Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp747-748

Nanowire-based telecom-band light emitting diodes

Guoqiang Zhang[1,2], Dominika Gnatek[1], Masato Takiguchi [1,2], Kouta Tateno[1,2],
Satoshi Sasaki[1], Takehiko Tawara[1,2], and Hideki Gotoh[1]

[1] NTT Basic Research Laboratories
[2] NTT Nanophotonics Center
NTT Corporation, 3-1 Morinosato-Wakamiya, Atsugi, Kanagawa, 243-0198, Japan

Abstract

Telecom-band light sources are extremely important for optical data communication. Bottom-up semiconductor nanowires offer the possibility of enhancing the degree of freedom for 3D integration. Here we demonstrate telecom-band nanowire light emitting diodes operating at room temperature by using multi-stacked InP/InAs heterostructure nanowires grown by self-catalyzed vapor-liquid-solid bottom-up approach.

1. Introduction

Telecom-band light sources are extremely important for optical data communication. Bottom-up semiconductor nanowires offer the possibility of enhancing the degree of freedom for 3D integration and enduring large lattice mismatch for breaking the limitation of material combination. Hence they are being extensively studied in optoelectronic devices. Although ultraviolet, visible, and near-infrared nanowire light emitting diodes (LEDs) have been demonstrated, room-temperature telecom-band nanowire LEDs have not been reported a lot [1]. Because of its high controllability in terms of composition, heterostructure, doping, and diameter, etc., the vapor-liquid-solid (VLS) mode has been widely utilized for the nanowire synthesis and is considered to be a versatile and promising approach. Here we demonstrate telecom-band nanowire LEDs operating at room temperature by using multi-stacked InP/InAs heterostructure nanowires grown by self-catalyzed VLS approach for the first time.

2. Experiments and results

InP/InAs heterostructure nanowires were prepared by metal-organic vapor phase epitaxy (MOVPE) system, where the InP/InAs nanowire was grown via indium-particle-catalyzed (or self-catalyzed) VLS mode [2,3]. The self-catalyzed VLS approach is chosen because of its potential application in the field of integrated optoelectronics for the CMOS-compatible process feature, i.e., gold-free and low-temperature (< 360 ºC) characteristics [4]. We used InP (111)B as the substrate for vertically aligned nanowires on the substrate by epitaxial growth (Fig. 1). Diethylzinc (DEZn) and ditertiarybutylsulfide (DTBS) are used as the source materials for the doping control of p- and n-type InP segments. The active region contains 5-10 periods of InP/InAs units (Fig. 1).

We found that indium particles at nanowire tips melted in annealing process during device fabrication due to its low melting point (~156 ºC). Melted indium particles then partly cover nanowire side surfaces. The metallic indium side layer is highly conductive and therefore induce high leakage current in LED operation. One way to suppress the indium particle effect is to shrink the indium particle into sub-100-nm diameter using in-situ diameter tuning technique we recently developed (Fig. 2) [5] .

For the device fabrication of LEDs, InP/InAs nanowires were embedded in transparent benzocyclobutene (BCB) material. The ITO and Au-Ni-Zn was deposited for the contact of n-type InP nanowire and p-type InP substrate (Fig. 3). We then fabricated nanowires with tiny indium particle at tips (Fig. 4a) into LED device (Fig. 4b). We attached nanowire LED samples onto ceramic substrates for subsequent electroluminescence (EL) measurement in Micro-PL system (Fig. 5a). Nanowire LED devices show typical I-V curve of a p-i-n diode (Fig. 5b).

We studied the EL property of single nanowires by using Micro-PL system. The device exhibits increasing luminescence intensity under increasing bias (Figs. 6 and 7). The EL and PL peaks of the nanowire are in good agreement (the inset in Fig. 7), indicating that carriers are injected into InAs layers and recombine with photon emission in telecom band by quantum confinement effect. The well-established growth technique of InP/InAs heterostructure nanowire also enabled us to tune the EL peak by the thickness of InAs layer in a wide range through quantum confinement effect (Fig. 8).

3. Conclusions

We demonstrate telecom-band nanowire LEDs operating at room temperature by using multi-stacked InP/InAs heterostructure nanowires grown by self-catalyzed VLS approach. This work paves the way for the integration of nanowire-based LEDs into CMOS process towards on-chip photonics.

Acknowledgements

We thank Drs. K. Kumakura for his support in MOVPE growth and T. Mitate for his measurement by TEM. Funding: This work was partially supported by Scientific Research grant (No.: 15H05735 and 16H03821) from the Japanese Society for the Promotion of Science.

References

[1] Saniya Deshpande, et al. ACS Photonics, **4**, 695–702 (2017);
[2] G. Zhang, et al. Nanotechnology **26**, 115704 (2015).
[3] G. Zhang, et al. ACS Nano **9**, 10580 (2015).
[4] H. Riel, et al. MRS Bull. **39**, 668-677 (2014)
[5] G. Zhang, et al. Nanotechnology **29**, 155202 (2018).

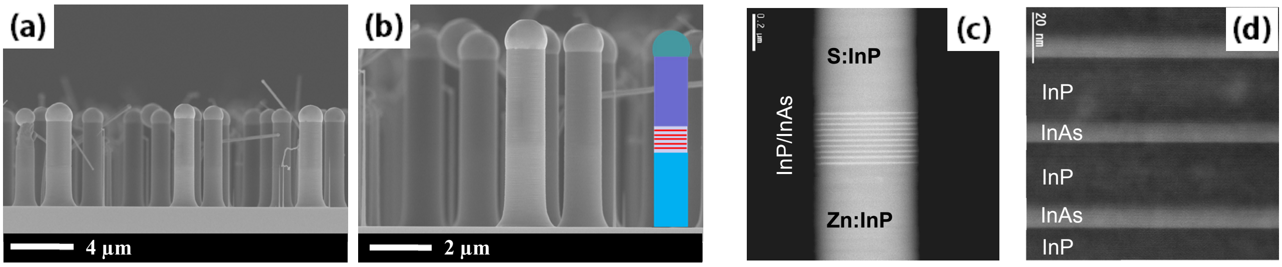

Fig. 1. (a) and (b) SEM images of vertically aligned InP/InAs nanowires. The inset in (b) shows schematic diagram of the p-i-n structured nanowire. (c) and (d) HAADF-STEM image of a nanowire with 10 InAs active layers.

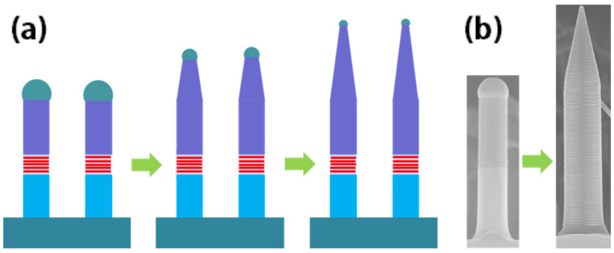

Fig. 2. Schematic diagram (a) and SEM images (b) of tuning indium particle into sub-100-nm diameter by modulating V/III ratio.

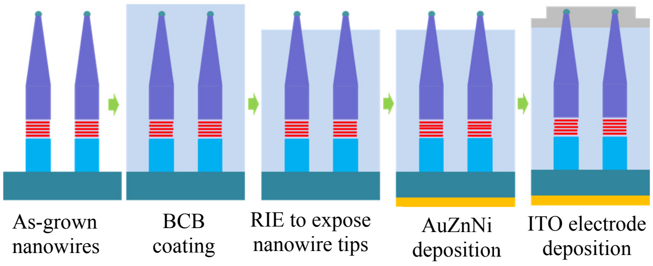

Fig. 3. Schematic diagram of device fabrication for nanowire LED. Nanowires were embedded in transparent BCB polymer material.

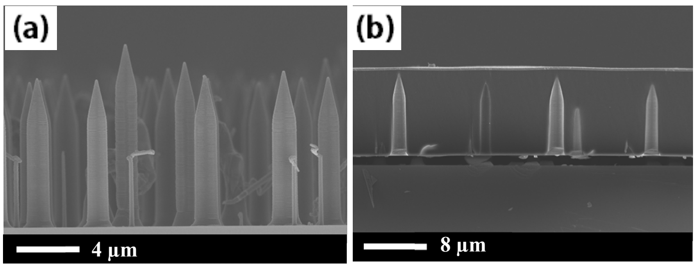

Fig. 4. Cross-section SEM images of (a) InP/InAs nanowires with tiny indium particles at tips after growth and (b) nanowire LED with nanowires embedded into BCB material.

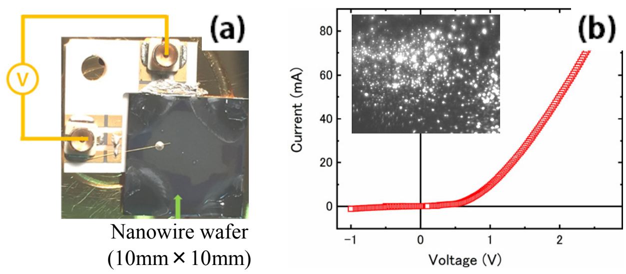

Fig. 5. Nanowire LED device and electrical performance. (a) Nanowire sample attached on a ceramic substrate. (b) Typical I-V curve. The inset shows an EL image taken by an infrared CCD camera in Micro-PL system (×20 lens). The image area is 380 μm×475 μm.

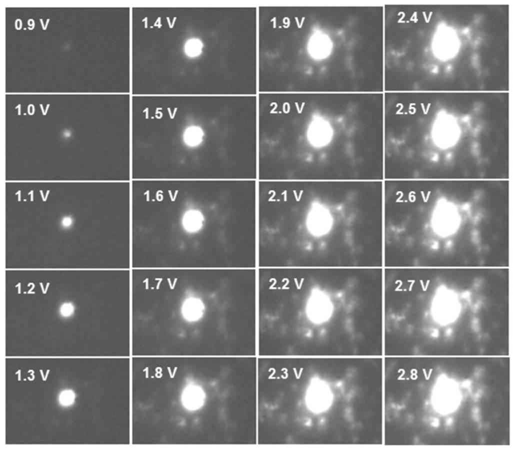

Fig. 6. EL images of a same single nanowire under bias voltage shown inside. Images were taken by an infrared CCD camera in Micro-PL system (×50 lens). Each image area is 47.6 μm×68.5 μm.

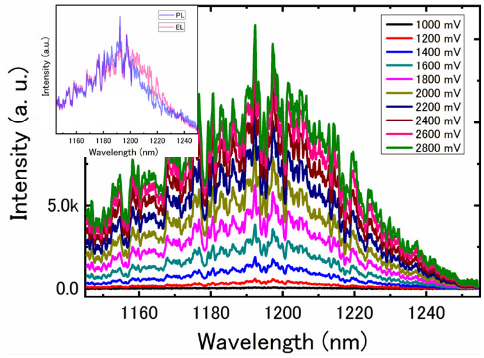

Fig. 7. EL spectra of the nanowire shown in Fig. 6 with increasing bias (step: 0.2 V). The inset shows PL and EL at 2.8 V bias, indicating good agreement of two peaks.

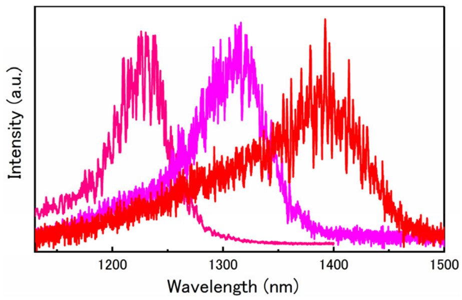

Fig. 8. EL spectra of three nanowire LED samples with increasing thickness of InAs layers modulated by flow rates of source materials of TMIn and TBAs.