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Multi-quantum structures of GaAs/AlGaAs Free-standing Nanowires

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1. Introduction

Free-standing nanowires are promising for future nano-scale devices. We have reported several structures using VLS (vapor-liquid-solid) grown nanowires: AlGaAs-capped nanowires, 3D heterostructures by alternating VLS growth and MOVPE (metalorganic vapor phase epitaxy), and nanoholes using nanowire templates [1,2]. To construct sophisticated functional devices, we have to know more about the size and quality of the grown structures and their corresponding quantum characteristics. The SNOM (scanning near-field optical microspectrometer) is a powerful tool for studying the optical properties of nanostructures. The spatial resolutions are beyond the diffraction limit of light, and the resolution has been improved to the point where the wave function in a confined exciton can be measured [3]. In this paper, we report on the growth of AlGaAs-capped multi-structure nanowires and their low-temperature photoemission characteristics measured with SNOM.

2. Growth of Multi quantum structures

The VLS growth and MOVPE were carried out in a low-pressure MOVPE reactor. Trimethylgallium and trimethylaluminum were the group-III sources, and AsH_3 was the group-V source. GaAs substrates were used in this study. After the Au deposition on the surface, the temperature was raised to 700 ˚C in the AsH_3/H_2 gas to form Au particles. The size of the Au particles corresponds to the wire width, so that by adjusting the Au amount, nanowires of various sizes can be made. The wires were grown at low temperature (400-500 ˚C) under the Au particles as VLS growth and the capping growth was performed at high temperature (600-700 ˚C) as MOVPE.

Figure 1 shows secondary electron microscopy (SEM) images of the GaAs/AlAs multi-structures capped with AlGaAs. The wires tend to grow in the [111]B direction so that they are normal to the surface on (111)B substrates, while they are tilted 29.5˚ from the surface normal direction on GaAs (311)B substrates. As shown in Fig. 1(a), we were able to make 30 pairs of GaAs/AlAs layers in the post structure. Here, the diameter of the Au particles was relatively large, i.e., around 100 nm. This structure is intended for use as a distributed Bragg reflector (DBR). By improving the growth conditions to obtain smooth and ordered rods and by controlling the thickness of each layer, we can make proper reflectors. Further, structures like vertical-cavity surface-emitting lasers will also be possible. Due to the small size of the wires, as shown in Fig. 1(b), sharp luminescence from excitons is expected. Here the diameter of Au particles was around 20 nm. These structures are promising for single-photon sources for quantum cryptography as well as for lasers and amplifiers for optoelectronics.

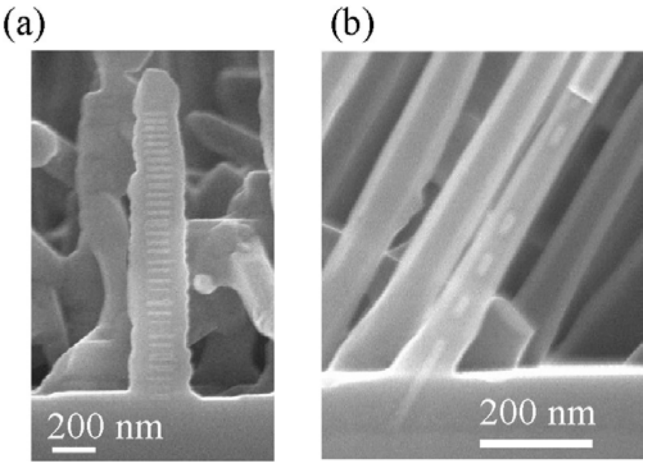

Fig. 1 Cross-sectional SEM images of GaAs/AlAs multi-structures. (a) 30 pairs of GaAs/AlAs layers capped with GaAs on GaAs (111)B and (b) alternating GaAs/AlAs wires capped with $Al_{0.3}Ga_{0.7}As$ on GaAs (311)B.

3. SNOM measurements

For the SNOM measurements, we used tilted wires grown on GaAs (311)B substrates in order to avoid optical interference by Au particles on the top of the wires. Considering from the quality of wires, as barriers we used AlGaAs layers with a low Al content. This is because carbon is likely to be incorporated in the AlGaAs layer at low growth temperature. Figure 2 shows the designed wire structures and a top-view SEM image of the grown wires. Since the structure was designed so that several peaks would appear, three kinds of pair of GaAs blocks (20-nm long) were made; the AlGaAs barrier in a GaAs pair is 50-, 20-, or 10-nm thick. The set of the three kinds of GaAs pairs is repeated 6 times. After the wire growth by the VLS method, the wire was covered with $Al_{0.4}Ga_{0.6}As$ and

$Al_{0.6}Ga_{0.4}As$ and GaAs as capping layers. From AlGaAs-capped GaAs/AlAs wires like those in Fig. 1(b), each AlGaAs layers was estimated to be about 50-nm thick and the GaAs to be about 10-nm thick. Actually, in the SEM image in Fig. 2, it can be seen that the wires were so long that some of them curved and also merged with each other. For this sample, the SNOM measurements were performed at low temperature (21 K). The size of the aperture in the metal coated optical fiber probe is about 50 nm. The input light was 532 nm in wavelength. It illuminated the sample through this aperture and the photoluminescence (PL) signal was collected through the same aperture. The excitation power from the aperture was estimated to be 6.0 nW. The collected luminescence was fed to a spectrometer equipped with a silicon-charged coupled device (CCD) detector.

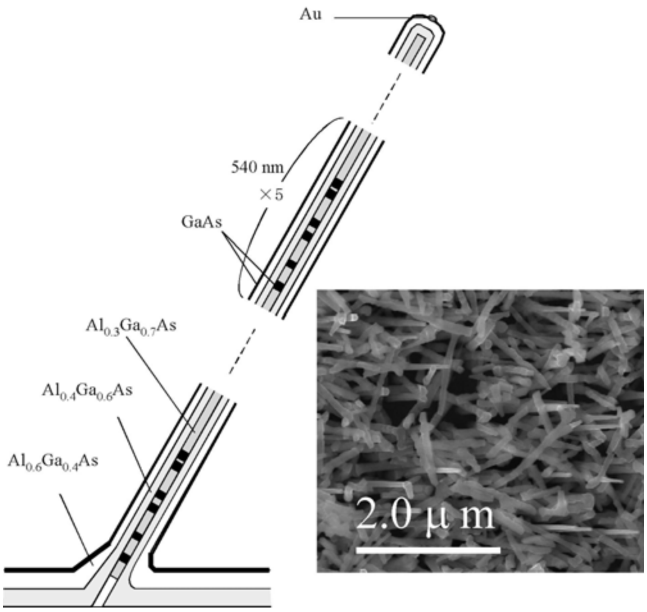

Fig. 2 Designed wire structure for SNOM measurements. The inset is top view SEM image of grown wires.

Figure 3 shows the results of the measurement. In this case, we measured a 1×1 μm^2 area at 20×20 measurement points. By plotting the luminescence intensity at several peak wavelengths, we were able to obtain X-Y images of some wires. From the mapping images at each peak, three kinds of wire images were mainly obtained so that we supposed that the peaks in the spectrum were derived from three main wires (A, B, and C in Fig. 3). Wire A seems to be linear and to lie at the top of the surface. In Fig. 3, we also show two typical mapping images at the A wire's derived peak wavelength. The intensity peaks seen for wire A seem to reflect the several quantum structures in the wire. These patterns are assumed to be emissions from the area of the GaAs blocks in the wire. In addition, some excited states may be involved because many fine peaks disappeared when the power of the input light was reduced. The emission wavelength in Fig. 3 seems to be a little short compared with that of previously reported GaAs/AlGaAs quantum dots [4]. One possible reason is that the GaAs blocks inter-diffuse with the AlGaAs barriers during the MOVPE capping growth. Clarifying the reason for this blue shift requires further investigation.

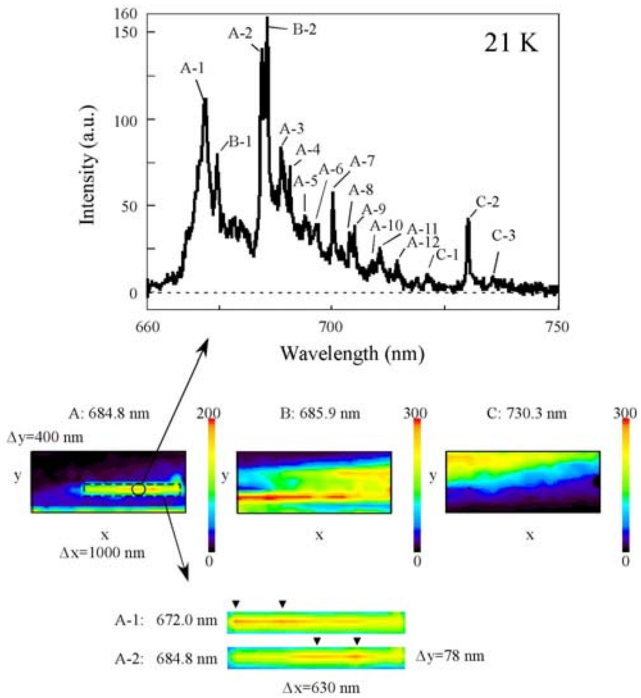

Fig. 3 PL spectrum in a linear wire region (A wire). Bottoms are several SNOM mapping images at the peak wavelength.

4. Conclusions

Using VLS growth, we made multi-layer structures of GaAs/AlGaAs nanowires. In small-diameter wires made by reducing the Au particle size, we were able to observe quantum structures with sharp excitonic emissions at low temperatures. Our method with VLS growth is promising for future nano-scale optical devices.

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