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Growth and Characterization of InGaAs Nanowires formed on GaAs(111)B by Selective-Area Metal Organic Vapor Phase Epitaxy

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1. Introduction

Semiconductor nanowires (NWs) have become a focus of attention in the field of nanoscale electronic/photonic devices and bio-devices [1]. To develop these devices, we have to control the size, atomic composition, and doping of the NWs. We have reported on the growth of group III-V semiconductor NWs using catalyst-free selective-area metal-organic vapor phase epitaxy (SA-MOVPE) [2]. This method has a great advantage in the crystal quality of NWs over those grown using the vapor-liquid-solid method, which needs a growth catalyst. However, the shape and alloy composition of NWs obtained by SA-MOVPE depend strongly on the growth conditions. Here, we report on the growth temperature dependence of InGaAs NWs grown on GaAs(111)B using SA-MOVPE and discuss the characteristics of the height and diameter of the NWs, crystal composition, and optical spectra obtained by micro-photoluminescence (μ-PL).

2. Experimental

Fabrication of the NWs (Fig.1) was started by preparing patterned GaAs(111)B substrates partially covered with a SiO_2 mask for SA-MOVPE. After a 20-nm-thick SiO_2 film was deposited on the GaAs(111)B substrate by plasma sputtering, hexagonal opening patterns were defined using electron beam lithography and wet chemical etching based on buffered hydrofluoric acid (BHF). The SiO_2 pattern was designed to be a periodic array of openings with a diameter, d_0, from 50 to 200 nm and a pitch, a, from 0.5 to 2 μm. SA-MOVPE growth of undoped InGaAs was carried out in a horizontal MOVPE system working at a pressure of 0.1 atm. The source materials were trimethylgallium (TMG), trimethylindium (TMI), and arsine (AsH_3) (5% in hydrogen). The growth temperatures varied between 600 to 700°C. The partial pressures of AsH_3, TMG, and TMI were 1.25×10^{-4}, 1.42×10^{-6}, and 1.22×10^{-7} atm, respectively.

The μ-PL was measured at 4.2 K. Excitation light from a He-Ne laser was focused on the NW arrays using ×50 microscope objectives with 0.42-N.A., which were also used to collect the PL from the NWs. The excitation power was 1.0 kW/cm^2, and the laser spot was less than 2 μm in diameter.

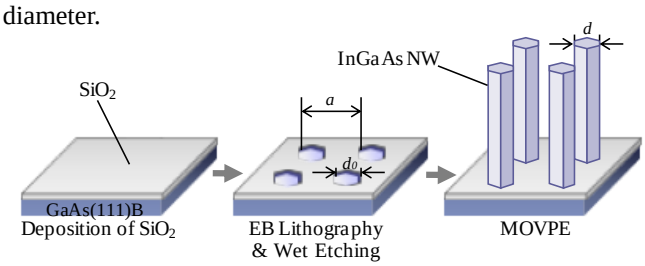

Fig. 1. Schematic of nanowire fabrication.

3. Results and discussion

Scanning electron microscope (SEM) images of SiO_2-patterned substrate surfaces after SA-MOVPE are shown in Figs. 2(a) to (e). The pattern pitch, a, and the diameter, d_0, are 500 and 100 nm, respectively. We can see particle-like depositions with diameters of 1 to 3 μm on the patterned areas. The density of the particle-like depositions was the highest at 600°C (Fig. 2(a)), but the deposition decreased in size and density with increasing temperature (Figs. 2(b) to (d)) and disappeared at 700°C (Fig. 2(e)). We believe the cause of temperature dependence of the particle-like depositions is related to nucleation, migration, and desorption of the source materials at the SiO_2-patterned areas. Hexagonal pillar shaped NW arrays were grown locally on the patterned areas where particle-like depositions were not observed, as shown in the close-up SEM images in Figs. 2(a) to (e).

The relationships between the growth temperature and the heights, growth rates, and diameters of the NWs are shown in Fig. 3. The heights and growth rates of the NWs (Fig 3(a)) increased at higher temperatures and for smaller d_0. This can be explained by the enhanced surface migration and incorporation of source materials into the NW crystal at higher temperatures. The grown diameters of the NWs for each d_0 appeared to be roughly equal and independent of the temperature, but the diameter increased with d_0 (Fig. 3(b)). This indicates that a larger mask opening is preferable for lateral growth.

The PL spectra obtained by μ-PL measurements are plotted in Fig. 4. The PL peak energy changed from 0.95 eV for NWs grown at 600°C to 1.31 eV for NWs grown at 700°C, indicating strong dependence on growth temperature. The full width at half maximum (FWHM) of the PL spectra for the NWs grown at 600°C was 30 meV, but this decreased to 22 meV as the growth temperature increased to 700°C. We speculate that the temperature dependence of FWHM in the PL spectra is related to the atomic composition of InGaAs and lattice mismatching between InGaAs and GaAs. The estimated In composition of InGaAs NWs, where we applied Vegard's law to obtain the composition by the peak energy position of the PL spectra [3], is shown in Fig. 5. The In composition decreased with increasing growth temperature. We believe this is caused by the relatively high desorption rate of In from the substrate surface compared with that of Ga during MOVPE.

4. Summary

We fabricated InGaAs NWs on GaAs(111)B substrates using SA-MOVPE and analyzed the dependence of NW height, growth rate, and grown diameter on the growth temperature. We also compared the FWHM of PL spectra

measured for the NWs and estimated the alloy composition from the spectral peak position. The results showed that the charasteristics of NWs strongly depend on their growth temperature.

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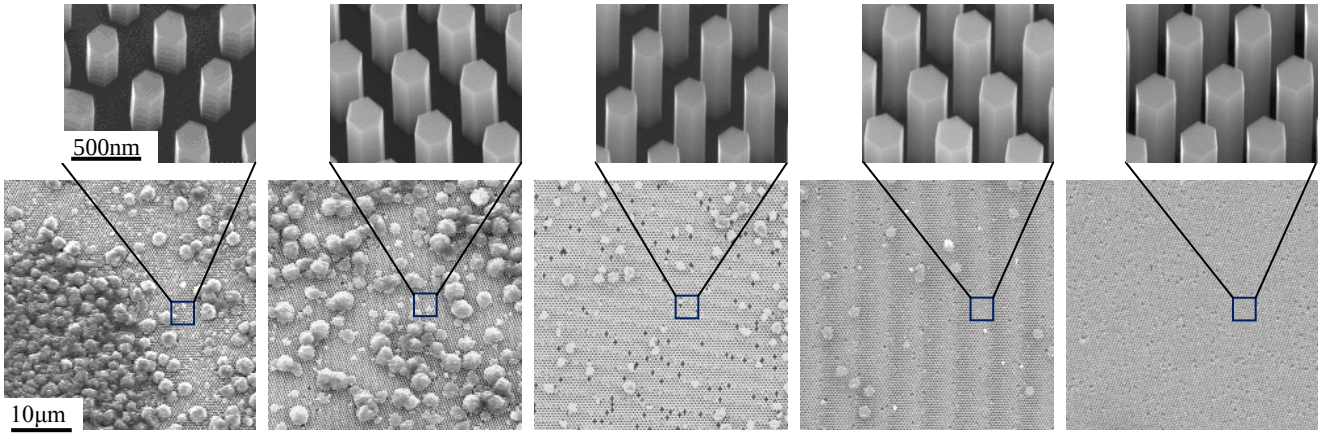

Fig.2. SEM images of InGaAs NWs grown at (a)600, (b)625, (c)650, (d)675, and (e)700 °C. The pitch *a*, and mask opening diameter d_0 are 500 and 100 nm, respectively.

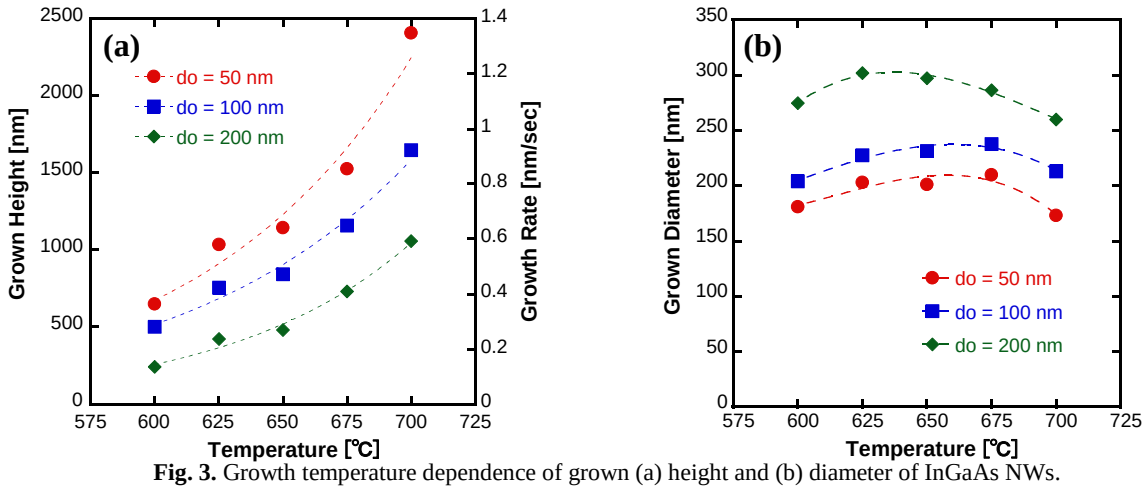

Fig. 3. Growth temperature dependence of grown (a) height and (b) diameter of InGaAs NWs.

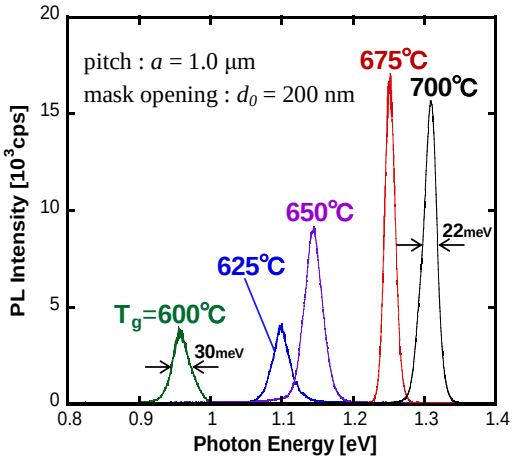

Fig. 4. PL spectra of InGaAs NWs.

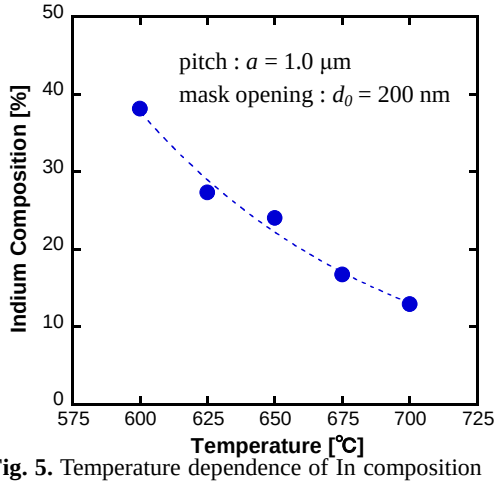

Fig. 5. Temperature dependence of In composition in InGaAs NWs.