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Annealing temperature effect on the GaAs nanowire growth on the FIB-modified Si substrate

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Abstract

This paper presents a *simple and inexpensive* (compared to analogues) *technology* that allows to fabricate *localized GaAs nanowire (NW) arrays* on a Si(111) substrate with a native oxide layer on the surface and to control NW properties such as: density, length, diameter, verticality of the NWs, as well as their location on the surface. This is achieved by the use of Si(111) surface pre-treatment with *a focused Ga ion beam* followed by *ultra-high vacuum annealing*, during which the native oxide layer is modified by the chemical interaction of diffusing embedded ions to the surface with oxide atoms and the formation of a masking layer at low doses, an array of nanopores at medium doses and an array of Ga droplets at high doses. Growth on such a prepared surface allows one to accurately set the parameters of future NWs. In this work, a series of experimental studies have been conducted to evaluate the degree of ion treatment parameters and growth influence on various properties of GaAs NWs on Si(111) within the FIB treatment areas. It is shown that an increase of the annealing temperature from 600 to 750°C leads, on the one hand, to an increase of the *nanowire density up to ~ 40 μm^{-2}* at the maximum dose value. On the other hand, this leads to an increase in the proportion of *vertically oriented nanowires up to 100% on a Si (111) substrate with a native oxide layer* on the surface. It was found that an increase in the annealing temperature leads to a sharp increase (by several orders of magnitude) in the integral photoluminescence intensity from the obtained arrays over the entire ion dose range. An increase in the dose range in which NW arrays with a single cubic crystalline phase are formed was also observed for a sample with an annealing temperature of 750°C which is supported by the Raman spectroscopy results.

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First of all, the Si(111) substrate with a native oxide layer on the surface was prepared by focused Ga ion beam treatment. Then the modified substrate was annealed and GaAs NW growth was performed (Figure 1).

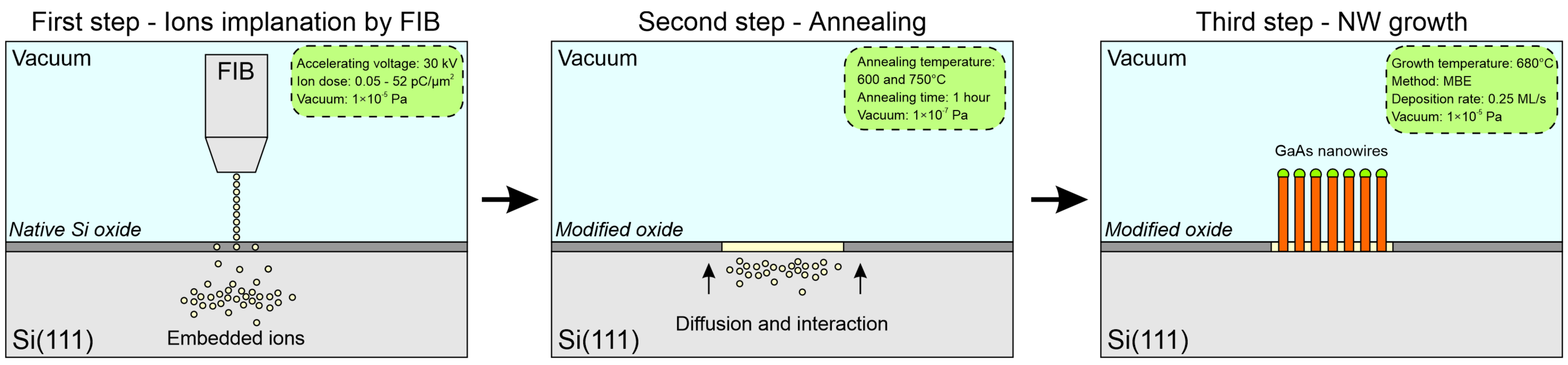

Figure 1 — Schematic representation of the developed technology based on Si(111) substrate treatment by focused ion beam.

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SEM studies (Figure 2) and statistical processing of GaAs NW arrays geometrical characteristics (Figure 3).

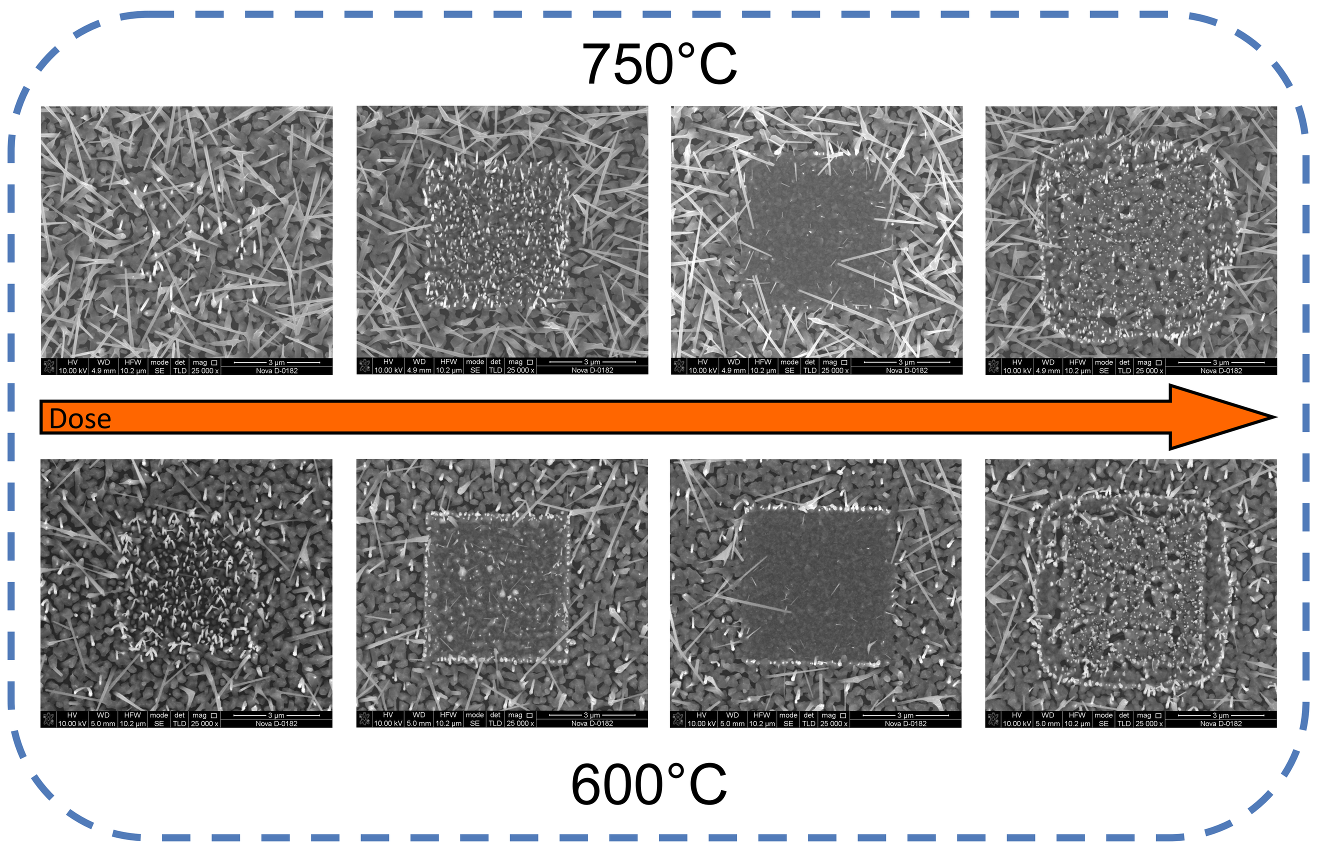

Figure 2 — SEM images of formed arrays at different annealing temperature.

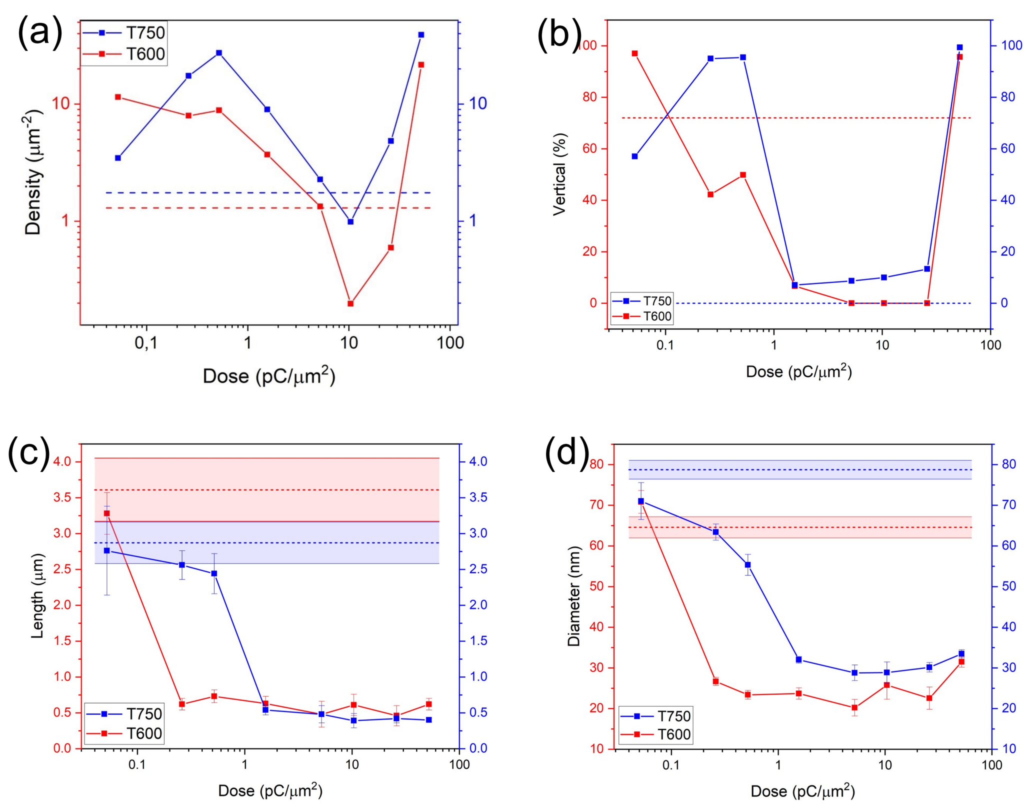

Figure 3 — Dependences of density (a), verticality (b), diameter (c) and length (d) of NWs on ion dose.

3

Raman studies of the formed GaAs NW arrays at different annealing temperatures (Figure 4).

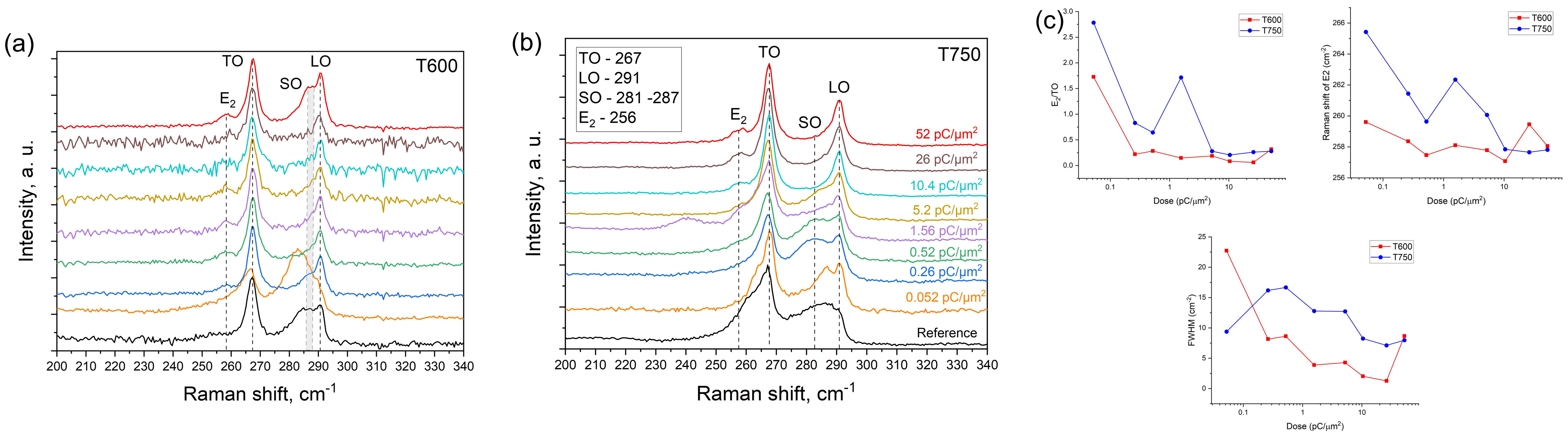

Figure 4 — Raman spectra from NW arrays formed within the FIB treatment areas at annealing temperatures: 600 (a) and 750°C (b). Raman spectra deconvolution (c).

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Photoluminescence results (Figure 5).

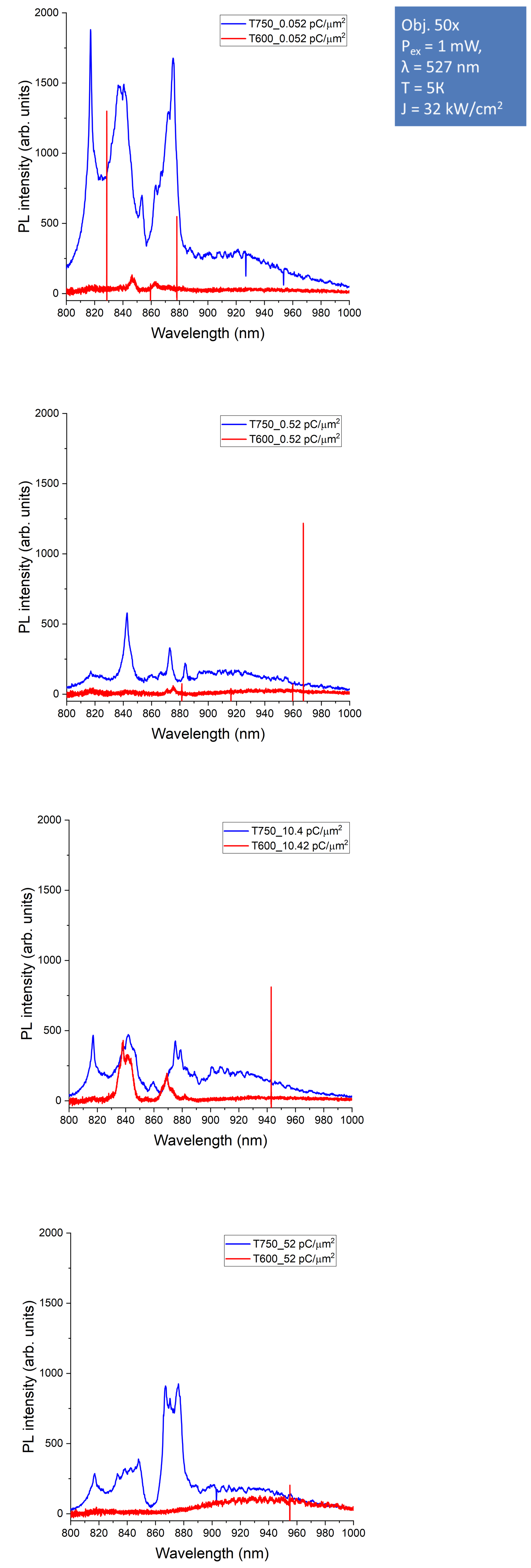

Figure 5 — Photoluminescence spectra for different ion doses.

Conclusion

Thus, a simple and inexpensive technology has been demonstrated that allows, after optimization of FIB processing and growth parameters, to form on a Si(111) substrate, without additional operations typical of traditional lithographic processes and application of additional oxide, local high-density arrays of GaAs NWs with 100% verticality and a single sphalerite crystal phase of NWs within a certain dose range and the ability to control their key characteristics in a wide limits range on a single substrate in a one-step technological process.

Acknowledgments

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