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Growth of Nanoscale InP Islands by VPE for Quantum Box Structures

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A novel method utilizing the island formation in hydride vapor phase epitaxy is used to fabricate structures, in which nanoscale InP islands are buried in InGaP. The structures are grown in one process without using photolitography or etching. The fabricated structures show intense photoluminescence blueshifted from the InP bulk emission. To control the island size and the areal density, the dependence of the island formation on the growth condition is investigated.

1. Introduction

Nanostructures showing confinement in three dimensions have attracted increasing attention due to their physical properties and, consequently, to the potential device applications. In the fabrication of these structures, process steps of nanolitography, dry etching and regrowth are usually used. Ways proposed to circumvent these steps are *e.g.* to utilize the droplet formation in MBE [1] or to grow fractional monolayers on tilted substrates [2].

In this work we have investigated the possibility to apply the island formation in hydride vapor phase epitaxy (VPE) as a novel approach for fabrication of quantum box structures. Whenever there exists a finite lattice mismatch between the substrate and the deposited layer, the equilibrium growth mode is three dimensional growth [3]. In VPE the growth proceeds almost in equilibrium, making the method suitable for the island growth. The advantages of this self-organizing method are, that no litography or etching steps are needed and a complete, buried structure can be grown without breaking the growth ambient, thus improving the quality of interfaces.

2. Experimental

Two kinds of samples were grown: 1) InP deposited on GaAs buffer layer for the investigation of the effect of growth condition on the island formation and 2) InP islands buried in InGaP, lattice matched to GaAs, to study the optical properties of island containing structures. In the latter type of samples, a thin GaAs layer is inserted on top of the lower InGaP cladding layer to initiate the island growth.

The samples were grown by conventional atmospheric hydride VPE. The source materials were InCl, GaCl, AsH_3 and PH_3 and the carrier gas was H_2. The chlorides were formed in a reaction between elemental metals and HCl gas. The growth apparatus has three separate growth chambers of which one is for the growth of GaAs, one for the growth of InP and InGaP and one is used during heating up and cooling down the samples. GaAs (100) wafers with 2°, 5° and 10° off-angles were used as substrates. Prior to the growth the substrates were degreased, etched for 1 minute in 3:1:1 H_2SO_4:H_2O_2:H_2O solution and rinsed in D.I. water.

To investigate the island formation dependence on the growth condition, the InCl partial pressure was varied from 0.1×10^{-3} atm to 1.8×10^{-3} atm with the V/III ratio kept constant 7, and the growth temperature from 610 °C to 665 °C. The total flowrate was 2100 sccm.

The grown structures were characterized using scanning electron microscope (SEM) and low temperature and spatially resolved photoluminescence (PL) measurements.

3. Results and Discussion

InP islands grown on GaAs (100) substrates are pyramid like with well developed side facets. The angle between the facet and the substrate surface is about 55° in the case of islands of the size of the order of 1 µm and about 35° and 25° in the case of smaller islands corresponding to (111), (211) and (311) planes, respectively.

The dependence of island size and density on InCl partial pressure and growth temperature is shown in Fig. 1. The map is based on SEM observation of samples grown with various growth conditions, shown as black dots on the map. At higher partial pressures only large islands with size of one micron or larger in densities of 10^6 to 10^7 cm^{-2} are formed. When the partial pressure is decreased, the average island size decreases and the areal density increases. At very low partial pressure no islands are formed, suggesting an existence of a threshold in the island formation. The mechanism causing this threshold at low partial pressure can be explained by the high desorption rate

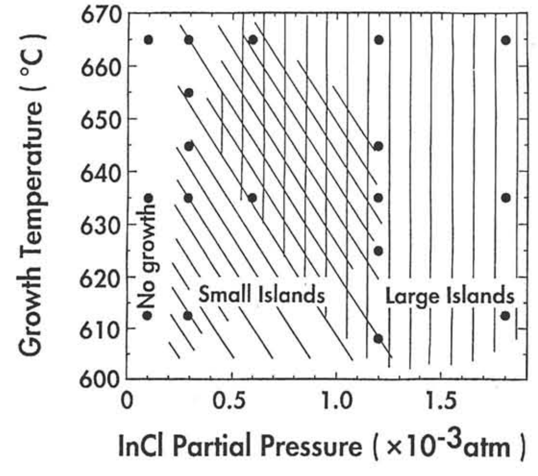


Fig. 1 Map of InP island size and density dependence on growth condition. The conditions used in experiments are shown with black dots. The growth time is 30 s and V/III ratio 7 in all of the experiments. Small Islands abbreviates to islands with majority smaller than 200 nm and with areal densities around 10^9 cm^{-2}. Large Islands abbreviates to conditions producing islands with size exceeding 1 μm.

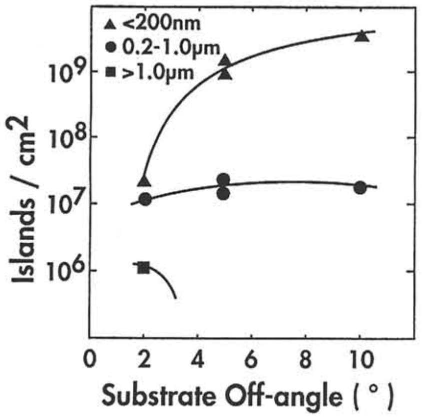
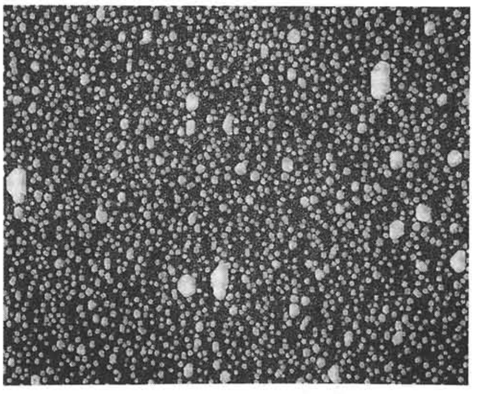


Fig. 2 Island size and density dependence on substrate off-angle. Triangles, circles and squares note islands with size of 200 nm, 200-1000 nm and over 1 μm, respectively.

from the substrate surface compared to the probability of formation of nuclei of critical size to initiatate the island growth. The island formation dependence on the growth temperature in the range studied is fairly weak.

The island density is a strong function of the substrate off-angle, as shown in Fig. 2. The low density and the appearance of large islands on a substrate with a small off-angle suggests an enhanced surface diffusion due to a low surface step density. Increasing the off-angle increases the island density. The dependence of the density on the off-angle, and thus on the step density, is superlinear. An example of islands on GaAs (100) 10° off substrate grown under optimized growth condition at 645 °C and with InCl partial pressure of 0.3×10^{-3} atm is shown in Fig. 3. The density of islands is about 4×10^9 cm^{-2} and the average size of the base of the islands of the order of 60 nm.



1 μm

Fig. 3 SEM micrograph of InP islands on GaAs (100) 10° off substrate. The average size of the base of the islands is 60 nm and the density 4×10^9 cm^{-2}. The islands are grown at 645 °C with InCl partial pressure of 0.3×10^{-3} atm.

A low temperature PL spectrum recorded using Ar^+ excitation from a structure, in which the islands are buried in InGaP, is shown in Fig. 4. The structure is given in the inset. Besides the peaks originating from the InGaP cladding layers and from the GaAs buffer layer, an intense emission is observed at around 825 nm. A reference sample, otherwise identical but with no islands, show only InGaP and GaAs related peaks suggesting, that the emission at 825 nm is related to InP islands. When the island containing sample is excited using Kr^+-laser lasing at 752 nm, the peak disappears, meaning, that the carriers responsible for the emission are generated in the InGaP cladding layers.

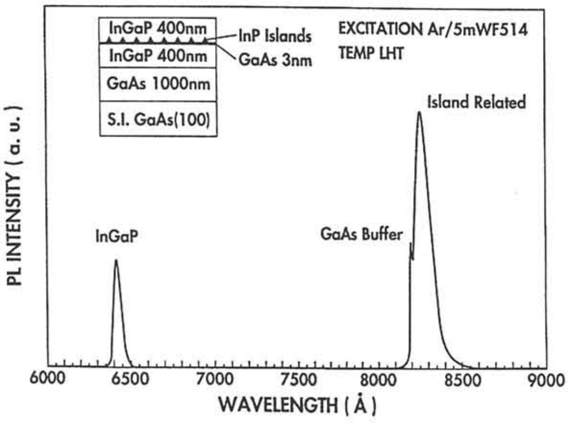


Fig. 4 4.2 K PL spectrum obtained from a structure, in which InP islands are buried in InGaP. The sample structure is shown in the inset. Besides the peaks originating from the InGaP cladding layers and GaAs buffer layer, a peak related to InP islands is observed. The island related peak is blueshifted 86 meV from the bulk InP emission wavelength.

For the spatially resolved PL measurements two samples were prepared. The growth conditions were chosen so that the samples contain only large or only small islands *i.e.* the samples were grown using high and low InCl partial pressures, 1.8×10^{-3} atm and 0.3×10^{-3} atm, respectively, at 655 °C. The large islands have a size exceeding 1 μm and a density of the order 3×10^{7} cm^{-2}. The small islands are smaller than 200 nm with a density close to 10^{9} cm^{-2}. The sample structure is the same as shown in the inset of Fig. 4. The obtained maps together with SEM micrographs from the corresponding unburied samples are shown in Fig. 5 a) and b). The maps are recorded at room temperature using Ar^{+}-laser excitation with 0.5 mW output focused to a spot with a diameter of 1 μm, corresponding to excitation intensity of 64 kW/cm^2. The resolution in this measurement is about 1 μm. The room temperature spectra are broad and the peak emission at this excitation intensity level occurs at 833 nm from the sample with large islands and at 819 nm from the sample with small islands. The maps are recorded using the peak wavelengths. The map in Fig. 5 a) show well resolved bright spots corresponding the island distribution in the SEM micrograph. The average distance between the small islands (Fig. 5 b)) is less than 0.5 μm and thus below the resolution limit of the measurement resulting in a fairly homogeneous map. Similar maps were also recorded at the high energy and low energy sides of the island related emission peaks. The patterns of these maps are identical to the maps in Fig. 5, confirming, that the source of the emission at various wavelengths of the island related peaks is the same.

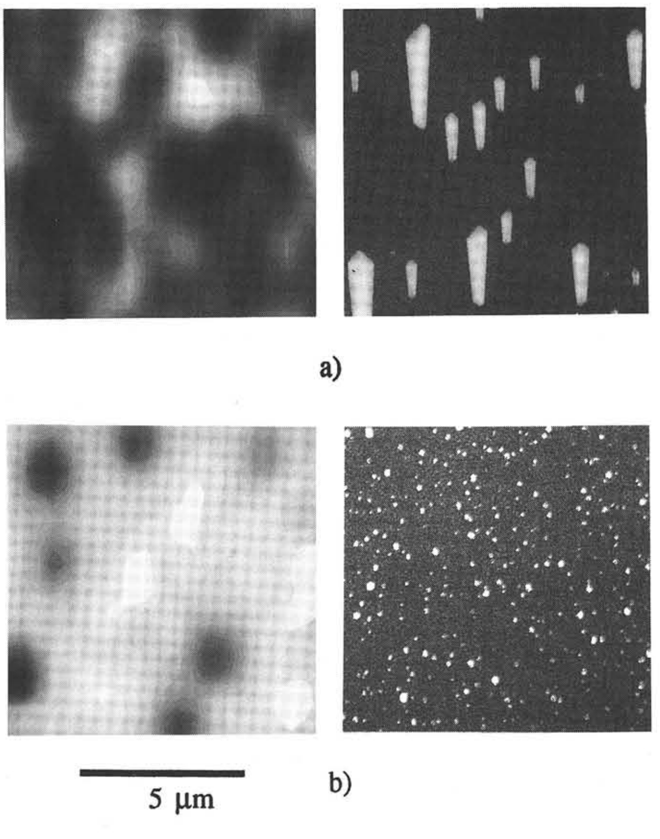


Fig. 5 Spatially resolved PL maps from samples containing only large a) and only small b) islands together with SEM micrographs from corresponding unburied structures. The samples for SEM observation were grown under the same growth conditions as the samples for PL mapping. The maps are recorded at room temperature using Ar^{+} excitation of 64 kW/cm^2. The map in a) is recorded at 833 nm and in b) at 818.5 nm. The resolution is about 1 μm. Well resolved bright spots, corresponding to the spatial distribution of islands, are seen in Fig. 5 a). The map in Fig. 5 b) is fairly homogeneous due to the limited resolution of the measurement.

The island related emission is relatively broad and blueshifted from the InP bulk emission. The emission wavelength shows dependence on the size of the islands, shifting to shorter wavelengths when the island size is decreased. The blueshift probably contains contributions arising from compressive strain and from quantum confinement. The strain, which may also be partially relaxed in islands of this size [4], is due to a lattice mismatch of 3.9 % between the islands and the cladding InGaP. Islands small enough to show confinement can be grown with the present method by choosing the growth condition properly. The grown islands have a size distribution of finite width and thus broadening of the emission spectrum can be expected.

4. Conclusion

In this work we have studied the formation of InP islands on GaAs (100) substrates in hydride VPE. The dependence of the island size and areal density on growth temperature and partial pressures of source materials was investigated. Using an optimized growth condition, islands with an average size of few tens of nanometers in densities exceeding 10^{9} cm^{-2} can be grown. Intense photoluminescence is observed from samples, in which the islands are buried in InGaP. The island related peak is blueshifted from the InP bulk emission wavelength and show dependence on the island size. The probable mechanisms contributing to the shift are the compressive strain in the islands and the quantum confinement of the carriers due to the small size of the islands. Further experiments are needed to clarify the relative contributions arising from these mechanisms.

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