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Strain characterization of InAs segment in Au-free InP/InAs heterostructure nanowires by micro-Raman measurement

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Abstract

Heterostructure nanowire with large lattice mismatch provides new opportunities in making use of strain engineering tool and developing new functional devices. Therefore, it becomes necessary to characterize the strain and understand the lattice deformation mechanism in the nanowire structure. Here, we report the strain characterization of InAs segment in Au-free InP/InAs heterostructure nanowires by performing micro-Raman measurement in the single nanowire level. We revealed that there is compressive strain in InAs segment and the strain increases with the diameter but decreases with the segment thickness.

1. Introduction

Strain in semiconductors has significant effect on the band gap structure and has become a very effective tool to tailor the optical and electronic properties of semiconductors. Semiconductors and heterostructure nanowires (NWs) will be the next-generation building blocks. Because of the particular one-dimensional structure, the lattice relaxation way is significantly different from the film structure [1]. This enables large lattice mismatch formations within heterostructure NWs without inducing dislocations. This provides new opportunities in making full use of the strain and engineering the optical and electrical properties. It is therefore necessary to characterize the strain and find a fundamental understanding of the lattice deformation mechanism. However, until now, there are very few reports about the topic, mainly by TEM, which is a destructive method [2]. Here, we report the strain characterization of Au-free InP/InAs heterostructure NWs by performing micro-Raman measurement, a nondestructive and very sensitive method. We revealed that there is compressive strain in InAs segment. The strain increases with the diameter and decreases with the segment thickness.

2. Experiments and results

NW growth

Au has been widely used to grow NWs in the vapor-liquid-solid (VLS) mode because of its versatility in various materials [3]. However, Au atoms could be incorporated into NWs and consequently degrade the NW properties [4,5]. By developing Au-free self-assisted VLS approach [6,7], we grew InP/InAs heterostructure NWs in indium-particle-assisted VLS mode [8] (Fig. 1). Figure 2 shows HAADF-STEM images of the NW with 60 InAs/InP layers. The inset in Fig. 2(b) shows a single InP/InAs/InP double heterojunction. The high-resolution TEM characterization indicates the coherent growth of the heterostructures in the NW.

Micro-Raman measurement

The micro-Raman method enables us to carry out the measurements in the spatial resolution of single NW level. NWs are dispersed from the as-grown substrate to Au-coated SiO_2/Si substrate with markers (Fig. 3). Using the markers defined on the substrate, we could identify the NW size by SEM measurement after Raman measurement. We used the 532-nm laser in the measurement. The use of ×50 lens enables to distinguish single NWs and make the laser spot with the diameter as small as 2-4 μm. The scattering light is collected by the same lens and then guided onto a spectrometer, and finally detected by a Si CCD camera.

Results and discussions

Due to the -3.1 % lattice mismatch of InAs/InP and the coherent growth, there should be high compressive strain in InAs segment. We characterized the strain in the InAs by Raman scattering in terms of the shift of TO phonon peak. The multilayer structure enables to detect Raman signals with enough intensity and therefore find the phonon-related peak structure.

Figure 4 shows the typical spectrum of a multi-stacked heterostructure NW. For comparison, we also show the Raman spectrum of pure InAs NWs. There is a blue-shift (~ 10 cm^{-1}) of the TO phonon peak from the InAs NW to the InP/InAs NW, indicating a highly compressive strain inside the InAs segment.

The NW diameter could be tailored by the initial indium particle size. The thickness of InAs segment can be tuned by the growth time. The high size controllability makes it possible to clarify the influence of the NW diameter and the length of the InAs segment on the strain by synthesizing NWs with varied diameters and InAs segment thickness.

We found that the shift increases with the increase of the NW diameter but decreases with the increase of the InAs segment thickness. This can be directly used to engineer the strain in the NW structure and then modify the optical and electronic property just by tailoring the diameter and the segment thickness.

3. Conclusions

In conclusion, we have characterized the strain in InP/InAs NWs for the first time by micro-Raman measurement. We confirmed the compressive strain in InAs segment and clarified the diameter and segment length dependence of the strain. These results are significantly important to develop new applications based on strain-engineered NWs.

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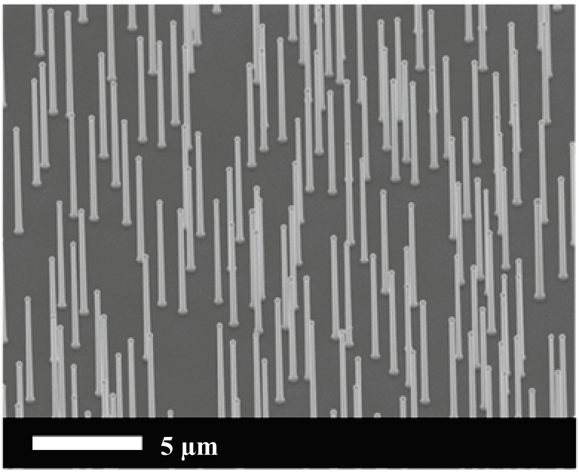

Fig. 1. SEM image (tilt: 38°) of InP/InAs NW heterostructure NWs grown on InP (111)B substrate.

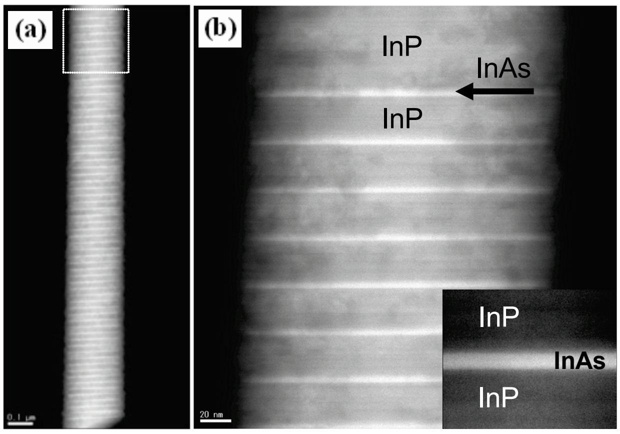

Fig. 2. HAADF-STEM images of (a) a multi-stacked InP/InAs NW with 60 InAs layers (b) the area indicated the dotted line in (a). The scale bar in (a) denotes 100 nm. The scale bar in (b) denotes 20 nm.

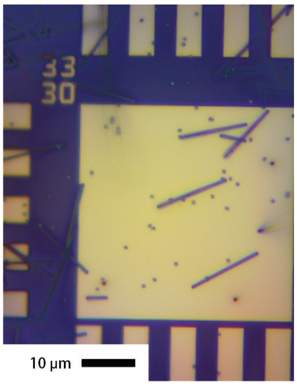

Fig. 3. Raman spectra of a single InAs NW. The dotted line indicates the TO phonon peak of the InAs NW. The inset shows the image in the micro-Raman measurement. One can see several NWs dispersed on the substrate. The scale bar in the inset is 10 µm.

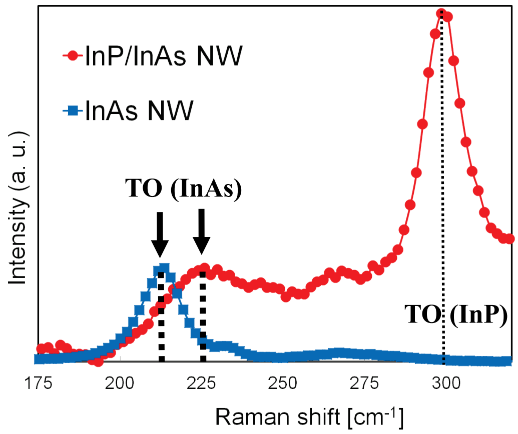

Fig. 4. Raman spectra of a multi-stacked InP/InAs NW and a pure InAs NW. TO phonon peaks from the InAs and InP segments of the two NWs are indicted.