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Self-assembled GaN nano-column grown on Si(111) substrate using Au+Ga alloy seeding method by MOCVD

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Abstract

We have studied the characteristics of the Au+Ga alloy seeding method. Single-crystal GaN nano-column arrays were growth using metalorganic chemical vapor deposition (MOCVD) technology by modifying growth parameters and Au thin film thickness. The diameter and length of as-grown nano-column ranged from 100 to 500 nm and 1 to 5 μm, respectively. The morphology of the nano columns was investigated using scanning electron microscopy. Energy dispersive X-ray spectrometer and photoluminescence were used for evaluating of its qualitative analysis and optical property, respectively.

Two important growth parameters were considered, the thickness of Au thin film and gallium flow rate. The density and tendency of the nano-columns depend on each of these growth parameters.

1. Introduction

The fabrication of nano sized Ⅲ-Ⅴ compound semiconductors on si substrates has gained considerable attention because of their potential uses in monolithic optoelectronic integrated circuits (OEIC), LD and LED. GaN material is an interesting material for nano devices on account of its large band gap and high melting point. For optoelectrical applications, while only certain types of carbon nano tubes are semiconducting, single crystal GaN is inherently semiconducting and GaN nano-columns are UV-photoconducting [1]. And GaN is a wide direct-band gap (3.4 eV at room temperature) semiconductor with a wurtzite structure and is a promising material for the fabrication of blue and even UV-emitting optoelectronic devices. GaN nano-columns can improve the performance of blue and UV-emitting optoelectronic devices [2]. The breakthrough technology of GaN nano-structure has been the most effective factor motivating significant research and development on optoelectronic and microelectronic devices utilizing GaN-based group-Ⅲ nitrides.

GaN materials with low-dimensional structures have been fabricated using various methods, such as laser-assisted catalyst, inside carbon nano-tubes, used metal and metal-oxide nano sized particle [1-2]. Nano-column LD for the realistic application could be fabricated OEIC with Si-MOSFET in Si/III-nitrides monolithic on-chip [3].

2. Experimental procedure

GaN nano-columns were grown on Au coated Si(111) substrates by MOCVD using a horizontal quartz reactor. The reactant precursors were TMGa and NH_3. Hydrogen was used as the carrier gas. Prior to nano-column growth, the Si(111) substrate surface was treated by conventional cleaning procedure and a gold thin film by ion coating system. The thickness of the Au thin film was controlled by deposition time. After preparation, the Si(111) substrate was heated to approximately 900 °C under hydrogen ambient for 4 min. The pre-deposition of gallium and nitrogen was performed for 20 sec, to form an Au+Ga and nitrogen solid solution, which acts as the initial nucleation islands. The gallium and nitrogen precursors were then introduced into the reactor to obtain nano-column single crystal on the prepared substrate surface. The growth time for the GaN columns on the Au coated Si(111) substrate was 30 min at 1040 °C with a reactor pressure of 150 torr. Using this process, high-optical quality GaN nano-columns with diameters and lengths ranging from 100~500 nm and 1 to 5 μm were fabricated, respectively.

3. Results and discussion

GaN nano-columns were grown on Au-coated Si(111) substrates by flowing TMGa in a NH_3 and H_2 at about 1040 °C for 30 min. The self-assembled technique approach involves four major steps: (i) Ion coating of the Au thin film on the Si (111) using an ion coating system, (ii) Thickness control of the gold thin film, (iii) the formation of nano sized Au+Ga and nitrogen alloy solid solution on Si(111) substrate surface, and (ⅳ) the growth of the GaN nano-columns. The first step for the growth GaN nano-column is the condensation and adhesion of Au atoms onto the surface of the Si(111) substrate to form a nano sized catalytic islands. The absorption and dissolution of evaporated Ga clusters onto the nano sized catalytic particles to form a supersaturated Au+Ga alloy. Ever since, the accomplishment of reaction between the absorbed or separated Ga clusters and NH_3 molecules on the Si(111) substrate surface of the Au+Ga alloy to grow GaN nano-columns. The dimensions of the nano-columns were controlled by the size of the metallic catalytic islands. Like this, we have considered three important growth parameters, thickness of Au thin film, Gallium flow rate and temperature.

Figure 1 shows SEM micrographs of the GaN nano-columns grown on Au coated Si(111). These grown nano-column diameters were in the range of 100~500 nm and the length ranged from 1 to 5 μm. The nano-columns densely grew on substrate surface and behaved vertical growing tendency, which may be attributed to overcrowding growth conditions. In our previous result, nano-columns were observed with the random direction. But uniform and vertical, smooth nano-columns surface were achieved by changing the MO-source flow rate, temperature and Au thin film thickness. Fig. 2 shows the EDX result of the GaN nano-column. Si signals came from Si substrate. The qualitative analysis show the Ga and N element, which means the GaN had been grown successfully. Fig. 3 shows the PL data of the GaN nano-column. The FWHM at the 365.7 nm band edge emission peak was 65 meV

4. Conclusions

The technology of Au coated Si(111) substrate can be accomplished and compatible with integrated circuits technology, GaN nano-columns can be integrated on silicon substrate for emitter and Photo-detector device applications in same silicon substrate at once. Characterizations had evaluated SEM, EDX and PL. It has been carried out to study the crystal structure and morphology of GaN nano-columns. SEM observations most of the GaN nano-columns have a very fine transverse dimension of about of 100~500 nm. EDX spectrum of GaN nano-columns grown on Au coated Si(111) substrate. We invested PL spectrum was observed for evaluating the optical property of the GaN nano-column. The FWHM of the band edge emission peak was 365.7 nm using 325 nm He-Cd lasers under room temperature with the 65 meV.

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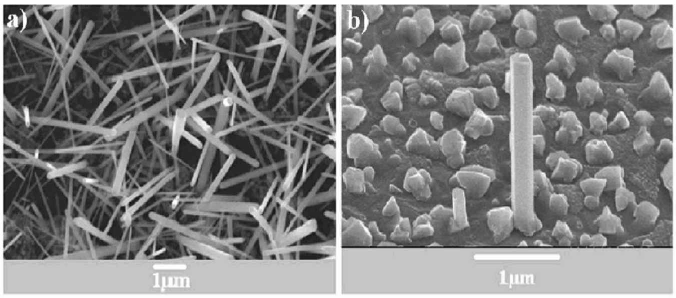

Fig. 1. SEM image of the structures grown on Au coated Si(111) substrate. Figure (a) shows a low magnifying power image, and (b) shows a higher magnifying power image of a GaN nano-column

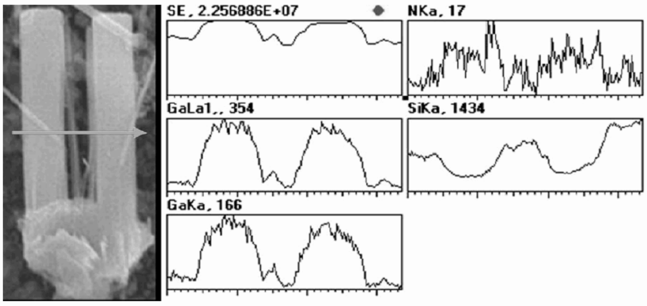

Fig. 2. SEM image and EDX spectrum of the GaN nano-columns grown on a Au coated Si(111) substrate. The Si signals are from the substrate and the other peaks correspond to the chemical composition of the columns by gallium and nitrogen.

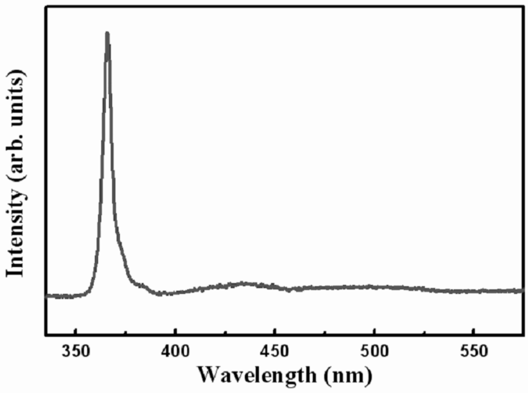

Fig. 3. Typical PL spectrum of the GaN nano-columns at the 365.7 nm band edge emission measured at room temperature with a FWHM of 65 meV.