논문 2009-46IE-3-1

RuO_2/n-GaN 구조의 Schottky Diode 특성

(Characteristics of RuO_2/n-GaN Schottky Diode)

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요 약

고전력, 고온에서 사용되는 소자에서 RuO2는 다른 전극 물질에 비해 많은 장점을 가지고 있으며, 특히 GaN를 이용하는 소자의 전극물질로서 매우 우수한 특성을 갖음을 확인할 수 있었다. RuO2을 이용한 GaN 소자의 제작은 새로운 전기화학 금속증착법을 통하여 금속배선을 형성하였으며, 과염소산(HClO4)용액을 수용액 사용하였다. RuO2의 두께는 인가전압과 시간에 의존하며, 두께를 조절함으로서 정류성 및 비정류성 소자의 전극으로의 사용 가능성을 확인할 수 있었다.

Abstract

In this paper, we study the electrical characteristics of RuO_2/n-GaN Schottky diodes fabricated by using electrochemical metallization. The solution for GaN Schottky electrodes of RuO_2 is perchloric acid($HClO_4$). Thickness of RuO_2 layer depend on supplied voltage and dipping time. We verified the possibility of the rectifying and non-rectifying devices' electrode which was depend on the thickness of RuO_2 layer.

Keywords : RuO_2, electrochmical metallization, n-GaN, Schottky diode.

Ⅰ. INTRODUCTION

GaN-based devices attract much interest for high power and high temperature electronic device applications. GaN has a high breakdown field(>5×10^6V/cm)[1], good thermochemical stability, high electron saturation drift velocity(2.7×10^7cm/s)[2], mobility(>900cm^2/Vs), and strong Ga-N bonding energy (8.92 eV/atom). Research on GaN devices focuses on field effect transistors (FET's)[3] including metal-oxide-semiconductor FET's (MOS-FET's), modulation-doped FET's (MODFET's), AlGaN heterojunction bipolar transistors (HBT's), GaN rectifiers and junction field effect transistors (JFET's). One of the electronic devices of interest for these applications is the AlGaN/GaN high electron mobility transistor (HEMT). Schottky junctions are required for field effect transistors and diodes. However, fabrication of the junction devices is limited by deep levels existing within the band gap of GaN. These recombination-generation centers reduce speed, gain, and efficiency of devices.

There are several methods and metals for formation of Schottky contact on n-type GaN. RuO_2 has been extensively investigated as an electrode for feroelectric random access memories. This metal is also a stable Schottky contact material for GaN-based devices. RuO_2 has a high metallic conductivity, good diffusion barrier property, good chemical stability[4], with a melting point of 2310℃ and binding energy of 280.3eV[5]. Its resistivity is approximately 35μΩ cm in bulk single crystal[6]. RuO_2

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접수일자: 2009년6월1일, 수정완료일: 2009년9월9일

with good surface morphology and crystallity was obtained[ty4y6]. Usually RuO_2 was deposited by sputtering and MOCVD[ty4]. As es approxemical[7] processing and adjustment of oxygen composition is easier than using other systems, in this paper we study es approxemical deposition of RuO_2 for n-type GaN Schottky junction[8~10]. The RuO_2 film was analysed by using x-ray diffractometer (XRD), scanning electron microscope (SEM) and energy dispersive x-ray spectroscopy (EDX). The electrical property of the devices was studied by I-V measurement[11].

Ⅱ. EXPERIMENTAL

The GaN films were grown by rf-plasma molecular beam epitaxy on sapphire (0001). This sapphire surface was transformed to AlN buffer layer by exposure of molecular nitrogen. GaN layer of 4㎛ thick was grown at a rate of 1㎛/h on AlN buffer layer. The carrier concentration of the GaN epitaxial layer is $1.2\times1017\mathrm{cm}^{-3}$, and the mobility is $47\mathrm{cm}^{-2}/\mathrm{Vs}$. The GaN layers were cleaned with trichloroethylene, acetone, methanol, and deionized water, and then deoxidized by HCl:D.I (1:1). Photolithography process was done before the metallization. Ohmic contacts were made with the multilayers of Ti/Al/Ti/Au(100Å/200Å/100Å/300Å) deposited on GaN surface using a thermal evaporator. Then these samples were processed by rapid thermal annealing at 800℃ for 1min under N_2 to increase the adhesion of the multilayers of Ti/Al/Ti/Au(100Å/200Å/100Å/300Å) and GaN and protect Ohmic electrodes from the electrochemical solution, perchloric acid ($HClO_4$). For Schottky contacts, electrochemical dipping was conducted in a solution prepared by dissolving $RuCl_3$ powder in $HClO_4$ liquid for various dipping time and under different bias voltage. A Pt mesh was used as the system cathode. Then the 500㎛ diameter Ni/Au(300Å/400Å) multilayers were deposited on RuO_2 surface by thermal evaporation.

Chemical reactions responsible for the electrochemical deposition are expressed as

$$\mathrm{RuCl_3(s) + HClO_4(l) + e- \rightarrow Ru3+(aq) + 3Cl^-(aq)} \quad (1)$$

$$\mathrm{Ru^{3+}(aq) + 2H_2O(l) \rightarrow RuO_2(s) + e^- + 4H^+} \quad (2)$$

$$\mathrm{3Cl^-(aq) \rightarrow Cl_3(s) + 3e^-} \quad (3)$$

Where $HClO_4$ in formula (1) works as solvent.

Ⅲ. RESULTS & DISCUSSIONS

Figure 1 shows the surface morphologies measured by scanning electron microscope (SEM) of the RuO_2 films deposited on GaN epitaxial layer. Desired morphology can be obtained by optimization of the dipping time and bias voltage. For example, when the bias voltage is 3.6V and dipping time is 20min, the RuO_2 film surfaces were smooth, uniform, and mirror-like. This can be seen by comparing Fig. 1(b) with Fig. 1(a) and (c). Fig. 2 shows the resistivity of RuO_2 from the four-point probe plotted against the annealing temperature in N_2 ambient after deposition at a bias 3.6V for 20 min. The RuO_2 resistivity decreases with increasing R.T.A temperature, possibly due to the reduction of lattice mismatch and full-width at half maximum (FWHM) by XRD[4].

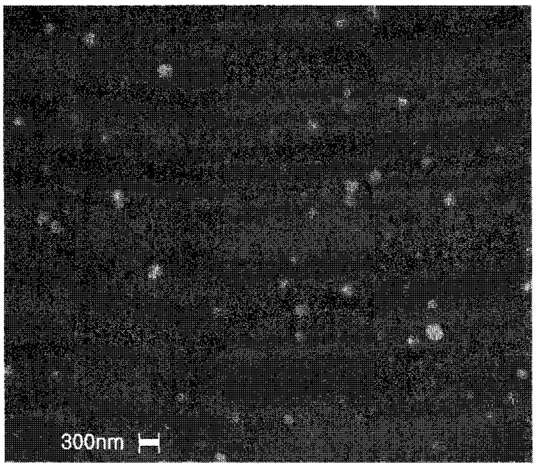

그림 1. (a) $RuCl_3$+$HClO_4$에 3.4V, 20분간 dipping 한 후 형성된 RuO_2 표면 영상

Fig. 1. (a) Surface morphology of RuO_2 formed by dipping GaN in $RuCl_3$+$HClO_4$ at a bias 3.4V for 20min.

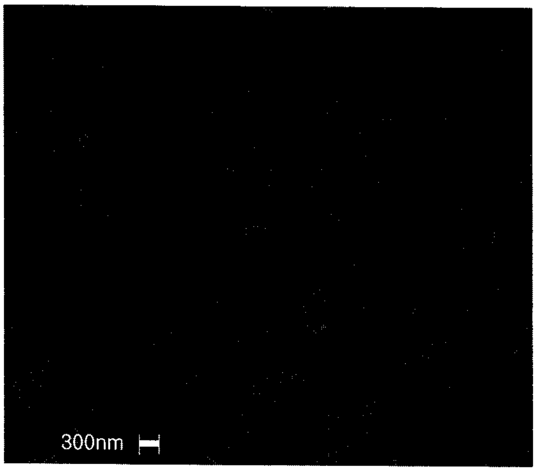

그림 1. (b) $RuCl_3+HClO_4$에 3.6V, 20분간 dipping 한 후 형성된 RuO_2 표면 영상

Fig. 1. (b) Typical surface morphology of RuO_2 formed by dipping GaN in $RuCl_3+HClO_4$ at a bias 3.6V for 20min.

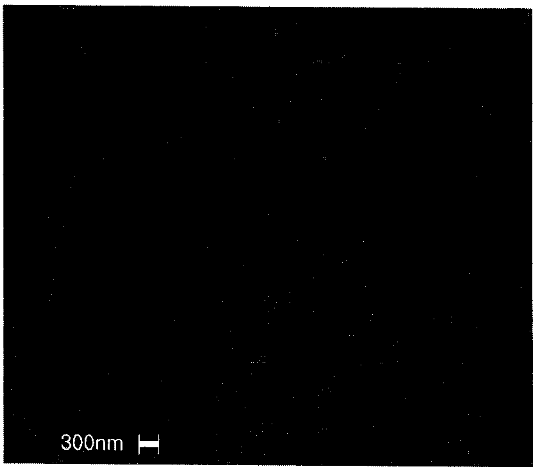

그림 1. (c) $RuCl_3+HClO_4$에 4.0V, 20분간 dipping 한 후 형성된 RuO_2 표면

Fig. 1. (c) Typical surface morphology of RuO_2 formed by dipping GaN in $RuCl_3+HClO_4$ at a bias 4.0V for 20min.

Approaching approximately 185μΩ cm at 750℃. In contrary, the lattice mismatch and porous increasing at 800℃ cause the increasing of RuO_2 resistivity.

The crystal structure of RuO_2 layer deposited on GaN was measured by x-ray diffractometer (XRD) and is shown in Fig. 3. It can be observed that only the RuO_2 (101) and (202) XRD peaks are present along with the GaN (002) and (004) peaks of the GaN epitaxial layers. Those peaks are close to GaN(002) and (004), suggesting preferential crystallization of RuO_2 along GaN (002) and (004) orientation. Peaks of RuO_2 (101) and (202) are narrow at Fig. 3 (c) compare with Fig. 3 (a) and (b). It shows that RuO_2 at Fig. 3 (c) is better crystallized than Fig. 3 (a) and (b).

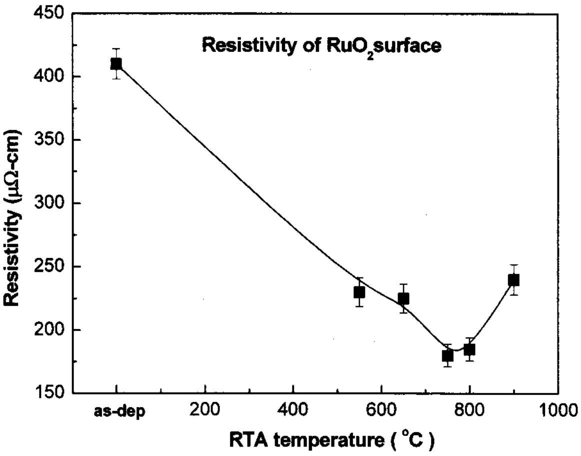

그림 2. R.T.A 온도에 따른 RuO_2 표면 저항(3.6V, 20분)

Fig. 2. Resistivity of RuO_2 surface depends on R.T.A temperature deposited at a bias 3.6V for 20min.

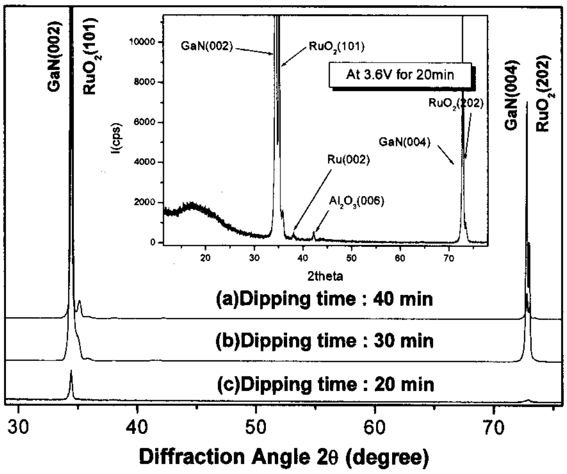

그림 3. $RuCl_3+HClO_4$에 3.6V, 20분간 dipping 한 후의 RuO_2/GaN X-ray 회절 스펙트럼

Fig. 3. X-ray diffraction spectra of RuO_2/GaN after dipping in $RuCl_3+HClO_4$ at a bias 3.6V for 20min.

The resistivity of the RuO_2 layers with different composition ratio of ruthenium and oxygen is shown in Fig. 4. The inset shows typical EDX spectrum of the RuO_2 layer. The variation of ratio of Ru and O depend on dipping time and the resistivity of RuO_2 surface depend on ratio of Ru and O. The resistivity decreased with increasing oxygen concentration. This

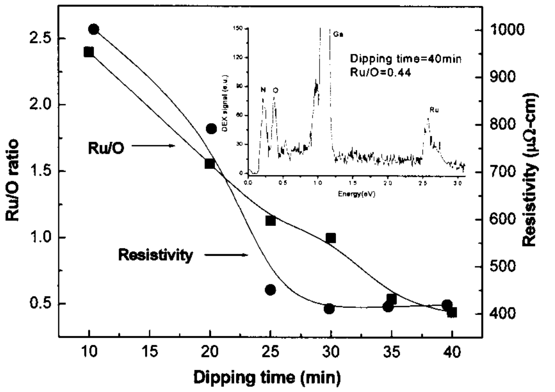

그림 4. Dipping 시간에 따른 Ru/O 비율 과 저항 변화
Fig. 4. Variation of ratio (Ru/O) and resistivity depend on dipping time.

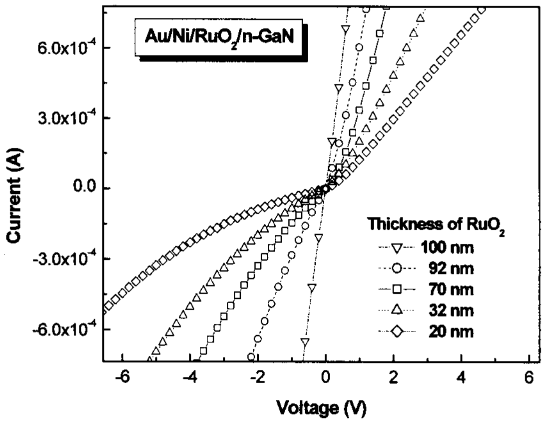

그림 5. RuO_2의 두께변화에 따른 n-GaN Schottky 장벽 다이오드의 I-V 특성
Fig. 5. Current-voltage (I-V) characteristics of n-GaN Schottky barrier diode with different thickness of RuO_2.

is due to reduced uniformity of RuO_2 Oxygen concentration increasing with dipping time may be attributed to oxygen diffusing into the RuO_2 layer. When dipping time is 30min, a low resistivity of RuO_2 surface is about 400μΩ cm at as-dep from Fig. 4.

Figure 5 shows the current-voltage (I-V) characteristics of the n-GaN Schottky barrier diodes. The I-V characteristics depend on thickness of RuO_2 layer. RuO_2/GaN structures with thinner RuO_2 layers show Schottky-like rectifying characteristic. In contrary, metallic diodes with a thicker RuO_2 layer have Ohmic-like characteristics. The electrochemical metallization improve the contact resistance of n-GaN Schottky diodes according to thickness of RuO_2 layer. From Fig. 5, we see resistances of Schottky diodes are high in our samples, because of high dislocation density due to lattice mismatch, and low carrier mobility.

Ⅳ. CONCLUSIONS

RuO_2 have high thermal stability for high power devices, and good electrical characteristics on based GaN. To research GaN devices using promising RuO_2 material, n-GaN-based Schottky barrier diodes were fabricated using a new method of RuO_2 electrochemical metallization. The uniformity of RuO_2 layers depend on oxygen concentration, and resistivity of RuO_2 layers is lowest for 30min dipping time and annealing at 750℃ R.T.A temperatetho (about 185μΩ cm). This new method improved the electrical characteristics of n-GaN Schottky diodes, despite the high dislocation density and relative low carrier mobillity. Wnd annescation density and relative lowmethod, it is possibti to improoan mobilmposition of mobbarrier material.y ur result.T.A ted possibility for fabrication of GaN-based devices using RuO_2.

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