Position control of GaN quantum dots by focused electron beam induced droplet epitaxy and fabrication of single electron transistors

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Quantum dot structures of wide band gap GaN and related III-V nitride materials are of great interest in electrical devices since conduction band offset larger than 2 eV at GaN/AlN interface provides strong electron confinement in their quantized levels. Quantum coherent state can be produced by coupled quantum dots of semiconductor. In the several ways to form coupled quantum dots, self-assembling technique is promising because of its simple process and small structural size of the dot less than a few ten nanometers. However, position control of each quantum dot is very important to form the coupled quantum dots. We have developed focused electron beam induced droplet epitaxy and GaN quantum dots were formed using this method, in which Ga droplets were formed at positions defined by thin carbonaceous resist deposited by focused electron beam exposure, and then they were crystallized by nitrogen supply.

After chemical treatments of the epitaxial AlGaN/SiC(0001) substrate, the surface was directly exposed to a focused electron beam with lattice patterns of several ten nanometer. After thermal cleaning at 660°C for 10 min. in the gas source molecular beam epitaxy system, Ga droplets were formed at 300-400°C in the lattice patterns and were annealed at 500-800°C in NH_3 gas environment for nitridation. Crystalline quality of quantum dots was investigated by photoluminescence (PL) using the He-Cd laser for excitation source. The single electron transistor was also fabricated using lift-off process of Au/Al electrodes.

Clear GaN dot array with a period of 100 nm and the average dot diameter of 40 nm was obtained as shown in Fig.1. It was also found that the distance between neighboring dots could be reduced by controlling annealing time as shown Fig.2. The minimum inter-dots distance of 2 nm was obtained. These structures less than 10 nm in the diameter showed quantum size effects in PL spectra at low temperature. So, we can control the position, the size and the distance between the quantum dots by our technique. The single electron transistor using self-assembling GaN quantum dot structure showed clear Coulomb staircase even at 200 K. The electrical transport properties of single electron transistors using position-controlled quantum dots will be also discussed.

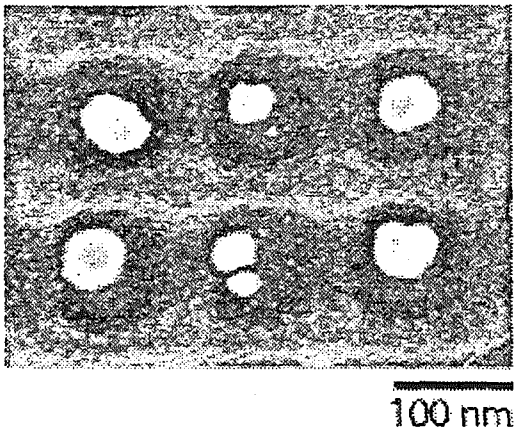

Fig.1 Scanning electron microscope (SEM) image of GaN dot array fabricated by focused electron beam induced droplet epitaxy.

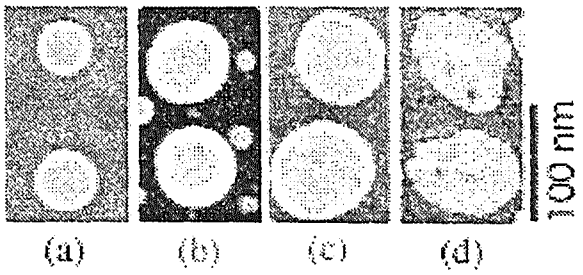

Fig.2 Dependence of inter-dots distance on annealing (nitridation) time of Ga droplets. Each SEM image corresponds to GaN dots formed after annealing of (a) 0 min., (b) 30 min., (c) 60 min, and (d) 120 min., respectively, at 500°C. The inter-dots distance in a pair of dots is clearly reduced by the annealing.