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Formation of InAs Dots on AlGaAs Ridge Wires Structure by Selective Area MOVPE Growth

Toyonori Kusuhara , Fumito Nakajima , Junichi Motohisa and Takashi Fukui

Reserch Center for Integrated Quantum Electronics (RCIQE), Hokkaido University
North 13,West 8,Kita-ku Sapporo, 060-8628,Japan
Phone:+81-11-706-7172 Fax:+81-11-716-6004 E-mail: kussu@rciqe.hokudai.ac.jp

1. Introduction

Recently, self-assembling formation of quantum dots (QDs) in Stranski-Krastanow growth mode is attracting attention, because the method provides us highly-quality and highly-density QDs. However, it has difficulty in obtaining uniformly sized QDs because of the random nature of their formation. It is also difficult to control the size, position and density of QDs. For these reasons, the most of the application of self-assembled QDs are limited for simple Fabri-Perot type laser diodes, and their application, in particular, for electronic devices is less attempted where the size and density-controlled QDs are required.

We have been reporting on the site selective growth of InAs quantum dots (QDs) on GaAs pyramidal and ridge structures by selective-area metalorganic vapor phase epitaxy (SA-MOVPE) [1~3]. As one of the application of position controlled QDs, we proposed floating gate type single electron memory device consisting of a single InAs QD and a ridge quantum wire (QWR) [3], where the the InAs QD is embedded in AlGaAs and is used as a memory node. In the present study, we investigated the formation of InAs QDs on AlGaAs and ridge wire structures. We studied, in particular, their size distribution on AlGaAs ridge structures, which is important for single electron memory fabrication.

2. Experimental procedure

The growth was carried out in a low pressure MOVPE system with working pressure of 0.1atm. Trimethylgallium (TMGa), trimethylaluminum (TMAl), trimethylindium (TMIn) and arsine (AsH3) were used as source materials. The growth rate of GaAs, AlGaAs and InAs was 0.23nm/sec, 0.32nm/sec and 0.1ML/sec on planer substrates, respectively.

AlGaAs wire structures were selectively grown on (001) GaAs substrates partially covered with SiON mask at 700°C. The mask pattern had periodic wire opening along the [-110] direction. The width of the openings W_0 was ranging form 160~220nm. This gives rise to the difference of the top width W of AlGaAs wires after SA-MOVPE with fixed growth amount. Next, InAs was grown on the top of AlGaAs wires at 440°C. The nominal amounts t_{InAs} of InAs supply was also varied from 1.75ML to 4.4ML. For reference, InAs is also grown on planer GaAs and AlGaAs surfaces.

3. Results and discussion

First of all, in order to investigate difference of the size and the density of InAs QDs on GaAs and AlGaAs 2ML-thick InAs was grown on the GaAs and AlGaAs planer substrate and ridge structures. As shown in the figure 1, the average dot size is larger on AlGaAs planer surface, and the density is smaller than those on GaAs surface. In addition, size distribution of InAs QDs on AlGaAs planer is more random. On the other hand, the difference of the size distribution of InAs QDs on wire structures seems to be smaller between GaAs and AlGaAs. This is presumably because the size of the dot is limited by top width of the wire as discussed later.

Figure 2 shows SEM images of InAs QDs formed on AlGaAs wire structures. Here, the top width W of AlGaAs wire was about 30~40nm, and the amount of InAs supply was 1.75ML, 2.0ML, 2.9ML, and 3.5ML. On the planer surfaces (not shown here), the size of InAs QDs increases and their density decreases as the increase of growth amount t_{InAs} of InAs. The density also increases as t_{InAs} for QDs on the trapezoidal AlGaAs

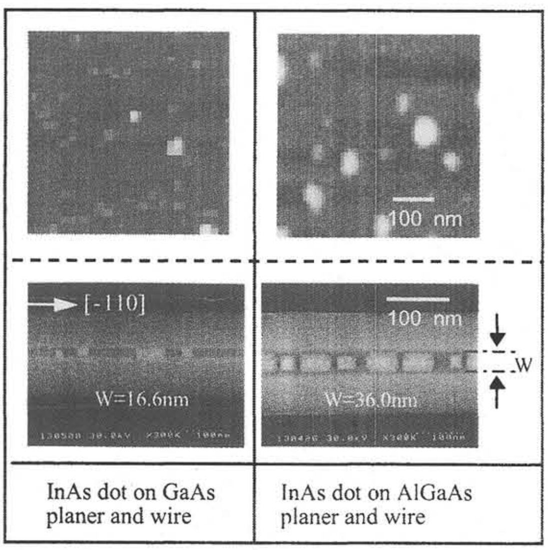

Figure 1 AFM images of InAs QDs (2.0ML) on GaAs and AlGaAs reference planer surfaces, and SEM images of InAs QDs formed on wire structures. The density of QDs is $2.74\times10^{10}cm^{-2}$ and $1.09\times10^{10}cm^{-2}$ for planer GaAs and AlGaAs surfaces, respectively.

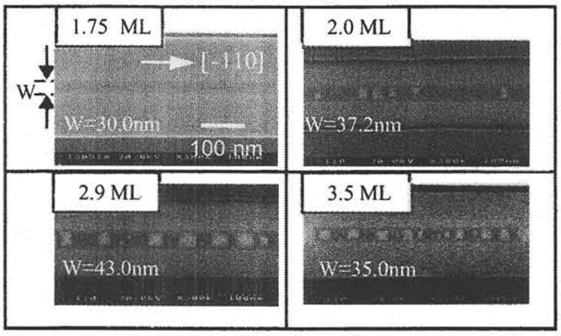

Figure 2 SEM images of InAs QDs formed on AlGaAs wire structures.

structures. We also note that, QD was not observed on the ridge structures for InAs supply of 1.75ML, which corresponds to the very beginning of QD formation on planer surfaces. This may suggest the outdiffusion of InAs from top surface to facet sidewall [2,4], though it requires detailed investigation.

Next, we measured the size distribution of InAs QDs formed on AlGaAs trapezoidal and ridge structures as a function of both W and t_{InAs}. As the shape of QDs are quite anisotropic, we defined the size along the [110] direction and along the [-110] direction as $d_\perp$ and $d_{//}$, respectively, as shown in Fig.3 (a). In Fig.3 (b), we plot $d_\perp$ as a function of top width W of the wire. Here, t_{InAs} is varied from 2.0ML to 4.4ML. With all some size distribution, it is noted that $d_\perp$ is limited by W independent of t_{InAs}. This result seems to be reasonable, as we have no evidence for the formation of InAs QDs on sidewall {111}A facets. Therefore, the result indicates that the QDs size across the wire can be controlled by the width of wires.

Figure 4 shows distribution of InAs QD size $d_{//}$ along the [-110] direction, plotted as a function of the amount InAs supply. Bars above and under the line represent maximum and minimum dot size, respectively, and small circles represent the average. Among the present experimental conditions, the best uniformity was obtained for t_{InAs}=2.0ML and W=20~40nm. This uniformity of QDs probably reflects the fact that the average dot size on AlGaAs planer surface is 17nm (see Fig 1) and is comparable to the top width of the wires which limits $d_\perp$.

Our result suggests that the size fluctuation of QDs can be reduced by the present SA-MOVPE method. In addition, as our preliminal numerical results [1] suggest the possibility of memory operation with the present size of the QDs and AlGaAs wire structures (~20nm). Therefore, the selective formation of QDs by SA-MOVPE is useful for single electron memory previously proposed.

4. Summary

We investigated the formation of InAs dot on GaAs and AlGaAs wires formed by SA-MOVPE. It was found that the QD size across the wire are limited by the top

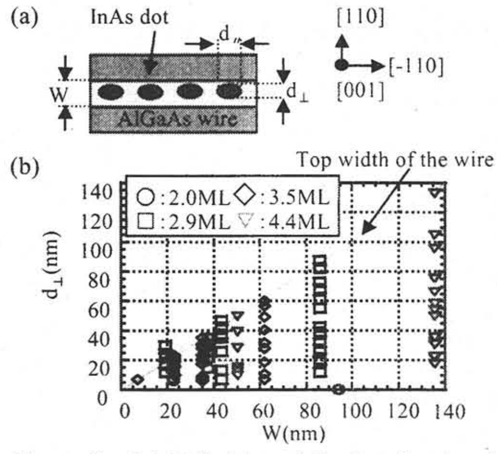

Figure 3 (a) Definition of the dot size $d_\perp$, $d_{//}$. (b) Size of QDs along the [110] direction $d_\perp$ plotted as a function of top width W of the wires. t_{InAs} is varied from 2.0ML to 4.4ML

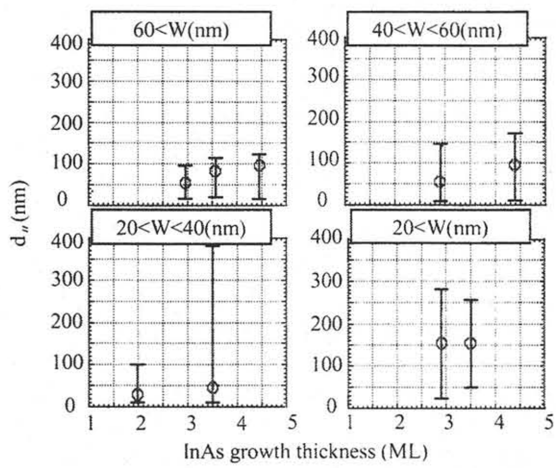

Figure 4 InAs QDs size distribution ($d_{//}$) along the [-110] direction, plotted as a function of the amount InAs supply.

width of the wire and the size uniformity of QDs could be improved by the proper choice of the top width of AlGaAs wires and the amount of InAs supply. Our results imply the effectiveness of SA-MOVPE for the application of memory devices consisting of InAs QDs and ridge quantum wires.

References

[1] C. K. Hahn, J. Motohisa and T. Fukui, Appl. Phys. Lett. 76, (2000) 3947

[2] C. K. Hahn, J. Motohisa and T. Fukui, J. Cryst. Growth 221 (2000) 599.

[3] J.Motohisa, T,Terasawa, T.Kusuhara, F.Nakajima, and T.Fukui, to be appeared in Proc. of IPRM'01.

[4] R. Zhang, R. Tsui, K. Shiralagi and H. Goronkin, Jpn. J. Appl. Phys. 38 (1999) 455.