Study of the photoluminescence properties of subcritical InAs/GaAs quantum dots formed onto structured substrates

"SPB OPEN 2024"
Saint Petersburg, May 14–17,

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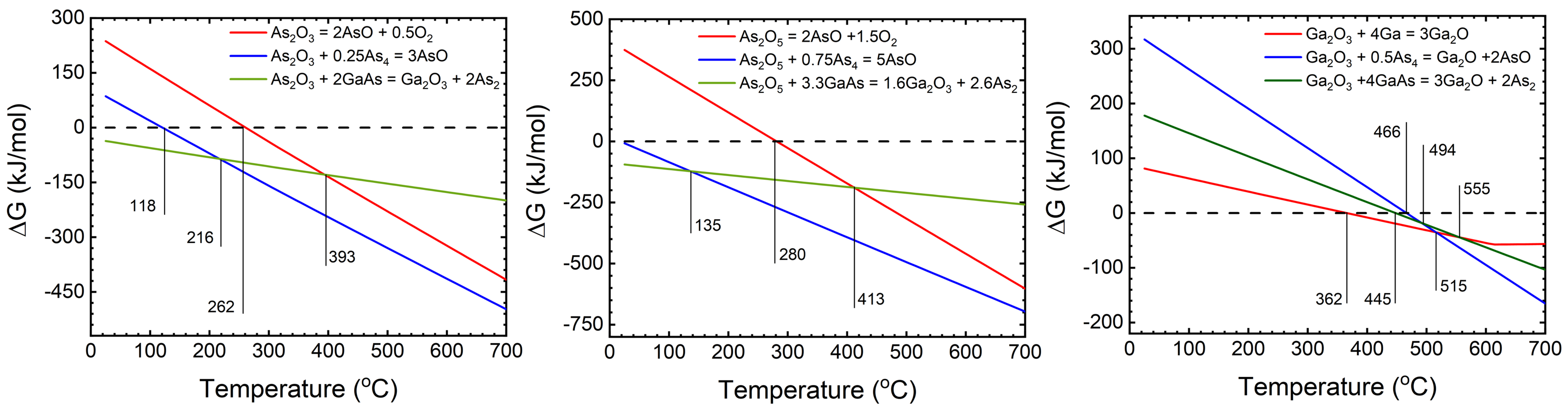
This work shows the results of experimental studies on the formation and optical properties of low-density InAs quantum dots obtained in subcritical growth modes on pre-structured substrates by thermal desorption of intrinsic oxides.

1

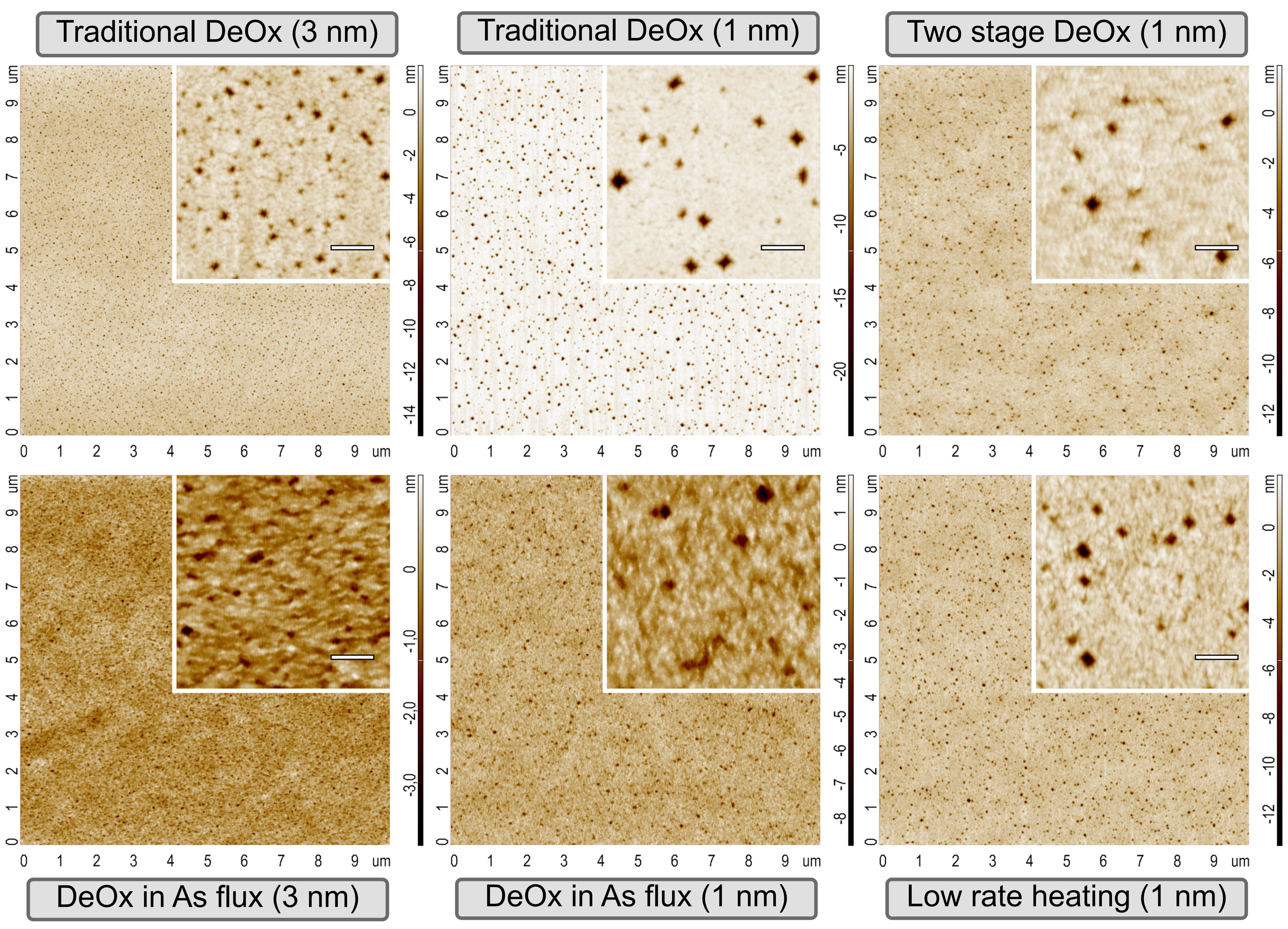
Analysis of the thermodynamics of the processes of interaction of GaAs native oxide components with gallium (Ga) and arsenic (As_4) species.



The decomposition of each oxide component in an arsenic atmosphere proceeds more efficiently than under other conditions. However, arsenic is also consumed in binding to gallium atoms, which are actively involved in the decomposition of gallium oxide. A decrease in the rate of oxide decomposition leads to the formation of nanoscale holes under local areas where oxide remains.

2

The substrates were structured by thermal desorption of native GaAs oxide (3 and 1 nm thick). Samples were prepared and analyzed with the different desorption modes.

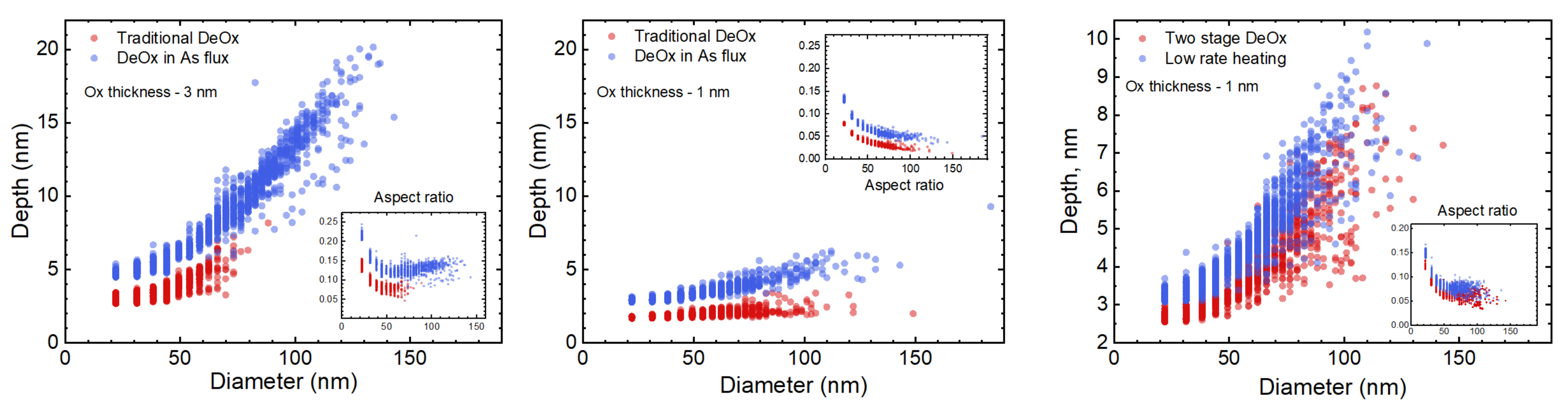


Scalebar in the inset - 200 nm

It was found that the most efficient method is a two-stage process of oxide thermal desorption. During this process, a low-density array of holes (1×10^9) with a facet orientation (111) is created.

3

Sample statistics obtained from more detailed analysis based on AFM images



Exposure of samples to the flux of molecular arsenic during the oxide removal not only leads to an expansion of the size range of the formed holes, but also changes their distribution. Based on the presented data, we found that with two-stage oxide removal, greater depth is achieved at the same diameter values. This is due to the first stage of the process, annealing at 500°C, where arsenic binds free gallium atoms, slowing down the oxide removal process at high temperatures.

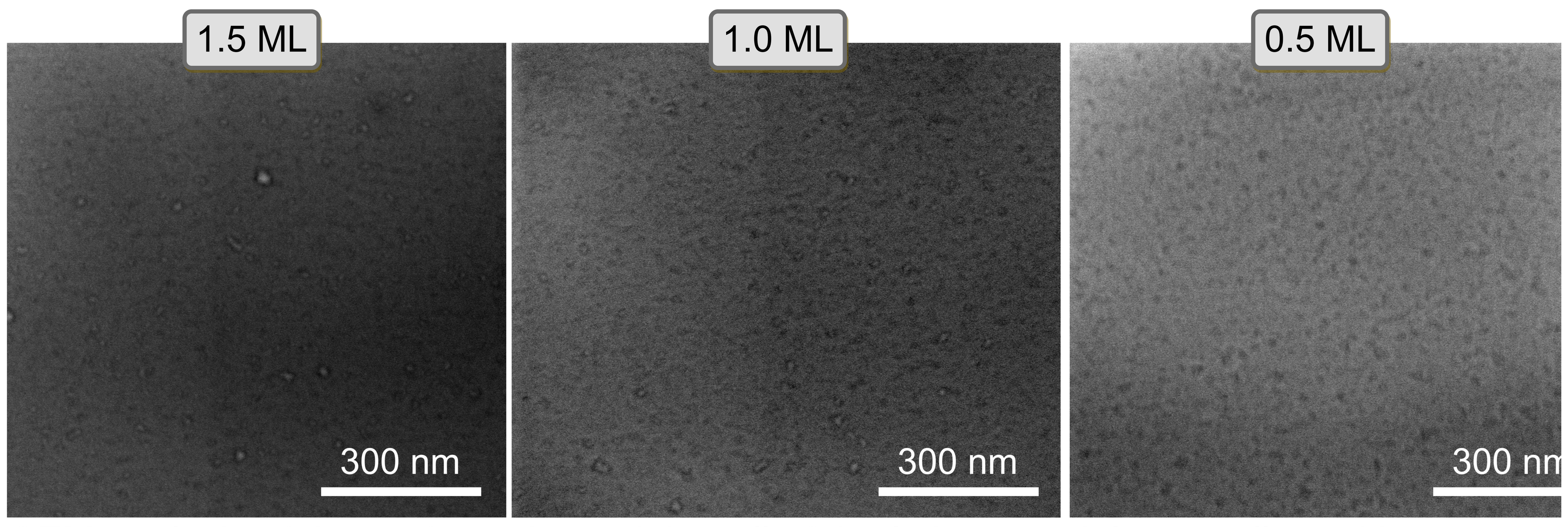
Ministry of Science and Higher Education of Russian Federation

Russian Science Foundation

Funding: This work was supported by the Russian Science Foundation Grant No. 22-79- 10251 and by the Ministry of Science and Higher Education of the Russian Federation Grant No. FENW-2022-0034 at the Southern Federal University.

4

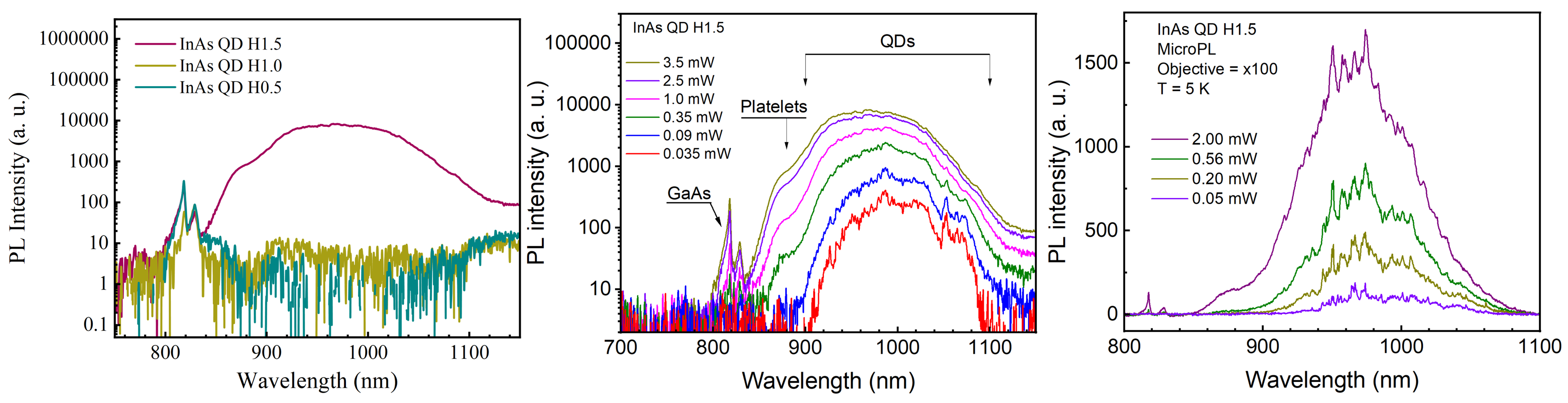
The study of InAs deposition on the structured surface is presented. The equivalent deposition thickness is 0.5-1.5 ML, which is insufficient for the formation of quantum dots in the SK mode. Surface structuring is achieved through a two-stage process of thermal desorption of the native oxides of the substrate.



SEM analysis of the surface showed that all of the InAs material was collected in nanoholes, forming 3D structures. The variation in size was caused by the inhomogeneity of the hole sizes themselves. It was found that decreasing the deposited material from 1.5 to 1.0 ML led to a decrease in the density of filled holes and a reduction in the size of the nanostructures. For the sample with a thickness of 0.5 ML, no structures were detected. This suggests that this thickness was not sufficient for the formation of 3D objects within the holes due to the high roughness of the surface.

5

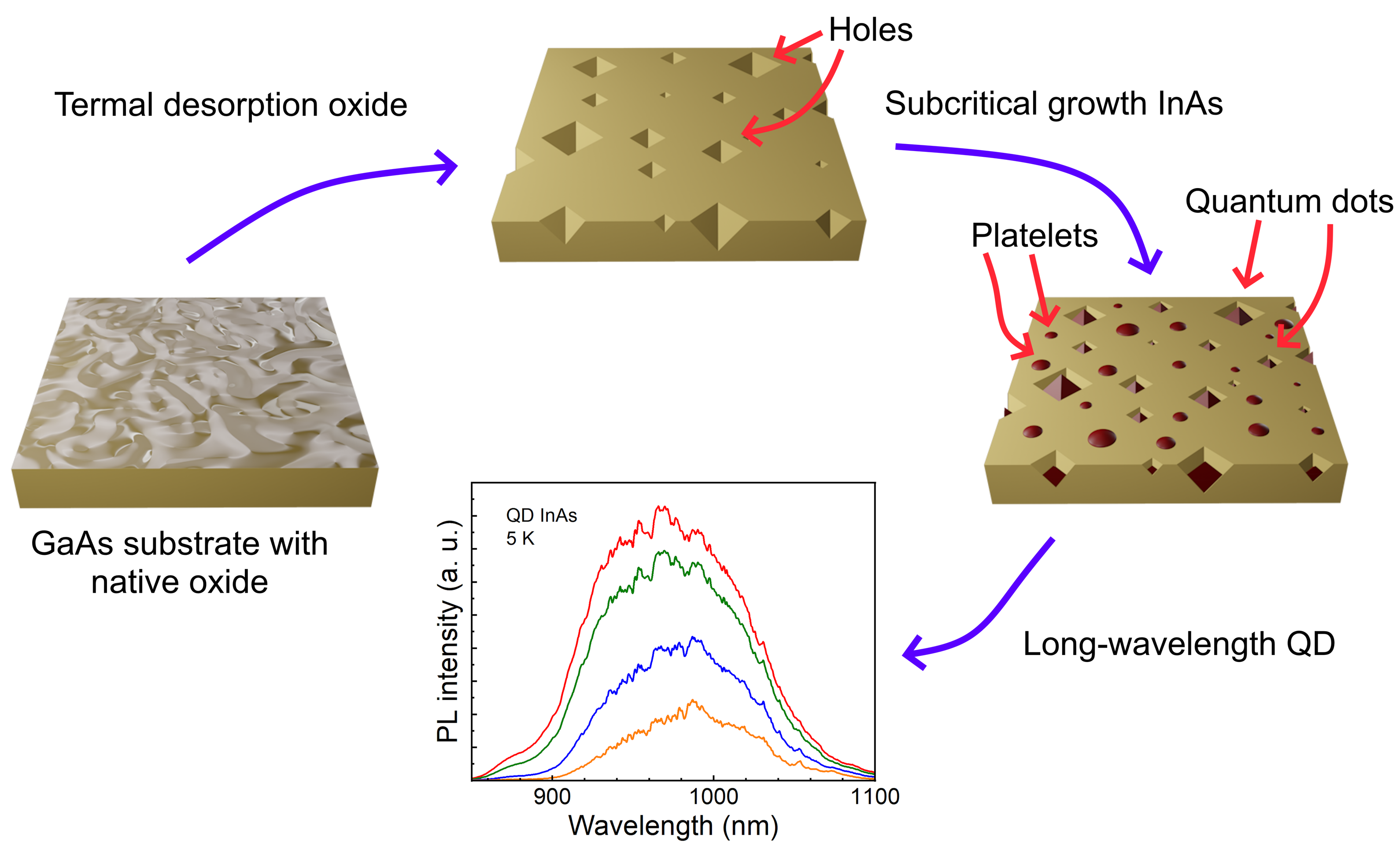
Study of the optical properties of formed quantum dots in subcritical growth modes



According to the results of the PL analysis, quantum dots (for the 1.5 ML sample) emit in a wide range of wavelengths from 870 to 1100 nm, which is due to the initially large size of the quantum dots. At different excitation powers, two contributions are observed in the spectrum. The first contribution is in the range of 900-1100 nm, with a maximum of about 970 nm. This corresponds to optical transitions within the quantum dots. The second contribution in the range of 850-900 nm may be associated with two-dimensional In(Ga)As structures - "platelets", that form between holes or on surface inhomogeneities. PL studies at the microscale level (at a magnification of x100 and a temperature of 5K) showed a pronounced discrete structure in the radiation spectrum, indicating a low density of quantum dots.

7

A schematic representation of the formation of low-density QDs of InAs on the GaAs(001) substrate, which emit in the wavelength range of 900-1100 nm.



7 Conclusion:

The conducted studies demonstrated the possibility of the formation of low-density InAs quantum dots in subcritical growth modes (QD densities ranging from 10^8 to 10^9 cm^{-2}). The opportunity of varying the QD density during the surface structuring stage was demonstrated. Maximum emission was achieved at a wavelength of 1100 nm. These results can be used to develop a technological process for creating single InAs QDs in O- and, eventually, C-bands without a wetting layer.