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Self-formation of High-Density and High-Uniformity InAs Quantum-Dots on GaSb/GaAs Layers by Molecular Beam Epitaxy

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1. Introduction

Self-assembled quantum dots (QDs) with delta - functional density of states have been much expected for new optoelectronic device applications, for example QD lasers (QD-LDs) and QD semiconductor optical amplifiers (QD-SOAs). However, high QD density and high uniformity in the QD size must be obtained for realization of high performance QD-LDs and QD-SOAs. In recent years, highly uniform InAs QDs on the GaAs have been demonstrated by the Stranski-Krastanov (SK) growth in molecular beam epitaxy (MBE) [1] and metal organic vapor phase epitaxy (MOVPE) [2]. Unfortunately, the QD density of such uniform QDs ($1\text{-}3\times10^{10}cm^{-2}$) was insufficient for the above applications because of a long migration length. More recently, we presented a new growth method using a GaSb/GaAs buffer layer for getting the high-density InAs QDs, and, as a result, high QD density of about $1\times10^{11}cm^{-2}$ was achieved [3].

In this conference, we present the high-uniformity and high-density InAs QDs on the GaSb/GaAs layers by MBE. In addition, we present a new method to control the QD density without a change of the dot structure in this Sb-mediated growth.

2. Experiments

The samples were grown by solid-source MBE. The GaAs buffer layer was deposited on the GaAs(001) substrate at 590°C, and then the substrate temperature was cooled down to 500°C. Prior to the InAs growth, the Sb_4 was supplied on the GaAs surface, and, the 1-monolayer (ML)-thick GaSb layer was formed on the GaAs buffer layer by an exchange reaction between Sb and As atoms [4]. The InAs QDs were grown on the GaSb layer under the low growth rate (0.035 ML/s) and low arsenic pressure (3×10^{-7} Torr) conditions.

3. Results and Discussion

Figure 1(a) shows an AFM image of highly uniform InAs-QDs grown on the conventional GaAs buffer layer, and, the dot density is $3\times10^{10}cm^{-2}$. On the GaSb/GaAs buffer layer, the high-density InAs QDs ($1\times10^{11}cm^{-2}$) is successfully obtained as shown in Fig. 1(b). In addition, the coalescence between the neighboring QDs is effectively suppressed in spite of the high dot density [3]. At the initial growth stage of the InAs (1.4 ML) on the GaSb layer, we found the 2-dimenisonal (2D) wire-like structures of the InAs as shown in Fig. 1(c). The InAs wires with about 2-3 ML in height align along the [1-10] direction and play an important role for the high-density nucleation of the 3D InAs islands. The formation of 2D wire-like structures and the suppression of the coalescence of 3D dots are probably related to a modification of the surface and interface energies, due to the segregated Sb atoms.

Figure 2 shows the QD density as a function of the total supply amount of the Sb. The InAs QD density increases with increasing the Sb supply amount and then saturates at $1\times10^{11}cm^{-2}$ for more than 4 ML. In general, the QD density increases under the low growth temperature and high growth rate conditions because of a short migration length. However, the different growth condition also provides the change of the dot structures. In Fig. 2, the dot structure is almost independent on the Sb supply amount. Therefore, the change of the Sb supply amount is an effective method to control the QD density in a wide range from 3×10^{10} cm^{-2} to 1×10^{11} cm^{-2} without the change of the dot structure.

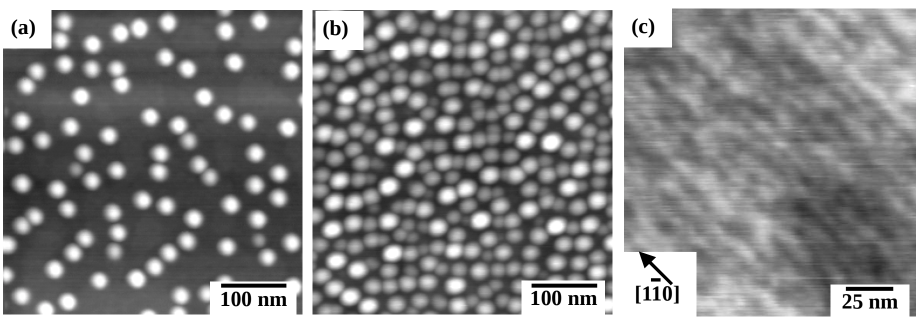

Fig.1. AFM images of InAs QDs on GsAs (a) and GaSb/GaAs (b). InAs coverages are 2.6 ML (a) and 3.1 ML (b), respectively. (c) shows an AFM image of 2D InAs islands (1.4 ML) on GaSb/GaAs.

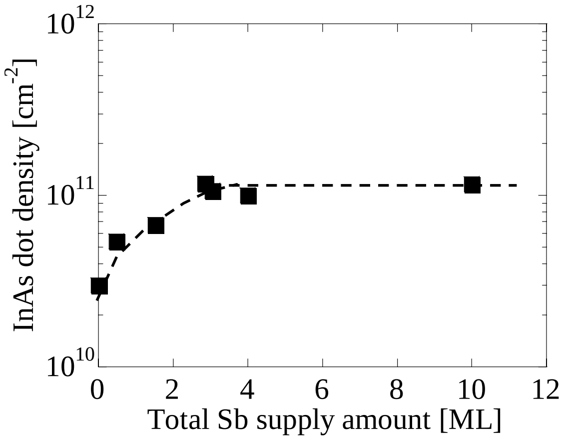

Fig.2. Relationship between InAs QD density and total Sb supply amount.

Figure 3 shows PL spectra of the InAs QDs as a function of the InAs coverage. As the InAs coverage increases, the PL spectra shift toward the long wavelength side. For more than about 4 ML, the PL peak wavelength saturates at 1180 nm, which is slightly longer than that of the uniform InAs QDs on the GaAs (Fig. 3(ref.)). The InAs coverage dependence of the PL properties can be explained by the self size-limiting effect due to the facet formation [1,5]. Indeed, the {110} facets limited the dot size and the shape for more than about 4 ML. As the result, we could obtain the high-density and high-uniformity InAs QDs, which reveal a narrow PL linewidth of about 30 meV (Fig. 3(e)). In addition, their PL integral intensity was about two times higher than that of low-density and high-uniformity QDs on the GaAs.

4. Conclusions

We demonstrated the high-density and high-uniformity InAs QDs on the GaSb/GaAs buffer layer by MBE. The coalescence of the highly dense QDs was suppressed, and the narrow PL linewidth of about 30 meV was obtained by the self size-limiting effect due to the {110} facet formation. In addition, we presented a new method using the Sb irradiation to control the dot density without the change of the dot structure. The Sb-mediated growth technique is expected for the device applications, such as the QD-LDs and QD-SOAs.

References

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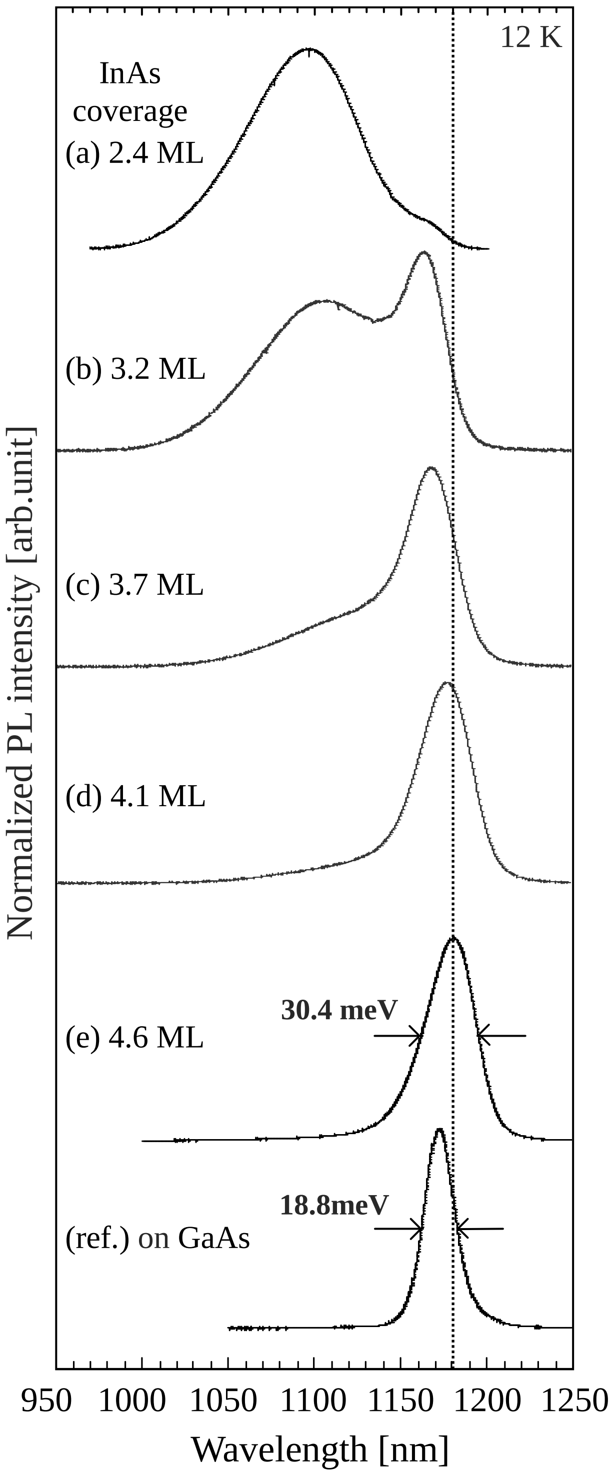

Fig.3. PL spectra (12K) of InAs QDs on GaSb/GaAs as a function of InAs coverage ((a)-(e)). A PL spectrum of uniform InAs QDs on GaAs is shown as a reference.