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Effects of As_2 Flux and Atomic Hydrogen Irradiation for Growth of InGaAs Quantum Wires by Molecular Beam Epitaxy

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I. Introduction

Semiconductor quantum wires, in which carriers are confined to one dimension, have been extensively studied for the application to novel optoelectronic devices. A large number of works of the GaAs or InGaAs quantum wire structures fabricated by the selective growth on non-planer substrates have been reported [1-6]. For the molecular beam epitaxy (MBE), InGaAs quantum wire structures were fabricated on the (411)A ridge structures which is formed during the growth at high temperature (≥580°C) [5]. The most common fabrication method for the quantum wires, where V-grooves are prepared by etching, has not been applied InGaAs/InAlAs quantum wire, because of the strong migration of In atoms which destroys the V-groove shape during the InAlAs buffer layer, or barrier layer, formation under the As_4 flux [7]. In this paper, we report the suppression of the In migration under the As_2 flux. Also we report the successful formation of the InGaAs/InAlAs quantum wire structures on the V-grooved InP substrates by As_2 flux at the temperature of 475°C. Furthermore, we demonstrate the effects of atomic hydrogen irradiation during the growth of the quantum wires.

2. Experimental

The V-grooved InP substrate having (211)A sidewalls was prepared by the photolithography followed by chemical etching in HCl: CH_3COOH: H_2O_2 (1:2:1 by volume) for 2.5min. The V-grooves are formed along [$1\bar{1}0$] direction. The substrate loaded into the MBE chamber was cleaned by atomic hydrogen at 350°C for 5min [8]. The $In_{0.53}Ga_{0.47}As$ quantum wire layers sandwiched in between two $In_{0.52}Al_{0.48}As$ barrier layers were grown on the V-grooved substrates. The first barrier layers were grown under As_4 or As_2 flux, and the quantum wire layers were grown with or without the atomic hydrogen. The growth temperature and the growth rate of $In_{0.53}Ga_{0.47}As$ and $In_{0.52}Al_{0.48}As$ were 475°C and 360nm/h, respectively. During the growth, the beam pressures of As_4 and As_2 were 1.5×10^{-3}Pa and 2.0×10^{-3}Pa, respectively. The background pressure of atomic hydrogen was 1×10^{-3}Pa.

3.Results and Discussions

Figure 1 demonstrates, by scanning electron microscopy (SEM), the effects of the As_2 flux and the atomic hydrogen irradiation for the fabrication of InGaAs/InAlAs quantum wires on the V-grooved InP substrates. The InAlAs barrier layer in Fig.1(a) was grown under As_4 flux and those of Figs.1(b) and 1(c) were grown under As_2 flux. All InGaAs quantum wire layers were grown under As_4 flux. Although the V-grooves before the barrier layer growth are the same for these three samples, they differ in their profile after the first barrier layer growth. For the As_4-grown sample, the V-shape disappears as shown in Fig.1(a) and no quantum wire is formed. The As_2-grown samples preserve the initial profile and distinct quantum wire structure is obtained as shown in Figs.1(b) and 1(c). These phenomena are caused by the difference in the surface diffusion of In atoms under As_4 and As_2 fluxes. The larger numbers of In atoms migrate to the bottom of V-groove from the sidewall surfaces under As_4 flux and the V-shape is destroyed. Under the As_2 flux, because the migration of In atoms is small, the V-shape is preserved.

The InGaAs quantum wire layers in Figs.1(b) and 1(c) were grown without and with the atomic hydrogen. In Fig.1(b), the deposition of InGaAs on (211)A can be observed, while negligible InGaAs was deposited in the sample grown with the atomic hydrogen as shown in Fig.1(c). These figures indicate that the difference in the growth rates of InGaAs between (001) and (211)A becomes larger by the atomic hydrogen irradiation. This phenomena maybe due to the enhancement of re-evaporation [9] of group-III atoms from the sidewall surfaces.

Figures 2(a) and 2(b) show cathode-luminescence (CL) and SEM images of the other InGaAs quantum wire structures grown without and with the atomic hydrogen, respectively. The barrier layers in Figs.2(a) and 2(b) were grown under As_2 flux. The CL measurement was performed at 15K. The emissions at 1200nm in FIg.2(a) and at 1190nm in Fig.2(b) originate from the bottom regions of the patterned substrates, which are the InGaAs quantum wires. The luminescence from the InGaAs quantum wires grown with the atomic hydrogen has better uniformity and narrower luminescence than that without the atomic hydrogen. The narrower luminescence maybe due to the absence of the quantum wells grown on (211)A sidewalls as shown in Fig.1(c). When the (211)A sidewall wells are grown, carriers can easily diffuse from (211)A to the bottom quantum wire regions, and the CL image will be observed broader. The good uniformity of the luminescence maybe due to the good surface morphology of the InGaAs layers grown at the bottom of the V-grooves. The InGaAs layers at the V-grooves grown with the atomic hydrogen had better surface morphology than that without the hydrogen in another experiment. Above results indicate that

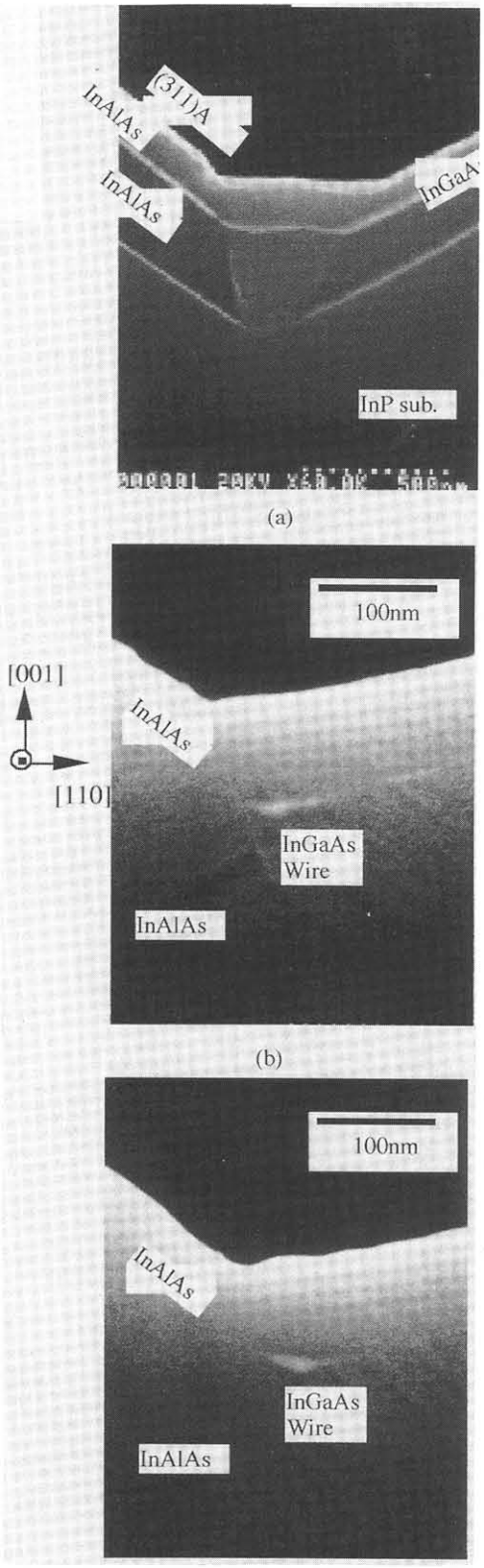

Fig.1 Cross-Sectional views of InGaAs/InAlAs quantum wire structures. The InAlAs barrier layer of (a) was grown under As_4 flux. Those of (b) and (c) were grown under As_2 flux. Only the InGaAs quantum wire layer of (c) was grown with atomic hydrogen.

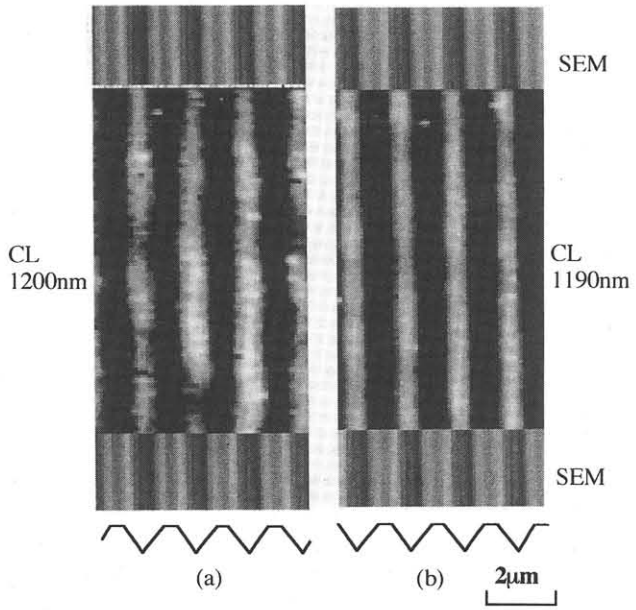

Fig.2 CL and SEM images of InGaAs quantum wire structures. The InGaAs quantum wire layers of (a) and (b) were grown without and with atomic hydrogen, respectively.

morphologically better quantum wire can be obtained by the atomic hydrogen irradiation during the growth of InGaAs/ InAlAs quantum wire structures.

4. Conclusions

We fabricated the InGaAs quantum wire structures having InAlAs barrier layer grown under As_2 flux on V-grooved substrates by MBE. The quantum wires could not be fabricated under As_4 flux. The quantum wires grown with the atomic hy drogen had no (211)A sidewall quantum wells. The CL image of the quantum wires grown with the atomic hydrogen had good uniformity.

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