自己触媒法 InP ナノワイヤ中の硫黄ドーピング濃度の NanoSIMS 測定
Controllable sulfur dopant concentration in InP nanowires revealed by NanoSIMS with nanoscale spatial resolution

◦Zhang Guoqiang[1,2*]、舘野功太[1,2]、俵　毅彦[1,2]、後藤秀樹[1]
◦Guoqiang Zhang[1,2*], Kouta Tateno[1,2], Takehiko Tawara[1,2], and Hideki Gotoh[1]
[1]NTT 物性科学基礎研究所, [2]NTT ナノフォトニクスセンタ, 神奈川県厚木市森の里若宮 3-1, 243-0198
E-mail: guoqiang.zhang.ta@hco.ntt.co.jp

Vapor-liquid-solid (VLS) grown wires have become key components of various devices. To maximize potential capability of electrical and optical device performance, knowledge of dopant control information is of utmost important [1]. Secondary ion mass spectroscopy (SIMS) method, a very powerful tool to investigate doping control, is typically used for films because of over hundreds of μm^2 analysis area. On one hand, embedding high-density wire ensemble into other materials is an alternative way to measure dopant concentration by conventional SIMS [2]. On the other hand, it is necessarily important to analyze dopant distribution in single wires for more precise measurement. NanoSIMS, recently developed with sub-microscale ion beam size, makes the measurement possible [3]. Here we report controllable S concentration (N_S) in VLS grown InP wires revealed by NanoSIMS with nanoscale-spatial-resolution mapping function.

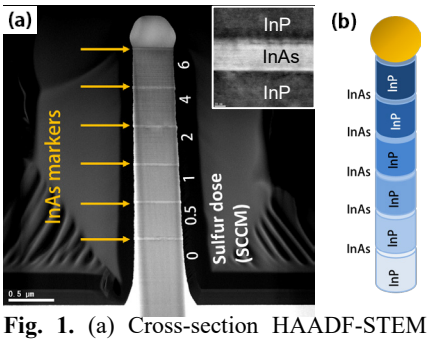

Fig. 1. (a) Cross-section HAADF-STEM image of an InP/InAs wire with increasing doping dose. The inset shows enlared InP/InAs double hetero structures. (b) Schematic of InP/InAs wire shown in (a). 1 SSCM is equal to 0.16 μmol/min. for DTBS of sulfur source material.

We synthesized InP/InAs wires in a metalorganic vapor phase epitaxy system in the self-catalyzed VLS mode [4]. In each wire, there are 6 InP segments with increasing S dose along growth direction. In order to localize these InP segments with different dose in measurement, we put a number of InAs disks into InP wires as markers (Fig. 1). We mechanically dispersed these InP/InAs wires onto a Si substrate. A Cameca NanoSIMS-50L was then used for dopant analysis with a 16 keV Cs+ primary ion beam at normal incidence. The ion beam size of 80-100 nm enables us to perform mapping analysis of phosphors (P), S, and As (arsenic) elements with nanoscale spatial resolution for single wires. Such mapping analysis can directly reveal S distribution along growth direction.

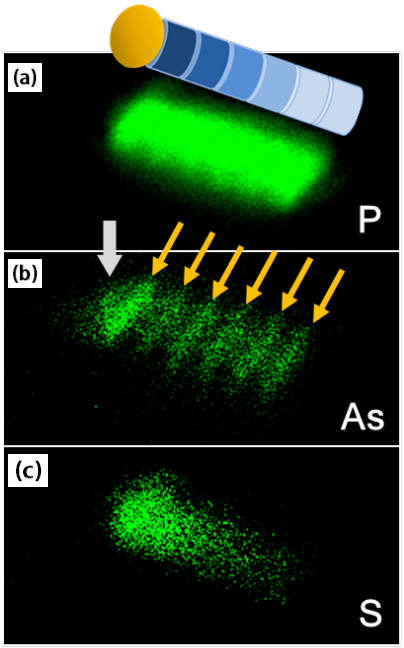

Fig. 2. Elemental mapping of P (a), As (b), and S (c) for a single nanowire. The yellow-color arrows indicate 6 InAs markers. The grey arrow indicates the indium particle. The area size is 2.5 μm × 5.0 μm with 128 pix × 256 pix.

Figure 2 shows the elemental mapping results. P profile shows homogeneous intensity along the axial direction, indicating the existence of InP segments. The high solubility of As in indium particles results in greater signal intensity in particle tip, revealing the particle position indicated by a grey arrow in Fig. 2b. The As profile clearly indicates the position of 6 InAs markers. S profile apparently shows increasing intensity along the growth direction, indicating an increasing N_S. The result is well in agreement with the doping dose profile used for the wire (Fig. 1b).

We also quantitatively extract the N_S in InP wires by estimate Relative Sensitivity Factor (RSF) value. The RSF can be obtained by doing the same measurement for a reference sample (S:InP crystalline substrate with N_S of 5.1E+16 cm^{-3}) under same condition. N_S is approximately linearly proportional to S doping dose. N_S in InP wires is roughly estimated to be 1.59~8.6E+18 cm^{-3}.

In conclusion, we show direct evidence of controllable S concentration in InP wires by using NanoSIMS method with nanoscale-spatial-resolution mapping function. This work is greatly helpful to access potential capability of electrical and optical device performance.

Acknowledgement: this work was supported by JSPS KAKENHI, 19H02636.

References:

[1] J. Wallentin, M.T. Borgström, Journal of Materials Research, 26 (2011) 2142-2156.
[2] A.C.E. Chia, N. Dhindsa, J.P. Boulanger, B.A. Wood, S.S. Saini, R.R. LaPierre, Journal of Applied Physics, 118 (2015) 114306.
[3] M.C. Putnam, M.A. Filler, B.M. Kayes, M.D. Kelzenberg, Y. Guan, N.S. Lewis, J.M. Eiler, H.A. Atwater, Nano Letters, 8 (2008) 3109-3113.
[4] G. Zhang, M. Takiguchi, K. Tateno, T. Tawara, M. Notomi, H. Gotoh, Science Advances, 5 (2019) eaat8896.