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Single-Electron Transistors with Large-Enegry Binary States in a GaN Quantum Dot

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1. Introduction

Quantum dot structures of wide bandgap III-nitride materials are of great interest in use for coherent quantum devices such as quantum logic gates [1] because the large conduction band offset of 2 eV at the GaN/AlGaN interface [2] provides strong electron confinement in their quantized levels. The energy separation between ground and exited states in the GaN dot of 5 nm in a diameter is as large as 120 meV. When magnetic field is applied to the dots, single-electron spin states confined by Coulomb blockade phenomena are formed. By irradiations of circular-polarized infrared pulses corresponding to the energy separation (10 μm), a spin in the ground state is excited to the upper state with a spin flip according to the selection rule. It can be realized new quantum logic gate in which the light forcibly oscillates the single-electron spin states. So, fabrication of ultra-small quantum dots devices is most important. In this work, single-electron transistors with large-energy binary states in a vertical GaN quantum dot formed by molecular beam epitaxy (MBE) selective area growth method are demonstrated.

2. Experimental

The vertical GaN quantum dot covered with AlN was form by MBE selective area growth method on the SiO_2 masked AlGaN/GaN/sapphire substrate as shown in Fig.1. Detail of the growth mechanism using MBE technique is described in elsewhere. [3] The structural sizes of the dots were in ranges from 50 nm to 100 nm in a diameter. Then, Au/Al electrodes were formed by lift-off process to form single electron transistors. The electron transport properties were measured at more than liquid-Helium temperature.

3. Results and discussion

Figure 2 shows a charge stability diagram of a vertical GaN quantum dot transistor measured at 6 K. The height and the diameter of the GaN dot were 5 nm and 100 nm, and the thickness of AlN barriers was 1nm each. The diagram periodically exhibits diamond-shapes at near zero source-drain voltages regions. The charging energy of 6 mV corresponds to self-capacitance of 13 aF. Figure 3 shows an I-V characteristics of another device of which dot diameter was 50 nm measured at 23.5 K. Large Coulomb blockade reagion as about 0.5eV can be observed. In addition, step structures of 200 meV periods can be observed. It is found that these structures arise from single electron transport in zero-dimensional (0D) states in the GaN quantum dots, comparing the energies of Coulomb gap and step periods. The energy of 0D binary states corresponds to the energy of infrared laser of which wavelength is 6.2 micron.

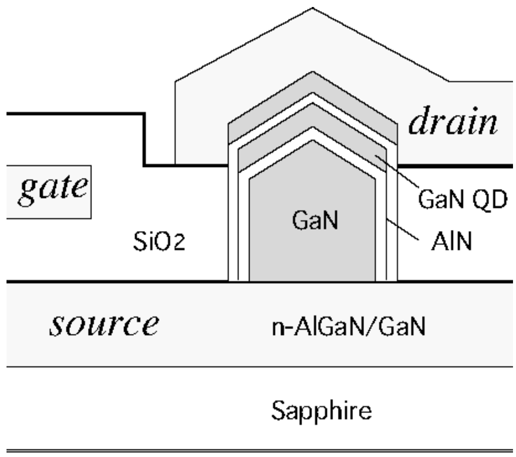

Fig.1 A typical device structure fabricated by MBE selective growth method and lift-off process.

4. Conclusions

Single-electron transistors with large–energy binary states in a GaN quantum dots were fabricated. The energy of binary states corresponds to 6.2 micron in wavelength. It is promising to fabricate quantum bits with nitride materials using infrared light source.

References

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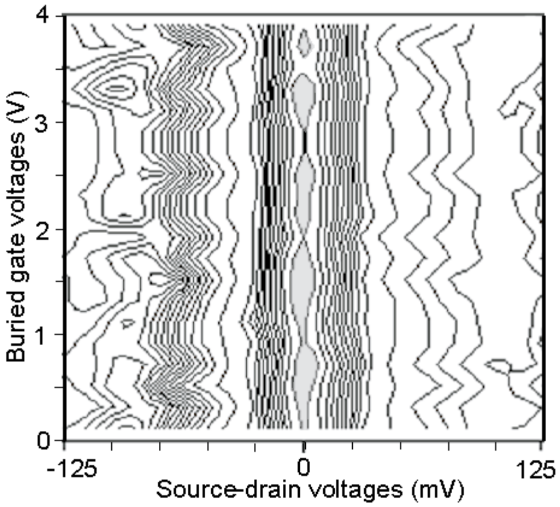

Fig.2 A charge stability diagram of a vertical GaN quantum dot transistor measured at 6 K. The height and the diameter of the GaN dot were 5 nm and 100 nm.

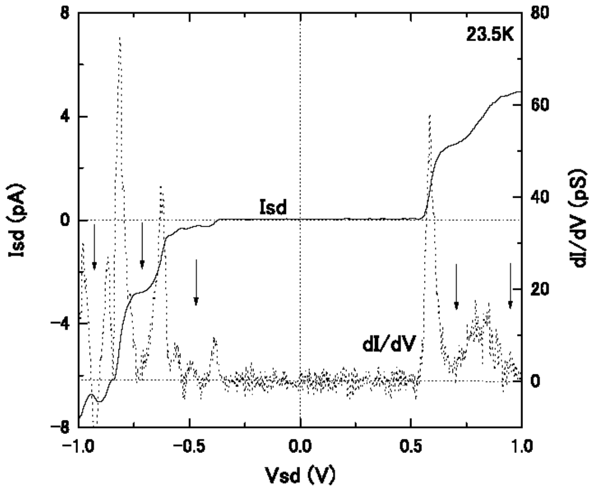

Fig.3 I-V characteristics of a vertical GaN quantum dot transistor measured at 23.5 K. The diameter of the dot was 50 nm.