Formation of GaInNAs/GaAs Densely Packed Quantum Dots by Chemical Beam Epitaxy

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We investigated the growth characteristics of GaInNAs quantum dots (QDs) by chemical beam epitaxy (CBE). The growth temperature dependence on the size and the density of GaInNAs QDs was quite different from GaInAs QDs. Nitrogen introduction may enable us to control the dot size and density independently.

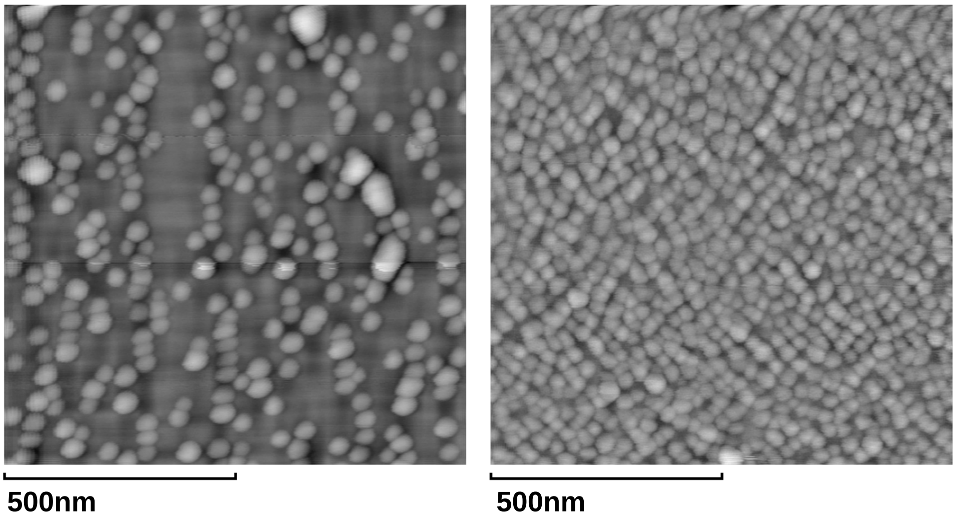
The quantum dot (QD) laser is expected to realize a drastic improvement of laser characteristics.[1)] Recently, 1.3 μm self-assembled In(Ga)As QD lasers and a 1.15 μm QD vertical cavity surface emitting laser (VCSEL) have been reported.[2-4)] However, QD lasers still have some problems, such as an increase of threshold current at high temperature, and low gain compared to quantum well (QW) lasers. These problems are due to difficulty in the independent control of the size and the density of QDs, which are related to the wavelength and the threshold, respectively. The GaInNAs system has been developed as QW for elongating the emission wavelength.[5,6)] The introduction of nitrogen (N) into In(Ga)As QDs may be an attractive choice for further wavelength extension. We have investigated the growth of GaInNAs QDs by CBE from the point of N introduction effect.

Self-assembled GaInNAs/GaAs QDs were grown by CBE with a RF radical cell. TMIn and TEGa with hydrogen carrier gas were used as In and Ga precursor, respectively. 100% AsH_3 was cracked at 1000 °C. Pure N_2 gas was cracked in a RF radical cell. N composition is estimated from a N_2 flow rate and a growth rate, since the N composition is almost proportional to the amount of supplied N for QW growth.[7)] The In and N composition of GaInNAs QDs were 70% and 1%, respectively. Growth rate was 0.1 ML/s. The amount of supply was 7 ML for all samples that were estimated from GaInNAs QWs grown at 500 °C. Substrate temperature was varied from 450 to 540 °C. Surface morphology was observed by atomic force microscope (AFM).

Figure 1 shows the AFM image of GaInAs (Fig. 1(a)) and GaInNAs QDs (Fig. 1(b)). Growth temperatures of these samples were 530 °C and 540 °C, respectively. GaInAs and GaInNAs QD were grown by the same condition except N supply. The lateral size of GaInAs QD was about 47 nm and the dot density was about 3×10^{10} cm^{-2}. On the other hand, the lateral size of GaInNAs QD was about 38 nm and dot density was about 9×10^{10} cm^{-2}. Introduction of the 1% of N into GaInAs QD caused the decrease in volume and increase in density. Figure 2 shows the dot density and the lateral size for various growth temperatures. For GaInAs QDs, the density decreased and the lateral size increased above 500 °C of growth temperature. The decrease in dot density below 500 °C is due to the decrease of decomposition efficiency of group III precursors. On the other hand, the dot density and the lateral size of GaInNAs QDs kept almost the same value above 500 °C. We also reported the N composition dependence of the QD formation.[8)] These results indicate that N atom is considered to affect the formation of self-assembled dot due to the surface energy change.

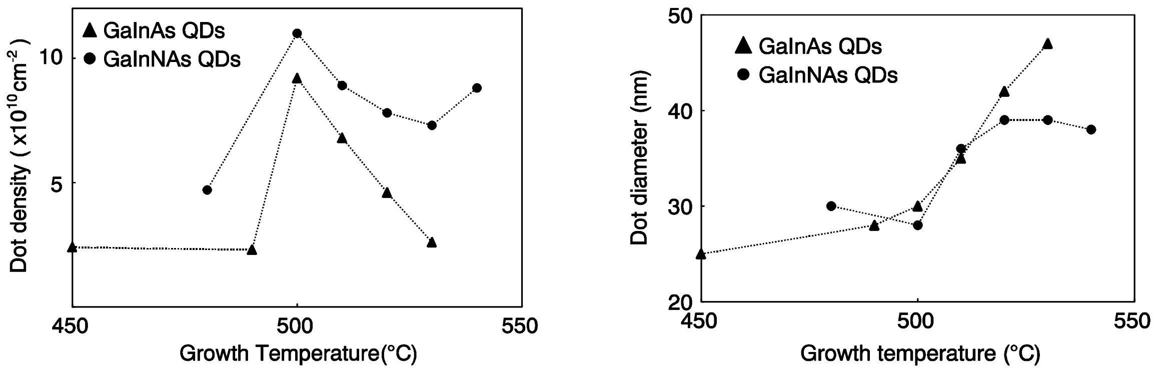
Figure 4 shows the relation between the dot density and the lateral size. Dashed lines show the calculated dot density for various lateral sizes when the distance between neighboring QDs is varied. A hexagonal close packed structure was assumed for calculation. Triangles and open circles show the experimental dot density and lateral size of GaInAs and GaInNAs QDs, respectively. For GaInAs QDs, the density decreased and the distance between neighboring QDs increased with increasing of the lateral size. On the other hand, the density of GaInNAs QDs was higher with closer packing than that of GaInAs QDs. This result suggests the possibility of controlling the dot size while keeping a high dot density.

In conclusion, we suggest a possibility to control the dot density and the size by N introduction. By optimizing the growth condition, it may be possible to realize a high performance QD laser emitting at long wavelength region beyond 1.3 μm.



(a) GaInAs QD, Tg=530°C (b) GaInNAs QD, Tg=540°C

Fig. 1 AFM image of GaIn(N)As QDs.



(a) Dot density vs. growth temperature. (b) Lateral size vs. growth temperature.

Fig. 2 Growth temperature dependence of GaIn(N)As QDs formation.

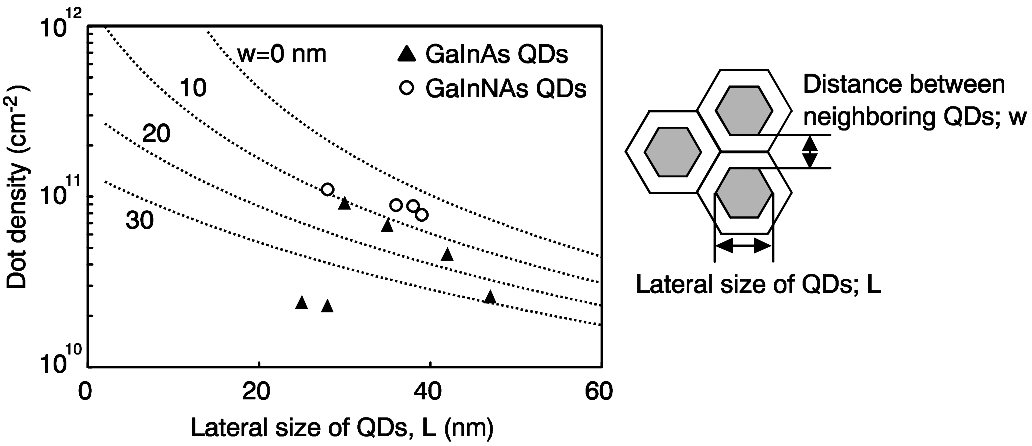


Fig. 4 The dot density vs. the lateral size of GaIn(N)As QDs. Dashed lines show the calculated density for various lateral size when the distance between neighboring QDs is varied.

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