High-Density InGaN Quantum Dots Fabricated by Selective MOCVD Growth

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InGaN quantum dots (QDs) have attracted much attention for physical properties as well as device applications [1]. Two growth methods have been reported for fabricating InGaN QDs: self-assembled growth [2-5] and selective growth [6,7]. In selective growth, the QDs have good uniformity, but it is problem how high density of the QDs is realized. In this paper, to realize high-density InGaN QDs with good uniformity, we have fabricated InGaN QD structures on GaN hexagonal pyramids using a substrate patterned by electron-beam lithography with square openings of side length as small as 300 nm. Electron-beam lithography is powerful for the uniform pattern and control of position in nanometer-scale. Uniform hexagonal pyramids were realized even when such a small pattern was formed. As the pattern size was smaller, stronger photoluminescence (PL) was observed at room temperature. This is because higher density of InGaN QDs is realized as the pattern size is smaller.

The samples were grown using an atmospheric-pressure two-flow metalorganic chemical vapor deposition (MOCVD) system with a horizontal quartz reactor. After 25-nm-thick GaN nucleation layer and 2-μm-thick GaN layer were grown on a *c*-face sapphire substrate, 40-nm-thick SiO_2 was deposited by sputtering. We have fabricated three grid-like patterns: (a) with period 4 μm and square openings of side length 2 μm by conventional photolithography, (b) with period 1 μm and square openings of side length 500 nm, and (c) with period 600 nm and square openings of side length 300 nm by electron-beam lithography. Selective growth of GaN was then performed using MOCVD again. Uniform hexagonal pyramids of GaN were realized, as confirmed by scanning electron microscopy (SEM). Selective growth of three periods of InGaN multiple quantum wells (MQWs) followed. The growth times for the InGaN QW and $In_{0.02}Ga_{0.98}N$ barrier materials were such as give 2.4 and 4.1 nm thicknesses, respectively, in planar growth. Then, a 14-nm-thick $In_{0.02}Ga_{0.98}N$ layer was capped. InGaN QD structures are thought to form on the tops of the hexagonal pyramids, as schematically shown in Fig. 1.

Figure 2(a) shows SEM bird's-eye-view of the final structures on a substrate with period 600 nm and square openings of side length 300 nm. As can be seen in Fig. 2(a), uniform hexagonal pyramids are realized even when such a small pattern was formed. Figure 2(b) shows a magnified photograph of a hexagonal pyramid. The hexagonal pyramids have {1-101} side facets. The radius of curvature is no more than 30 nm, as confirmed by cross-sectional SEM images. This indicates that very sharp tops were realized. The lateral size of InGaN QDs is considered to be comparable to the radius of curvature at the tops of hexagonal pyramids.

PL spectra were measured at room temperature. The excitation source was a He-Cd laser giving light with wavelength of 325 nm and excitation power at the sample of 5 W/cm^2. The diameter of the laser spot on the sample was 0.7 mm. Figure 3 shows the PL spectra from these samples, in which the spectra are normalized at the value of GaN emission peak around 363 nm. InGaN PL peak is observed around 420 nm in these spectra. The PL intensity increases drastically as the pattern size is smaller. This means that the number of the excited QDs increases as the pattern size is smaller.

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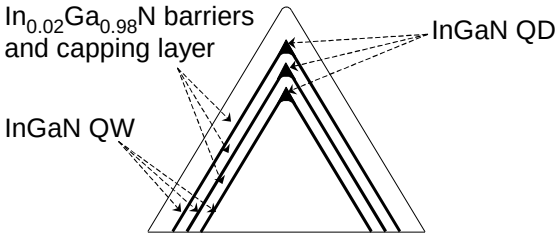


Fig. 1: Schematic of InGaN QD structures on hexagonal pyramids of GaN.

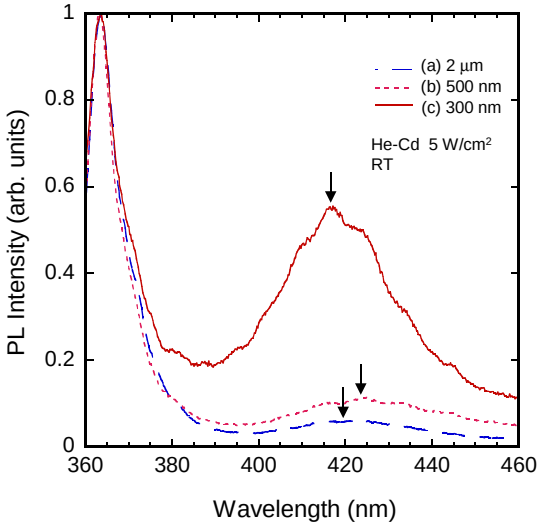
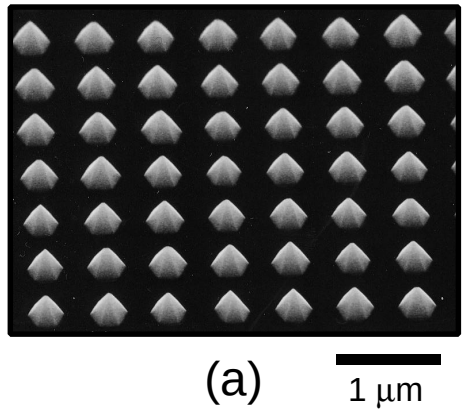


Fig. 3: PL spectra from InGaN QD structures patterned with square openings of side length: (a) 2 μm, (b) 500 nm, and (c) 300 nm. The arrows show InGaN emission peak and the spectra are normalized at the value of GaN emission peak.



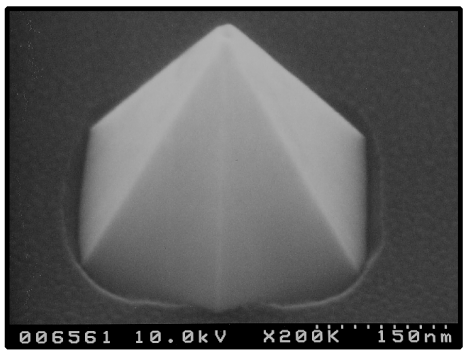


Fig. 2: (a) SEM bird's-eye-view of InGaN QD structures patterned with square openings of side length 300 nm and (b) magnified image of a structure.