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Study of InAs/GaAs quantum dots formation in sub-critical growth modes on patterned substrates

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Motivation

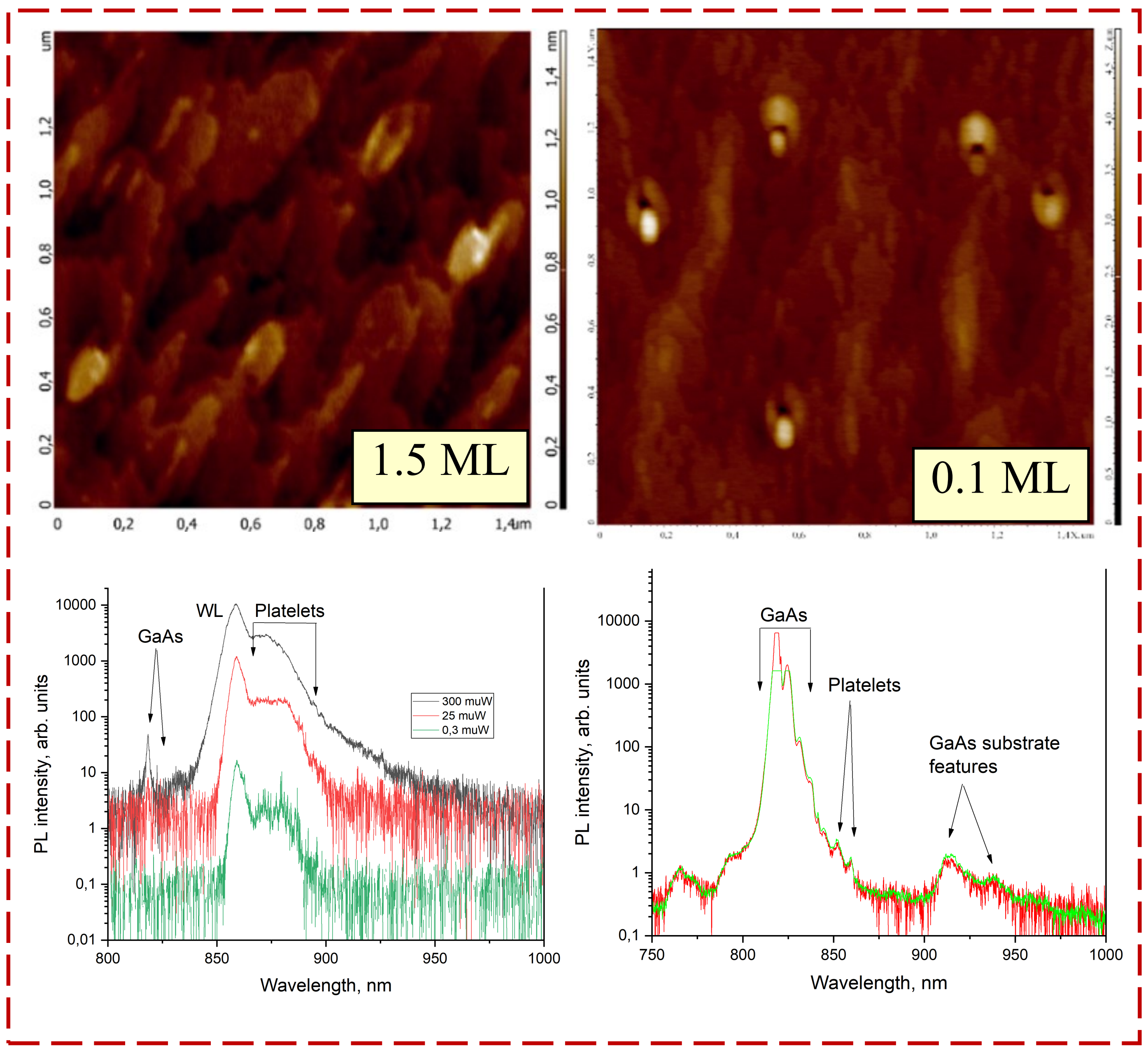
The unique properties of semiconductor quantum dots (QD) make them promising objects for creating micro- and nanoscale light sources on their basis, including non-classical light, which act as active elements of integrated nanophonomics and systems of quantum communications and quantum computing. In this regard, there is a need to develop methods for precise control of QD parameters, such as size, shape, chemical composition, etc. From this point of view, the most promising approach seems to be based on the pre-growth structuring of the substrate surface, i.e. controlled formation of nanoholes on the surface, which later act as nucleation centers for self-organizing nanostructures. The aim of our work is to study the influence of the method of forming nanoholes, as well as their sizes and shapes, on the processes of formation of nanostructures in them, as well as the possibility of obtaining QDs at subcritical thicknesses and without a wetting layer.

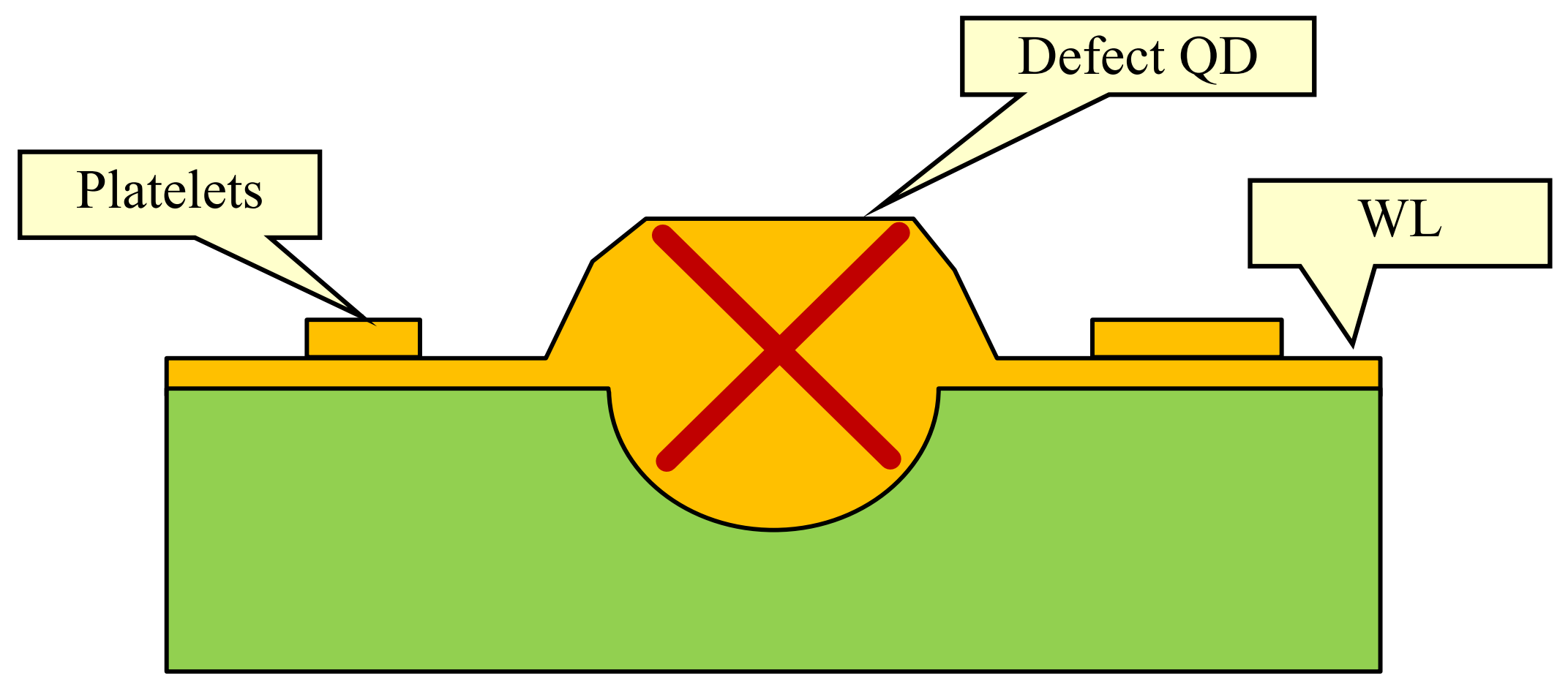
Experiment

For experimental study we used two ways to nanopattern GaAs substrates: local droplet etching (LDE) and modified oxide desorption technique. Both methods allow in situ formation of nanosized pit (or nanoholes) on the surface, but their shape is quite different. During LDE processing, bowl-shaped nanoholes with a diameter of about 100 nm, a depth of several nanometers and a density of about 10^8 µm^{-2} are typically formed on the surface. In the case of oxide desorption patterning, an array of faceted nanoholes with 35 nm in diameter, at least 5 nm in depth (according to AFM data) and 10^9 µm^{-2} in density is formed on the surface. After surface nanopatterning stage we grew of InAs layer with thickness varied from 0.1 to 1.5 monolayers (ML). Also, we grew the same heterostructure with InAs layer (1.5 ML) without nanopatterning surface which we used as a reference sample. For PL study we repeated the same structures placed them in the central part of AlGaAs/GaAs/AlGaAs heterostructure.

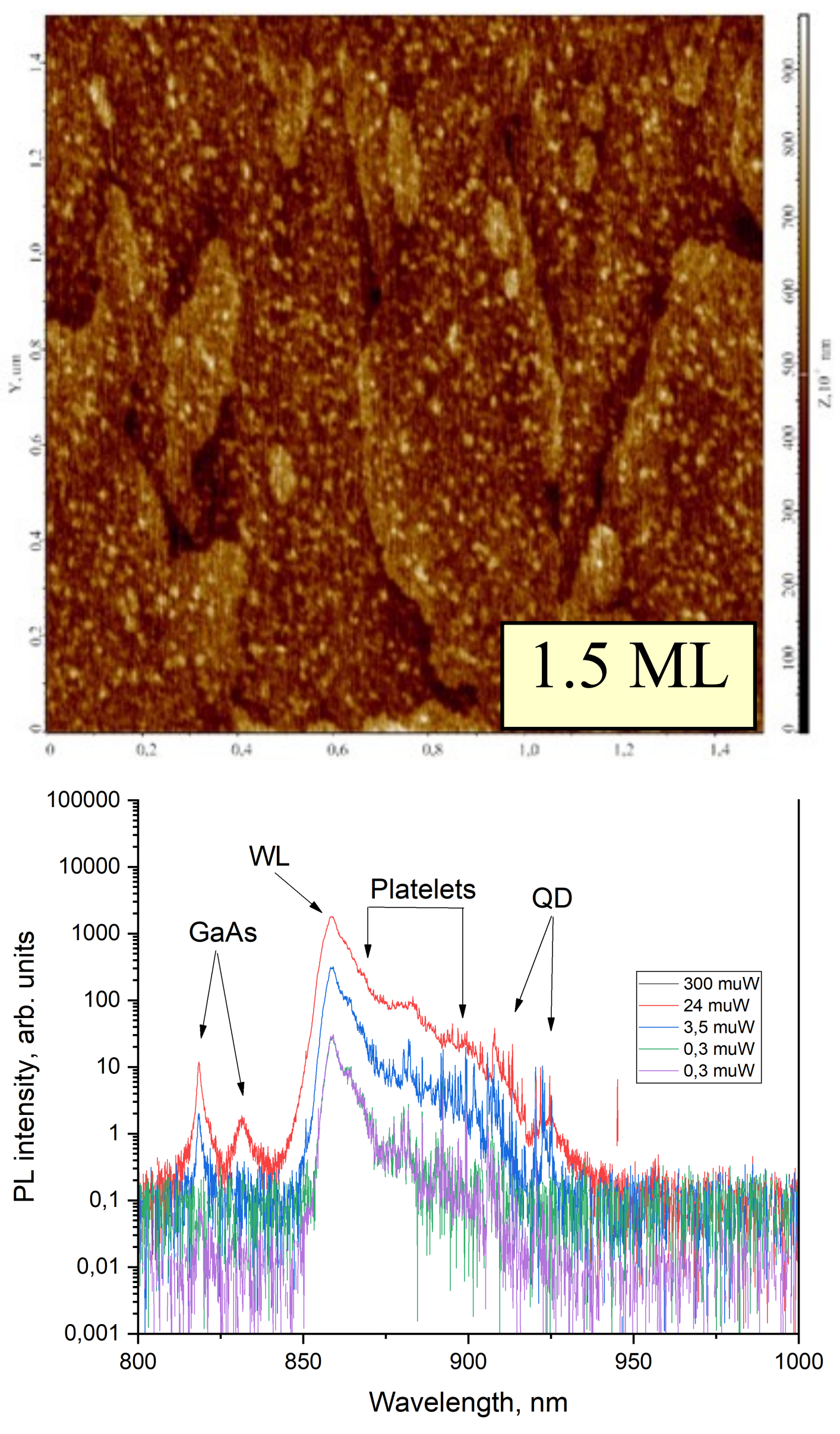
Results

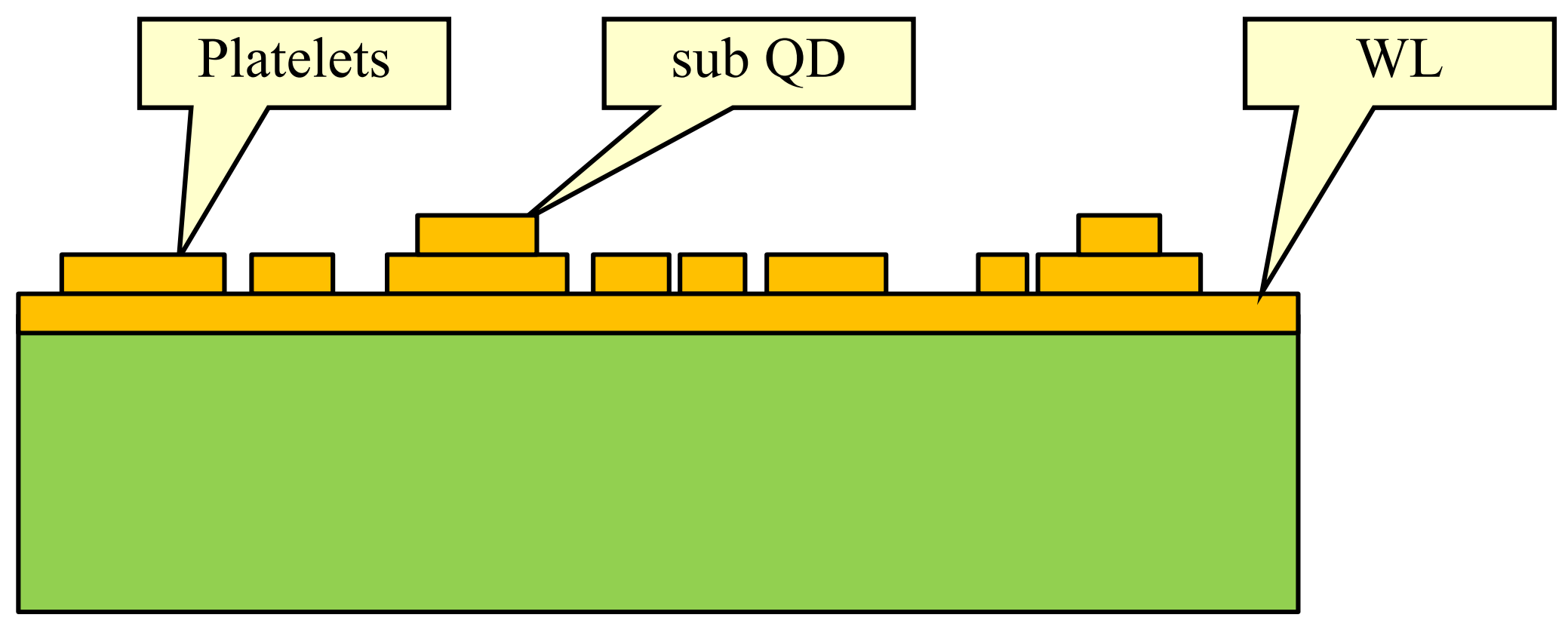
Local droplet etching (LDE)



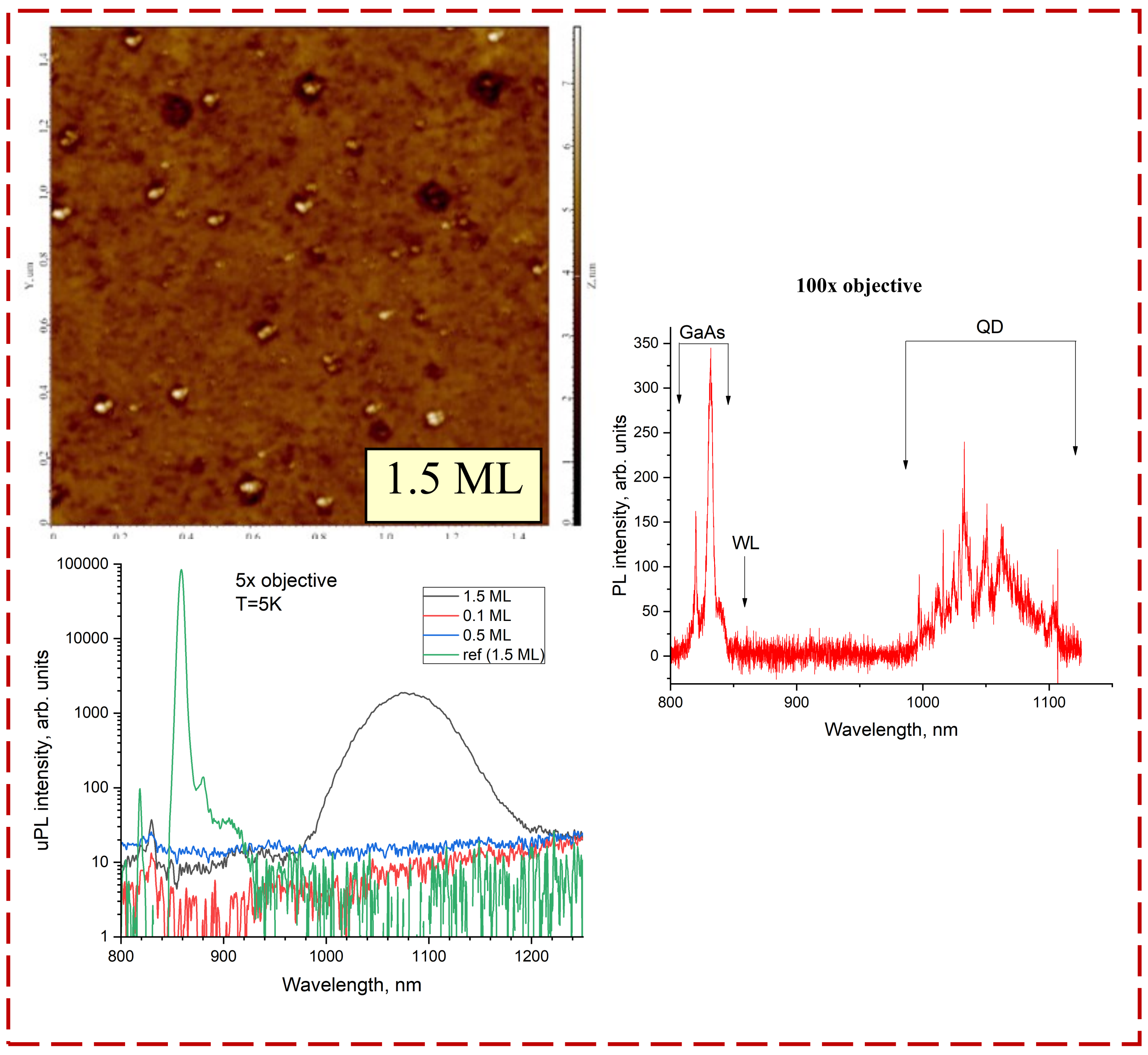


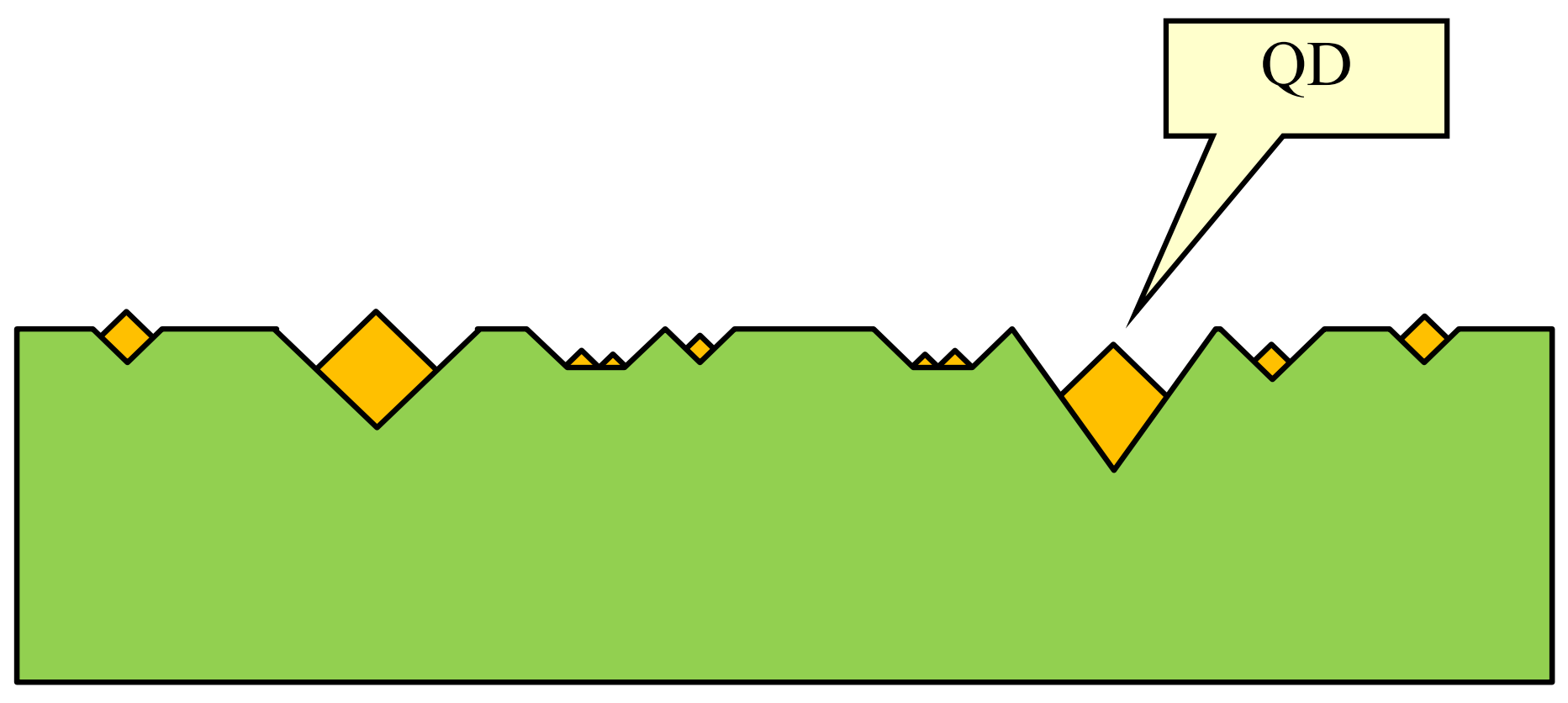
Without structuring





Oxide desorption patterning





Conclusion

We have shown that the shape of a nanohole, which largely depends on the method of formation, has a decisive influence on the nucleation and growth of self-organizing nanostructures and their optical properties. The bowl-shaped nanoholes (with a small aspect ratio and the absence of a pronounced faceting) is not optimal for the formation of QDs, despite the pronounced selectivity of growth processes. A possible reason for the complexity of QD formation in such pits is polycentric nucleation, which leads to the formation of relaxed QDs with a high defect density. Faceted nanoholes are optimal for the selective formation of QDs without a wetting layer. Presumably, large QDs are inactive (dislocated), which leads to PL suppression at 300 K. Thus, it has been experimentally shown that the use of nanostructuring of the growth surface makes it possible to localize the formation of self-organizing nanostructures (including QDs) in nanoholes at subcritical deposition thicknesses and to suppress the formation of a wetting layer.

Acknowledgments

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