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Self-assembled GaAs antiwires in $In_{0.53}Ga_{0.47}As$ matrix on (100) InP substrates

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The growth of GaAs antiwires in the $In_{0.53}Ga_{0.47}As$ matrix on InP substrate has been investigated. The periodic, wire-like structure was obtained when a proper amount of GaAs was deposited. The grown antiwires have a height about 1.2–2.0 nm and a period about 23 nm. Using an $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ modulation-doped structure, the effect of the GaAs antiwires on the two-dimensional electron gas mobility was investigated. For the sample with antiwires near the two-dimensional channel, a significant anisotropy in low temperature mobility was observed.
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Semiconductor nanostructures, such as quantum wells, quantum wires, and quantum dots (QDs) have attracted much attention in recent years. In these structures, carrier confinement and their energy quantization make them interesting in both physics and device applications. The inverse of these structures, quantum antidots and antiwires also posses interesting physics but are seldom studied. Several interesting phenomena related to the antiwires have been observed.[1,2] However, in these studies, all the antiwires were fabricated using external processing techniques, such as electron-beam lithography and focused ion beam. Recently the self-assembled growth of one-dimensional, wire-like quantum structures has been achieved.[3–7] The spontaneous formation of the one-dimensional (1D) quantum structure was discussed in detail and several mechanisms have been proposed, including an-isotropic stress, orientation dependent chemical bonding, and asymmetric surface energy for different facets. From these reports, it was found that special material and growth condition were necessary to form such structures.

In this work, we investigated the growth of GaAs in the $In_{0.53}Ga_{0.47}As$ matrix on (100) InP substrates. Comparing with the case of $In_{0.5}Ga_{0.5}As$ QDs in the GaAs matrix on (100) GaAs substrates, the strain is about the same but with opposite sign. From the atomic force microscopy (AFM) results, we found strong anisotropy in the GaAs growth. For 3 ML GaAs deposition, 1D, periodic GaAs antiwires were observed. The height and the period of the wires were determined with the AFM images. To understand the property of the grown antiwires, we have also studied the low temperature mobility of the two-dimensional electron gas (2DEG) channel of a modulation doped $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ structure with and without the GaAs antiwires. A strong anisotropy in the channel mobility was observed in the sample with antiwires.

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The samples were grown on (100) InP substrates by a solid-source Varian Gen II molecular beam epitaxy system equipped with an arsenic cracker cell. After native oxide desorption at 515 °C under arsenic flux, a 0.5 μm $In_{0.53}Ga_{0.47}As$ buffer layer was deposited before the GaAs growth. According to the measured x-ray result, the lattice mismatch between the InP substrate and the grown $In_{0.53}Ga_{0.47}As$ was less than 0.2%. To understand the transition behavior of surface morphology, several samples with different number of monolayers (MLs) of GaAs were grown under the same growth condition. After GaAs deposition, the uncapped sample was cooled down under arsenic flux. The III/V beam equivalent pressure ratio, the growth temperature, and the growth rate for GaAs deposition were 10, 500 °C, and 0.1 μm/h, respectively.

Figure 1 shows the AFM images of the grown samples with 2, 3, and 5 ML of GaAs. The measurement was performed with the tapping mode by a DI-5000 AFM system in the air. From the image in Fig. 1(a), an almost flat surface morphology was observed for 2 ML of GaAs deposition. From the cross-section analysis, the surface roughness was less than 0.3 nm. It means that the GaAs growth remains in the 2D layer-by-layer growth mode. However, as the thickness of the deposited GaAs increased to 3 ML, the morphology changed significantly. As shown in Fig. 1(b), clear wire-like structure was observed. The periodic, wire-like pattern formed along the [110] direction with a period around 23 nm. The height of the wires was about 1.2–2.0 nm. If the amount of deposited GaAs is increased beyond 3 ML, the wire-like morphology transforms gradually into separate islands with isotropic distribution, as shown in Fig. 1(c). In this study, we have grown six samples with GaAs varied from 2 to 7 ML with 1 ML increment. The wire-like pattern was obtained only in the sample with 3 ML GaAs.

We have also investigated the property of the GaAs antiwires using an $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ 2DEG struc-

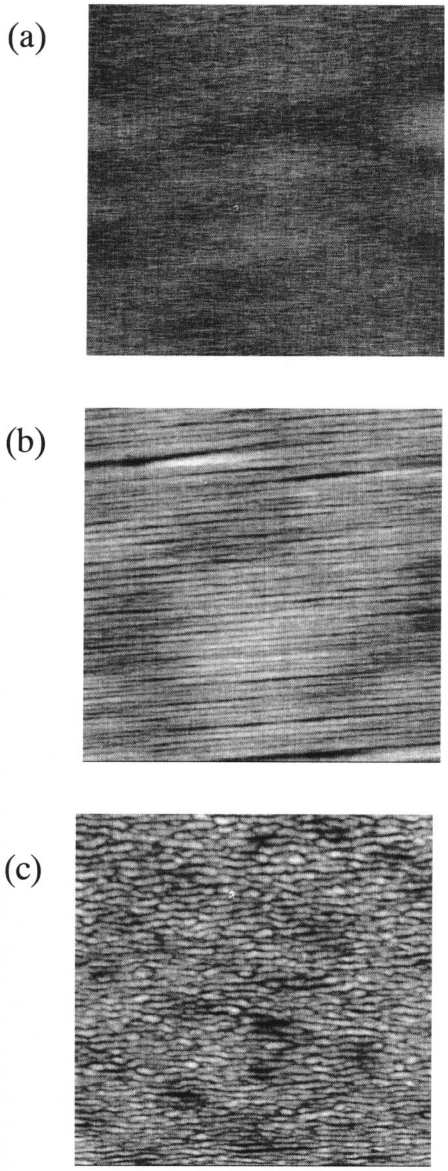

FIG. 1. The AFM images of the samples with (a) 2, (b) 3, and (c) 5 ML of GaAs.

$In_{0.53}Ga_{0.47}As$ 20nm
$In_{0.52}Al_{0.48}As$ 20nm
$In_{0.52}Al_{0.48}As$ 5nm
Si-doping $1x10^{12}cm^{-2}$
$In_{0.52}Al_{0.48}As$ 5nm
Si-doping $1x10^{12}cm^{-2}$
$In_{0.52}Al_{0.48}As$ 20nm
Si-doping $5x10^{11}cm^{-2}$
$In_{0.52}Al_{0.48}As$ 70nm
$In_{0.53}Ga_{0.47}As$ 5nm
0 or 3ML GaAs
$In_{0.53}Ga_{0.47}As$ 95nm
$In_{0.52}Al_{0.48}As$ 500nm
(100) S. I. InP substrate

FIG. 2. The detailed sample structure of the $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ modulation doped structure used in this study.

ture. The GaAs antiwires were embedded 5 nm below the 2DEG interface. Detailed structure is shown in Fig. 2. For comparison, another sample with the same structure but without the wires was also grown under the same conditions. After the growth, the samples were made into Hall bars using standard lithography and wet chemical etching processes. Then the temperature-dependent mobility was measured in the temperature range between 8 and 295 K. The longitudinal resistance (R_{xx}) and the Hall resistance (R_{xy}) were measured by the low-frequency (17 Hz) ac lock-in technique.

For the sample without GaAs antiwires, isotropic 2DEG mobility was observed as expected. The low-temperature mobility was around 50 000–60 000 $cm^2/V\,s$. However, for the samples with antiwires, clear difference between the devices perpendicular and parallel to the wires was observed. Figure 3 shows the measured mobility as a function of temperature for the two devices with antiwires. From the figure, we can see that there is a large difference in mobility for these two devices, which are orientated perpendicular to each other, although the temperature dependence is similar. For the device with the hall bar parallel to the wires, the maximum mobility achieved was about 23 000 $cm^2/V\,s$. But, for the device perpendicular to the wires, the maximum mobility was less than 4500 $cm^2/V\,s$. This anisotropy can be readily explained by the difference in the electron's scattering cross section along the two different directions because of the presence of the wires near the conduction channel. When the electrons move parallel to the wires, the scattering cross section is much less than that perpendicular to the wires. In previous reports, similar phenomena were observed in samples with anisotropic surface roughness and/or anisotropically distributed scattering centers.[8–10].

In conclusion, growth of GaAs antiwires in $In_{0.53}Ga_{0.47}As$ matrix on InP substrates has been studied. The periodic, wire-like structure was achieved when a proper amount of GaAs was deposited. The grown antiwires had a height about 1.2–2.0 nm and the period of the wires was about 23 nm. Using an $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ modula-

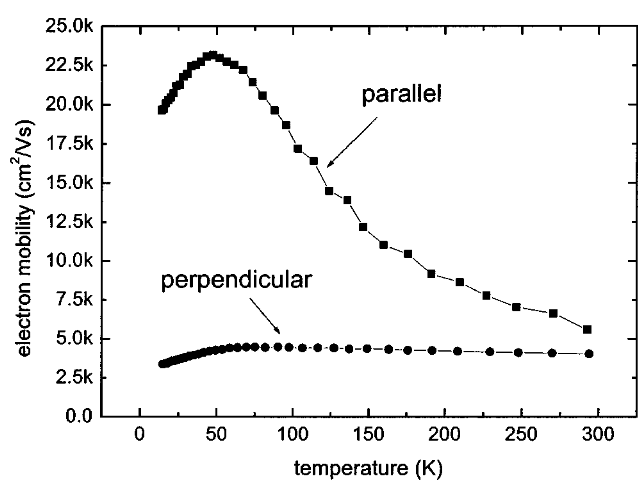

FIG. 3. The temperature-dependent mobility for the devices with GaAs antiwires.

tion doped structure, the effect of the GaAs antiwires on the 2DEG mobility was investigated. For the sample with antiwires near the 2D channel, a significant anisotropy in low temperature mobility was observed.

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[1] G. M. Gusev, P. Basmaji, Z. D. Kvon, L. V. Litvin, Yu. V. Nastaushev, and A. I. Toropov, Solid State Commun. **85**, 317 (1993).

[2] D. Huang, G. Gumbs, and N. J. M. Horing, Phys. Rev. B **49**, 11463 (1994).

[3] K. C. Hsieh, J. N. Baillargeon, and K. Y. Cheng, Appl. Phys. Lett. **57**, 2244 (1990).

[4] K. Y. Cheng, K. C. Hsieh, and J. N. Baillargeon, Appl. Phys. Lett. **60**, 2892 (1992).

[5] B. J. Ohisson, M. S. Miller, A. Gustafsson, and M.-E. Pistol, J. Appl. Phys. **89**, 5726 (2001).

[6] H. R. Gutiérrez, M. A. Cotta, and M. M. G. de Carvalho, Appl. Phys. Lett. **79**, 3854 (2001).

[7] J. M. García, L. González, M. U. González, J. P. Silveira, Y. González, and F. Briones, J. Cryst. Growth **227–228**, 975 (2001).

[8] M. Y. Simmons, A. C. Churchill, G. H. Kim, A. R. Hamilton, A. Kurobe, D. R. Mace, D. A. Ritchie, and M. Pepper, Microelectron. J. **26**, 897 (1995).

[9] Y. Nakamura, T. Noda, J. Motohisa, and H. Sakaki, Physica E (Amsterdam) **8**, 219 (2000).

[10] G. H. Kim, D. A. Ritchie, C. T. Liang, G. D. Lian, J. Yuan, M. Pepper, and L. M. Brown, Appl. Phys. Lett. **78**, 3896 (1995).