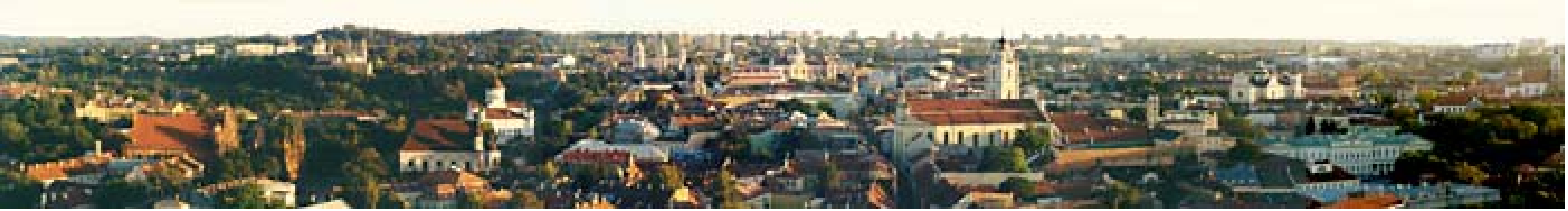
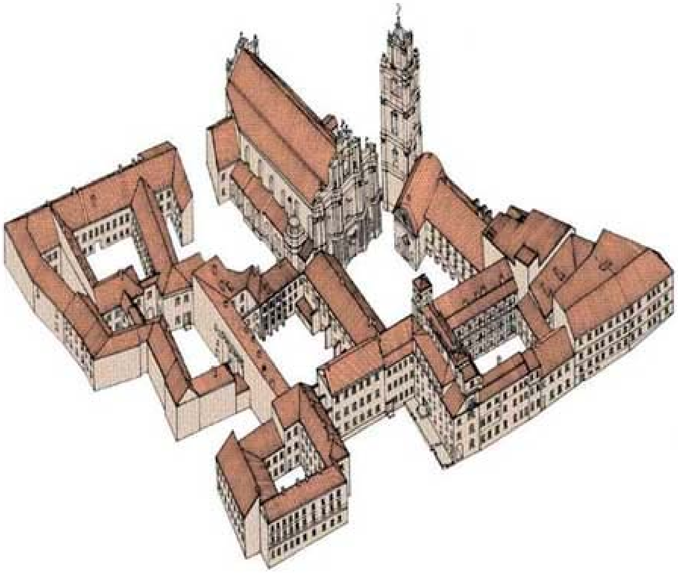
Properties of thick semi-insulating GaN

J.Vaitkus [1)], E. Gaubas[1)], V.Kazukauskas[1)], A.Blue [2)], W.Cunningham[2)], K.M.Smith[2)] and P.Gibart [3)]

1) Institute of Materials Science and Applied Research, Vilnius University, Lithuania
2) Department of Physics and Astronomy, Glasgow University, Glasgow, UK
3) LUMILOG,Ltd., France



Maybe ever RD50 in Vilnius?



Motivation & short history

♪ ***Two years*** *ago - here in Florence a first demonstration of GaN as a material for ionising radiation detection.*

It was proposed that GaN has to be more radiation hard than neighboring materials, as SiC, Si, GaAs due to different chemical bonding: a larger ionic component causes bigger density of material.

Property	Diamond	Si	a-Si(H)	4H- SiC	6H-SiC	GaN	GaAs
Z	6	14	14	14/6	14/6	31/7	31/33
E_g [eV]	5.5	1.12	1.7	3.3	3.03	3.39	1.4
μ_e [cm^2/Vs]	1800	1450	1-10	800-1000	370	1000	≤8500
μ_h [cm^2/Vs]	1200	450	0.01- 0.005	50-115	50	30	≤400
Saturated electron drift velocity (cm/s)		$1.0x10^7$		$2.0x10^7$	$2.0x10^7$		$1.2x10^7$
e-h pair creation [eV]	13	3.6	4-4.8	8.4	-	8.9	4.3
eV/µm for MIPs	36	81		51			
Displacement [eV]	43	13-20		25		Ga – 20; N -10	10
Density [g/cm3]	3.5	2.3	2.3	3.2	3.2	6.2	5.3
ε_R				9.7	10		
Breakdown voltage, [MV/cm]	10	0.5		2.2 - 4	2.4		≈0.4

Motivation & short history

♪ *Two years ago was only a surprise that 2.5 micron thick samples were tested.*

A half year ago was shown that semi-insulating GaN is quite radiation hard: the detectors were "alive" after high fluences:

Properties of GaN detectors before and after irradiation.

Sample irradiation /fluence	CCE,% /@ bias, V	I_{10V}, nA cm^{-2} /character	τ_{fast}, μs
Non-irradiated	**95** / 30	0.06 /barrier	0.1-0.5
X-rays (10 KeV) / 600 MRad	**100** / 26	5.50 /barrier	0.08
Neutrons / 5 10^{14} cm^{-2}, (reactor, 100 KeV)	**77** / 28	0.35 /resist.	0.015
10^{15} cm-^{2},	**10** / 30	0.65 /barrier	0.02
10^{16} cm-^{2}.	**5** / 16	0.23 /resist.	<0.01
Protons, 24 GeV/ 10^{16} cm-^{2}.	**13.6** / 30	0.40 /barrier	0.034

A low bias was related to breakdowns at the defects

The promising results related to radiation hardness "allowed"

1. to "force" Lumilog Ltd., to grow thicker samples (12 microns);

2. to ask Tokushima University & Nitride Ltd., to repeat the growth of semi-insulating GaN epi-layers to have a possibility for better statistics and more detail investigation.

Both companies supplied epi-GaN layers on two inches wafers:

one *- 12 micron thick and* ***three*** *– 2.5.micron thick*

3. to receive a reaction of South Carolina University & Sensors, Ltd., and to discuss a possibility to grow free standing thick high resistivity GaN for characterisation.

Next steps:

♪ *The key issue is to perform in a short term the tests that for other materials has many years history.*

Now it is known: GaN properties depends on material quality, mostly induced by substrate induced high dislocation density.

Also, the knowledge of different defects: vacancy type point defects, shallow and deep donor-acceptor pairs, and their transforms under heavy irradiations by different particles is necessary.

This talk:

♪ *The presenting some data characterizing the SI-GaN material properties before and after irradiation*

and

♪ *to characterize the difference of thin and thick GaN epi-layers.*

Samples

- *non-doped n-type GaN epilayers of 12 μm thickness grown by MOCVD on sapphire substrates using n-GaN buffer*

- *non-doped n-type GaN epilayers of 2.5 μm thickness grown by MOCVD employing ammonia and trimethylgallium as precursors, and different trimethylgallium (TMG) flow rates and growth temperatures*

Irradiations

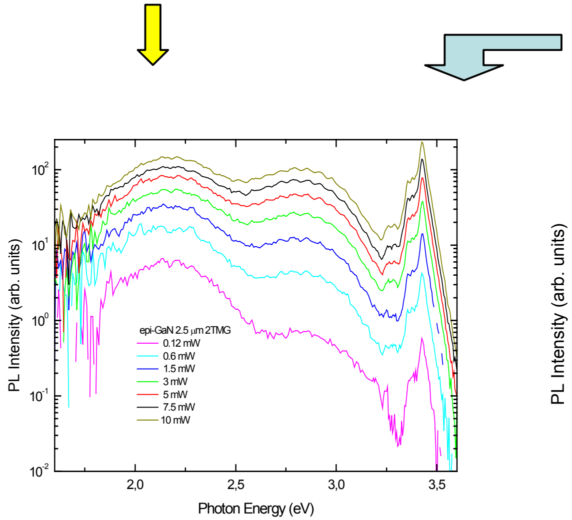
- *10-keV X-ray irradiation with the dose of 600 Mrad*
- *100 keV neutrons with the fluence of 5 $\times$ 10^{14} cm^{-2} , 10^{15} cm^{-2}* and *10^{16} cm^{-2}*
- *24 GeV/c protons with fluence of 10^{16} cm^{-2}*
- *C.C.E. testing - 5.48 MeV Am^{241} α-particles*

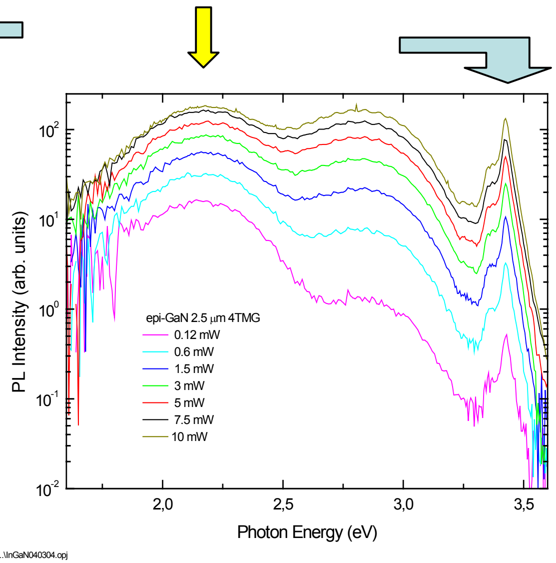
Photoluminescence spectra at ~10 ns pulse excitation

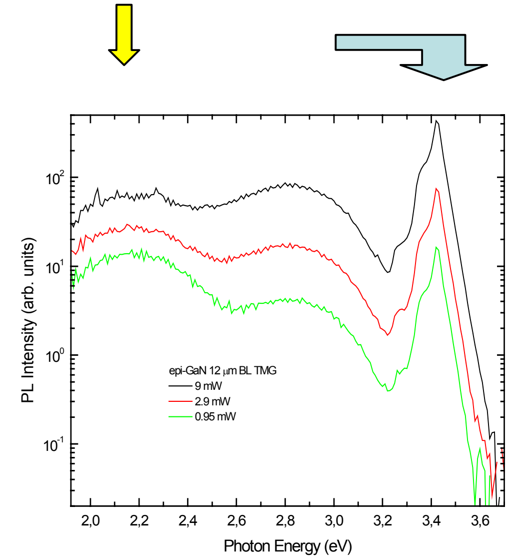
2.5 μm MOCVD 2TGM

2.5 μm MOCVD 4TGM

12 μm MOCVD BL





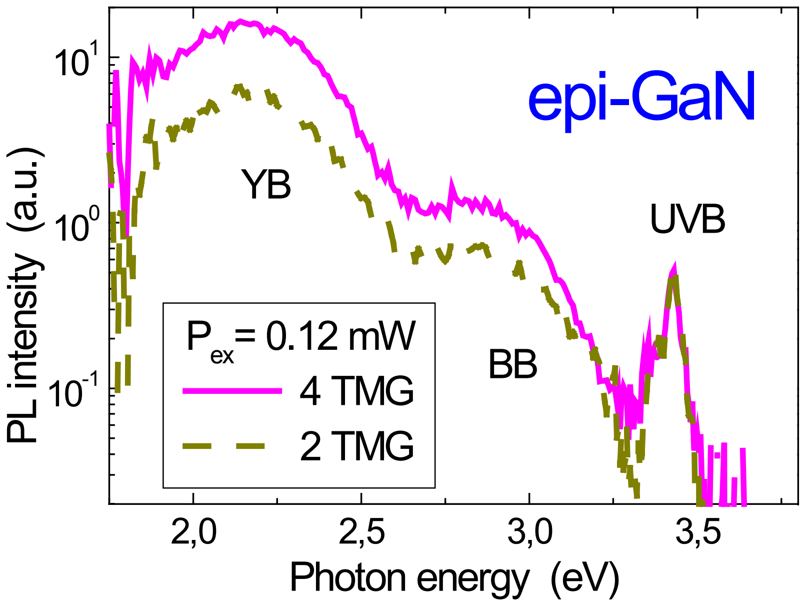


Synchronous enhancement of the intensity of UV band, with well expressed edge luminescence structure, is observed in 12 μm thick layer relatively to those of 2.5 μm thickness.

The native defects concentration estimated in* 2.5 μm thick layer *from the luminescence spectra dynamics with the excitation density:

"yellow" trap (point defects V_{Ga}) : $N_Y < 10^{15}$ cm^{-3}, "blue" levels (dislocation-related): $N_B \geq 10^{18}$ cm^{-3}.

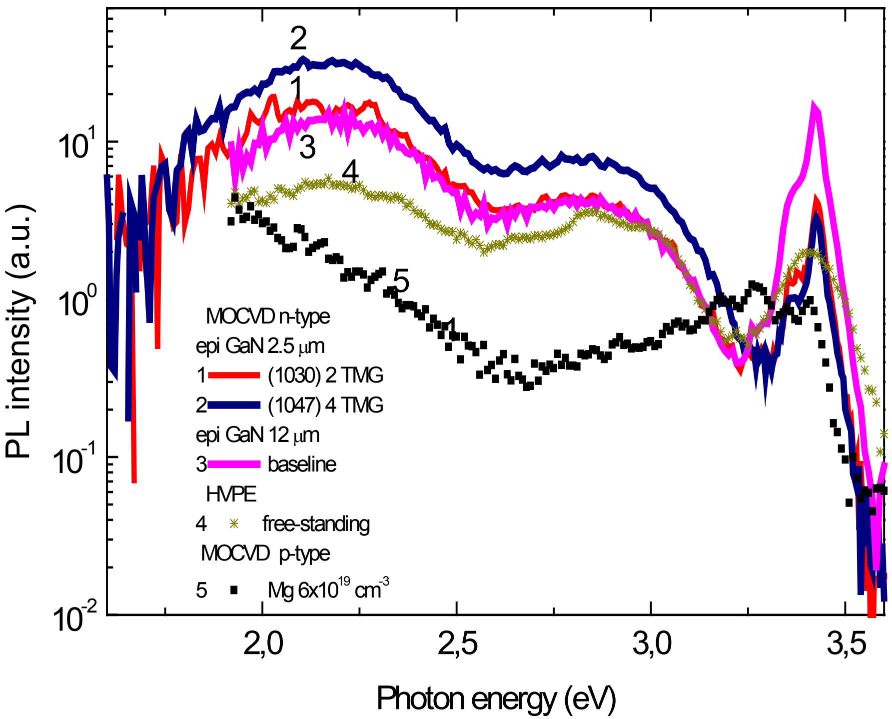
Comparison photoluminescence spectra in GaN, grown @ different TMGa flow



Enhancement of the intensity of the PL bands attributed to defects, vacancy complexes (YB) and dislocations (BB) due to an increase in native defect concentration with trimethylgallium (TMG) flow.

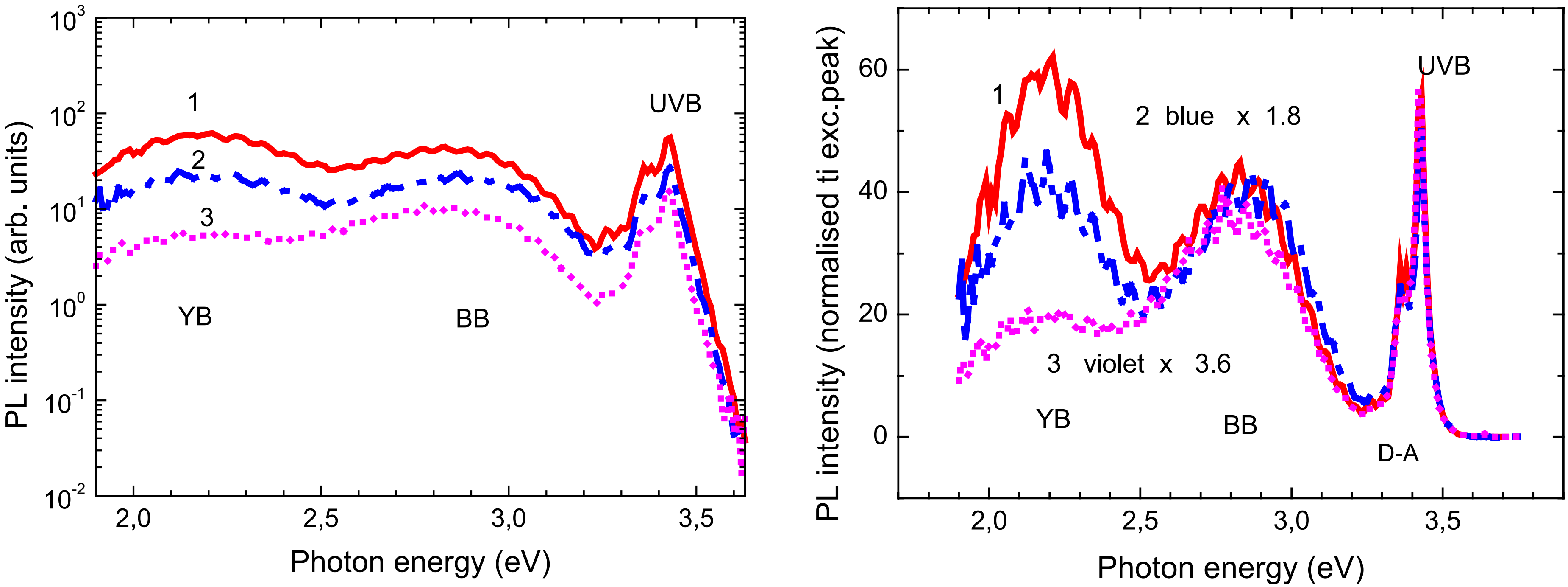
The native defects concentration increases with TMG flow rate in MOCVD grown intrinsic n-type GaN layers

Photoluminescence spectra variations in different GaN materials



Comparison of PL spectra under cw excitation of the same intensity in the intrinsic n-type MOCVD (1-3) and HVPE (4) grown GaN layers of 2.5 μm thickness (1, 2), by using TMG flow rates 2 (1) and 4 (2), relatively to the baseline regime, and of 12 μm thickness (3) compared with the Mg doped p-type GaN (5).

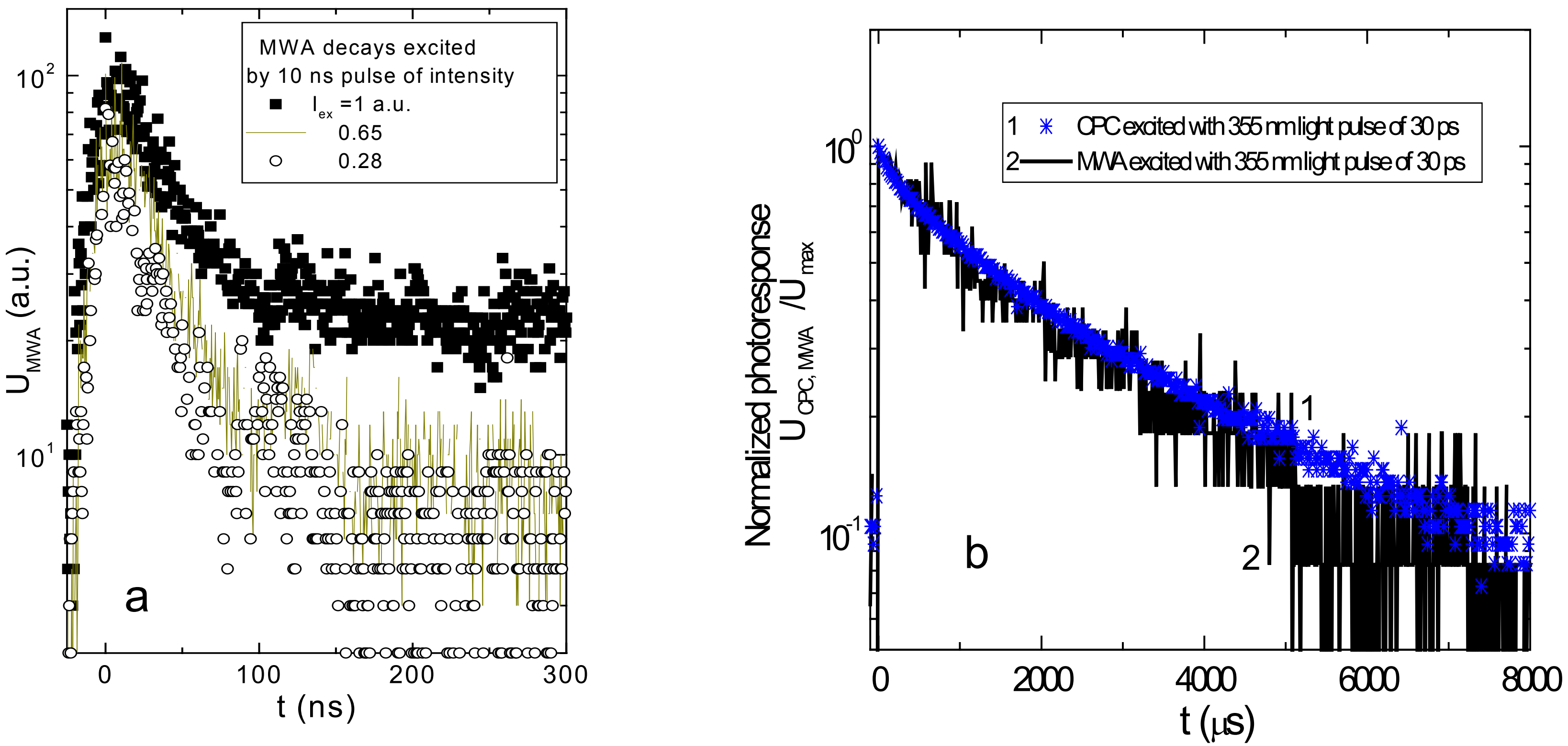
Photoluminescence spectra variations with excitation density before and after irradiation



PL spectra under cw excitation of the same intensity in as-grown 2.5 µm GaN epitaxial layer (1) and after irradiation by x-rays (2) and neutrons with fluence $5x10^{14}$ cm^{-2} (3), respectively.

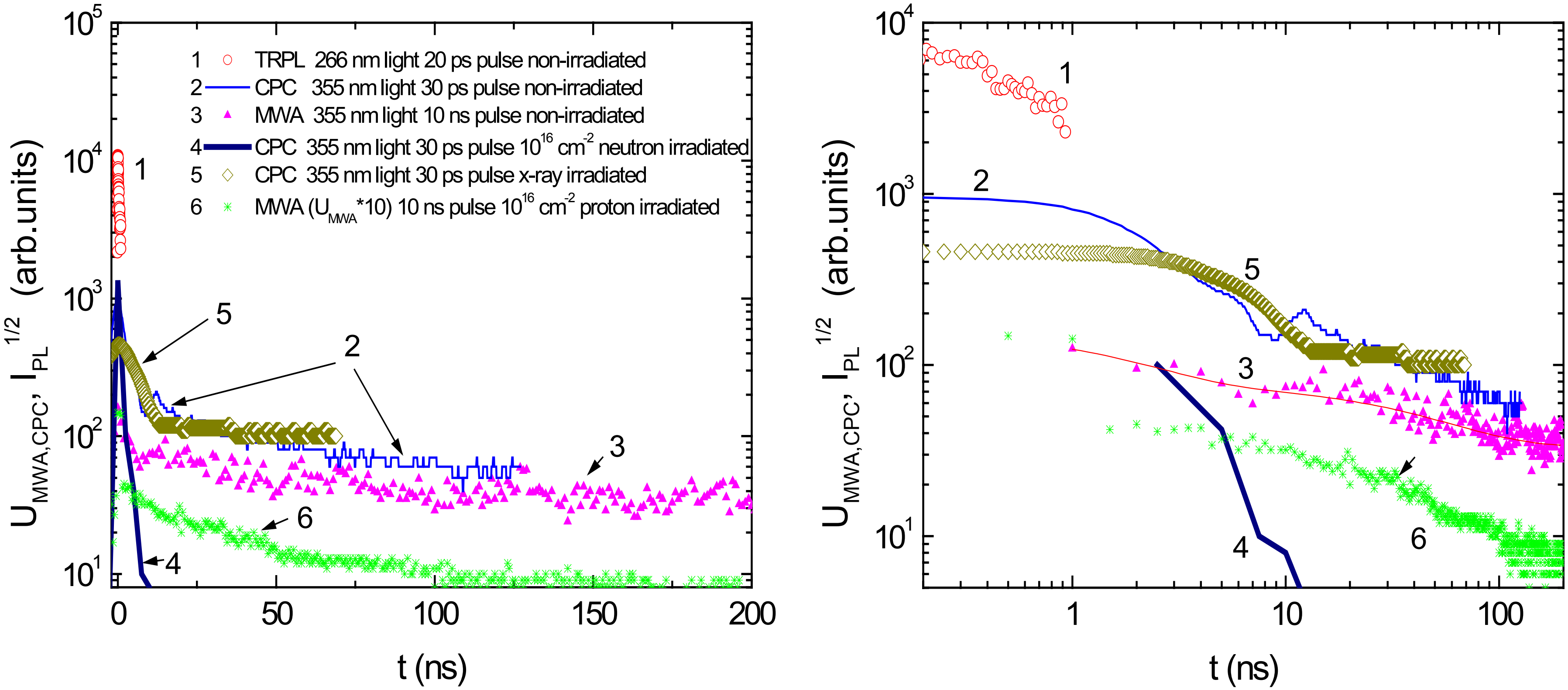
Formation of non-radiative recombination centres!

Photoconductivity (CPC) and microwave absorption (MWA)



Variation of the initial MWA transients as a function of excitation density (a) in MOCVD as-grown GaN 2.5 μm thick epi-layer, and asymptotic CPC and MWA decays (b). CPC and MWA transients exhibit the same excess carrier decay rate in the asymptotic of a photoresponse.

Photoconductivity (CPC) and microwave absorption (MWA) in GaN epi-layer (2.5μm).

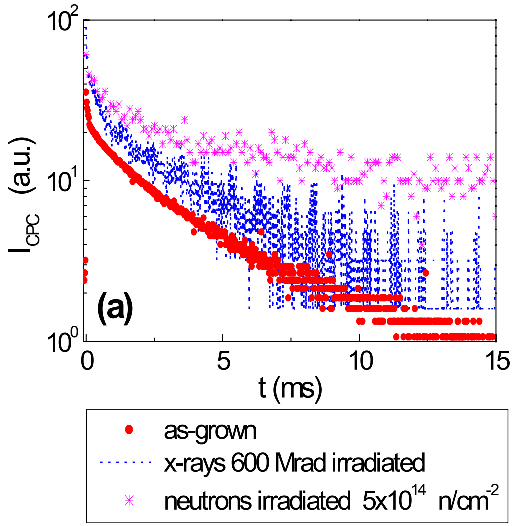


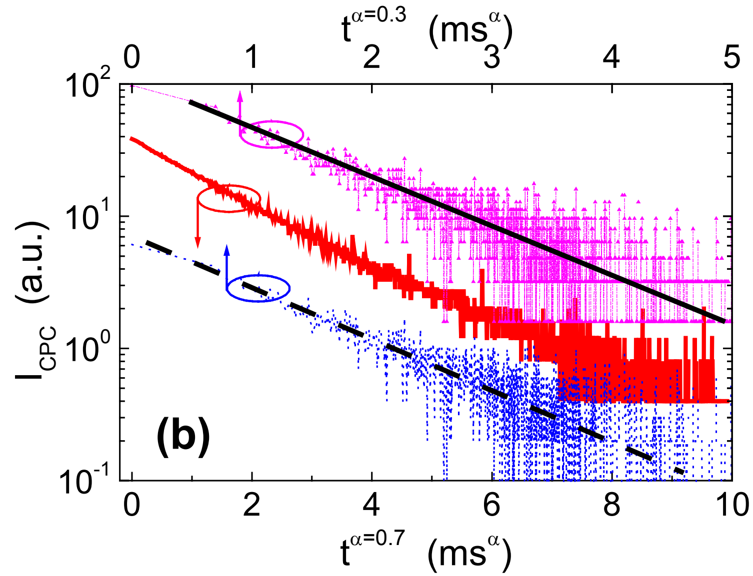
TRPL decay (1) collated with the initial stages of CPC (2,4,5) and MWA (3,6) decays in as-grown (1-3) and irradiated by neutrons (4) and protons (6) of fluence 10^{16} cm^{-2} and x-rays (5)

The trapping caused long-tail decay amplitude decreases with radiation induced defects density (curves 4 and 6) in very heavily irradiated material due to diminished carrier diffusion (increases scattering by defects inside crystallite) towards crystallite boundary.

For large fluence of proton irradiation (curve 6) the asymptotic decay amplitude crucially falls down, while for the same fluence of neutron irradiation in the range of 10^{16} cm^{-2} the asymptotic decay component is non-resolvable (curve 4).

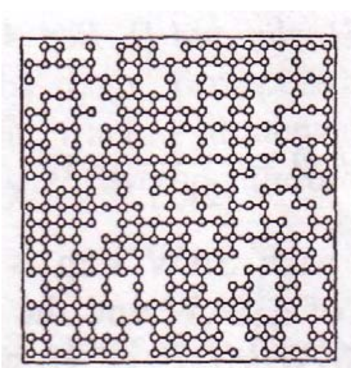
Trapping and disorder





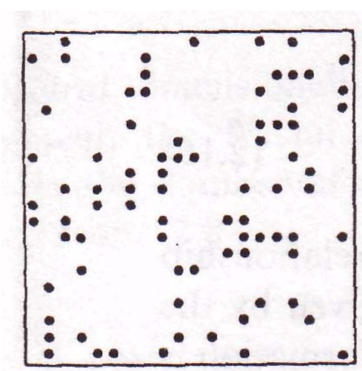
Variation of the asymptotic photoconductivity decay due to irradiation measured under UV photoexcitation on a semi-log scale (a) and within a stretched-exponent approximation (b). Irradiation by neutrons is seen to change the time-stretching factor from 0.3 to 0.7.

This implies that the character of carrier motion changes from percolation on an infinite cluster of dislocation net to that on a fragmented cluster.



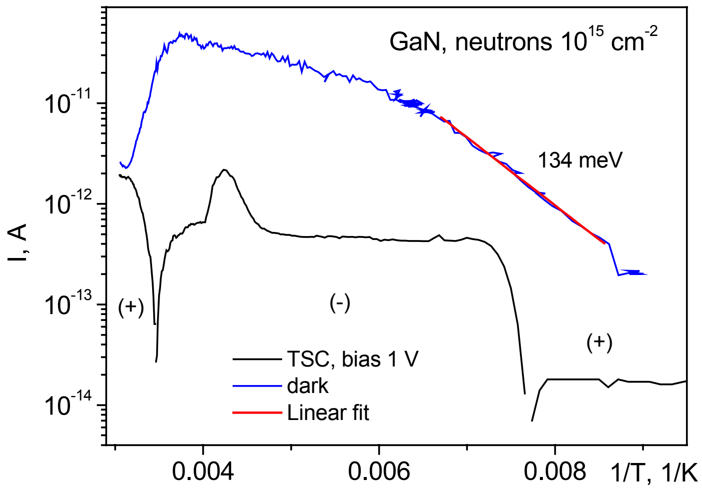
Infinite dislocations net in the as-grown layer

Fragmented fractons of crystallites after irradiations

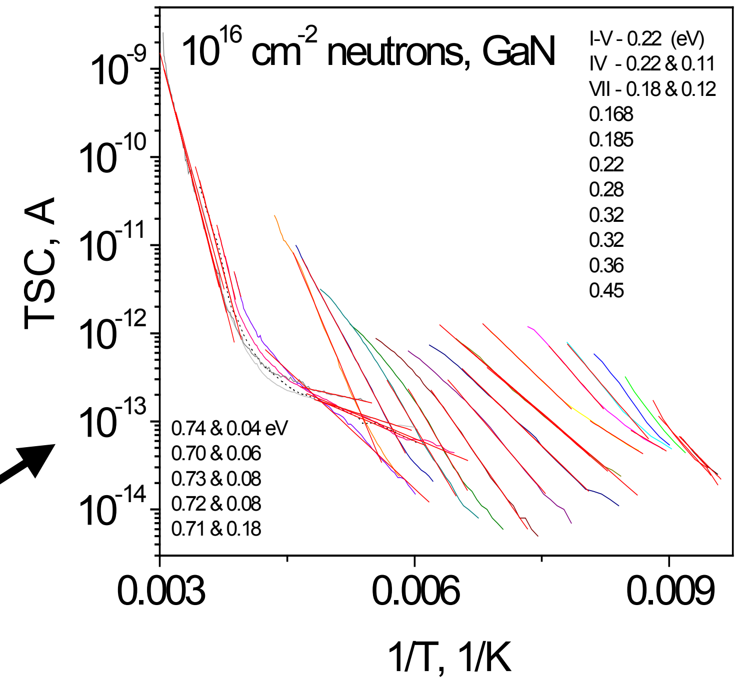


Disorder facilitates capture of carriers into relatively shallow levels, characterized by increase in capture time with occupation of trapping centers and a carrier-density dependent capture cross-section, thus reducing the occupation of the recombination centers.

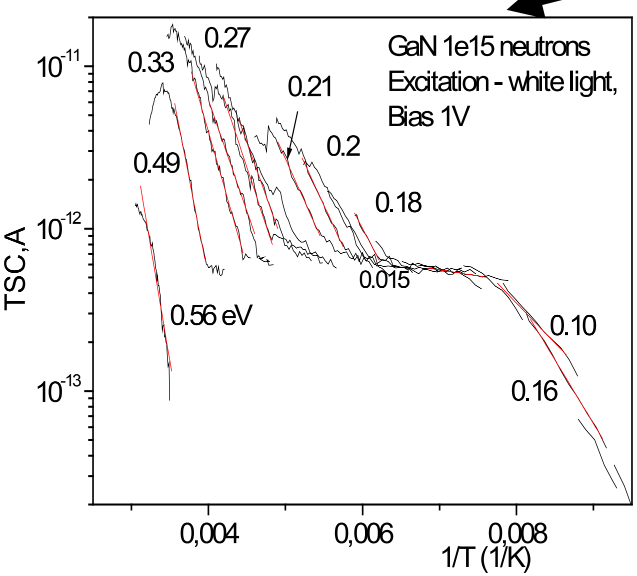
Thermally stimulated current and polarisation



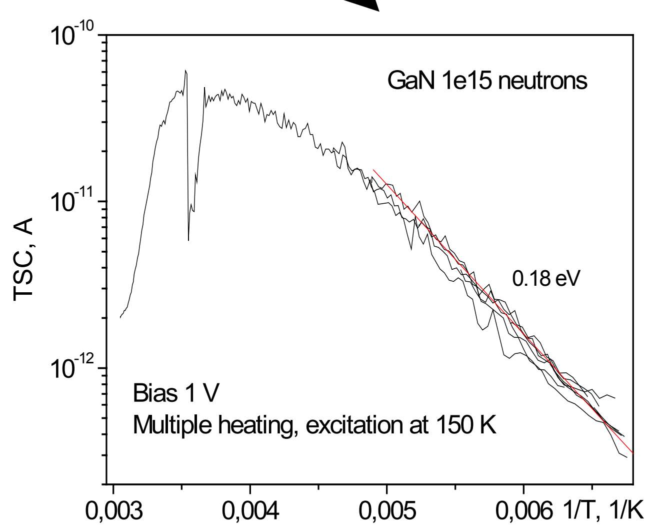
TS Current - blue, TS Depolarisation - black



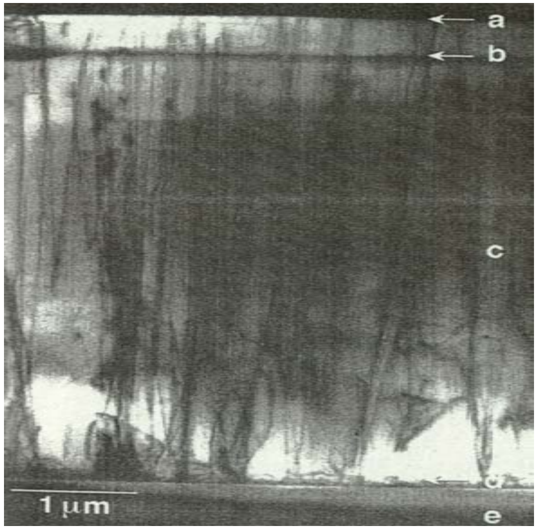
TS Current - multiple annealing



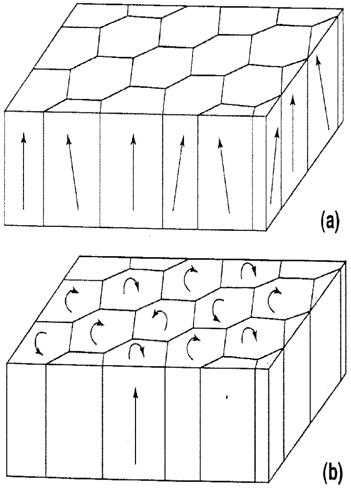
TS Current at different bias

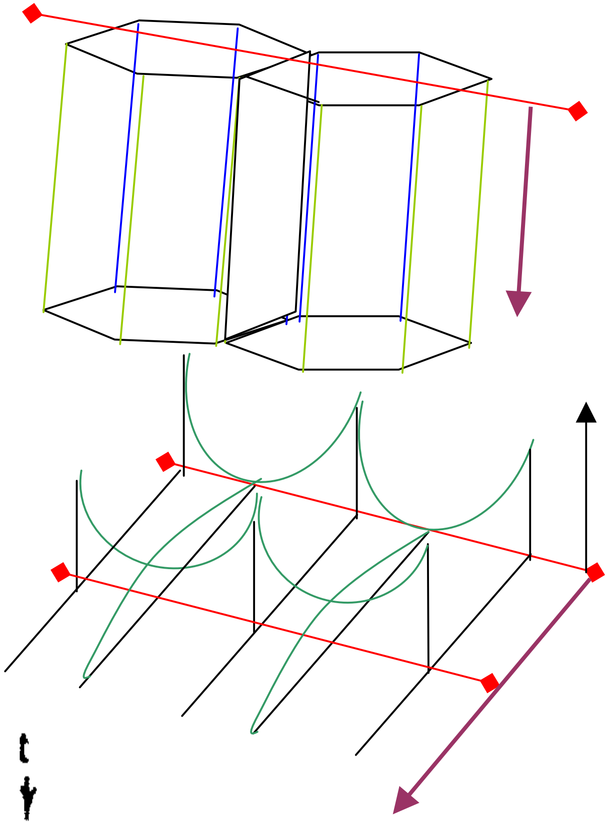


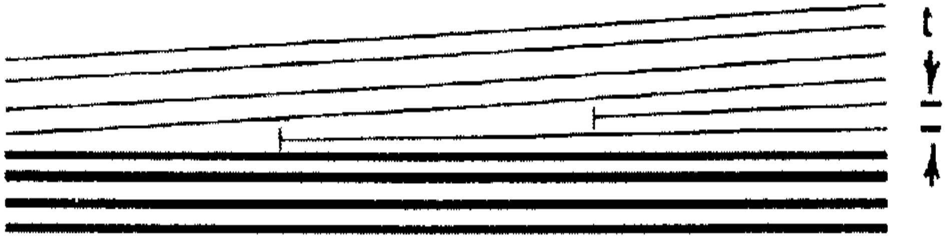
MODEL



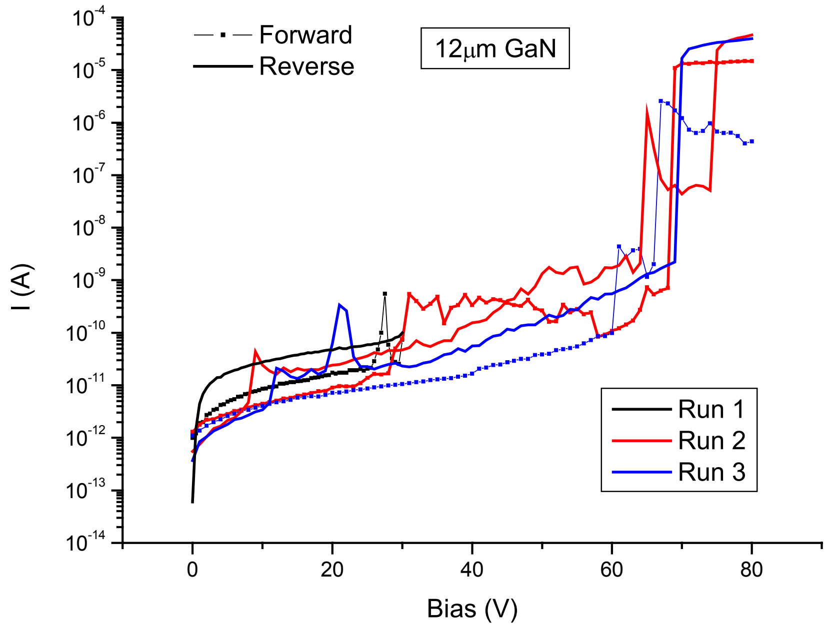
TEM image

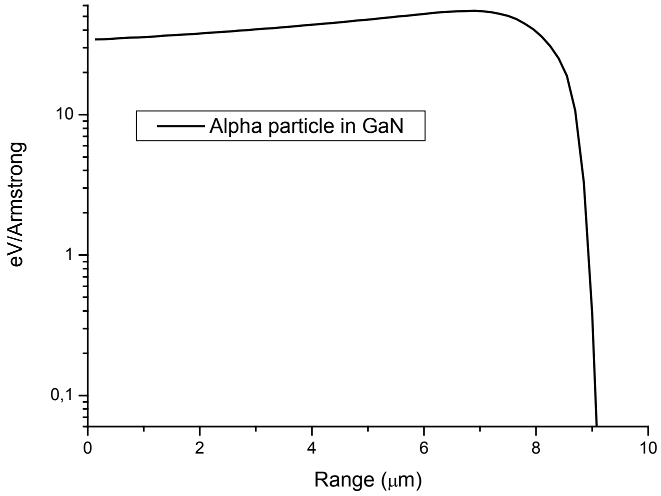


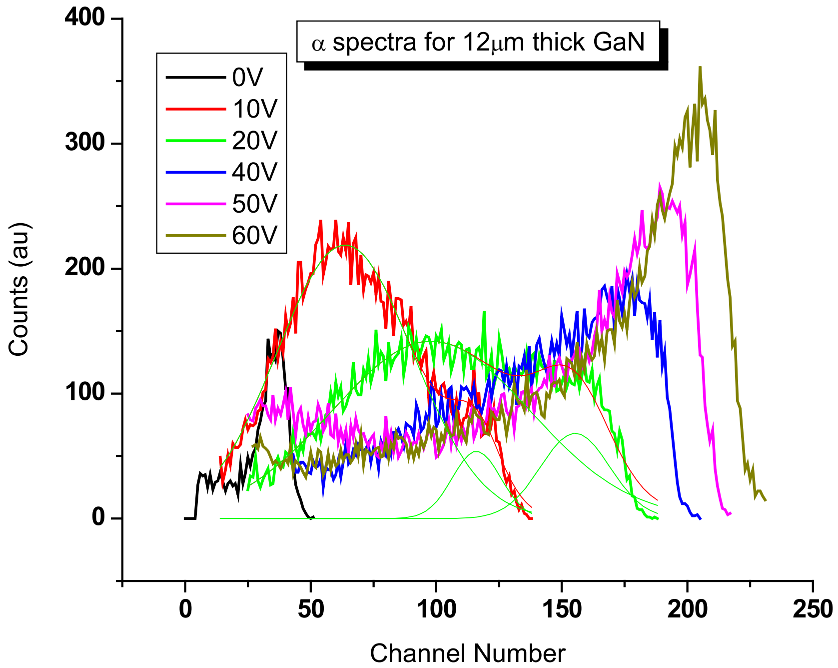




Detection of 5.48 MeV Am^{241} α-particles







C.C.E. = ~ 50 %

Conclusions

The correlated investigations of the photoluminescence (PL) spectroscopy, contact photoconductivity (CPC) and microwave absorption (MWA) transients have been performed to clarify a role of grown-in and radiation-induced defects in the MOCVD- and HVPE-grown epitaxial GaN layers.
The TS current and polarisation results show the changes of inhomogeneity structure caused by irradiation.

 # Irradiation by x-rays of 600 Mrad and neutrons of 5×10^{14} cm^{-2} fluence induces an increase of the non-radiative trap density, which yields PL quenching in all the observed bands: ultraviolet (UV), blue (B), and yellow (Y).
The trapping caused long-tail decay amplitude decreases with radiation induced defects density for very large fluences of neutron and proton irradiation in the range of 10^{16} cm^{-2}.

Radiation defects modify the grown-in structure (characterized by by time-stretching factor β =0.7) of an infinite cluster of dislocations net by formation of localized fractons characterized by time-stretching factor of 0.3.

Report from crystal growers:

----- Original Message -----
To: juozas.vaitkus@ff.vu.lt
Sent: Monday, October 11, 2004 12:43 PM
Subject: Re: High resistivity or semiinsulating GaN
•

Dear Juozas,

- We will be able to grow thick layers of NID GaN on sapphire (~50 μm), the final layer will however exhibits a bow.

Pierre

P.S. *Free standing 50 μm thick will be too brittle, the thickness should be at least 200 μm.*
We can re-growth a conducting layer on the SI GaN to make a back contact.

The cost of SI-GaN wafer will be much less than SiC.

Thank You for attention !