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# GROWTH PARAMETERS OF INAS/GAAS QUANTUM DOTS GROWN BY MOVPE

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## ABSTRACT

Quantum dots are zero dimensional structures and therefore have superior transport and optical properties compared to either 2-dimensional or 3-dimensional structures. Quantum dots show promise for use in diode lasers, amplifiers, and biological sensors. They are also vigorously researched for use in solid-state quantum computing. Indium arsenide quantum dots are currently studied for their use in the photoelectronic and semiconductor fields. In our research, Indium Arsenide (InAs) quantum dots are grown on Gallium Arsenide (GaAs) substrate using Metal Organic Vapor Phase Epitaxy (MOVPE) in the Stranski-Krastanov Growth mode. Several parameters influence the growth of InAs quantum dots greatly. We will be describing these growth parameters, which we have identified in our current growth attempts. We are currently trying to achieve device quality InAs/GaAs quantum dots by varying these parameters we have identified. These growth parameters include the V/III ratio of both InAs and GaAs, In/As growth temperature, and quantum dot growth time. By carefully fine tuning the parameters above, we will be able to grow device quality quantum dots. Deviations from the optimized value will result in either no formation of quantum dots, or the formation of large islands which are particularly susceptible to dislocations. The effects of differing growth parameters are observed by using an Atomic Force Microscope (AFM) located at Faculty of Science, UTM. The MOVPE is located at Ibn Sina Institute for Fundamental Science Studies, UTM.

***Keywords:*** Indium Arsenide, Gallium Arsenide, Quantum Dots, MOVPE, Growth Parameters

## INTRODUCTION

The term quantum dot (QD) refers to zero dimensional structures that possess superior transport and optical properties. Compared to 2-dimensional (2D) structures like the quantum well, the superior attributes of the quantum dot has encouraged further research and has thus far proved a fruitful endeavor. InAs quantum dots have shown promise in the use optical devices such as diode lasers and solar cells. Since the discovery that semiconductor QD's could be formed by a self assembly process in the Stranski-Krastanov growth mode, these devices have become a reality and have gained much attention [1]. Self-assembled growth of InAs/GaAs QDs has advanced quickly by MBE with the routine fabrication of QD laser diodes exhibiting low threshold current densities, reasonable differential efficiencies and output powers and lasing at 1.3μm for telecommunications [2], [3]. However due to the high lattice mismatch and rapid nucleation process in the InAs/GaAs system, growth by MOVPE has proven to be a challenge [1].

This paper details the many parameters which influence the growth quality of self assembled InAs quantum dots on a GaAs substrate. The parameters that we studied are the QD growth temperature, V/III ratio, and the QD growth time. Our aim was to obtain good quality QD formation by avoiding the formation of large islands and also to obtain good densities of QD which are necessary for device applications.

## EXPERIMENTAL DETAILS

The samples were grown on a (001) GaAs substrate with the growth pressure being 76 Torr. The sources used were trimethylgallium (TMGa), trimethylindium (TMIn), $AsH_3$ and $H_2$ as the carrier gas. Before the growth of QD, a GaAs buffer layer must be grown. The first layer of GaAs buffer is grown at 750 °C. This is than followed by another GaAs buffer layer grown at 525 °C or at the temperature the QD will be grown. The first GaAs buffer layer is grown to obtain a high quality crystalline base which further growth can be attempted. The second layer of GaAs is grown so that there will be no temperature difference between the growth surface and the QD layer.

The InAs QD are than grown and a small interrupt time is given after each growth of the QD. This helps the coalescing of InAs QD which will improve dot density and helps in obtaining a more homogenous dot size. Each interrupt is followed by the growth of a GaAs buffer layer, which in turn will be the base of the next layer of QD's.

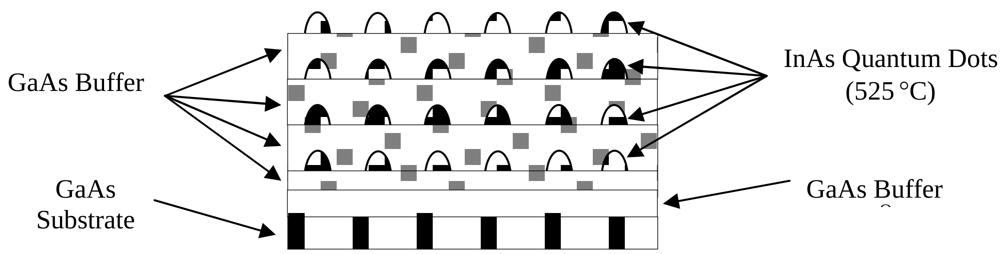


**Figure 1:** Cross section of a sample grown on a GaAs Substrate (001) with the growth temperature of each layer is labeled.

An Atomic Force Microscope (AFM) is used to obtain the surface morphology of each sample. Currently we have only characterized our samples using AFM, but we will also be characterizing the samples further to obtain the Photoluminescence (PL) Spectra. For a good PL characterization, a QD sample should at least have 5 stacks of QD. That is the reason behind us growing multiple stacks of QD on each of our samples.

### Qd Growth Temperature

Temperature affects the adatom mobility and therefore the density and size of QD's. Each nucleation site acts as a sink for the surrounding material creating a depleted zone within which the adatoms are collected and further dot nucleation inhibited [1].

Figure 2 and Figure 3 were grown at 550 °C and 525 °C respectively. The AFM result shows no formation of InAs QD's on either samples. Figure 4 on the other hand shows much better QD development. The dots are larger and are spaced out fairly well. Further tweaking of other parameters should enable us to achieve a more refined version with a more homogenous make up of QD's.

It must be noted that the optimal temperature for each MOVPE is varied. InAs QD's are typically grown at 485 °C to 550 °C [4], [5]. The MOVPE reactor design itself plays an important role in the growth of structures.

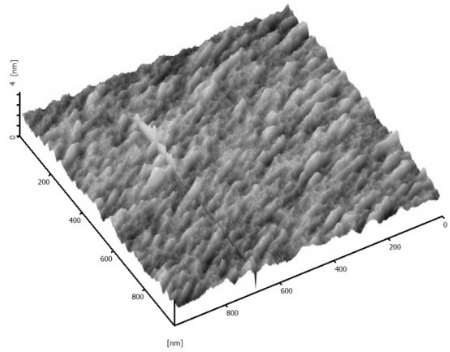

**Figure 2**: InAs QD is grown at 550 °C. No formation of QD is observed

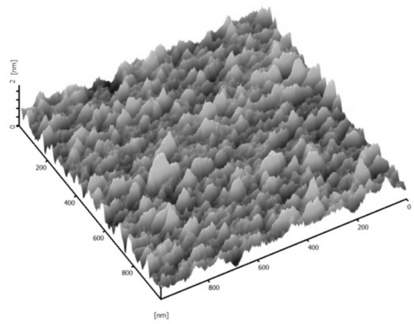

**Figure 3**: InAs QD is grown at 525 °C. The sample here shows barely any formation of dots

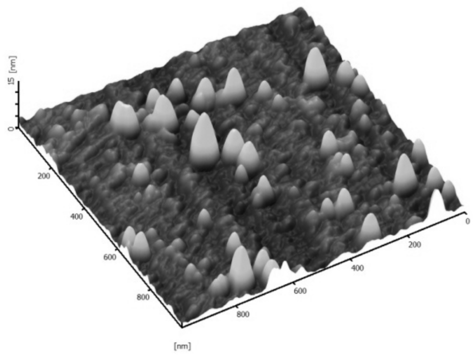

**Figure 4**: In As QD is grown at 500 °C. The sample shows better development ofInAs QD's as well as a smoother buffer layer.

## V/III Ratio

The V/III ratio is the ratio of the group V flow rate ($AsH_3$) to the group III flow rate (TMIn and TMGa). It is convention in MOVPE growth to always supply the group V in excess because $AsH_3$ is a more volatile species [6]. The V/III ratio plays a crucial role in the growth of QDs. It is generally accepted that in epitaxial growth that a lower V/III ratio increases the adatom mobility [6]. Therefore, with the increase of the V/III ratio and the subsequent increase of the adatom mobility, reduces QD density and increased QD size should be observed [1]. But several MBE groups report that decreasing the V/III ratio has had the effect of increasing QD size and decreased QD density [7]. It seems that the role of the V/III ratio is still not properly defined and is subject to conflicting reports.

Based on our results, we see that our findings correlate to the latter MBE group. We observe that by decreasing the V/III ratio from 10.2 to 7.5 and to 5.1, QD size increases dramatically and the dot density is reduced severely as well. Further study is needed before a conclusive theory can be put forward.

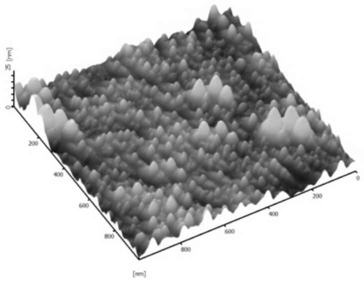

**Figure 5:** InAs V/III ratio of 10.2. Gooddot density and fairly homogenous dot size is observed

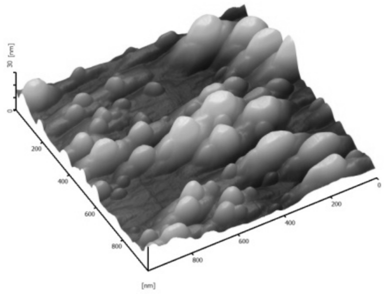

**Figure 6**: InAs V/III ratio of 7.5. QD dots have started to coalesce into large islands and dot density is reduced

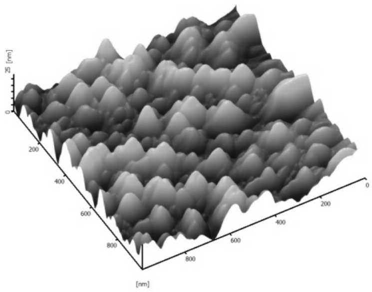

**Figure 7**: InAs V/III ratio of 5.1. Very large island formation is observed, as well as severely reduced dot density

## QD Growth Time

QD growth time influences the size as well as the dot density of the QD. Longer growth time results in thicker deposition of indium which results in larger dots. Larger dots are easier to dislocate and coalesce into larger islands; this in turn reduces the dot density. By manipulating the growth time, it is possible to produce small dots which have a good dot density.

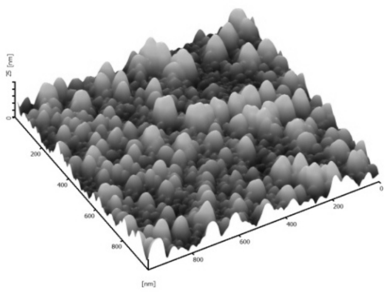

**Figure 8:** Growth time of 2.0 seconds. QD's are small and closely packed

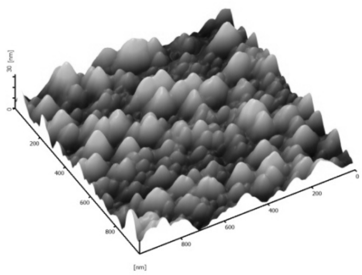

**Figure 9:** Growth time of 4.0 seconds. Longer growth time creates larger QD formation, larger QD's are also susceptible to dislocate.

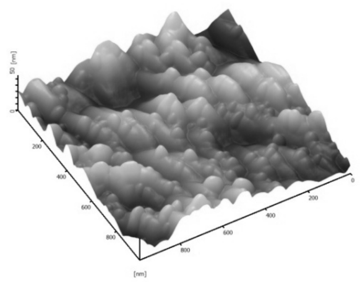

**Figure 10:** Growth time of 6.0 seconds. Further increasing the growth time results in QD's getting growing to become large islands.

Figure 8 shows InAs QD's which are tightly packed and have small sizes. This sample was grown at 525 °C and has a QD growth time of 2.0 seconds. By increasing the growth time to 4.0 seconds, the dots get larger and coalesce. In figure 9, it can be observed that there are far more large islands rather that QD's. Further increase of the growth time results in large islands and a very small number of QD's. Figure 10 show QD's which have coalesced into large islands and there are only a few small QD's left. If the growth time is further increased, even the large islands will merge and form a smooth layer. By this time, the growth mode will not follow the Stranski-Krastanov mode any more.

## CONCLUSION

In summary, we have investigated the effect of QD growth temperature, V/III ratio and QD growth time. We have shown the importance of manipulating each of these values to obtain good formation of QD's. Deviating from these optimal values will ultimately result in the formation of islands which are prone to dislocation. Further research must be done to obtain a superior growth of QD with optimal QD size and density as well one which can produce good PL results.

## ACKNOWLEDGEMENT

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