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Invited

Ordered Quantum Dots: A New Self-Organizing Growth Mode on High-Index Semiconductor Surfaces

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Ordered arrays of quantum dots form in a new self-organizing growth mode in the MOVPE of strained InGaAs layers over AlGaAs buffer layers on GaAs (311)B substrates. A morphological transition occurs from a uniformly modulated InGaAs layer to the formation of disk-shaped InGaAs dots inside AlGaAs microcrystals due to lateral mass transport. The size and distance are varied by the In composition and the InGaAs layer thickness, respectively. The disks exhibit narrow PL linewidth and high efficiency at room temperature. Similar structures form also on InP (311)B and other GaAs (n11)B substrates.

1. INTRODUCTION

We introduce a new growth mode in the MOVPE of a sequence of AlGaAs and strained InGaAs layers on high-index GaAs (311)B substrates to directly form ordered arrays of quantum dots with controllable size and density. For increasing InGaAs layer thickness, growth temperature and In composition, a transition occurs from a uniformly modulated InGaAs layer to the formation of disk-shaped InGaAs dots buried spontaneously beneath AlGaAs microcrystals (Fig. 1) [1]. Similar structures are formed also on InP (311)B and other GaAs (n11)B substrates [2,3]. On GaAs (n11)A substrates, one- and zero-dimensional self-faceting occurs [4].

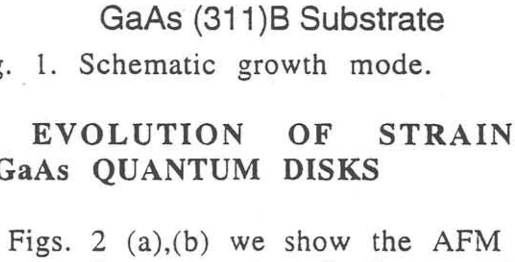

Fig. 1. Schematic growth mode.

2. EVOLUTION OF STRAINED InGaAs QUANTUM DISKS

In Figs. 2 (a),(b) we show the AFM top views after growth of 5 nm thick

$In_{0.2}Ga_{0.8}As$ at 750°C and 10 nm thick $In_{0.2}Ga_{0.8}As$ at 800°C over $Al_{0.5}Ga_{0.5}As$ buffer layers on GaAs (311)B substrates, respectively. For increasing InGaAs layer thickness and growth temperature the modulated $In_{0.2}Ga_{0.8}As$ layer transforms into ordered arrays of AlGaAs microcrystals covering the InGaAs disk due to lateral mass transport from the buffer layer (see the SEM image in the inset).

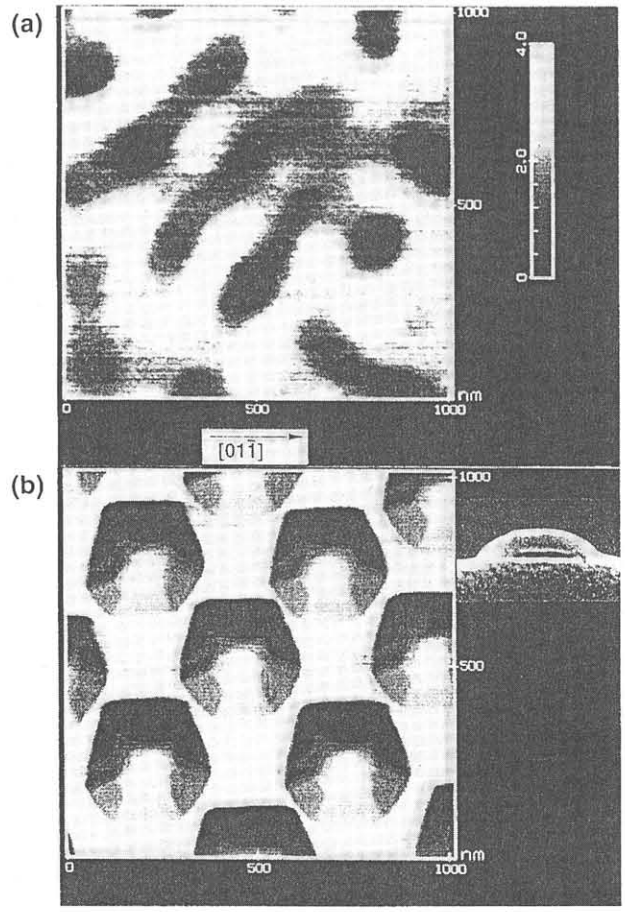

Fig. 2. AFM top views of (a) the modulated InGaAs layer and (b) the final AlGaAs microcrystals.

The direction of alignment is not along any step edge directions of the (311)B plane. However, the AFM image suggests, that it is related to the faceted surface of the microcrystals that selects distinct directions for surface migration during the formation process. This may result in the evolution of the edges of the microcrystals just in front of the facets of the neighboring ones.

The schematic growth mode is directly imaged at the onset of the transition where the modulated InGaAs layer coexists with the AlGaAs microcrystals. This stage is established after growth of 10 nm thick $In_{0.2}Ga_{0.8}As$ at 750°C (Fig. 3). The bottom level of the microcrystals is about 30 nm below the

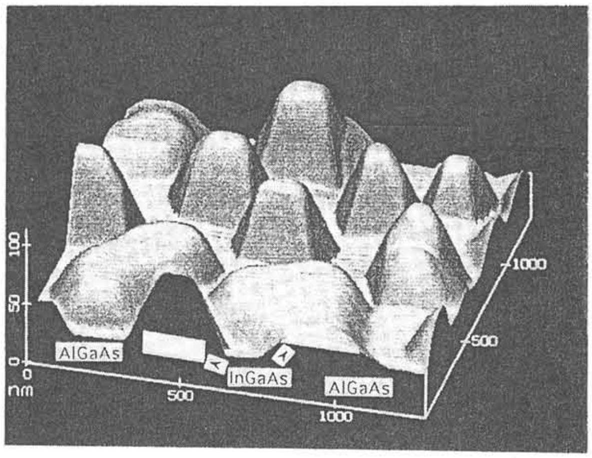

Fig. 3. AFM image of the initial stage.

average level of the initial surface. This is three times the InGaAs layer thickness and reveals lateral mass transport from the AlGaAs buffer to form the microcrystals coating the InGaAs disks.

For increasing In composition, microcrystals form already for thinner InGaAs layers and lower growth temperature. Moreover, the size of the microcrystals is reduced for higher In composition due to the reduced InGaAs islands size (down to 20-30 nm) at higher strain. The uniformity in shape and size are maintained upon size reduction. Once the microcrystals are formed, their size and shape does not depend on the growth temperature and on the InGaAs layer thickness. A thicker InGaAs layer solely decreases their distance [2]. The high uniformity and crystal quality of the InGaAs quantum disks manifests itself in the high PL efficiency at room temperature and the narrow linewidth [5]. The PL efficiency is highest in coupled quantum disks made from modulated InGaAs layers with linewidths as narrow as 13 meV. This linewidth indicates reduced thermal broadening of the photogenerated carriers due to strong lateral confinement and localization inside the disks.

3. STRAINED QUANTUM DISKS ON OTHER (N11)B SUBSTRATES

Ordered microcrystals are formed also on InP (311)B substrates after the growth of compressively strained $Ga_{0.2}In_{0.8}As$ layers at 650°C over $Al_{0.48}In_{0.52}As$ buffer layers (Fig. 4(a)) [3]. Tensile strained $Ga_{0.75}In_{0.25}As$ layers form a rough surface. For GaInAs layers grown on InP buffer layers, zero-dimensional microstructures form for compressively and tensile strained layers but they exhibit less pronounced faceting and ordering (Fig. 4(b)). Here, PH_3 is supplied after growth to minimize exchange reactions of surface group-V atoms. When AsH_3 is supplied the microstructures are again similar to those for AlInAs buffer layers, indicating strong exchange of P and As, to form an As stabilized surface.
Buried InGaAs quantum disks are formed also on GaAs (211)B and GaAs (511)B substrates, but they exhibit less uniformity in size and ordering [2].

4. CONCLUSION

Well-ordered quantum dots form in a new self-organizing growth mode in the MOVPE of strained InGaAs layers over AlGaAs buffer layers on GaAs (311)B substrates. A morphological transition occurs from a uniformly modulated InGaAs layer to the formation of disk-shaped InGaAs quantum dots buried beneath AlGaAs microcrystals due to lateral mass transport. Similar structures are formed also on InP (311)B and other GaAs (n11)B substrates indicating this growth mode to be a rather common feature for strained layers growth on high-index semiconductor surfaces.

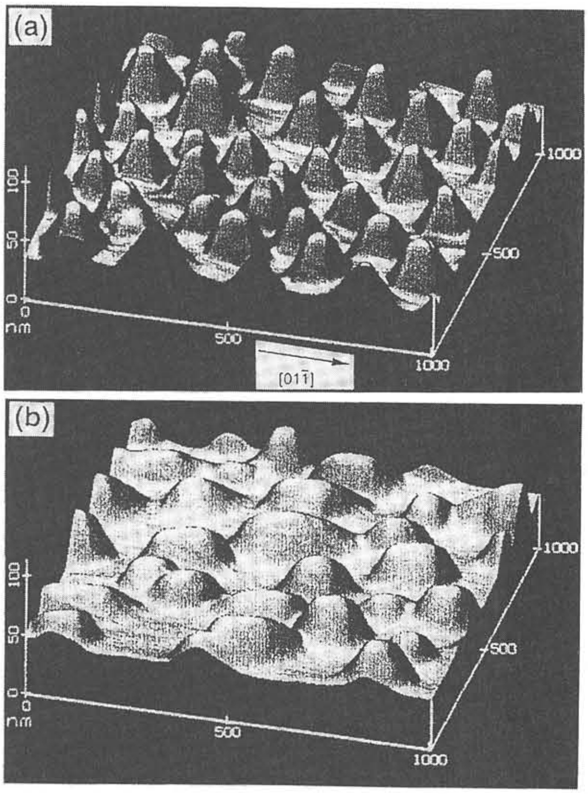

Fig. 4. AFM images of the structures formed on InP (311)B substrates.

5. REFERENCES

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