Trench-type narrow InGaAs quantum wires fabricated on a (311)A InP substrate

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InGaAs quantum wires (QWRs) with cross sections as narrow as 10 nm×20 nm have been fabricated on a (311)A InP V-grooved substrate under an As 2 source. Trench-type InGaAs QWRs consist of (111)A and (331)B facets with an angle of about 22°. Cathode-luminescence and photoluminescence measurements confirmed the luminescence peak arising from the QWRs.

Semiconductor quantum wires (QWRs), in which carriers are confined to one dimension, have been extensively studied in terms of their application in electronic and optical devices. Selective growth of III–V semiconductors on nonplanar substrates has been accepted as a promising method for fabricating QWRs, and a large number of papers on QWR structures fabricated by selective growth using metalorganic chemical–vapor deposition (MOCVD), as well as molecular-beam epitaxy (MBE), have been published.1–7 The QWR structures formed at the bottom of V grooves using MOCVD have been applied to a laser structure.1,2 Pre-}

Previous briefs, we have fabricated InGaAs QWR structures on (001) nonplanar InP substrate by selective growth using MBE.5,7 A QWR field-effect transistor with a channel width of 100 nm has been demonstrated showing good electrical properties and clear negative differential resistance.8,9

In this letter, we report the formation of narrower InGaAs/InAlAs QWR structures with the dimensions of 10 nm×20 nm on a (311)A InP nonplanar substrate. Trench-type InGaAs QWRs consisting of (111)A and (331)B facets were fabricated under an As2 source on the (311)A InP substrates.

The V grooves were prepared on a (311)A InP substrate using conventional photolithography followed by chemical etching in HCl:H3PO4:H2O2 (50:10:1 by volume) for 2 s. The V grooves were formed along the [01-1] direction. The substrate had flat (311)A regions, while the V grooves, with an angle of 90°, consisted of (100) and (011) sidewalls. The etching depth was about 0.7 μm. The substrate loaded into the MBE chamber was cleaned by atomic hydrogen at 430 °C for 3 min.10 In0.53Ga0.47As quantum wire layers sandwiched in between two In0.52Al0.48As barrier layers were grown on the V grooves. The thicknesses of the InGaAs QWR layer and the first and second barrier layers of InAlAs were 10, 400, and 200 nm, respectively. These thicknesses were measured on the flat (001) substrate. The first barrier layer was grown under an As2 source. The QWR and second barrier layers were grown under an As4 source. The flux intensities of As2 and As4 were 8.3×10−4 and 1.3×10−3 Pa, respectively, as measured using an ionization gauge at the substrate position. The epitaxial layers were grown at a temperature of 500 °C. The growth rates of In0.53Ga0.47As and In0.52Al0.48As were 0.91 and 0.92 μm/h, respectively. The flux intensities of In, Ga, and Al were 3.2×10−5, 1.3×10−5, and 1.0×10−5 Pa, respectively. Scanning electron microscopy (SEM) observations, cathodoluminescence (CL), and photoluminescence (PL) measurements of these structures were performed.

Figure 1 shows a cross-sectional view of the InAlAs trench structure grown on a (311)A V-grooved substrate perpendicular to [01-1]. The trench structure of the InAlAs barrier layer consists of (111)A and (331)B facets grown under an As2 source as shown in Fig. 1, while it was not formed under an As4 source. Under the As4 source, the flat (311)A surface adjacent to the (100) and (011) sidewalls is observed and the V grooves are destroyed after the InAlAs growth. The difference between As2 and As4 sources originates from the difference in the surface diffusion of group-III atoms under As2 and As4 sources.11

Figure 2 shows a cross-sectional view of the InGaAs QWR grown on the InAlAs trench structure. The InGaAs QWR layer was grown under an As4 source in order to enhance the migration of group-III atoms to the bottom of the InAlAs trench structure. The trench-type InGaAs QWR has a cross-section thickness of 10 nm and a side dimension of 20 nm. The trench angle between the crystal facets of (111)A and (331)B is about 22°. Such a narrow angle has not been observed in the MBE growth previously reported.

Figures 3(a) and 3(b) show CL and SEM images of the trench-type QWRs and the (311)A ridge-top quantum wells (QLWs), respectively. The CL measurement was performed at 15 K. The bright regions in the SEM images indicate the (011) sidewall surfaces. The emissions at 1340 nm in Fig. 3(a) originate from the bottom regions of the patterned sub-

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strate which correspond to the InGaAs QWRs. The CL image indicates that trench-type QWRs with dimensions of 10 nm × 20 nm are almost as smooth as InGaAs QWRs with dimensions of 11 nm × 70 nm along [01-1] on a (100) InP V-grooved substrate. The emissions at 1460 nm in Fig. 3(b) are from the (311)A ridge-top QWLs.

The InP sub. and InAlAs layer are shown in Fig. 2. The trench-type InGaAs QWR has a cross section of 10 nm × 20 nm side dimension.

FIG. 2. Cross section of a QWR structure including a schematic of the structure. The trench-type InGaAs QWR has a cross section of 10 nm × 20 nm side dimension.

FIG. 3. SEM and CL images of InGaAs QWRs and (311)A ridge QWLs. The emissions at (a) 1340 nm and (b) 1460 nm originate from InGaAs QWRs and (311)A ridge QWLs, respectively.

Figure 4 shows a PL spectrum of the grown sample. The PL measurement was performed at 14 K using an Ar+ laser (λ = 514.5 nm) and a Ge photodetector. The number of excited QWRs was about 50, judging from the area of excitation. The PL peaks at 1560 and 890 nm correspond to the InGaAs and InAlAs bulk transitions, respectively. The peaks at around 1340 and 1460 nm originate from the InGaAs QWRs and (311)A ridge QWLs, respectively, as shown in Fig. 2. The full width at half maximum of the QWR peak is 45 meV. The transition energy of the QWR is 0.925 eV and

The peaks at 1560 and 890 nm correspond to the InGaAs and InAlAs bulk transitions, respectively. The peaks at around 1340 and 1460 nm originate from the InGaAs QWRs and (311)A ridge QWLs, respectively.
the energy difference from the InGaAs bulk transition is 130 meV. We calculated the electronic state of the QWR by numerically solving the two-dimensional single-band Schrödinger equation using the finite-element method. The theoretical value of the transition energy of the QWR is 0.927 eV, which is in good agreement with the result of the PL measurement. The energy separation of electrons between the first and the second subband level is estimated to be as large as 90 meV. Emissions from the (100) and (011) sidewall QWLs were not observed. This may be due to the rough morphology of the (100) and (011) sidewall surfaces.

A field-effect transistor using the trench-type InGaAs QWR as a channel had clear negative differential resistance with a low onset voltage of 0.12 V. The low onset voltage of the negative resistance indicates a smaller scattering probability of electrons along the QWR. The details will be reported elsewhere.

In conclusion, we fabricated InGaAs QWRs with cross sections of 10 nm x 20 nm on a (311)A InP nonplanar substrate. Trench-type InGaAs QWRs consisting of (111)A and (331)B facets were fabricated under an As$_2$ source. The angle between the crystal facets was about 22°, which has not previously been observed in MBE growth. The CL and PL measurements confirmed the luminescence peak arising from the QWRs.

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