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Effect of Growth Condition on Well-Arranged InGaN/GaN Nanocolumns Grown by Selective Area Growth (SAG) of rf-Plasma-Assisted Molecular-Beam Epitaxy

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1. Introduction

GaN nanocolumns are self-organized one-dimensional columnar nano-crystals of 20-200 nm diameter, 1 μm height, and ~10^{10} cm^{-2} column density [1]. The nanocolumns, which are expected to possess excellent optical characteristics due to almost dislocation-free property, are grown on sapphire and silicon substrates, by rf-plasma-assisted molecular-beam epitaxy (rf-MBE). InGaN-based nanocolumn light-emitting diodes (LEDs) emitting in the wavelength range from ultraviolet to red were reported [2-4]. However, random and spontaneous self-organization of the nanocolumns generated spatial distribution of the nanocolumn height and size, bringing about variation in thickness and In-composition of InGaN quantum wells. For the development of high performance nano-devices, the size and position control of nanocolumn were essential issues. To meet the situation, recently we have developed the selective area growth (SAG) of GaN nanocolumn by the use of Ti nano-pattern [5].

2. Experiments and Results

In this talk, the effect of the growth parameter on well-arranged InGaN/GaN nanocolumns grown on GaN template by the Ti mask SAG technique of rf-MBE is described. Figure 1 shows schematically the SAG procedure of InGaN/GaN nanocolumns. A Ti film of 5 nm in thickness was evaporated on the GaN surface. Various nano-hole arrays with the nano-hole size of 100 to 550 nm, arranged in triangular or square lattice, were prepared on the same substrate by focus ion beam (FIB). On the patterns, the GaN nanocolumns with 3-period InGaN/GaN multi quantum wells (MQWs) were grown. In the growth, firstly the surface nitridation of the Ti film was performed at 400 °C for 10 min, followed by the growth of GaN nanocolumns on them for 3 hours. In this study, the growth temperature (T_g) and supplied nitrogen flow rate (Q_{N2}) were changed as growth parameters from 880 to 926 °C and from 3.5 to 1.0 sccm, respectively. Figure 2 shows SEM top surface images of the GaN nanocolumns grown at the T_g values of 880 to 926 °C. Note that 900 °C was the critical temperature for the SAG. Below that, no SAG of GaN was observed. At the T_g above 900 °C, the regular arrangement of GaN nanocolumns was obtained, but an excess increase in T_g introduced fluctuation and decrease in column size. At the same time the reduction of Q_{N2} from 3.5 to 1.0 sccm decreased the column size. Thus, the T_g and Q_{N2} are parameters strongly contributed to the SAG of GaN nanocolumns. From the experiment the growth mechanism can be explained in relation to the diffusion and desorption of Ga adatoms, and the dissociation of GaN. The SEM images and the size distribution of the nano-hole and the nanocolumns are shown in Figs. 3 and 4, respectively. The size deviations for the nano-holes and the nanocolumns were 101 nm ± 2.8% and 204 nm ± 2.8%, respectively. The size variation of nanocolumns was determined by that of the underneath nano-holes. PL spectra of well-arranged GaN nanocolumns and an HVPE-grown GaN substrate are shown in Fig.5. The yellow emission was well suppressed for the GaN nanocolumns and the PL peak intensity of GaN nanocolumns was ~10 times as strong as that of the HVPE-GaN.

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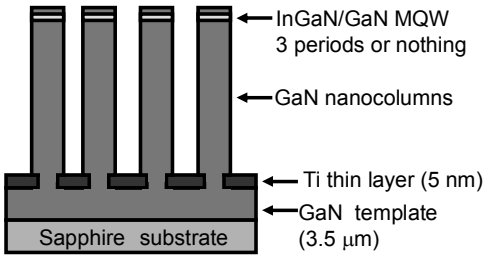

Fig. 1 Schematic diagram of regular arranged nanocolumns

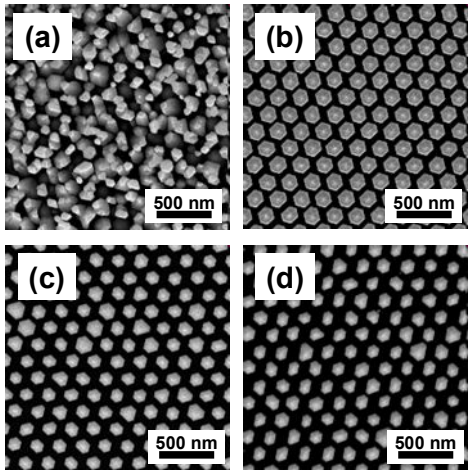

Fig. 2 Growth temperature dependency of the selective area growth of nanocolumns ((a)880°C, (b)900°C, (c)917°C, (d)926 °C)

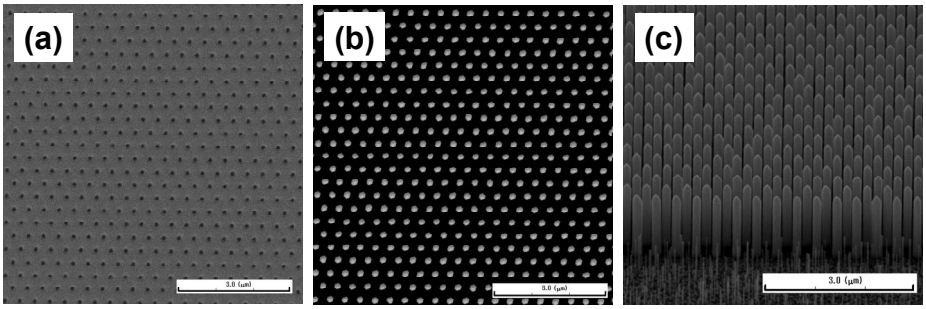

Fig. 4 SEM images of nano-hole and GaN nanocolumn with the supplied nitrogen flow rate of 1.0 sccm ((a)top view of nanohole, (b)top view of nanocolumn, (c)bird's eye view of nanocolumn)

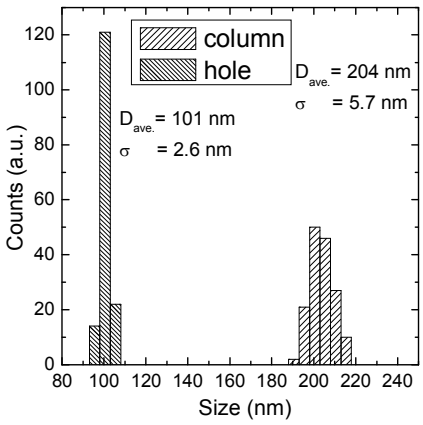

Fig. 5 Size distribution of nano-hole size and nanocolumn size

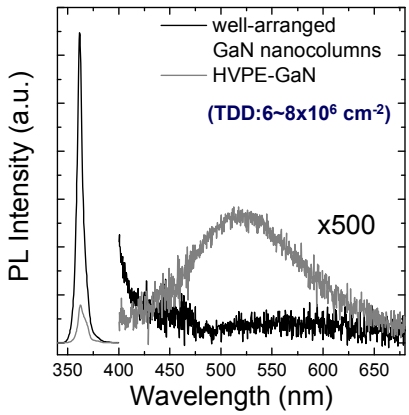

Fig. 6 PL spectra of GaN nanocolumn and HVPE-GaN