Academic Journal of Engineering and Technology Science
ISSN 2616-5767 Vol.5, Issue 4: 43-47, DOI: 10.25236/AJETS.2022.050408

Growth and Characterization of InGaAs Nanowires

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***Abstract:** In this paper, high crystal quality InAs, GaAs and InGaAs nanowires were grown by chemical vapor deposition in a double temperature zone tubular furnace by accurately controlling the source material and substrate temperature. Scanning electron microscopy (SEM) showed that the nanowires had uniform diameter, smooth surface and length up to tens of microns. XRD results showed that the nanowires were evenly distributed in composition and have a single crystal wurtzite structure. Raman spectral images further verified the crystal structure and composition of the nanowires. They showed that high-quality InGaAs nanowires were grown. The photodetector has good spectral response characteristics and sensitive sensing ability to rapidly changing optical signals.*

***Keywords:** InGaAs nanowires, High crystal quality, Morphology and characterization*

1. Introduction

One-dimensional nanowires refer to nanomaterials with at least one dimension in the range of 1-100 nm in the three-dimensional spatial scale and with highly anisotropic morphology.With the rapid development of the semiconductor industry, the requirements of modern industry for materials and devices are also developing towards miniaturization and integration. One-dimensional nanowires have attracted extensive attention due to their high surface-to-volume ratio, excellent light absorption capability and compatibility, and high mechanical flexibility, which are very suitable for fabricating highly integrated microdevices [1].

III-V semiconductor materials have the characteristics of high carrier mobility, direct band gap, abundant surface states, etc., and have inherent advantages in the manufacture of high mobility and high-speed electronic devices, high-frequency, low-power electronic devices, etc. InGaAs is a typical III-V ternary compound semiconductor material. At 300K, the band gap width of InGaAs can be adjusted from 0.35eV (InAs) to 1.42eV (GaAs), and it has high photoresponse performance and dark current, which makes InGaAs free from the restriction of cooling. The lattice mismatch that InGaAs nanowires can tolerate is relatively large, which effectively solves the problem that planar devices are limited by the lattice matching of heterojunction materials. It is a suitable material for the preparation of short-wave near-infrared photodetectors. At present, InGaAs and other III-V nanostructures are mainly synthesized by metal organic vapor deposition (MOCVD) and molecular beam epitaxy (MBE), but these methods are not suitable for popularization due to the expensive production cost and the characteristics of highly toxic V-group precursors[2].

In this paper, InGaAs nanowires with high crystal quality were synthesized by chemical vapor deposition (CVD) by accurately controlling the temperature of materials and substrates. It effectively reduces the production cost and eliminates the problem of the highly toxic characteristics of traditional V-group precursors. The grown nanowires were characterized by XRD, SEM, Raman and PL. The results showed that thenanowires had good crystal quality and optical performance.

2. Experiments

2.1 Growth of nanowires

High crystal quality nanowires were grown by chemical vapor deposition (CVD) with solid InAs powder, In powder and GaAs powder as raw materials and Au as catalyst. The experimental device is shown in Figure 1. First, prepared a clean silicon substrate to deposit nanowires: cut the silicon wafer into small pieces with a length of 1.2cm and a width of 0.8cm, placed it in an ultrasonic machine, ultrasonic for ten minutes with acetone, ethanol and deionized water, and then blew dry with a nitrogen gun. A 1 nm thick Au film was evaporated on the surface of silicon wafer by thermal evaporation equipment. Next was the specific preparation process: used a high-precision electronic balance to weigh the InAs powder, In powder and GaAs powder in a certain proportion, loaded them in three quartz boats and placed them in the high-temperature area of the quartz tube of the double temperature zone CVD system. Among them, GaAs powder was placed in the high temperature area, and In powder was placed 3cm away from the GaAs powder in the high temperature area. InAs powder was placed 20cm away from the edge of the quartz tube. During the growth, it was slowly pushed to the high temperature area at a uniform speed. The silicon substrate with Au film thermally deposited in advance was placed vertically on a rectangular quartz sheet with a length of 20cm and a width of 3cm, and the quartz sheet was pushed into the low temperature zone of the tubular furnace for the growth of nanowires. Before heating, the mixed gas of hydrogen and argon (Ar 90% +H_2 10%) was introduced into the quartz tube at a flow rate of 350 sccm. At the same time, the vacuum pump was turned on to remove the oxygen in the quartz tube. After venting for 40 minutes, adjusted the gas flow rate to 50 sccm, kept the pressure in the quartz tube at 370Pa, started the CVD system program, raised the left temperature zone to 900 ℃ within 45 minutes and the right temperature zone to 400 ℃. After 60 minutes of growth, cooled the CVD system naturally to room temperature and took out the sample. It could be seen that a layer of yellowish flocculent precipitation was deposited on the silicon substrate.

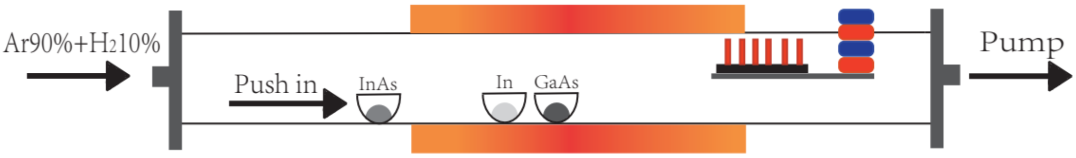

Figure 1: Schematic diagram of the experimental process of growing alloy InGaAs nanowire sample

2.2 Morphology and characterization

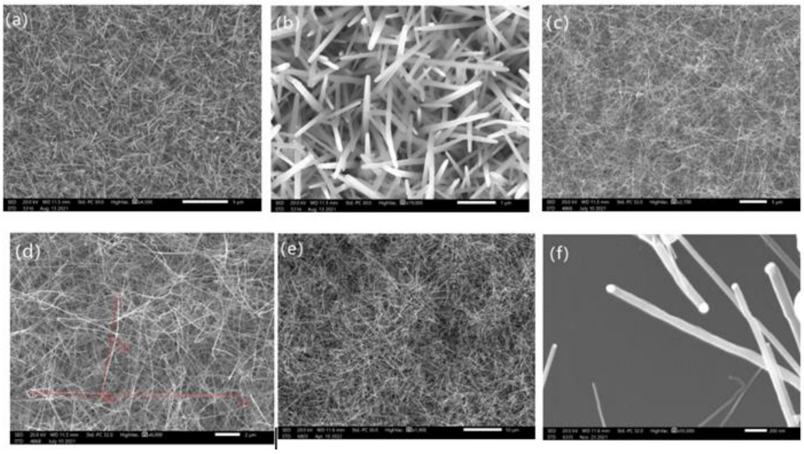

Figure 2: (a) - (b) low and medium magnification SEM images of InAs nanowires respectively; (c) - (d) SEM images of GaAs nanowires magnified 2700 times at 5 μ m scale and 8000 times at 2 μ m scale respectively, and the red line is the length calibration line; (e) - (f) scanning electron microscope morphological images of InGaAs nanowires at low and high magnification were obtained respectively.

The morphology of the samples was characterized by scanning electron microscope (SEM). Fig. 2 (a) and (b) are the low and middle magnification scanning electron microscope (SEM) images of the InAs nanowire samples respectively. It can be seen from the figure that the surface of the InAs nanowires is smooth without other impurities or visible particles. In Figure 2 (b), the nanowires have obvious gold catalyst tips, indicating that the growth of InAs nanowires follows the gas- liquid -solid (VLS) mechanism. Fig. 2 (c) and (d) respectively show the SEM images of the prepared GaAs nanowire samples at 2700 times magnification and 8000 times magnification. It can be seen from the figure that the GaAs nanowires are very dense and the length reaches more than ten microns. Figure 2 (e) and (f) are low and high magnification scanning electron microscope images of InGaAs nanowire samples respectively, which show that the InGaAs nanowires have uniform diameter, smooth surface, and no obvious bending, visible particles and impurities.

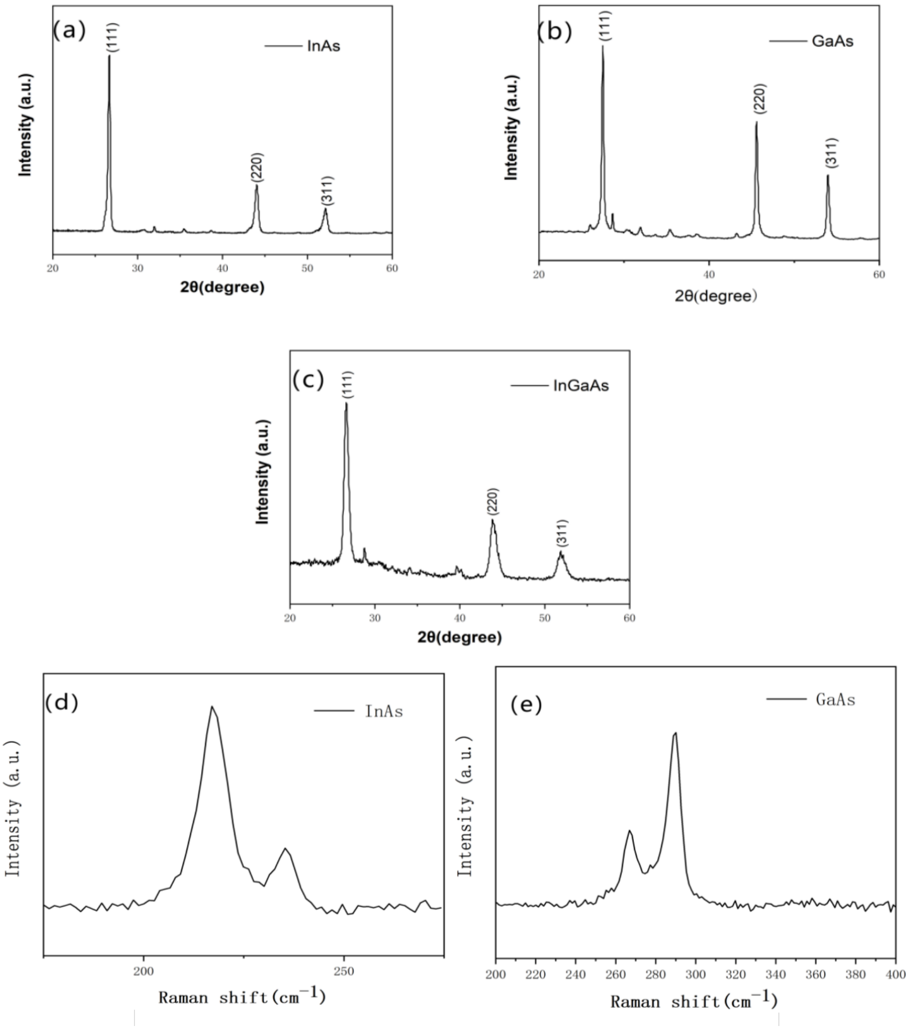

Figure 3: (a) - (c) are the X-ray diffraction images of InAs, GaAs and InGaAs nanowire samples respectively, (d) - (e) are the Raman spectrum images of InAs and GaAs nanowire samples respectively.

Figures 3(a)-(c) are the X-ray diffraction patterns of the InAs, GaAs, and InGaAs nanowire samples, respectively. The test range of the samples is from 20° to 60°. The corresponding angles of the diffraction peaks InAs (111), InAs (220) and InAs (311) of InAs nanowire samples are (26.665°), (44.014°), (52.103°) respectively, and there are no peaks of other oxides. The angles corresponding to the diffraction peaks GaAs (111), GaAs (220) and GaAs (311) of the GaAs nanowire samples are (27.456°), (45.681°), (54.047°), respectively. The diffraction peaks of the InGaAs nanowire samples are located between InAs and GaAs, and the corresponding angles are (26.665°), (43.886°), (51.950°), respectively. The sample values are basically consistent with the literature values. Figures 3(d)-(e) are the confocal laser Raman spectrometer images of the InAs and GaAs nanowire samples, respectively. The laser wavelength used in the measurement is 785nm, and the test range is 100cm^{-1} to 600cm^{-1}. The test results are shown in the figure 3(d) and 3(e). The transverse optical phonon (TO) phonon of InAs nanowire sample is (218cm^{-1}), the longitudinal optical (LO) phonon is (236cm^{-1}), the transverse optical phonon (TO) phonon of GaAs nanowire sample is (268cm^{-1}), the longitudinal optical (LO) phonon is (290cm^{-1}), and the two phonon modes of InGaAs nanowire sample can be clearly seen in (220cm^{-1}) and (243cm^{-1}). The transverse optical phonon modes are InAs-like and GaAs-like respectively. It can be found that the sample values are basically consistent with the literature values by comparing the literature values. Fig. 4 shows the photoluminescence spectrum (PL) detected from the dispersed GaAs nanowire sample. From the PL results, GaAs nanowires show an emission peak at 880 nm and the FWHM is 8.73 nm, which indicates that GaAs nanowires have good luminescence properties[3]-[7].

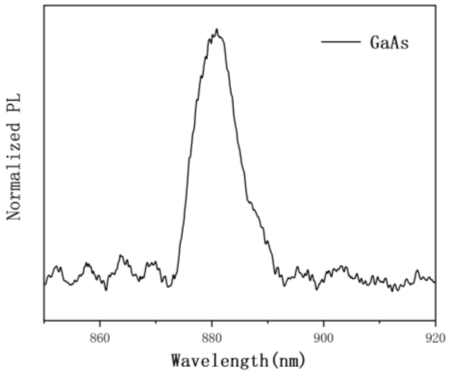

Figure 4: photoluminescence spectra (PL) of GaAs nanowire samples

Fig. 5 (a) shows a schematic diagram of a photodetector and an optical microscope image of a single nanowire. The specific steps of constructing the photodetector are as follows: firstly, the nanowires are dispersed on the p-type silicon substrate coated with 300 nm thick SiO_2 layer, and then two Ni / Au electrodes are evaporated at both ends of the nanowires. After fabrication, the light response characteristics of V_{bia} = -1V to 1V on the double ended structure were measured by illuminating with a 650nm laser with a power intensity of 150mW / cm^2. As shown in Figure 5 (b), the spectral response rate (Rλ)And external quantum efficiency (EQE) are two key parameters of photodetector, which can be obtained by formula Rλ= Iph / PS and EQE = Rhc / eλ (Iph is the difference between photocurrent and dark current, P is the illumination intensity, S is the effective illumination area, h is the Planck constant, c is the speed of light, λ is the wavelength of incident light.) By calculation, it can be concluded that the photodetector has good spectral responsivity and external quantum efficiency. Fig. 5 (c) shows the image obtained by periodically turning on and off the laser at a power intensity of 150mW / cm^2 under a 1V bias. This reflects the ability of the photodetector to respond to rapidly changing optical signals. When the light switch is turned on, the device current rises rapidly, reaching a steady state of about $0.17\mu A$, and when the light switch is turned off, the device current drops rapidly to $0.155\mu A$, indicating that the device has good stability and reversible switching characteristics. Rise time (τ_{Rise}) and fall time (τ_{Fall}) are defined as the time it takes for the current to rise to 90% and fall to 10% of the peak value, which approximately 200ms and 300ms, respectively, according to the magnified curve Figure 5(d).

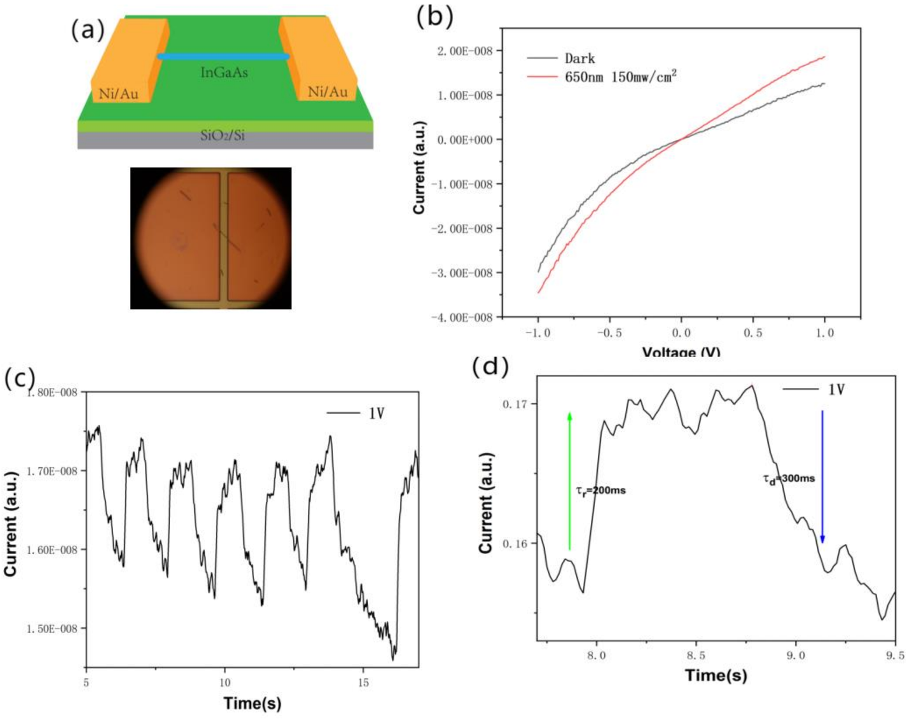

Figure 5:(a)Schematic and Optical microscope image of a nanowire photodetector;(b)I-V curves of the InGaAs nanowire photodetector illuminated with 650nm wavelength lights(150mW/cm^2) or under dark conditions;(c)Time-resolved switching behavior of the device under laser intensity of 150mW/cm^2 at Vbia=1V;(d)Enlarged rise and fall sides over round of 7.7-9.5s

3. Conclusion

To sum up, high crystal quality InAs, GaAs and InGaAs nanowires were grown by chemical vapor deposition by accurately controlling the temperature of raw materials and substrates. The analysis of XRD, SEM, PL, Raman and other test methods shows that the grown nanowires have high crystal quality and good luminescence characteristics. The photoelectric detector has good optical response characteristics. The fabrication of photoelectric integrated devices with nanowires has broad application prospects.

Acknowledgements

This work was supported by the Guangxi Zhuang Autonomous Region-level College Students' Innovation Training Program (No. S202110602297) and Research on Nanowire Multicolor Near Infrared Photodetectors.

This work was supported by the Guangxi Zhuang Autonomous Region-level College Students' Innovation Training Program (No. S202110602307) and Preparation of Gold-Silver Alloy Nanoparticles Based on SERS Effect and Its Application in the Detection of Pesticide Fumei Shuang.

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