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Room-temperature Electroluminescence of Radial p-i-n InP Nanowires with InAsP Quantum Wells in the 1.5-μm Wavelength Region

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Abstract

MOVPE growth of radial p-i-n InP nanowires (NWs) with InAsP quantum wells (QWs) was studied, and vertical NW light-emitting devices were fabricated. Radial p-i-n NWs were formed using position-controlled n-type InP NW cores. By optimizing Zn source flow rates, Zn-doped p-type InP shells were grown on the sidewall of InAsP QWs while maintaining luminescence intensity. The fabricated devices showed current rectification coming from the p-i-n diode structures. Moreover, electroluminescence (EL) in the 1.5-μm wavelength region was clearly observed at room temperature for the first time.

1. Introduction

Vertically-grown InP-based NWs using bottom-up growth methods have attracted much attention as building blocks for small near-infrared optoelectronic devices. In particular, radial heterostructures [1], where the multiple layers are formed on the sidewall of NWs, are expected to have an advantage in the creation of a larger active region in each NW owing to their high aspect ratio. Upon the implementation of processes on these NW heterostructures in order to fabricate devices, the NW position must be defined. Recently, we have reported VLS growth of position-controlled InP NWs using an SiO_2-mask patterned substrate with Au catalysts, which produced NW templates suitable for 2-dimensionally arrayed devices [2]. In addition, we have confirmed that undoped InAsP QWs can be grown radially on the sidewall of the InP NW cores [3]. In order to realize current-injection devices such as light-emitting diodes or laser-diodes, p-i-n diode structure should be introduced in these NWs, and it is necessary to fabricate metal contacts.

In this work, we grew radial p-i-n NWs with InAsP QW active layers and fabricated light-emitting devices. As a result, we successfully demonstrated room-temperature EL in the 1.5-μm wavelength region.

2. Experimental Procedures

A schematic description of the fabrication steps for the radial p-i-n NW devices is shown in Fig. 1. NW heterostructures were grown using MOVPE. SiO_2-mask-patterned InP(111)B substrates with regularly aligned mask openings filled with Au catalysts were used. The diameter and pitch of the Au catalysts were 100 nm and 10 μm respectively. On the patterned substrates, S-doped n-type InP NW cores with a length of approximately 3μm were grown at 415°C by supplying $(CH_3)_3In$ (TMIn), PH_3 and H_2S. To control the NW core shape, HCl gas was also introduced during core growth. After the Au catalysts were removed [4], undoped, single In(As)P/$InAs_{0.4}P_{0.6}$/In(As)P QWs and a p-type InP/InGaAs shell were radially grown at 530°C. AsH_3 and $(C_2H_5)_2Zn$ (DEZn) were used as As and Zn sources, respectively.

Light-emitting devices were fabricated by depositing SiN passivation film, p-electrode metals on the NW sidewall, and n-electrode metals on the back surface. A common p-electrode was fabricated on the 10×10 2-dimensional NW array. Ti/TiW/Au and AuGe/Au layers were used for p-type and n-type electrodes, respectively. Light emissions were extracted from the top of the NWs.

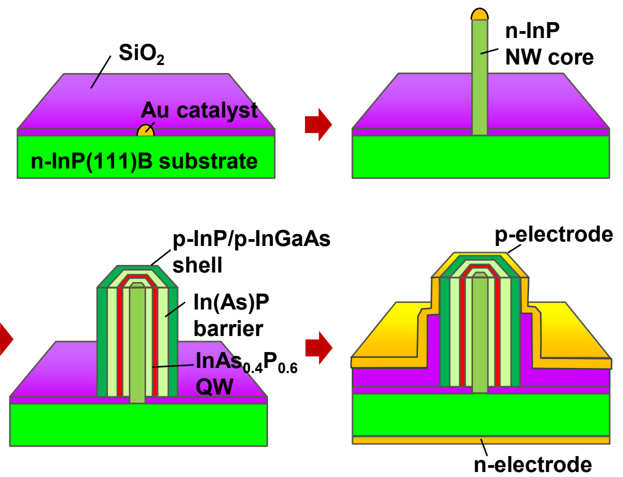

Fig. 1 Schematic description of fabrication steps of a NW light-emitting device with radial p-i-n heterostructure.

3. Results and Discussion

Growth of p-i-n NWs

Typical SEM images of the n-InP NW core and p-i-n NW with a p-InP shell grown using the highest DEZn/TMIn flow ratios (D/III) of 0.16 are shown in Fig. 2. An increase in NW diameter was clearly observed after the radial growth. There was no significant difference observed in p-i-n NW shape by varying D/III ratios.

However, we found that the Zn concentration strongly affected optical properties. The PL spectra of p-i-n NW with varying D/III ratios for the p-InP shell growth are shown in Fig. 3. A high D/III ratio of 0.16 caused strong reduction of PL intensity due to the diffusion of excess Zn atoms into the QW layers. On the other hand, the PL intensity maintained for the D/III ratio of 0.08 in which the estimated Zn concentration was ~10^{18} cm^{-3}, and we obtained p-i-n radial NWs applicable to device fabrication.

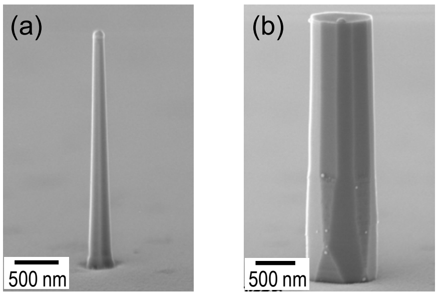

Fig. 2 SEM images of (a) n-InP NW core and (b) p-i-n NW.

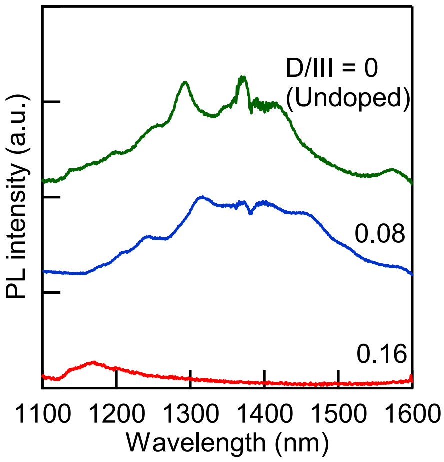

Fig. 3 PL spectra of p-i-n NWs with varying Zn-doping concentration of p-InP.

Device characteristics

The current-voltage curve is shown in Fig. 4. Current rectification due to the p-i-n structure was clearly observed, and the series resistance of the device was estimated to be 42 Ω.

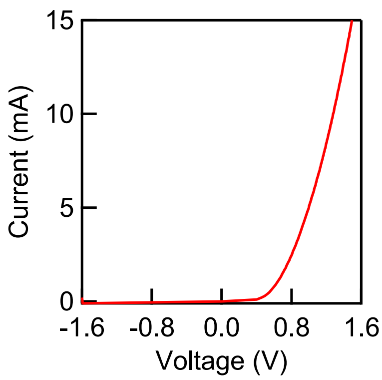

Fig. 4 Current-voltage curve of radial p-i-n NW device.

The EL spectrum of the device is shown in Fig. 5. The PL spectrum of the p-i-n NW before the contact process is also shown for comparison. For the EL measurement, a CW current of 15 mA was used. A clear peak in the 1.5-µm wavelength region was observed. The EL peak wavelength corresponds well to the PL peak wavelength, which indicated that the current injection worked properly.

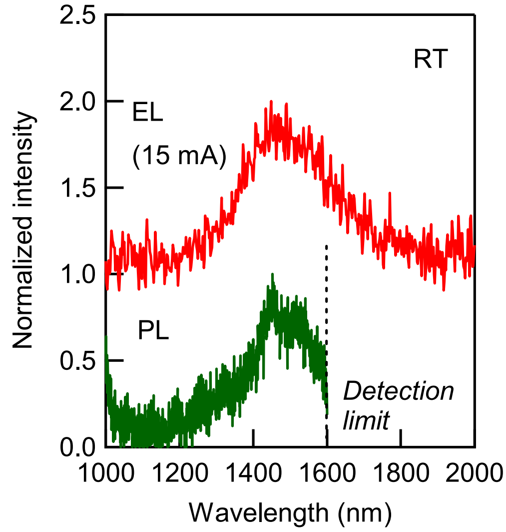

Fig. 5 EL and PL spectrum of p-i-n nanowires at room temperature.

4. Conclusions

We investigated the MOVPE growth of radial p-i-n NWs with InAsP QWs and fabricated vertical NW light-emitting devices. We successfully grew p-type InP shells on the sidewall of undoped In(As)P/InAsP/In(As)P QWs while maintaining the PL intensity. In the device characterization, we confirmed current rectification coming from the p-i-n diode structure and successfully demonstrated light emission in the 1.5-µm wavelength region by CW operation at room temperature. These results show that these NW structures are promising for realizing compact arrayed light emitters in the near-infrared region.

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