Increasing the density of InAs quantum dots using InAlAs quantum dots as a seed

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1 - Abstract

Pre-deposition of InAlAs quantum dots (QDs) is an effective method to increase the areal density of InAs Stranski-Krastanov quantum dots (SK-QDs) grown just on top of them. Since Al adatoms have a very low surface diffusion, they create more nucleation centers and lead to a very high density of small InAlAs SK-QDs. In the present work, we optimized the Al content of the InAlAs layer in order to get a density of InAlAs QDs as high as possible. Then, we varied the thickness of the GaAs spacer between the InAlAs and InAs layers to get the highest density of InAs QDs in the top layer.

2 - Experimental results

2-1 Ultra-high density of InAlAs QDs

To determine the highest possible density of InAlAs QDs as a function of their Al content, we deposited all the InAlAs layers with 125% of their critical thickness. Figure 1 shows that the density of InAlAs QDs of such layers has a maximum around 50% of Aluminum. Below that value, the Al atoms are to scarce to effectively increase the density, while, above that value, the In content becomes too low, and the lower strain present in the system favors the nucleation of a lower density of larger QDs.

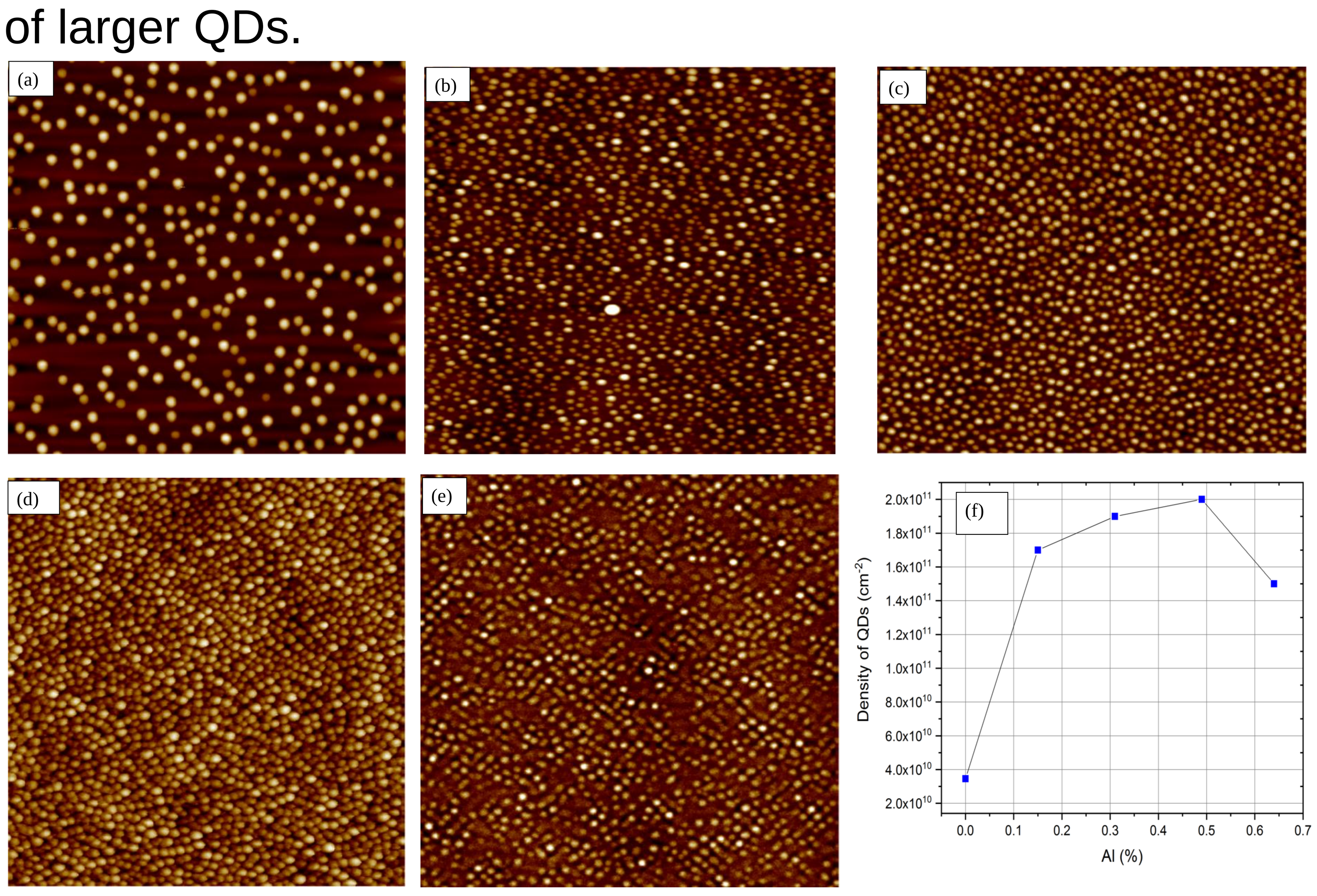

Figure 1: 1×1 μm^2 AFM images showing the surface of a single layer of $In_{1-x}Al_xAs$ QDs with a) x=0; b) x=0.15; c) x=0.30; d) x=0.50; and e) x=0.65. f) Density of QDs in the $In_{1-x}Al_xAs$ layers of figures (a) to (e).

2-2 Influence of pre-deposition of InAlAs QDs on the density of InAs QDs

Figure 2 shows that, when InAs QDs are grown on top of these InAlAs QDs, their density can increase up to a factor of three when compared to a single layer of InAs QDs. Figure 2b also reveals that pre-deposition of $In_{0.7}Al_{0.3}As$ QDs yields a higher density of InAs QDs than with $In_{0.5}Al_{0.5}As$ QDs, although the latter had originally a slightly higher density than the former (figure 1f). This is most probably due to the fact that $In_{0.5}Al_{0.5}As$ QDs contain less In than $In_{0.7}Al_{0.3}As$ QDs and therefore generate a weaker local strain field that is not able to influence as effectively the nucleation of the InAs QDs in the top layer.

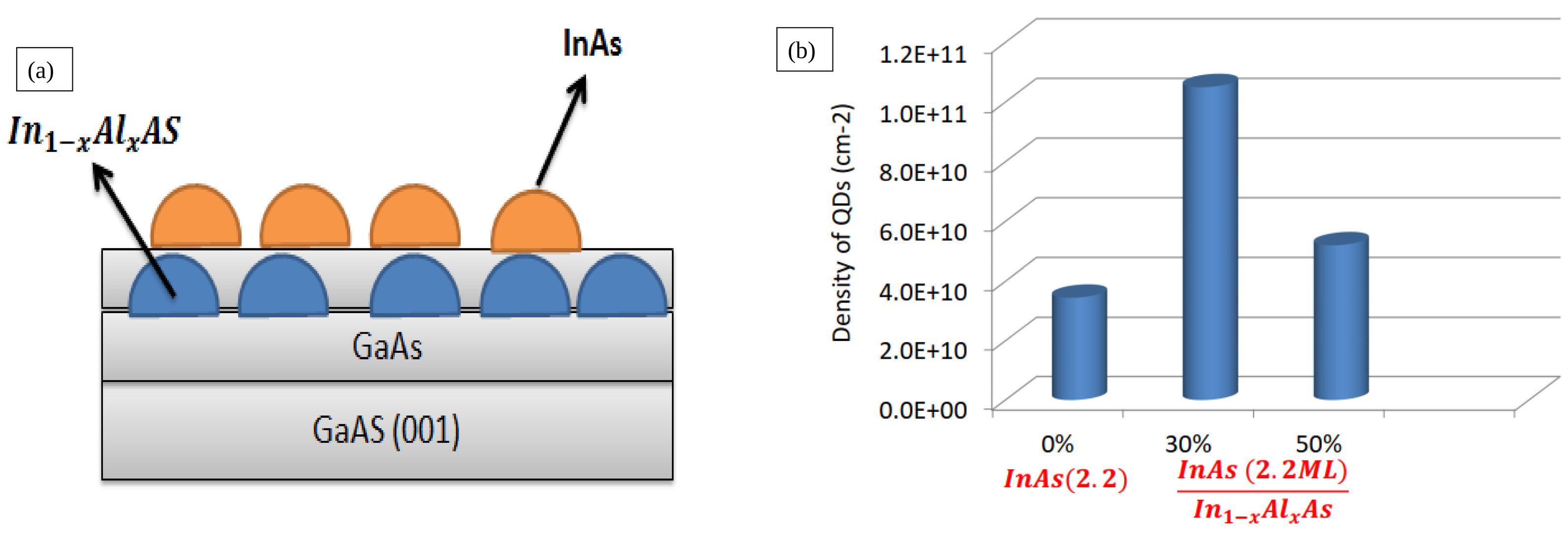

Fig. 2: a) Pre-deposition of InAlAs QDs, acting as a seed, and, on the top of them, deposition of InAs QDs separated by a few nm of GaAs. b) Density of QDs in the top InAs layer of an InAlAs/InAs bilayer as a function of the Al content. The GaAs spacer was 4 nm.

2-3 Optimization the GaAs thickness between the bilayers of InAlAs/InAs QDs

Finally, we optimized the thickness of the GaAs spacer between the layers of $In_{0.7}Al_{0.3}As$ and InAs QDs. Several samples containing bilayers of $In_{0.7}Al_{0.3}As$/InAs QDs were grown with a different thickness of the GaAs spacer ranging from 2 to 7 nm. Then, all the samples were analyzed by AFM and PL at 77K.

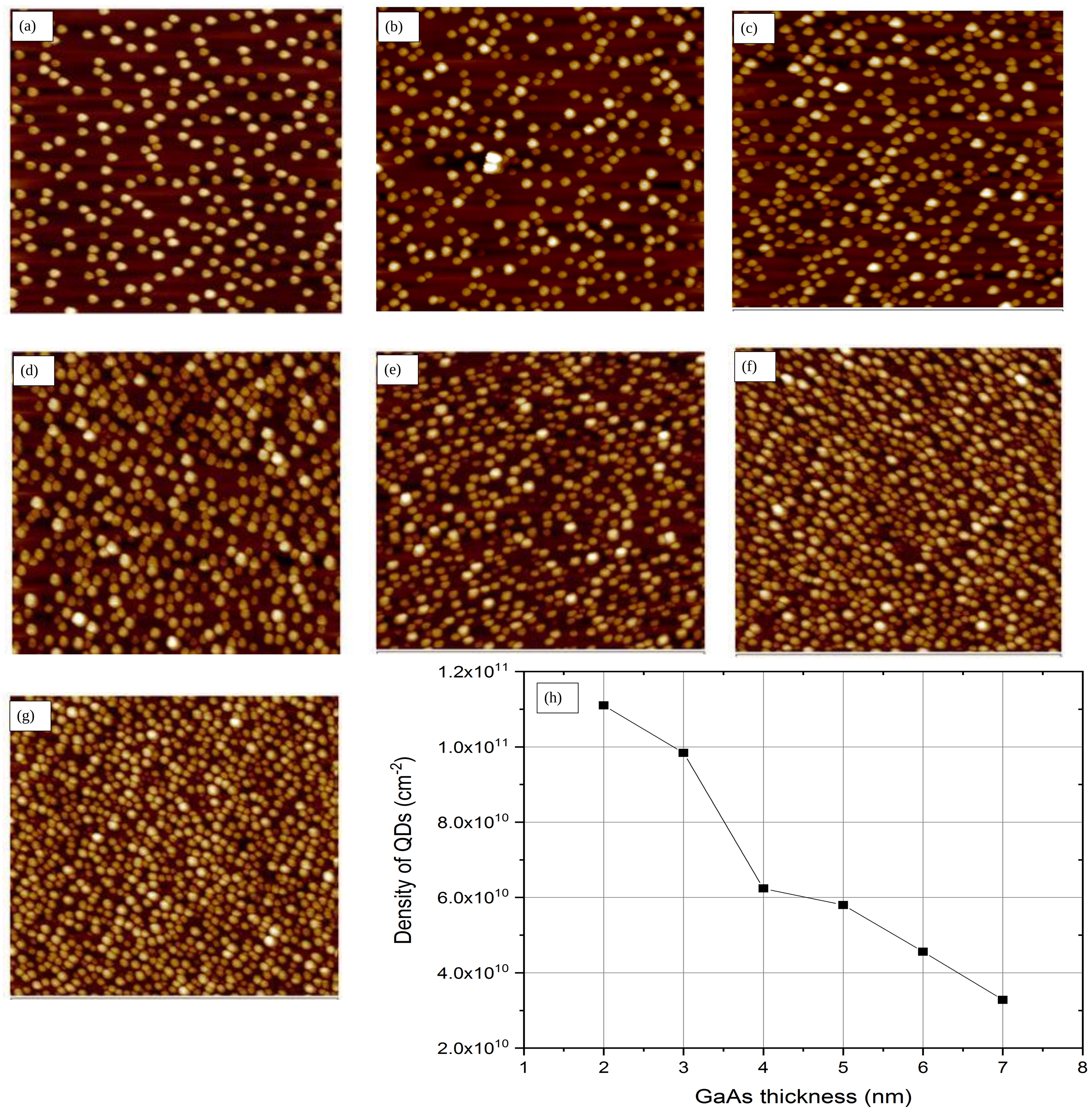

Figure 3: 1x1 μm^2 AFM images of samples containing $In_{0.7}Al_{0.3}As$/InAs QD bilayers separated by a GaAs spacer having a thickness of (b) 7 nm, (c) 6 nm, (d) 5 nm, (e) 4 nm, (f) 3 nm, and (g) 2 nm. (a) Reference sample containing only InAs QDs with a density of 3.2×10^{10} cm^{-2}. (h) Density of InAs QDs from images (b) to (g).

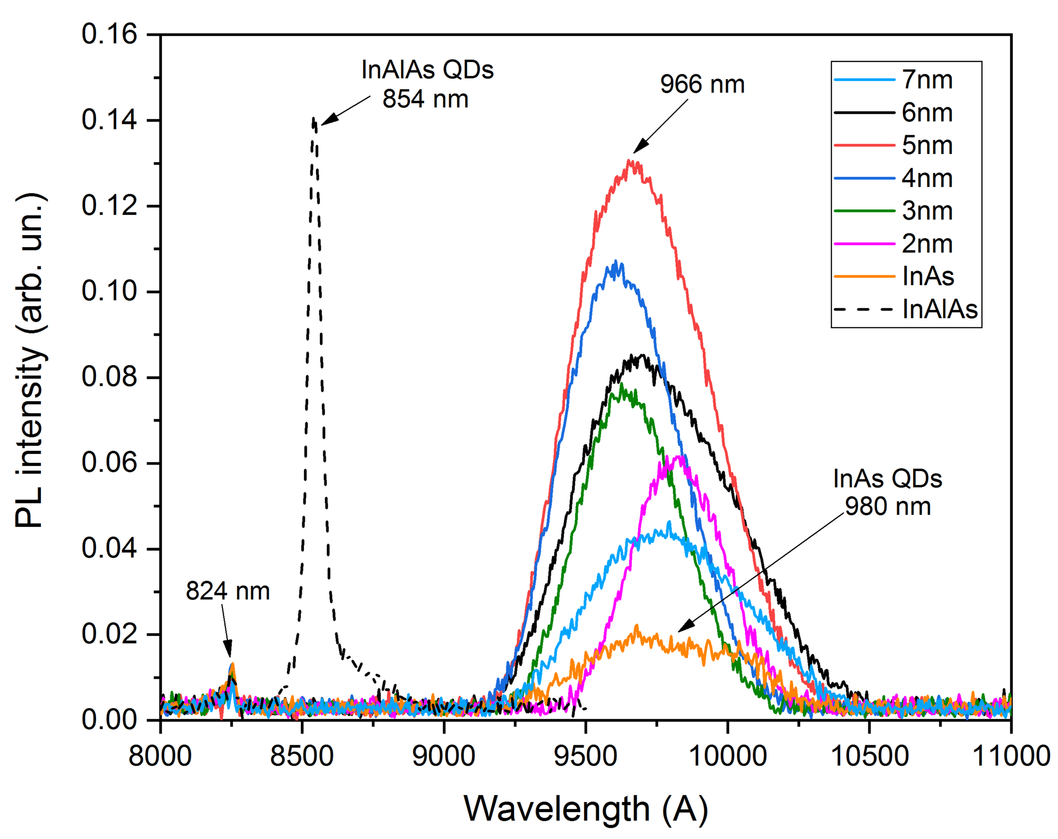

Figure 4: PL spectra at 77K of the same $In_{0.7}Al_{0.3}As$/InAs QD samples of figure 3, differing only by the thickness of the GaAs spacer. The PL signal of samples containing only InAs or $In_{0.7}Al_{0.3}As$ QDs are plotted as a reference.

We can see from figure 3 that, for this range of spacer thickness, the density of InAs QDs in the top layer increases linearly with decreasing values of the spacer thickness. Figure 4 shows that all the samples containing bilayers have an emission close to that of usual InAs QDs, suggesting that the InAlAs QDs are not optically active. This is most probably due to the smaller size and lower In content of the InAlAs QDs that, consequently, have a ground state much higher than that of InAs QDs that favors optical recombination from the latter only.

3 - Conclusion

We optimized the growth conditions of InAlAs QDs and InAlAs/InAs QD bilayers in order to increase as much as possible the density of InAs QDs in the top layer using InAlAs QDs as a seed. We concluded that a layer of In0.7Al0.3As QDs and a GaAs spacer of 2 nm were necessary to provide the best results.

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