# Capping of InAs quantum dots by migration enhanced epitaxy

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# Summary

1. Growth and applications of InAs quantum dots.
2. Capping of InAs quantum dots.
3. Migration Enhanced Epitaxy (MEE).
4. Experimental procedures and results.
5. Optimization of GaAs growth by MEE.
6. Conclusion.

# Growth and applications of InAs quantum dots

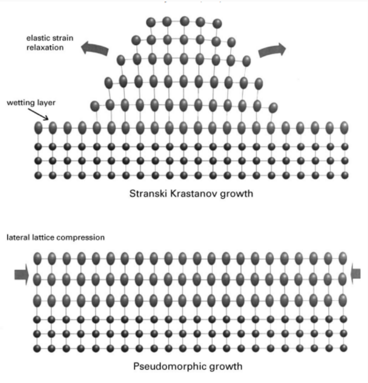


**Figure 1:** Stranski Krastanov Growth [1]

The epitaxial growth is performed essentially in three modes. One of them is the Stranski Krastanov growth mode, in which the layers are grown initially in 2D until a critical thickness. If the deposition exceeds this thickness, islands are nucleated on the surface.

[1] "Self-assembling quantum dots for optoelectronic devices on si and gaas," Physica E: Low-dimensional Systems and Nanostructures, vol. 9, no. 1, pp. 164–174, 2001.

# Growth and applications of InAs quantum dots

InAs quantum dots can be formed by the deposition of InAs over a GaAs substrate; due to the lattice mismatch between the two materials, islands are nucleated on the surface, which are the quantum dots.

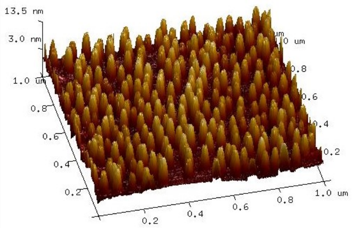


**Figure 2:** AFM image of InAs QDs

# Growth and applications of InAs quantum dots

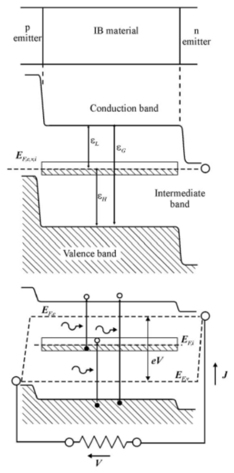


Figure 3: Intermediate Band Solar Cell [2]

One of the main properties of the quantum dots is the discrete density of states, which is extremely useful for optoelectronic devices.

[2] "Novel semiconductor solar cell structures: The quantum dot intermediate band solar cell," Thin solid films, vol. 511, pp. 638–644, 2006.

# Capping of InAs quantum dots

During the epitaxial growth, the top crystal atoms can be substituted by another atom species coming from the effusion cell, this phenomenon is thermally activated and is called segregation.

The segregation of In from the InAs islands alters the morphology, and consequently the electronic properties of the quantum dots. Therefore, the GaAs cap layer must be grown at lower temperatures to preserve the QDs.

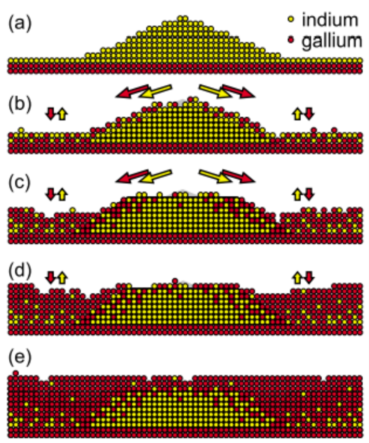


**Figure 4:** Segregation [3]

[3] Change of inas/gaas quantum dot shape and composition during capping," Journal of Applied Physics, vol. 104, no. 12, p. 124301, 2008.

# Migration Enhanced Epitaxy

The growth of GaAs and InAs is usually done at approximately 570ºC and 515ºC, respectively.

In molecular beam epitaxy (MBE) the elements are deposited simultaneously on the substrate.

The alternative epitaxial technique, called migration enhanced epitaxy (MEE) involves the alternate deposition of a single monolayer of each element sequentially. Therefore, to grow GaAs, 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, while MBE would require the opening of both Ga and As shutters at the same time.

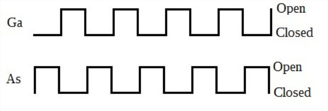


**Figure 5:** Shutter sequence in MEE.

# Migration Enhanced Epitaxy

The differences between the growth of GaAs by MEE and MBE can be observed by RHEED (Reflection High-Energy Electron Difraction). This technique consists of an electron beam that is directed onto the substrate under a grazing angle (around 1°) and then hits a phosphorus screen to produce a diffraction pattern which reflects the instantaneous atomic configuration of the surface.

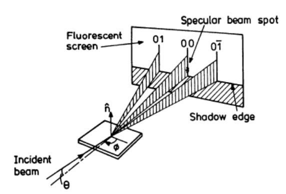


**Figure 6:** RHEED diffraction pattern formation [4]

[4]Dynamical Phenomena at Surfaces, Interfaces and Superlattices: Proceedings of an International Summer School at the Ettore Majorana Centre, Erice, Italy, July 1–13, 1984, vol. 3.

# Migration Enhanced Epitaxy

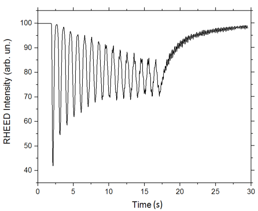


**Figure 7:** MBE RHEED intensity oscillation

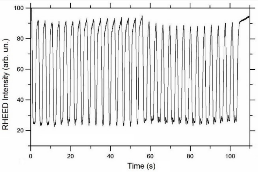


**Figure 8:** MEE RHEED intensity oscillation

In MBE the maximum occurs each time that a full monolayer is completed, and the minimum when only half monolayer is completed.

In MEE the signal is maximum after a full monolayer of As and minimum after a full monolayer of Ga.

# Experimental procedures and results

Five samples containing InAs quantum dots grown by MBE were capped with GaAs using MBE or MEE in different conditions.

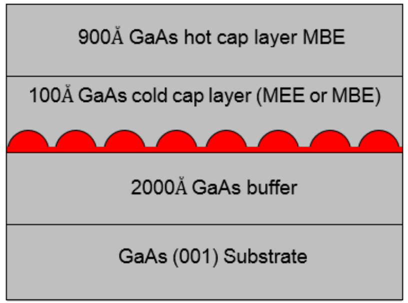


**Figure 9:** Structure of the samples

| Sample | Parameters |
|---|---|
| A | Cold cap by MBE @ 515ºC, $P_{As} = 7.0 \times 10^{-7}$ Torr |
| B | Cold cap by MEE @ 515ºC, $P_{As} = 2.6 \times 10^{-7}$ Torr |
| C | Cold cap by MEE @ 515ºC, $P_{As} = 1.3 \times 10^{-7}$ Torr |
| D | Cold Cap by MEE @ 450ºC, $P_{As} = 2.4 \times 10^{-7}$ Torr |
| E | Cold cap by MEE @ 450ºC, $P_{As} = 1.2 \times 10^{-7}$ Torr |

**Table 1:** Growth parameters of the cold cap layer

The Ga flux was 1ML/s for all samples, and the As shutter was opened for 2s whatever its flux.

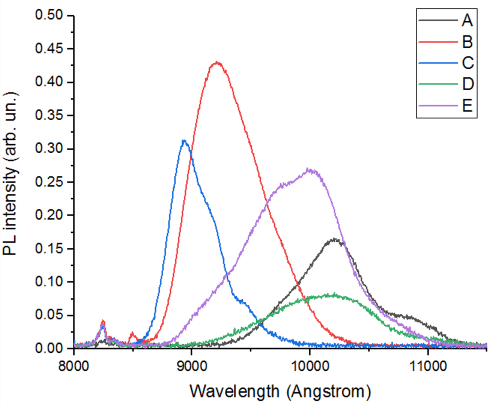


**Figure 10:** Photoluminescence Results

The blueshift indicates the increase of segregation. At high temperatures, the excess of arsenic increases the PL peak intensity. at low temperatures, the excess of arsenic decreases the PL peak intensity.

# Optimization of MEE growth of GaAs

By AFM measurements of GaAs grown by MEE, was observed the formation of Ga droplets on the surface, even with sufficient supply of As. This phenomenon occurs due to the Ga-rich and As-rich surfaces stoichiometries. 1ML of Ga is sufficient to create droplets on the surface, therefore, to avoid the creation of droplets, one must deposit less than 0.75ML of Ga per MEE cycle.

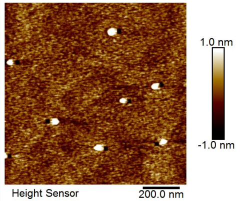


**Figure 11:** 1ML Ga

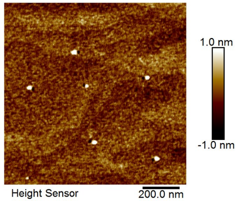


**Figure 12:** 0.75ML Ga

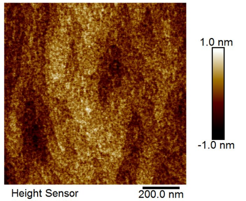


**Figure 13:** 0.6ML Ga

# Conclusion

MEE shows to be a promising technique to grow GaAs at low temperatures, which is important to reduce In segregation and obtain InAs QDs of better structural and optical quality than by MBE.

AFM measurements shown that the usual MEE with 1ML of Ga per cycle creates Ga droplets on the surface and to avoid these droplets one must deposit less than 1ML of Ga per cycle.