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Area-Controlled Growth of InAs Quantum Dots by Selective MOCVD

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1. Introduction

Semiconductor lasers with quantum dots serving as the active layer are expected to show improved characteristics such as low threshold current density and low temperature sensitivity[1]. Furthermore, using photonic crystals as the optical resonator, threshold current density should be reduced because of photonic crystals' high reflectivity. Therefore, by fabricating quantum dot lasers with photonic crystals as the optical resonator, big improvement in optical characteristics should be obtained. In such lasers, no quantum dots should exist in the optical resonator to avoid optical absorption. This means that a technique to control where quantum dots grow is required. In this paper, we demonstrated a novel scheme for area-controlled growth of quantum dots by using selective metal organic chemical vapour deposition (MOCVD)[2] [3].

2. Laser structures

An illustration of laser structures with photonic crystals is shown in Fig. 1. Note that the active layer contains InAs quantum dots, while no quantum dots exist in the optical resonator to avoid optical absorption. Such structures can be made by the areal control of quantum dots using selective area growth (SAG). Using this technique, the deposition of material within mask windows can be controlled by varying the width of the SiO_2 mask. In the growth of self-assembled quantum dots, the density of quantum dots depends on the amount of group III sources. Therefore, by optimizing the growth conditions such as growth temperature and growth time, it is possible to grow quantum dots selectively only on the active region.

3. Experiments

First, SAG of InAs quantum dots was studied. A 30-nm-thick SiO_2 mask pattern was formed on a (001) GaAs substrate along the (011) direction by photolithography and wet chemical etching. The mask pattern is shown schematically in Fig. 2, where the mask width is 20, 50, 100 and 145 μm for W_1~W_4 respectively, and w = 5 μm is defined. InAs quantum dots were grown by low pressure MOCVD (76 torr) at 450 °C with TMI and AsH_3 as source materials. The AsH_3 pressure was kept at 3.3×10^{-5}torr while InAs quantum dots were grown. AFM images of different areas of the sample surface are shown in figure 2. Where the width of the mask was 20 and 50 μm, no quantum dots were formed. However, a high density (2.4×10^{11} /cm^2) of InAs quantum dots grew on the areas where the mask width was 100 and 145 μm. This is due to the enhancement of InAs quantum dots growth rate with increasing the mask width.

Then, SAG of quantum dots was studied using the mask shown in Fig. 3, which was specially designed for quantum dot lasers with photonic crystals. In this experiment, the mask had width W_5=145 μm for the active region, W_6=75 μm for the resonator region. We prepared two different patterns with active regions of lengths 1mm and 500 μm. InAs quantum dots were grown by low pressure MOCVD (76 torr) at 450 °C. The AFM images of InAs quantum dots are shown in Fig 3. By optimizing the growth conditions, quantum dots could be grown selectively only on the active layer (where W_5 = 145 μm). We measured the density of quantum dots at several positions along the (0$\bar{1}$1) direction by AFM. The density distribution of InAs quantum dots is shown in Fig. 4. In the sample with active layer of length 1mm, the density of quantum dots was almost constant around the middle of active region. Using this mask, an InAs quantum dot laser structure with photonic crystals was fabricated by Electron-beam(EB) lithography and RIE dry etching.

4. Conclusions

We demonstrated a novel scheme for area-controlled growth of quantum dots by using selective MOCVD. Using this technique, quantum dots could be grown selectively only on the active layer. In the sample with active layer of length 1mm, the density of quantum dots was almost constant around the middle of active region. An InAs quantum dot laser structure with photonic crystals was fabricated. Further optimization of the laser structure and growth conditions are still required for lasing oscillation.

References

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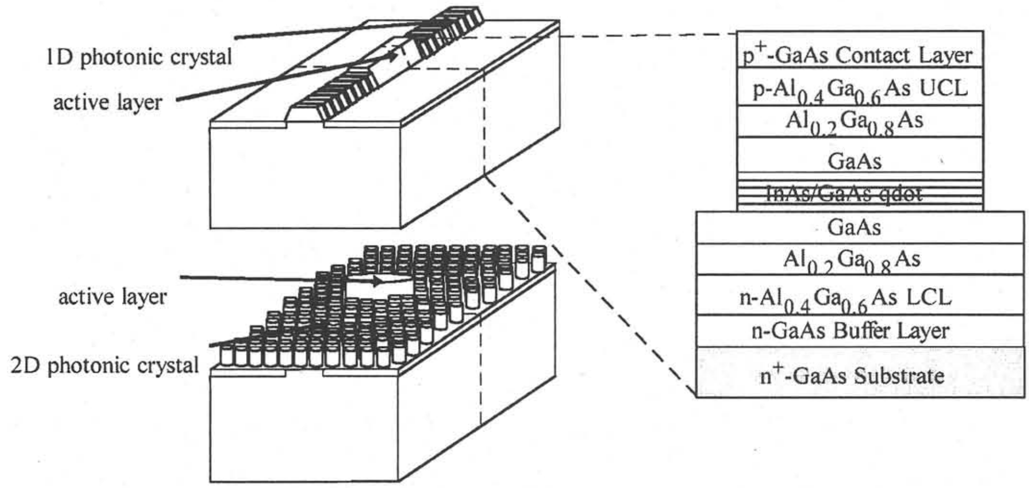

Fig. 1 Quantum dot laser structure with photonic crystals

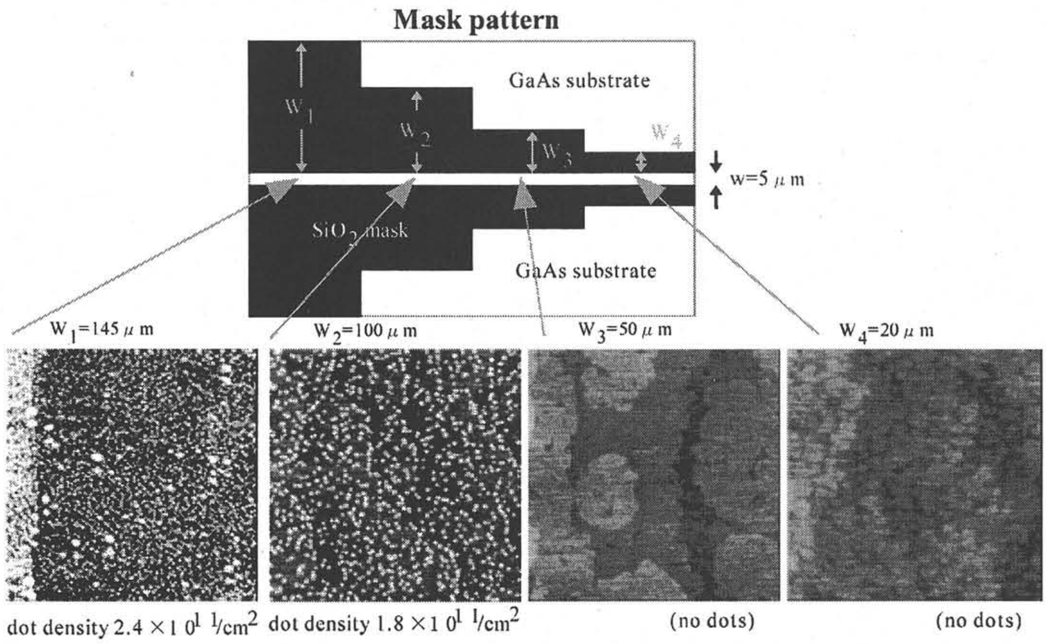

Fig. 2 Selective area MOCVD growth of InAs quantum dots

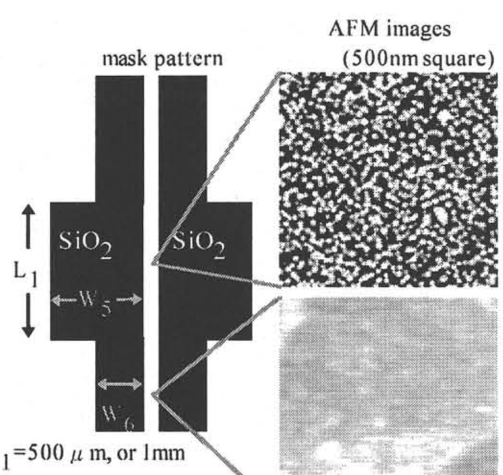

Fig. 3 Mask pattern for laser structures and AFM images of InAs quantum dots

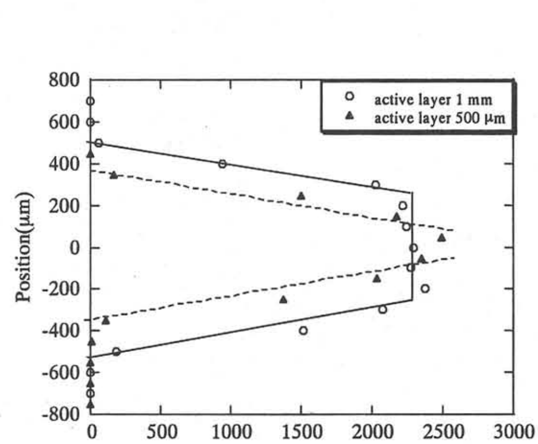

Fig. 4 Distribution of quantum dots on GaAs substrate using the mask shown in Fig. 3