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Photoluminescence of the single wurtzite GaAs nanowire with different powers and temperatures

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A B S T R A C T

High quality GaAs nanowires with wurtzite structure were grown by molecular beam epitaxy. The micro-photoluminescence from a single GaAs nanowire is carried out with different excitation powers to investigate both intrinsic and extrinsic emissions in wurtzite GaAs nanowires. The variation of emission energy of free exciton peak with temperature is also investigated. It is found that the electron–phonon interaction is weaker in wurtzite GaAs than that in its zinc-blende counterpart. The time-resolved photoluminescence is performed to study the life time of free exciton at last. By capping GaAs nanowires with an $Al_{0.3}Ga_{0.7}As$ shell layer, the life time of free exciton increases significantly, which provides the possibility for the device application of the GaAs-based nanowires.

1. Introduction

III–V semiconductor nanowires, as candidate material for the building blocks of electronic and optoelectronic devices, have been intensively investigated with regard to their electrical and optical properties during the last decade. Among them, research on GaAs nanowires, mainly grown by MOCVD, has developed most rapidly because of the widespread application in optoelectronic devices (such as lasers [1], light-emitting diodes [2] and solar cells [3]). Compared with MOCVD, molecular beam epitaxy (MBE) has a priority in the aspect of growing nanowires of high purity due to its ultra-high vacuum condition. However, GaAs nanowires grown by MBE are not studied so widely [4–6]. Since MBE-grown GaAs nanowires are generally of wurtzite (WZ) structure [7], as opposed to zinc-blende (ZB) structure of its MOCVD-grown counterpart [8], it is desirable to explore and understand the optical properties of WZ GaAs nanowires. Although some works, mainly focusing on the intrinsic emission in GaAs nanowires, have been done [6,9], the extrinsic emission in WZ GaAs nanowires has not yet been studied systematically. Because of their high aspect ratio, GaAs nanowires have a high density of surface states, which have to be decreased before device applications. Capping the nanowires with AlGaAs shell layers is one of the best ways, and after that, GaAs nanowires can be used for device applications such as room-temperature lasers [10]. However, few studies have been done on the MBE-grown WZ GaAs–AlGaAs core–shell nanowires.

In this paper, we investigate the impact of different excitation power levels on the photoluminescence, finding both intrinsic and extrinsic emissions in WZ GaAs, and study the variation of the free exciton peak emission energy with temperature. The time-resolved photoluminescence is performed to study the lifetime of free exciton of GaAs nanowires at last. By covering the GaAs nanowires with an AlGaAs shell layer, the life time of free exciton in GaAs–AlGaAs core–shell nanowires increases significantly, which is the base of the device application of the nanowires.

2. Experimental

GaAs nanowires were prepared by Au-catalytic vapor–liquid–solid growth mechanism [11] in a Riber 32 MBE system on GaAs $(111)_B$ substrates. The growth temperature is 400–450 °C and the V/III flux ratio is about 20, under which the nearly pure WZ GaAs nanowires were obtained. After growth, the morphology and microstructure of GaAs nanowires were examined by scanning electron microscopy (SEM, FEI Sirion 200) and transmission electron microscopy (TEM, Philips F20).

The micro-photoluminescence spectroscopy (μ-PL) from GaAs nanowires, including those covered with an $Al_{0.3}Ga_{0.7}As$ shell layer, was carried out by a confocal PL system (JY-Horiba LabRam), with the excitation wavelength of 532 nm from a semiconductor laser. The measurement was done at several temperatures, from

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10 K to 120 K. The time-resolved photoluminescence (TRPL) of an ensemble of NWs was obtained using pulsed 300 fs, 532 nm excitation at 4.5 K. All the measurements were carried out on nanowires transferred onto a silicon substrate.

3. Results and discussion

The microstructure of MBE-grown GaAs nanowires was characterized firstly by SEM and TEM. Fig. 1a shows the typical morphology of GaAs nanowires. Their length and diameter are approximately 7 μm and 110 nm respectively. Under the low growth temperature of 400 °C, we have obtained the pure, defect-free WZ GaAs nanowires as is shown by the high-resolution TEM (HRTEM) and selected area electron diffraction (SAED) images in Fig. 1b. According to our reported work [7], at a relatively high temperature we could obtain longer GaAs nanowires, which favors the performance of μ-PL. Although GaAs nanowires grown at 450 °C have a few stacking faults denoted by an arrow in Fig. 1c, they are of nearly pure WZ structure, only with several stacking faults that are well separated from each other.

The μ-PL of these high-temperature grown GaAs nanowires was then carried out at low temperature of 10 K with different excitation powers. It can be seen from Fig. 2a that all emissions with different excitation powers contain a main narrow peak at 1.515 eV (its average full width at half-maximum is 4.1 ± 0.6 meV), which coincides with some reported observations in wurtzite GaAs nanowires [6,12]. This main narrow peak (denoted as FX in Fig. 2a) is ascribed to the intrinsic emission-the free exciton (FX) recombination in wurtzite GaAs nanowires [6]. The low-energy broad peak (their peak position is 1.493 eV) shown in the inset in Fig. 2a is related to the carbon impurity, which was also observed in the GaAs nanowires grown by MOCVD [13]. However, increasing the excitation power to $10P_0$ leads to the occurrence of a new shoulder *S* at the low energy side of the FX peak. Compared with the carbon-related peak, the *S* peak shows a significant blue shift of ~15 meV. Therefore, the *S* peak should not be related to carbon impurity. Bearing in mind that MBE-grown GaAs nanowires are weak-n-type doped unintentionally, this shoulder could possibly be attributed to the donor-bound exciton. Since unintentionally doped, the density of donor dopants in GaAs nanowires is usually small, and the quasi-Fermi level for electron lies well below the shallow donor level. Therefore, the donors in the semiconductor remain their ionized states under the low light level excitation. Under this condition, the neutral-donor-related emission is not expected to be observed. When illuminated by a strong incident light, the quasi-Fermi level for electron approaches, or even exceeds the donor levels [14]. Such condition leads to the donors trapping electrons and the neutral donors occurs. In this case, the extrinsic neutral-donor-related emission should appear. Since a portion of free exciton is bound to those neutral donors, the intensity of the FX-related peak decreases accordingly. By fitting the PL spectra line shape, a 5.8 meV red shift of the S peak from the FX-related peak is observed, which is in accord with the binding energy of Si donors in GaAs [15].

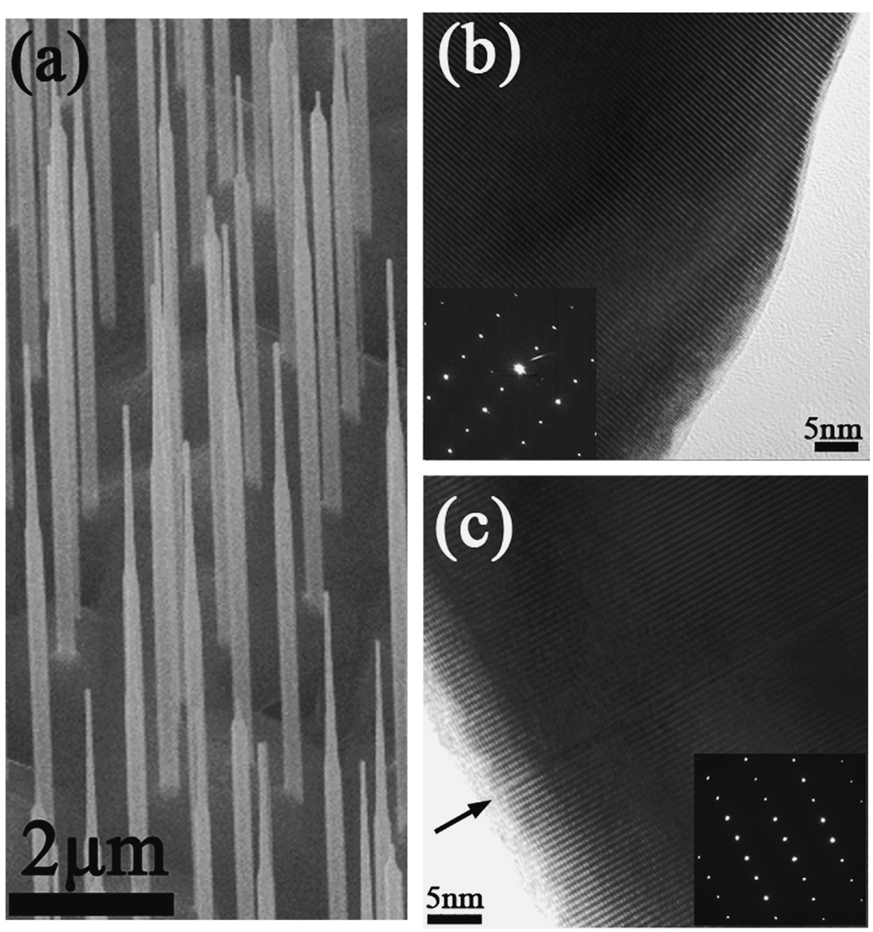

Fig. 1. (a) The typical morphology of GaAs nanowires grown under the growth conditions listed in the manuscript and HRTEM images of GaAs nanowires grown, (b) at 400 °C, with no defects and (c) at 450 °C, with a few defects. The insets in (b) and (c) both show the WZ structure in GaAs nanowires. The black arrow in (c) denotes the stacking faults in GaAs nanowires.