

Analysis of dose-dependent resistance of capped InGaAs quantum dots to ^{60}Co γ -rays

Oksana Strilchuk^{*1,2}, *Galyna Rudko*^{1,2}, *Evgen Gule*¹, *Volodymyr Yukhymchuk*¹ and *Yuriy I. Mazur*⁵

¹V. Lashkaryov Institute of Semiconductor Physics, National Academy of Sciences of Ukraine, 45 Nauky Ave., Kyiv 03028, Ukraine

²National University "Kyiv-Mohyla Academy", 2 Skovorody Str., Kyiv 04070, Ukraine

³Institute of Nano Science and Engineering, University of Arkansas, Fayetteville, AR 72701, USA

CHOICE of the OBJECTS UNDER STUDY

- Nanoparticles:** Wide possibilities to tailor the properties: to change elemental composition; to vary size; to vary surface conditions.
- Utmost controllability of growth:** Molecular beam epitaxy
- Targeted applications:** Optoelectronic devices - superluminescent diodes, lasers, photodetectors, etc.
- Post-growth tuning of properties:** By γ -irradiation

SAMPLES FABRICATION

Semi-insulating GaAs (100) substrate

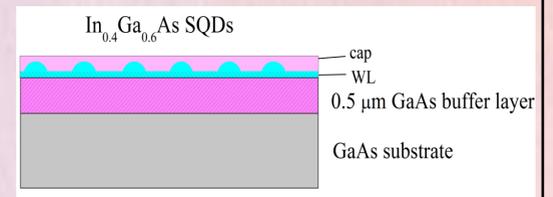
Deposition:

- ✓ 0.5 μm GaAs
- ✓ 8 MLs of InGaAs
- ✓ 50 nm GaAs



Resulting structure:

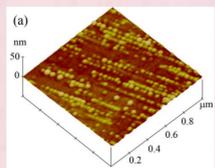
- ✓ buffer layer
- ✓ single-layers of $\text{In}_x\text{Ga}_{1-x}\text{As}$ ($x = 0.4$) SQDs
- ✓ capping GaAs layer



Goal

The purpose of the present study is to analyze the changes induced by γ -radiation in the arrays of epitaxially grown capped quantum dots and to estimate the range of these arrays tolerance to radiation damage and, thus, to find the limits for operation of prospective devices under radiation hazardous conditions

AFM characterization of uncapped QDs arrays



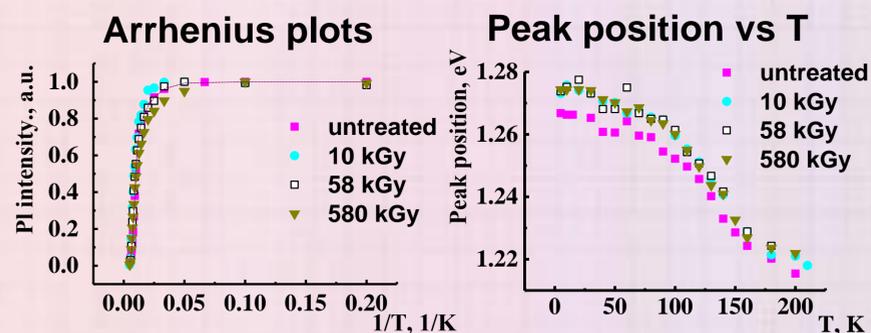
Structure of InGaAs QDs arrays BEFORE overgrowing of GaAs capping layer:

- ✓ Lateral size of QDs - 40 nm
- ✓ Surface density of QDs - $2.78 \times 10^{10} \text{ cm}^{-2}$

Photoluminescent (PL) measurements

Excitation wavelength – 632.8 nm
Temperature range 5 – 200 K
Registration – MDR-23 with PMP-62

PL vs temperature



Activation energies: $E_1 = 78.8 \text{ meV}$, $E_2 = 6.5 \text{ meV}$

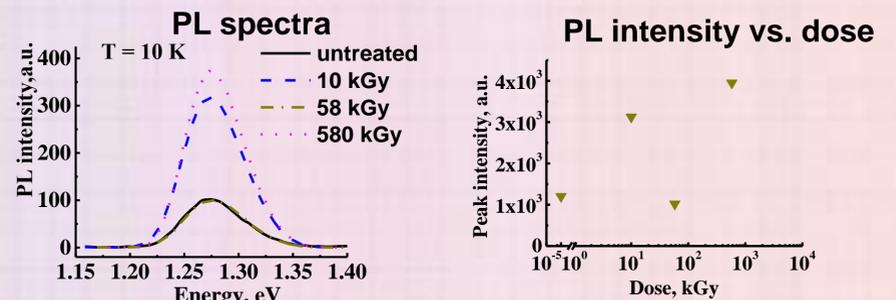
Radiation treatment details

- ✓ Ex-situ after-growth treatment
- ✓ γ -radiation of ^{60}Co source
- ✓ γ -quanta energy of 1.2 MeV
- ✓ room temperature
- ✓ doses varied in the range $1 \div 10^3 \text{ kGy}$

Factors of radiation influence

- ✓ Radiation-induced heating
- ✓ excitation of electronic subsystem
- ✓ formation of radiation-induced defects
- ✓ enhanced mobility of both intrinsic defects and newly created defects

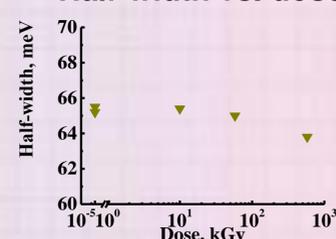
PL characterization



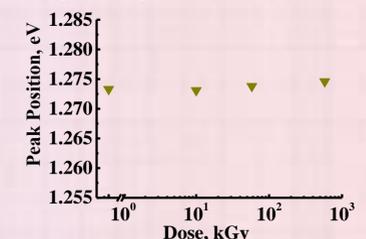
Spectral shape almost does not change with dose

With increasing γ -irradiation dose the intensity of PL grows

Half-width vs. dose



PL peak position vs. dose



Half-width and peak position do not change in the dose range up to 10^3 kGy

Discussion

We observed:

- Invariability of QDs PL spectral characteristics under increasing radiation dose.
- Invariability of activation energy values;
- thus, the transitions involved in light-emitting processes are not altered by gamma-quanta treatment.

In contrast to the above, we see the increase of PL intensity with gamma irradiation, so, based on these 3 observations we conclude that suppression of non-radiative recombination takes place.

The latter effect can be explained in the framework of "low dose behavior" model [1]:

at low doses the density of radiation-induced point defects is low as compared to the density of the defects that existed in the structure before γ -treatment → the improvement of optical characteristics occurs due to annihilation of the newly formed and original defects.

Conclusions

1. The noticeable increase of PL intensity is ascribed to the improvement of the quality of the structure as the result of the "effect of low doses" – annihilation of the initially existing defects of the structure with new defects introduced by radiation.
2. Non-sensitivity of both spectral position of QDs PL and activation energy is attributed to the radiation-resistant nature of light species in QDs.

[1] M. Dmytruk and R. Konakova, "Surface-enhanced radiative ordering in semiconductor heterostructures," *Visnyk AN URSR*, vol. 6, pp. 18–22, 1989.