Morphological characterization of InGaAs QDs MOCVD−grown in Nitrogen atmosphere

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The optical properties of self−assembled semiconductor quantum dots (QDs) are a subject of intense investigation, due to their potential applications to optoelectronic devices such as ultra−low−threshold−lasers, micro cavity light emitting diodes, photodetectors, single photon sources, and memory systems. In particular there is a great interest in using InGaAs QDs for 1.3µm diode lasers, key components for fiber−optic communication systems in the low attenuation losses window. The electronic states of QDs critically depend on size, shape and composition of the nanostructure, therefore the way these structures are fabricated plays a crucial role in their optical behaviour. It has been already demonstrated that the QD structure is strongly influenced by the growth kinetics. One of the most relevant parameters governing the growth kinetics is the carrier gas. The most common carrier gas used in the epitaxial growth is Hydrogen, due to the highest purity level. The use of Nitrogen as the carrier gas in the MOVPE of III−V materials has also proved to be advantageous in terms of obtaining highly homogeneous and pure layers. In particular, the oxygen and carbon incorporation in the III−V alloys is reported to be lower in N_2 atmosphere. Moreover, the use of N_2 as carrier gas can be more useful in terms of safety. However, the two gases have different physical characteristics(i.e. thermal conductivity, heat capacity, viscosity and density), which strongly affect the growth dynamics. In this work we describe the influence of the carrier gas during the MOCVD growth of InGaAs QDs. We found that the epitaxial growth of InGaAs QDs is completely modified if the growth is performed in N_2 atmosphere, due to the different adatom mobility of the precursors and the different incorporation and cracking efficiency of the precursors. The growth of the studyed samples was performed in an AIXTRON 200 low pressure (20mbar) metal−organic chemical vapour deposition (MOCVD) horizontal reactor, equipped with a rotating substrate holder. The employed precursors were Trimetilindium (TMIn), Trimetilgallium (TMGa) and arsine (AsH3). A getter purified Nitrogen flow was used as carrier gas. The samples were grown on (100) exactly oriented semi−insulating (SI) GaAs substrates, which were cleaned and etched by standard procedures. The sample structure, grown at 550°C, is as follows: 200 nm GaAs buffer layer, an InxGa1−xAs (x = 10%) 5 nm−thick layer and 4 MLs thick InxGa1−xAs (x = 55%) for the QD growth. In the experimental set of QD growths we kept TMIn partial pressure constant to the value of $2.15x10^{-6}$ bar and varied the AsH3 partial pressure between 4.8×10^{-5} bar and 2.9×10^{-4} bar. The QDs were grown at a constant growth rate of 1 ML/s. The InGaAs QD morphology was studied in the uncapped samples by an atomic force microscope (AFM) used in contact mode configuration to get information about the dot size, density and distribution. Because the higher density and viscosity of N_2 , the diffusion coefficients of the precursors in the boundary layer are lower. In addition, the thermal conductivity and the heat capacity are higher in H_2 than in N_2 leading to a more abrupt thermal profile at the interface gas−substrate. As a consequence, the growth rate and the incorporation efficiency under N_2 growth conditions are different respect to H_2 conditions. Moreover an higher decomposition rate of hydrides (AsH_3) is expected in N_2 . In order to directly compare the effect of N_2 as the carrier gas on QD structures with H_2 ambient we performed a carefully calibration of growth rate and InGaAs composition on thick layer growth under N_2 conditions. In particular, to obtain the same growth rate under N_2 conditions we need to increase the group III partial pressure from 1.11×10^{-6} bar to 2.15×10^{-6} bar. In fig1,2 we compare a QD sample grown in N_2 ambient with the reference QD sample grown in H_2 ambient. In H_2 ambient, we observe the formation of InGaAs QDs (fig.1) with a density of 3.7×1010dot/cm^2 , 4 nm high and with the average diameter of 20 nm. On the contrary, as shown in Fig.2, the same growth conditions (growth rate and InGaAs composition) do not produce any dot formation on the N_2 −grown sample surface.

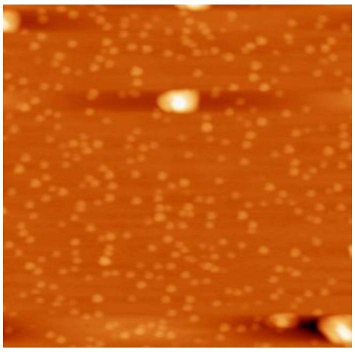

Fig.1

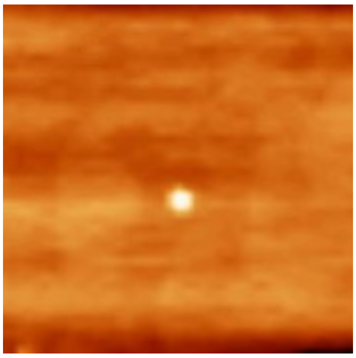

Fig.2

Fig 3,4 show the AFM images of N_2 QD samples in which the AsH_3 partial pressure has been progressively reduced from 2.9×10^{-4} bar to 4.8×10^{-5} bar. Under the highest AsH_3 pressure the dot formation is completely suppressed (Fig.2). At the value of 7.7×10^{-5} bar (fig.3) the formation of bidimensional islands is observed. This morphology is tipically found just before the QD formation. A further decrease to 4.8×10^{-5} bar leads to the surface V/III ratio necessary for QD self organisation (Fig.4). In fact, the sample shows a dot density of 2×1010dot/cm2, with height of 2−3 nm and average radius of 15 nm. A reduction of AsH_3 by a percentage of 80% has needed to reach nearly the same dot density reported in H_2 grown sample. Moreover we can see from fig.4 an higher dispersion and a lower high/base ratio in N_2 atmosphere respect to H_2 atmosphere as found when growth conditions that lead to higher adatom mobility are used.

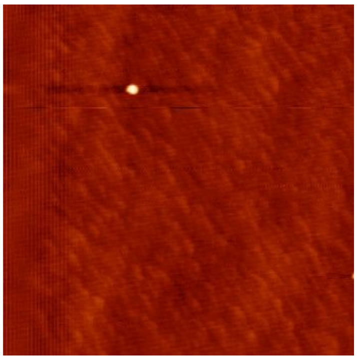

Fig.3

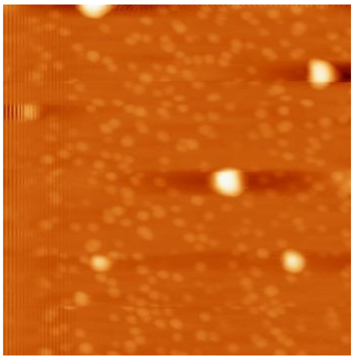

Fig.4

Our results show that the formation of self organized QD under N_2 growth condition require a sensible reduction of V/III ratio, due to the stronger cracking efficiency of AsH_3 . As it has been already demonstrated the high V/III ratio on the growing interface increase the CLT for QD formation.This parameter results even more important when N_2 carrier gas is used. Moreover the N_2 ambient affects the QD shape due to the different surface dynamic, leading to a reduction of the island aspect ratio.