Improvement of InAs quantum dots by migration enhanced epitaxy

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1 - Abstract

Molecular beam epitaxy (MBE) is a deposition technique able to produce high-quality epitaxial layers. In general, the growth is realized at high temperature, and the pure elements are provided by individual Knudsen cells that are opened simultaneously to form the alloys that are requested. However, in some specific cases, the growth has to be performed at low temperature, and the usual deposition conditions may lead to a low mobility of the adatoms and, consequently, to a worse crystalline quality. To solve this problem, an alternative epitaxial technique, called migration enhanced epitaxy (MEE), was developed. Instead of depositing the elements simultaneously, MEE involves the alternate deposition of a single monolayer of each individual element of the alloy.

In this work, we grew InAs quantum dots by MBE and covered them with a thick GaAs layer grown by MBE or MEE at different temperatures in order to investigate its influence. Low-temperature photoluminescence measurements were performed to check the quality of the samples.

2 – Migration enhanced epitaxy (MEE) and Molecular beam epitaxy (MBE)

To grow GaAs by MEE, one must deposit a single monolayer of Ga atoms followed by a single monolayer of As atoms, repeating the cycle as many times as necessary to achieved the required thickness, while MBE would only demand the opening of both cells together at the beginning. In such conditions, the mobility of each type of adatom is much higher for the MEE technique, and the high crystalline quality of the samples can be maintained at much lower temperature.

Reflection high energy electron diffraction (RHEED) is a powerful tool that can be used *in situ* to monitor the growth rate, composition, surface reconstruction, and flatness of the epitaxial layers before, during or after the growth.

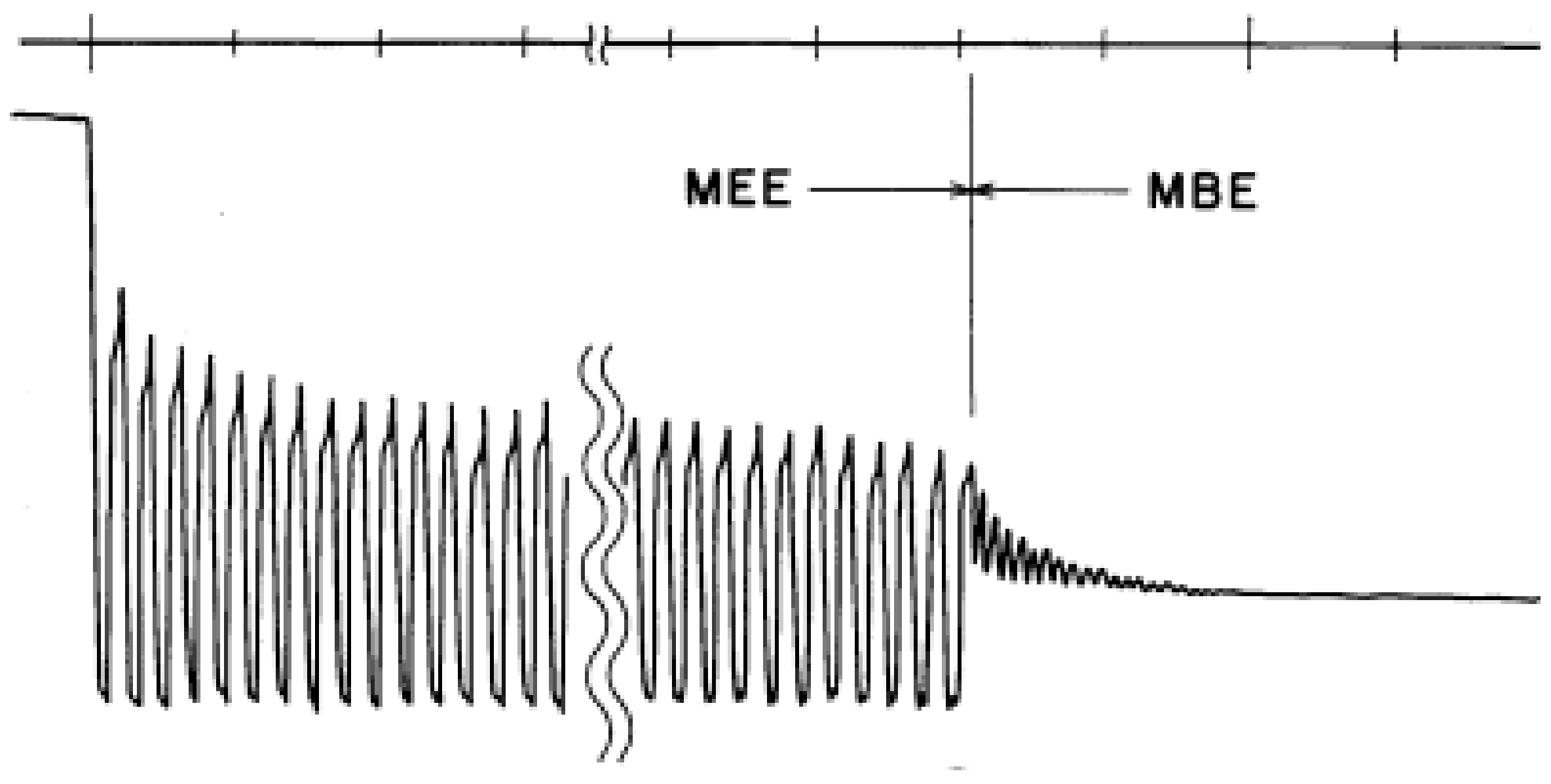


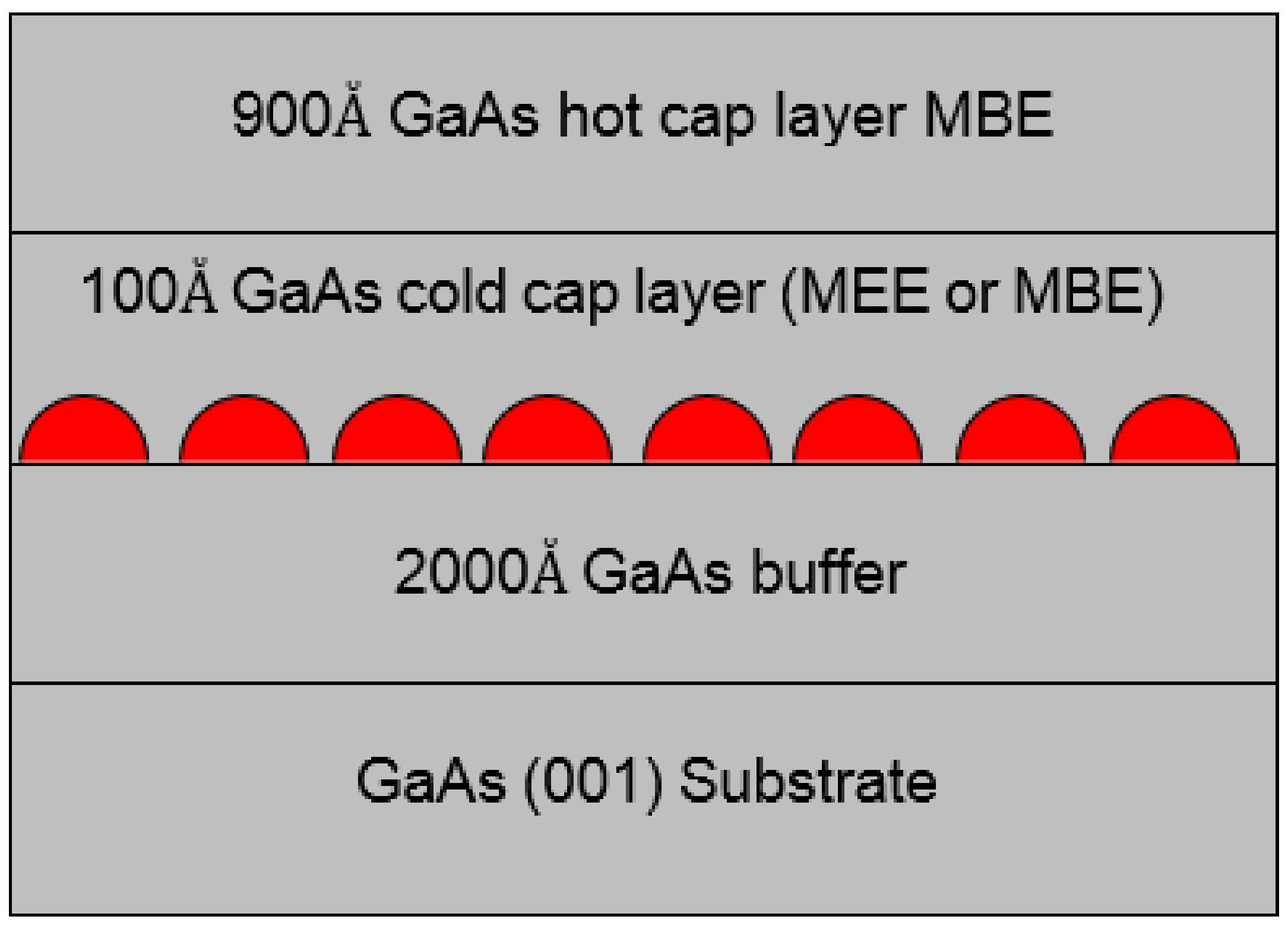
Figure 1: Intensity of the RHEED specular beam during MBE and MEE. [1]

In MEE, the RHEED intensity increases after As deposition and decreases after Ga deposition, due to the different reflectivity of the As-stable and Ga-stable surface resulting from their different surface reconstruction. The oscillation can be maintained indefinitely, confirming the high quality and excellent flatness of the layers.

In MBE, the maxima and minima correspond to a full or half layer of material, respectively, and the much stronger damping indicates a rougher growth front that, at lower temperatures, will lead to a worse crystalline quality.

3 – Experimental procedures and results

Five samples containing InAs quantum dots (QDs) grown by MBE were capped by a thin GaAs layer grown by MBE or MEE in different conditions. The general structure of the samples is explained in Figure 2 and Table 1. Sample A was fully grown by MBE and is a reference for this study. The other samples had their QDs covered by MEE using a different sample temperature or arsenic coverage (flux). The MEE deposition time was set to grow exactly 1 monolayer of Ga in each cycle, and was fixed to 2 s for the As material, whatever its flux.



900Ǻ GaAs hot cap layer MBE

100Ǻ GaAs cold cap layer (MEE or MBE)

2000Ǻ GaAs buffer

GaAs (001) Substrate

Figure 2: General structure of the five samples.

Samples	Structure
A	Cold cap layer by MBE at 515°C
B	Cold cap layer by MEE at 515°C with high As flux.
C	Cold cap layer by MEE at 515°C with low As flux.
D	Cold cap layer by MEE at 450°C with high As flux.
E	Cold cap layer by MEE at 450°C with low As flux.

Table 1: Growth parameters of the cold cap layer.

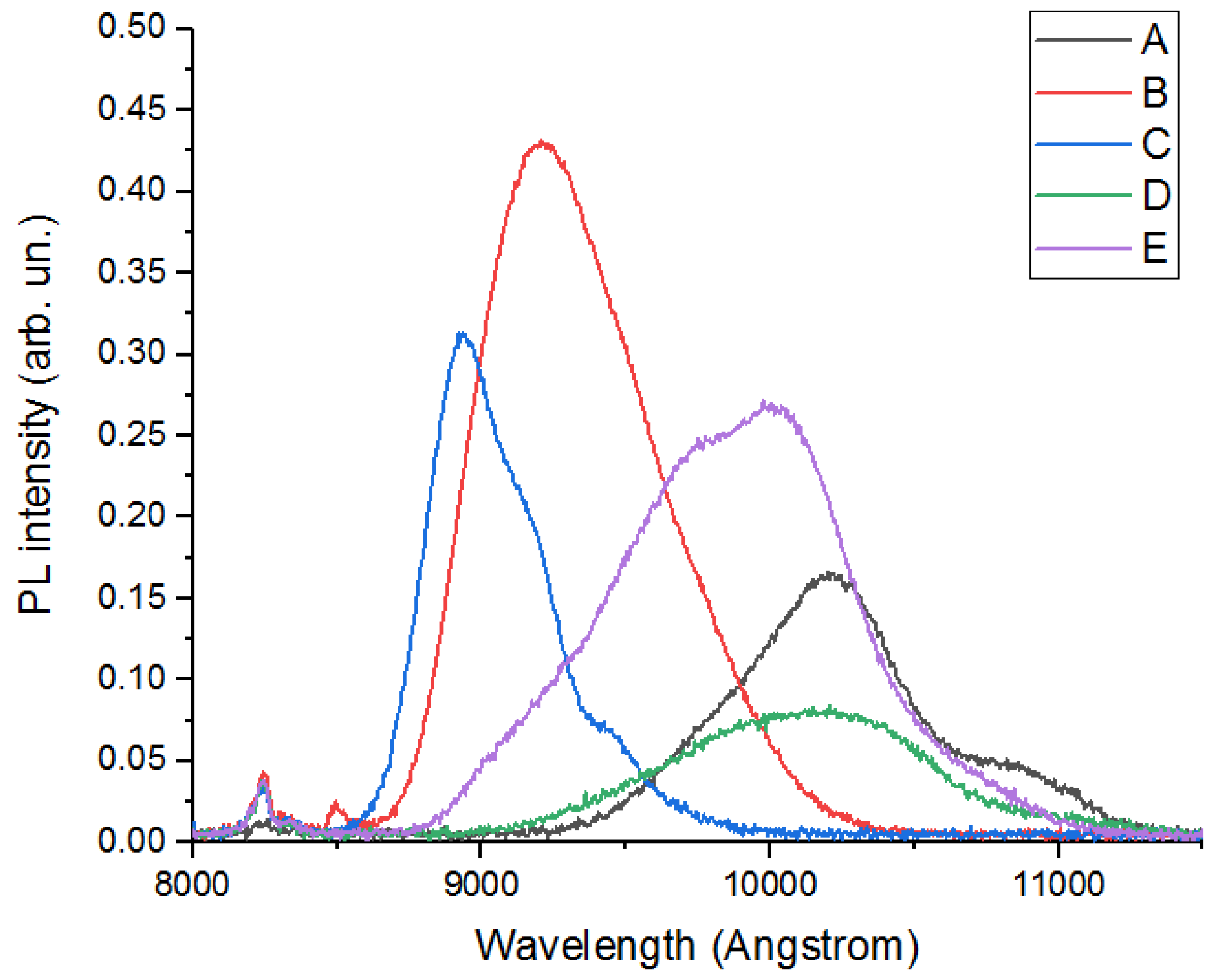


Figure 3: Photoluminescence at 77 K of the five samples.

Photoluminescence (PL) measurements of samples A, B, and C grown at 515°C show that the MEE samples have a higher signal that is blueshifted compared to the MBE sample. This is due to the higher quality of the MEE layers (less defects) and to stronger segregation of the In atoms that leads to nanostructures with less In and a larger band gap.

When the temperature of the cold cap layer is reduced to 450°C (samples D and E), the PL emission redshifts, suggesting that In segregation is reduced, as expected. However, this time, the sample with a lower As flux is superior as, at such a low temperature, less arsenic is evaporated from the surface, and a smaller amount of arsenic coming from the cell is required to complete a full monolayer.

4 - Conclusion

In this work, we used MEE to grow the cold GaAs cap layer of InAs QDs. This technique is able to produce high quality GaAs layers, even at low temperatures that are necessary to reduce In segregation and mantain the original size and composition of the QDs. However, the growth at even lower temperatures still needs to be optimized to avoid the excess of arsenic that is harmful to the quality of the layers.

[1] Yoshiji Horikoshi *et al* 1988 *Jpn. J. Appl. Phys.* **27** 169

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