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Spectroscopy and imaging of GaAs/InGaAs/GaAs nanowires grown by selective-area metalorganic vapor phase epitaxy

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1. Introduction

Semiconductor nanowires (NWs) are promising candidates as building blocks for nanoscale electronic and photonic devices such as field effect transistors [1], light emitters [2] and sensors [3]. So far, most of the semiconductor NWs were grown by vapor-liquid-solid (VLS) growth using metal catalysts [4]. In this method, however, metal catalysts might be incorporated and create deep nonradiative centers in NWs, resulting in insufficient emission efficiency as light emitters. We have been attempting alternative method to fabricate NWs using selective-area metalorganic vapor phase epitaxy (SA-MOVPE) as catalyst-free growth [5], which has the advantage of controllability for crystal quality, positioning and size uniformity. Here, we report on the highly efficient photoluminescence from SA-MOVPE grown single GaAs/InGaAs/GaAs NWs and their spectral and spatial imaging using micro-photoluminescence (μ-PL) measurement.

2. Experimental Procedure

The fabrication process of NWs is essentially the same as the one reported in Ref. [6]. After the deposition of 30 nm thick SiO_2 by plasma sputtering on GaAs (111)B substrates, periodic circular opening of SiO_2 mask were formed by electron beam (EB) lithography and wet chemical etching techniques. The opening diameter was about 100nm. Then, SA-MOVPE growth of GaAs/InGaAs/GaAs heterostructured NWs was carried out on partially masked GaAs (111)B substrates using a horizontal low-pressure MOVPE system working at 0.1 atm. Trimethylgallium (TMGa), trimethylindium (TMIn) and arsine (AsH_3) were used as source materials. The growth temperatures were 750 and 600 °C for GaAs and InGaAs growth, respectively. AsH_3 partial pressure during GaAs and InGaAs growth were 2.5 x 10^{-4} and 6.3 x 10^{-5} atm, respectively. Indium composition and layer thickness of InGaAs layers on planar (001) GaAs substrates grown as a reference in the same growth runs were 2.4 % and 5 nm, respectively. The designed thickness for planar substrates was 200nm, 5nm, and 50nm for the bottom GaAs, InGaAs, and upper GaAs, respectively, and becomes thicker for NWs.

After the growth, NWs were dispersed onto a SiO_2-coated Si substrate and μ-PL measurement was carried out in confocal microscope geometry at 4 K. The excitation laser was focused on < 2 μ m diameter region using micro-scope objective with numerical aperture of 0.42. The PL signal from the sample collected with the same microscope objective and was focused onto a pinhole. Light which went through was further fed into a spectrometer equipped with a liquid-nitrogen-cooled charge coupled device (CCD) for spectrally resolved measurement. In addition to the spectrally resolved study, two types of measurements, which we refer to ``collection mode" and ``excitation and collection mode", were carried out to get spatially resolved emission images of NWs. In the former, the detection spot on the sample was scanned by scanning a lens in front of the pinhole, while the excitation position on NWs was fixed. On the other hand, excitation laser spot and detection spot were simultaneously changed by scanning the microscope objective or sample in the cryostat. Spectrally integrated image was also taken without the pinhole using a high-sensitive CCD camera.

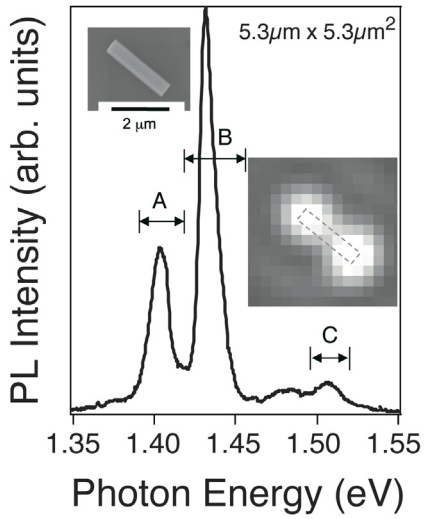

Fig.1 .Spacially integraed PL spectra of a InGaAs/GaAs heterostructured NWs.

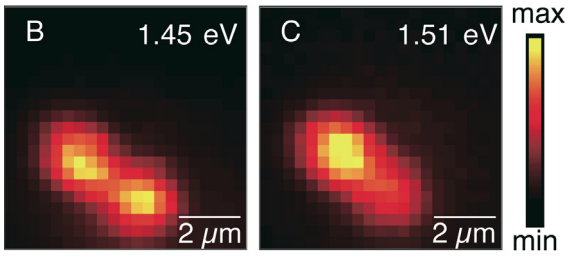

Fig. 2 Spectrally and spatially resolved PL image of the NW taken in the collection mode.

3. Results and Discussions

Figure 1 shows a spatially integrated PL spectra of the sample. In addition to the GaAs band-to-band and impurity-related transitions (at around C in Fig. 1), clear InGaAs related emissions were observed at around 1.40 eV (A) and 1.44 eV (B). Their relative intensity depended on the excitation power, and the peak at B become dominated at high excitation. In the spectrally integrated image, strong PL emission was observed from the both the end of the NW when the excitation was focused close to its center, as shown in the right inset of Fig. 1. This indicates that the NW works as a waveguide, or that the photons come out where its confinement is the weakest.

Figure 2 shows a spectrally and spatially resolved images of the sample tyke in the collection mode. Strong emission at the edges was also confirmed. Furthermore, the result also indicates that the InGaAs related emission (peak at around A (not shown) and B) was mainly from the both edge of the NW, whereas the GaAs related emission (peak at C) was only on the one side of the NW. On the other hand, spectrally and specially images taken with the excitation and collection mode showed that the InGaAs-related emission was localized inside the NW, as shown in Fig. 3. It also suggested that the spatial origin of peak A and B was different inside of the NW; the peak B seemed to be localized on the sidewall of the NW, whereas the peak A was in the middle of the NW. From these results, we concluded that the peak A is from the InGaAs QW formed on the top and sidewall of the NWs, which indicates the formation of lateral heterostructures. On the other hand, the peak B is an evidence for the formation of vertical heterostructures inside of the NW.

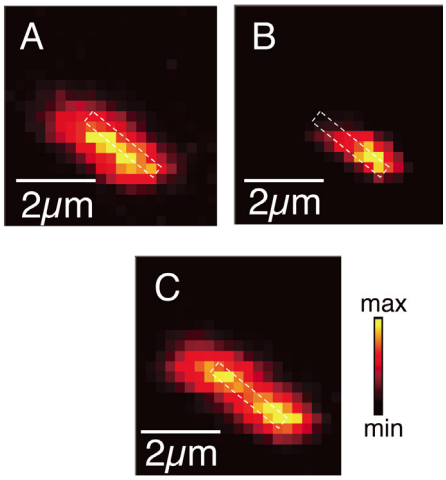

Fig 3. Spectrally and spectrally resoved PL images taken in the excitation and collection mode. Each image is obtained by integrating the spectrum in the energy range shown in the arrows in Fig.1.

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