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Novel Selective Growth on a Cleaved(110)-Facet of AlGaAs/GaAs Superlattice -Application to Multi-Layer and Dense Quantum Wires-

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We investigate low-pressure MOVPE selective growth on a cleaved surface of AlGaAs/GaAs superlattice for an application to fabricating multi-layer and dense quantum wires. It has been found that native oxide on the AlGaAs region can be used as a good selective growth mask, and the different oxidizability of GaAs and AlGaAs enables us to form a grating structure on the cleaved (110) surface. Using this grating as a patterned substrate, we can fabricate stacked GaAs wire structures whose size and density is determined by the thickness of the superlattice. Owing to the fact that MOVPE growth on the (110) surface remarkably differs from that on the (001) surface, we can stack the wire array unlimited by the depth of grating.

1. Introduction

Recently various types of quantum wire structures have been fabricated and several quantum confinement effects have been confirmed. However, these fabricated structures do not have sufficient volume and density, especially when considering optical device application such as laser diodes or optical nonlinear devices.

Concerning volume, it is difficult to stack wires in the vertical direction. This is because if we grow a thick layer on a laterally patterned substrate, the pattern will flatten out, because a flat surface has a smaller surface energy than a corrugated surface.

The density of wires is limited by the lithographic process in most cases. To overcome this, formation of one-dimensional electrons on a cleaved facet of superlattice (SL) has been proposed [1)2)]. With that method, however, the lateral confinement is very weak and stacked structures are difficult to fabricate.

In this report, we demonstrate a novel selective growth on a cleaved (110) facet of AlGaAs/GaAs superlattice by low pressure MOVPE. In this technique the superlattice is used as a starting pattern to fabricate stacked wire structures.

2. Selective growth on the cleaved facet

Selective growth techniques have been widely used to fabricate quantum size structures because the structures can be formed without exposing the well layer to air. In the selective growth method, the starting pattern is normally a SiO_2 selective mask pattern formed through e-beam lithography. Therefore, the pattern density and the undulation are limited by the lithographic process. To overcome this, we have to use other starting patterns. If a cleaved facet of the semiconductor superlattice were used as a selective growth mask, it would act as a very fine mask pattern with very small undulation in comparison with the conventional e-beam patterned SiO_2 mask.

There have been several reports of MOVPE selective growth utilizing an oxide layer on semiconductors. [3)] When this is done, the selected area is strongly oxidized by exposure to ozone gas or boiling water, resulting in an very thick oxide layer. However, a result on MOMBE selective growth using a very thin oxidized GaAs surface as a selective mask [4)] suggests that a thin native oxide on a semiconductor can also be used for MOVPE selective growth. Moreover, considering the difference in oxidizability between AlGaAs and GaAs, it must be possible that an oxide on only an AlGaAs layer acts as a selective mask and that an oxide on GaAs does not. If so, this means that we can use a cleaved facet of AlGaAs/GaAs superlattice as a starting selective mask pattern.

This is a basic idea of our fabrication method. First, we investigated the possibility of selective growth using a native oxide on the cleaved facet of a superlattice. We prepared several sets of $Al_{0.7}Ga_{0.3}As$/GaAs superlattice samples that were oxidized in various ways after cleavage: ozone gas, O_2-RIE, H_2O_2, H_2O, and boiling water. Next, we inserted the samples in a horizontal-type MOVPE reactor and grew a GaAs layer on a cleaved facet at a pressure of 76 torr. The growth temperature was 700 °C.

As a result, a GaAs was selectively grown on the GaAs region of the superlattice cleaved facet, and

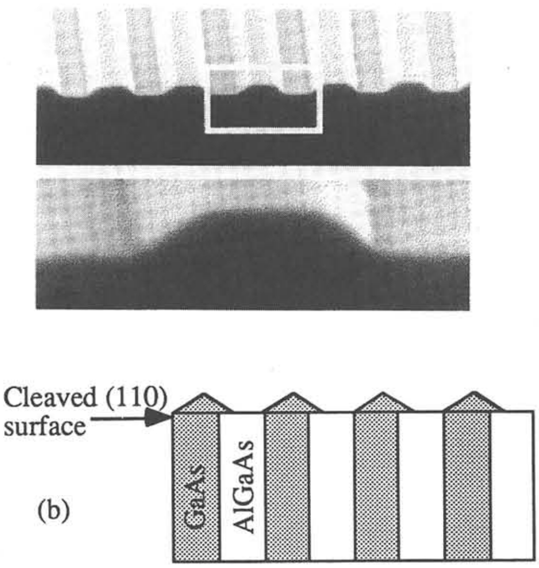

Fig. 1. SEM photograph of selective growth GaAs on the cleaved surface of AlGaAs/ GaAs superlattice (a) and its schematic of the structure (b).

surprisingly, selective growth was possible on all the differently processed samples including ones with as-cleaved surfaces. This means that an as-cleaved AlGaAs is oxidized enough to prevent growth and a considerably oxidized GaAs surface does not inhibit the succeeding growth. Figure 1 (a) shows a SEM photograph of the grown structure, while (b) shows a schematic of the fabricated structure. In the figure, the pitch of the AlGaAs/GaAs superlattice is 160 nm. It is clear that GaAs was selectively grown on the GaAs region of the cleaved facet. Triangular prisms are surrounded by (111)A and (111)B facets tilted 35° from the (110) plane. The appeared facets are extremely smooth, which is due to using the epitaxial interface as the growth mask.

Although it is generally accepted that MOVPE growth of GaAs on flat (110) substrates is not easy, no difficulty was encountered in this case because the substrate was not a flat, but patterned.

3. GaAs/AlGaAs growth on the (110) corrugated surface

In the previous section, we described the successful selective growth on the cleaved facet of a superlattice using a native oxide on the AlGaAs region. Next, we discuss the application of this selective growth in the fabrication of quantum wire structures.

In the selective growth on the cleaved facet, there was no growth on the (111)B facet, but considerable growth on the (111)A facet. The growth on the (111)A surface was accompanied by lateral growth over the

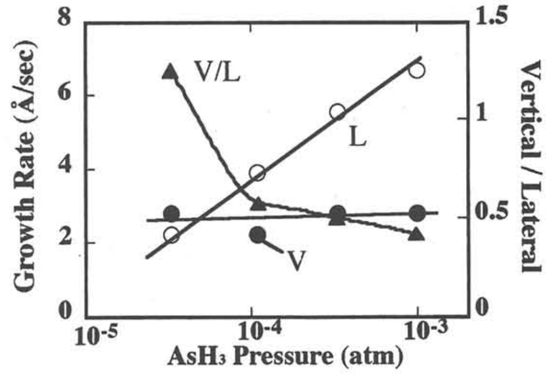

Fig. 2. AsH_3 pressure dependence of growth rate for vertical (toward (110)) and lateral (perpendicular to (110)) directions. The vertical / lateral ratio is also plotted.

AlGaAs region. Lateral growth over the AlGaAs region was smooth, which is quite different from the selective growth with an SiO_2 mask. This might be because the selective mask in this case was extremely thin compared with the SiO_2 mask. This is advantageous for overgrowth on fabricated structures without removing the selective mask.

In order to fabricate small pitch patterns, we have to control both lateral growth and vertical growth because, if lateral growth is faster, the lateral pattern will be diminished especially for the small pitch patterns. After investigating the effect of the growth parameters on the vertical / lateral growth rate, we found that this ratio strongly depends on the AsH_3 pressure. Figure 2 shows the vertical and lateral growth rate versus AsH_3 pressure. The lateral growth rate is

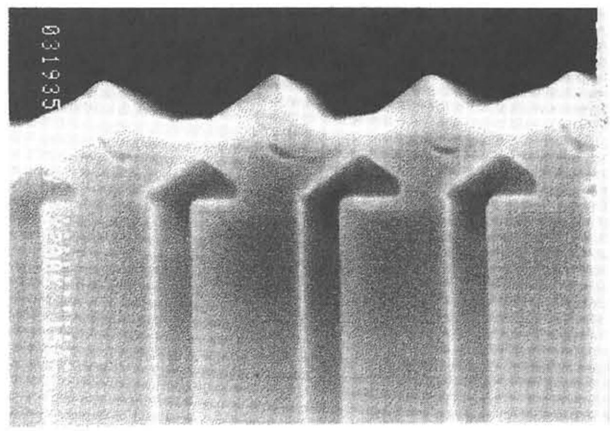

Fig. 3. SEM photograph taken after growing a wire structure sandwitched between AlGaAs layers on the triangular prisms.

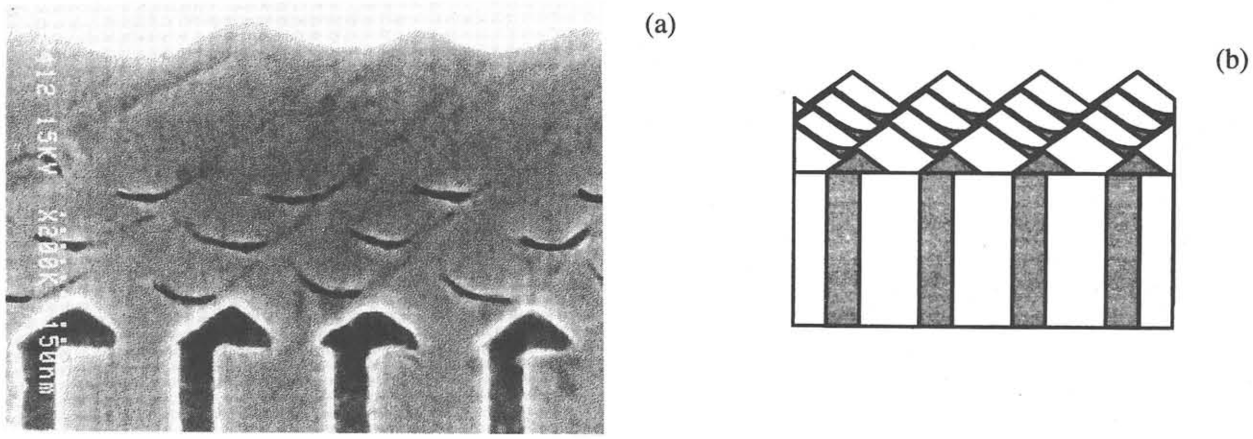

Fig. 4. Fabricated stacked-wire structure on the cleaved facet of AlGaAs/GaAs superlattice (a) and a schematic of the stacked wires (b).

considerably small for low AsH_3 pressure. Therefore we used this growth condition for fabricating small pitch patterns. So far, 80-nm pitch patterns have been successfully fabricated.

Next, we tried to form a stacked wire structure on the fabricated triangular prism. For this, we used the prism as a patterned (110) substrate and formed wires around the bottom of the grooves. A key point is whether the corrugated structure can be preserved after a relatively thick layer is grown. If on the grating-shaped (001) substrate we grow a thick layer—comparable to the depth and pitch of the grating—, the grating becomes shallower and shallower and finally vanishes. This is because a surface tends to have a low surface-energy shape. However, several papers reported that a GaAs (110) surface is considerably unstable during growth and likely to decompose into a corrugated shape. [5-7] Therefore, we can expect that this tendency can affect the stability of the corrugation after a thick growth on (110) surface.

Figure 3 shows an SEM photograph taken after the growth of a GaAs/$Al_{0.8}Ga_{0.2}As$ single quantum well on the prism. It is clearly shown that the *AlGaAs* layer preserves the grating shape even after a fairly thick layer is grown. This is strikingly different from the case of GaAs growth on the same structure, where the grating tends to rapidly vanish and a smooth (110) surface appears. On the other hand, AlGaAs growth on the relatively shallow grating results in the self-formation of a deep grating structure. This characteristic can be used to make stacked wire structures.

Figure 4 shows the fabricated three-layer wire structure. The GaAs wires are located near the bottom of the AlGaAs grating. Although the grating shape becomes rounded after the GaAs growth, it is restored to a sharp corrugated shape after the AlGaAs growth.

So far the origin of the difference between the GaAs growth and the AlGaAs growth is not clearly understood, but it might be connected with the stability of (110) surface, which would differ for different materials.

4. Conclusion

In conclusion, we have confirmed that MOVPE selective growth is possible using a native oxide on a cleaved AlGaAs/GaAs superlattice. We found that the native oxide on only the AlGaAs region acts as a selective growth mask. In this process, no special treatment of oxidation is required, and the native oxide on the as-cleaved surface exposed to air exhibits good selectivity. Furthermore, GaAs/AlGaAs growth on the grating of a (110) facet showed a quite different behavior compared with the case of (001) surface and it is this difference in behavior that enables the fabrication of stacked wire structures. This technique can be applied in the fabrication of stacked dense quantum wire arrays.

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