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論文内容要旨

報告番号	甲　先　第　228　号	氏　名	江　瀅
学位論文題目	Development of device isolation technologies for GaN-based field-effect transistors （窒化ガリウムトランジスタにおける素子間分離技術の研究）		

内容要旨

Gallium nitride (GaN) semiconductor has the great advantage in the application of high-temperature and high-frequency power electronic devices owing to its unique properties, such as wide band-gap, high electron saturation velocity, high breakdown field and high electron conductivity of the two-dimensional electron gas (2DEG) in AlGaN/GaN heterostructure. AlGaN/GaN heterojunction field-effect transistor (HFET) and GaN metal-oxide-semiconductor field-effect transistor (MOSFET) are the classic devices of GaN-based field-effect transistors (FETs), which can be applied to microwave amplifying devices for wireless communication, military radar and power conversion devices for motor inverter. In practical device fabrication, mesa structure is widely adopted for device isolation through dry etching in AlGaN/GaN HFET and GaN MOSFET. However, dry etching damages causes high surface leakage current and off-state power loss, which restrains the inherent device performance. A parasitic MOSFET also exists in the mesa-isolated region of a bar-type GaN MOSFET. In addition, field isolation is necessary for development of GaN MOSFET power integrated circuits. Hence, device isolation is one of key technologies for GaN-based FETs.

In this thesis, the basic fabrication processes, test methods and evaluation technology of AlGaN/GaN HFET and GaN MOSFET were introduced, especially evaluation on isolation effectiveness using transmission line model (TLM) and MOSFET structures; the effective O_2 plasma treatment condition was established, the defect levels and chemical properties of the treated GaN surface were characterized through photoluminescence (PL) spectrum and X-ray photoelectron spectroscopy (XPS), and AlGaN/GaN HFETs were fabricated with O_2 plasma treatment and characterized; the parasitic MOS-channel in the isolation region of GaN MOSFET was eliminated through boron ion implantation, and the field isolation for GaN MOSFET was successfully achieved by improving the processes of annealing and boron ion implantation. The contents and conclusions of this thesis are as follows:

In chapter 2, the basic fabrication processes, test methods and evaluation technology for AlGaN/GaN HFET and GaN MOSFETs were described in details. The basic fabrication processes included cleaning, mesa etching, ohmic contact, gate contact, recess etching (for GaN MOSFET), and gate oxide deposition (for GaN MOSFET). The current-voltage (I-V) and capacitance-voltage (C-V)

measurements were conducted for AlGaN/GaN HFET and GaN MOSFETs and the TLM and MOSFET structures were used to evaluate the isolation effectiveness. In the TLM structure, the region between every two ohmic electrodes is formed by different isolation methods, and *I-V* test and sheet resistance under different temperature was measured. Ring-type and bar-type GaN MOSFETs were fabricated to examine the existence of a parasitic MOSFET-like device and evaluate the effectiveness of the isolation process, *I-V* and *C-V* characteristics were measured and the field-effect electron mobility was calculated by a method of gate capacitance-transconductance.

In chapter 3, the influence of O_2 plasma treatment on the mesa-isolated region of AlGaN/GaN HFETs was studied. The condition of O_2 plasma treatment at 300 °C for 15 min at 250 W was established by *I-V* characteristics, and the *I-V* results indicated that isolation current were strongly dependent on treatment temperature. The defect levels and chemical properties of the treated GaN surface were characterized through PL spectrum and XPS. The PL spectrum showed a decrease in the density of defects related to the yellow luminescence band and the occurrence of defects related to the blue luminescence band. XPS results showed that O_2 plasma treatment can form high amounts of Ga_2O_3 than O_2 gas treatment, and the defect of substitutional oxygen on the nitrogen site ON was also probably formed. AlGaN/GaN HFETs were fabricated with O_2 plasma treatment and characterized. The AlGaN/GaN HFETs with an on/off drain current ratio of 1.73×10^{7} was obtained and the breakdown voltage of the mesa-isolated region increased from 171.5 to 467.2 V. O_2 plasma treatment can be regarded as an effective method for improving device isolation.

In chapter 4, GaN MOSFETs using boron ion implantation as field isolation process were fabricated and the effectiveness of boron field implantation was evaluated. The implantation profile of boron ions and the sheet resistance of implanted region were described. The ring-type MOSFET fabricated on the ion-implanted region showed a drain current of 2×10^{-4} mA/mm and 6×10^{-8} mA/mm before and after adjusting the process sequence of annealing and boron field implantation, demonstrating that boron field implantation could prevent the formation of parasitic MOSFET in the isolation region. By adjusting the process sequence, the high-temperature annealing process was avoided and the implanted region presented high resistivity. The *I-V* characteristics indicated that the off-state drain current of the bar-type MOSFET with boron field implantation isolation was reduced to 6×10^{-7} mA/mm, which was only one order of magnitude higher than the 7×10^{-8} mA/mm of the ring-type MOSFET. The field isolation for GaN MOSFETs was successfully achieved by boron field implantation.

Keywords: Gallium nitride, device isolation, field isolation, AlGaN/GaN HFET, GaN MOSFET

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論文審査の結果の要旨

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学位論文題目

Development of device isolation technologies for GaN-based field-effect transistors (窒化ガリウムトランジスタにおける素子間分離技術の研究)

審査結果の要旨

本研究は窒化ガリウムトランジスタにおいて、AlGaN/GaN HFETの素子間分離技術とGaN MOSFETのフィールドアイソレーション技術の研究を目的にした。

まず、AlGaN/GaN HFET及びGaN MOSFETにおけるデバイス設計、基本試作プロセス、評価方法を述べた。特に、寄生MOSFETや素子間分離効果を評価するため、リングタイプとバータイプGaN MOSFETを設計した。次に、素子間分離リーク電流を減らすため、AlGaN/GaN HFETの素子間分離領域に酸素プラズマ処理効果を調べ,最適化した処理条件を得た。PLやXPSの方法を用い、処理した表面の欠陥のエネルギーレベル、化学性質を評価した。この素子間分離技術を用い、AlGaN/GaN HFETを試作し、評価した。ドレイン電流のON/OFF比が1.73・107になり、素子間分離領域の耐圧は171.5 Vから467.2 Vになったことが得られ、酸素プラズマ処理は有効な素子間分離方法であることが判った。さらに、フィールドアイソレーション方法として、GaN MOSFETにおけるホウ素イオン注入を行い、その効果を調べた。プロセス順序を調整することにより、イオン注入領域に形成したリングタイプMOSFET において、ドレインOFF電流は2・10-4 mA/mmから6・10-8 mA/mmに減少したことが判った。バータイプGaN MOSFET においてもイオン注入により、OFF状態ドレイン電流は6・10-7 mA/mm になったことを示し、リングタイプMOSFET と近い値が得られた。ホウ素イオン注入はフィールドアイソレーション方法として有効であることを証明した。

以上本研究は，窒化ガリウムトランジスタにおける素子間分離技術に関する研究であり，本論文は博士（工学）の学位授与に値するものと判定する。