the 0.6 μm GaN top epilayer within layered structure of GaN/AlN on Si substrate (1), for 50 μm thick free-standing GaN wafer (2) and for 2.5 μm GaN epi-layer on sapphire substrate (3) measured under 355 nm light pulsed excitation. (b) PL spectra measured in different as-grown materials, namely, GaN/AlN on Si substrate (1), free-standing GaN wafer (2) and GaN epi-layer on sapphire (3), with layer thicknesses mentioned in (a).

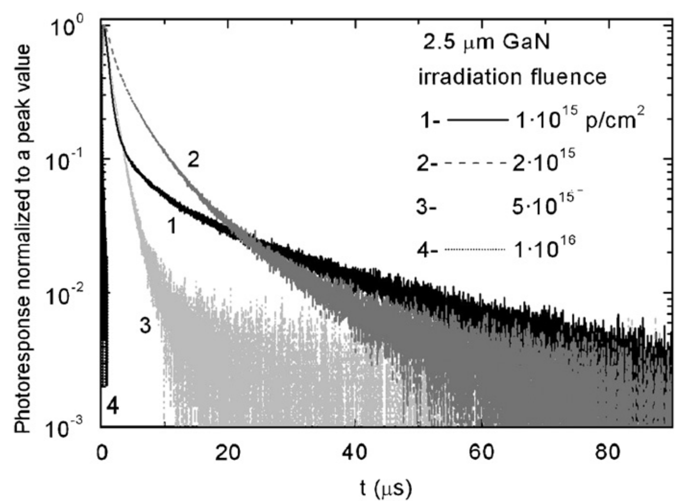


Fig. 2. Evolution of the CPC transients in 2.5 μm thick GaN epilayers irradiated with protons of fluence of $1 \times 10^{15}$ (1), $2 \times 10^{15}$ (2), $5 \times 10^{15}$ (3), and $10^{16}\,cm^{-2}$ (4). The signal is normalized to the peak value.