Extended Abstracts of the 1995 International Conference on Solid State Devices and Materials, Osaka, 1995, pp. 725-727

Formation of (411)A Faceted GaAs Ridges Using Chemical Beam Epitaxy

JEONG-RAE RO, SEONG-JU PARK[1], SUNG-BOCK KIM and EL-HANG LEE

Research Department, Electronics and Telecommunications Research Institute, Yusong P. O. Box 106, Taejon 305-600, Republic of Korea

Abstract : (411) and (100) faceted ridges of GaAs/AlGaAs were successfully grown on mesa-etched GaAs(100) substrates using chemical beam epitaxy. The growth-interruption was found to cause very efficient evolution and formation of (411) faceted ridge structures. The formation of (411) ridge structures were attributed to the Ga migration enhanced by growth-interruption and also to the increased desorption of Ga on the (411) face compared to (100) face. We demonstrated that the growth of triangular-shaped GaAs structure consisting of (411)-(100) planes which are surrounded by AlGaAs layer to show the potential implication of this method for the formation of quantum wires.

1. INTRODUCTION

Studies of selective area epitaxy by facet growth on nonplanar substrates have shown interesting and potentially useful growth feature for low dimension structure of compound semiconductor, such as quantum wells, wires and dots. These structures are expected to exhibit new electrical and optical properties. There have been several attempts to fabricate quantum structures by electron beam or focused ion beam lithography which produces damaged and contaminated interfaces. The process-induced defects at the interface are known to seriously reduce quantum efficiency of quantum structure. Therefore, the selective area epitaxy without air-exposed and etching damaged interface is highly recommended for device quality application. Several studies have been reported on the selective area epitaxy of low dimensional structures at the bottom of V grooves[1,2] and on the top of ridge structures.[3-5]

Over-growth on ridges or grooves in the (011) or $(0\bar{1}1)$ direction of patterned GaAs(100) substrate has been used to fabricate quantum wires, but high uniformity of quantum wires along these directions has been difficult to obtain because of rather poor morphology of (111) or (311) side facets. For quantum device application, however, it is required to have surfaces and interfaces in such structures very flat on an atomic level. MBE growths on (411) GaAs substrates are reported to provide extremely flat interface in GaAs/AlGaAs quantum well due to the intrinsically large migration of Ga atoms and layer growth in the step-flow mode on the (411) plane.[6] Epitaxial layers with good optical and electrical properties were also grown on (311) and (411) substrates. The (411) facet was observed during the overgrowth of GaAs on channeled substrates having (100) flat regions and (111) side slope regions. The surface of this (411) facet was quite smooth over a wide range of growth temperature and V/III ratio. This preferential growth could be explained by the reduced incorporation rate of Ga adatom from the adatom phase to the crystal phase on the (411) surface and enhanced migration of Ga atoms.

In this work, we report successful growth of (411) and (100) faceted ridges of GaAs/AlGaAs on mesa-etched GaAs(100) substrates by chemical beam epitaxy(CBE) using unprecracked monoethylarsine(MEAs), trimethylgallium(TMG), and dimethylethylamine-alane(DMEAA). Since the selectivity between (411) and (100) planes is lower than that of (111)-(100) system, growth-interruption method was introduced to improve the selectivity between (411) and (100) via enhancement of Ga migration and desorption of adatom. We have found that growth-interrupted CBE is a very effective method in the (411) ridge formation and ,to the best of our knowledge, not much or no work has been

1. Permanent address : Department of Materials Science and Engineering, Kwangju Institute of Science and Technology, Kwangju, Korea

known to report on the method of forming (411) faceted ridges.

2. EXPERIMENTALS

The selective area epitaxy of GaAs/AlGaAs was carried out in a CBE apparatus. The detailed configuration of CBE system is described in our previous work.[8] In this study, we used TMG and DMEAA as group III source materials and unprecracked MEAs as arsenic source. MEAs was found to be a novel replacement for arsine(AsH_3) source for CBE growth, showing the feasibility of growing layers with low carbon contamination and good selectivity.[9] The growth of GaAs/AlGaAs was performed on patterned GaAs(100) with 2° off toward (110). GaAs(100) substrates were patterned using photolithography and wet etching using H_2SO_4 : H_2O_2 : H_2O = 1 : 8 : 40 at room temperature and then rinsed and degreased. The pattern comprised mesa stripes with various widths along the [0 $\bar{1}$ 1] direction. The GaAs layers were grown using TMG and unprecracked MEAs by interruption method to increase the Ga migration length and consequently to decrease growth temperature. The source materials for GaAs were alternately fed into the growth chamber with an evacuation period between each gas supply while AlGaAs layers were grown in continuous gas supply mode.

3. RESULTS AND DISCUSSION

GaAs layers were grown by growth interruption mode at the growth temperature of 500℃. Fig. 1 shows a SEM micrograph of evolution of (411) facet between (111) side and (100) top regions. As shown in Fig. 1. the (411) facet is formed at the edge region of (100) top plane. This facet evolution indicates the migration profile of Ga elements which come from the (111) sidewall on the mesa-etched substrate. This facet growth is due to the migration of Ga adatoms from the (111) side to the (100) top face. A (311) facet was also observed between (111) and (100) faces depending on pattern width and growth condition, .

Figure 2 shows a close-up of the edge region of GaAs/AlGaAs ridge structure. GaAs and AlGaAs layers were grown by growth-interruption and continuous mode at growth temperatures of 500 and 600℃, respectively. This photograph clearly shows that the GaAs epilayers were selectively grown only on the (100) plane and AlGaAs layers were formed uniformly on (100) and (411) region. These results can be explained by effective Ga migration from (411) to (100) plane and also by the fast desorption of Ga adspecies from the thermodynamically stable (411) plane compared to (100) face. In the MBE growth, the ratio of the growth rate of (411) to (100) is reported to be 0.8-0.9[10,11]. In this work using growth-interrupted CBE, the ratio of the growth rate of (411) to (100) was improved to have a value of less than 0.2. Therefore, the growth-interruption method is believed to play a crucial role in the evolution and formation of (411) faceted surfaces in the GaAs/AlGaAs ridge structure.

A ridge structure was grown using the characteristics of growth-interruption for GaAs and

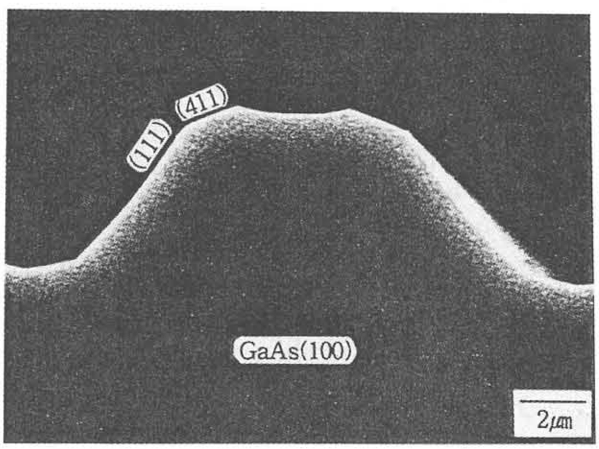

Fig. 1. SEM micrograph of evolution of (411) facet between (111) side and (100) top regions.

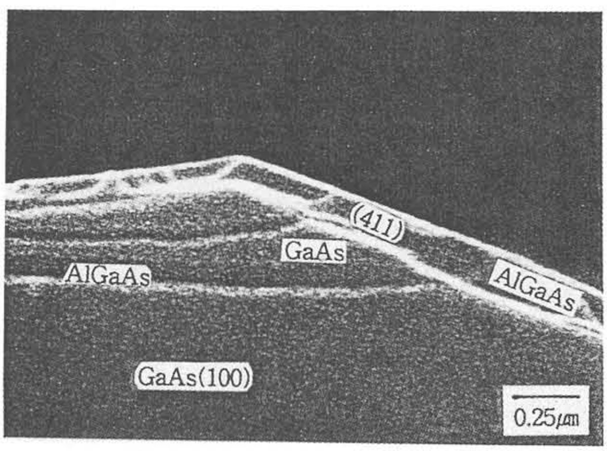

Fig. 2. SEM micrograph of the close-up the edge region of GaAs/AlGaAs ridge structure.

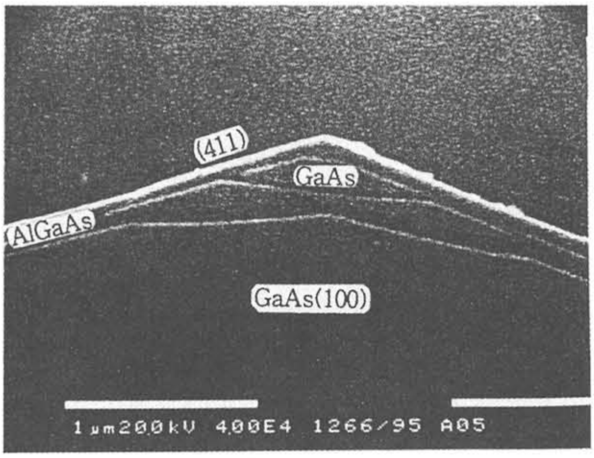

Fig. 3. SEM micrograph of the cross-section of the ridge structure with (311) and (100) facets.

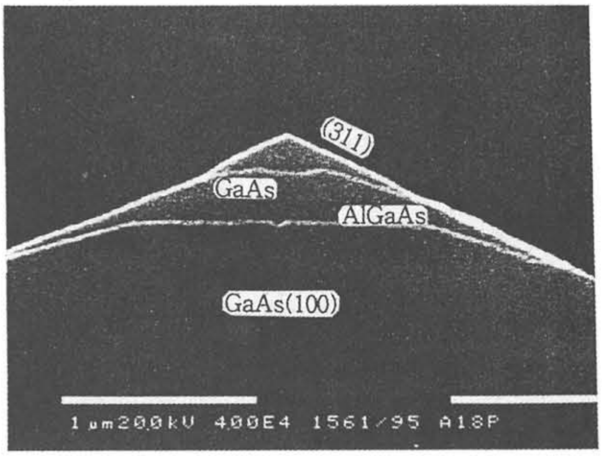

Fig. 4. SEM micrograph of the cross-section of the ridge structure with (311) and (100) facets. Top AlGaAs layer was removed during the stain etching process.

continuous mode for AlGaAs layer. Fig. 3 shows a well defined triangular-shaped GaAs structure consisting of (411)-(100) planes which were surrounded by AlGaAs layer. The formation of this structure is attributed to the efficient Ga migration from (411) plane to (100) on the AlGaAs surface and appropriate control of each layer thickness. Moreover, AlGaAs layers with constant film thickness over the different crystal planes could be grown by continuous growth mode which is suitable for the effective one-dimensional confinement of GaAs.

Figure 4 shows a GaAs ridge structure with (311) and (100) facets which is formed on the (411) buffered mesa stripes. This structure was grown without an evacuation time between alternating gas supplies. Inefficient Ga migration and desorption due to zero evacuation time are believed to cause the (311) facet formation and a significant growth of GaAs on (411) planes.

4. SUMMARY

(411)-(100) and (311)-(001) faceted ridges of GaAs/AlGaAs were grown on the mesa-etched GaAs(100) substrates by CBE using TMG, DMEAA, and unprecracked MEAs. In particular, the growth-interruption method played a crucial role in the evolution and formation of (411) faceted surfaces in the GaAs/AlGaAs ridge structure. The formation of ridge structures were attributed to the effective Ga migration by growth-interruption and also to the fast desorption of Ga on the (411) faces. The results also indicate the growth-interrupted CBE can be applied to the formation of quantum wires on the ridge structure.

REFERENCES

1) E. Kapon, D. M. Hwang, and R. Bhat, Phy. Rev. Lett. 63 (1989) 430.
2) S. Tsukamoto, Y. Nagamune, M. Nishioka, and Y. Arakawa, J. Appl. Phys. 71 (1992) 533.
3) C. S. Tsai, J. A. Lebens, C. C. Ahn, A. Nouhi, and K. J. Vahala, Appl. Phys. Lett. 60 (1992) 240.
4) S. Tsukamoto, Y. Nagamune, M. Nishioka, and Y. Arakawa, Appl. Phys. Lett. 62 (1993) 49.
5) K. Kojima, K. Mitsunaga, and K. Kyuma, Appl. Phys. Lett. 55 (1989) 882.
6) S. Shimomura, A. Wakejima, A. Adachi. Y. Okamoto, N. Sano, K. Murase, and S. Hiyamizu, Jpn. J. Appl. Phys. 32 (1993) L1728.
7) W. T. Tsang, and A. Y. Cho, Appl. Phys. Lett. 30 (1977) 293.
8) S. J. Park, J. R. Ro, J. K. Sim, and E. H. Lee, Mat. Res. Symp. Proc. 281 (1993) 37; S. J. Park, J. K. Sim, J. R. Ro, B. S. Yoo, K. H. Park, and E. H. Lee, Mat. Res. Soc. Symp. Proc. 240 (1992) 207.
9) J. R. Ro, S. J. Park, S. B. Kim and E. H. Lee, J. Cryst. Growth, in press; S. J. Park, J. R. Ro, J. K. Sim, and E. H. Lee, J. Cryst. Growth 136 (1994) 138.
10) J. S. Smith, P. L. Derry, S. Margalit, and A. Yariv, Appl. Phys. Lett. 47 (1985) 712.
11) M. Ohtsuka, and S. Miyazawa, J. Appl. Phys. 64 (1988) 3522.