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Ohmic Contact Property of Ti/Al/Ni/Au on AlGaN/GaN Heterostructures for Application in Ultraviolet Detectors*

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Abstract: Ohmic contacts of Ti/Al/Ni/Au multi-layer metal on $Al_{0.27}Ga_{0.73}N$/GaN heterostructures were fabricated. Specific contact resistivities were measured by the linear transmission line method (LTLM) and the circular transmission line method (CTLM), respectively. A minimum specific contact resistivity of $1.46\times10^{-5}\Omega\cdot cm^2$ was obtained by evaporating a Ti(10nm)/Al(100nm)/Ni(40nm)/Au(100nm) multi-layer and annealing for 30s at 650℃ in ultra-high purity N_2 ambient. $Al_{0.27}Ga_{0.73}N$/GaN photoconductor ultraviolet (UV) photodetectors were prepared. The dark current-voltage (*I-V*) characteristics of the detectors were measured and the result shows that the *I-V* curve was linear. Experimental results indicate that good ohmic contact on the $Al_{0.27}Ga_{0.73}N$/GaN heterostructure is obtained and it can be applied in high-performance AlGaN/GaN UV photodetector fabrications.

Key words: AlGaN/GaN; ohmic contact; specific contact resistivity; transmission line method; Ti/Al/Ni/Au; ultraviolet detectors
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1　Introduction

As a wide direct bandgap semiconductor material, gallium nitride (GaN) has the advantages of a large bandgap, high breakdown field, high saturation velocity, and high heat conductivity. It is a promising material for high temperature and microwave high power devices[1~3]. Due to its wide direct bandgap, GaN is especially suitable for the fabrication of semiconductor UV photodetectors. The detectors based on it have high-absorption coefficients and are insensitive to visible background light and infrared radiation, which is important to detect UV in an infrared and visible background. The tailorable bandgap of AlGaN from 3.4eV (GaN) to 6.2eV (AlN) by the proper choice of the Al mole fraction enables a wide range (200～365nm) of UV photodetector applications[4,5], and the ternary alloys make it feasible to select the cut-off wavelength by changing the mole fractions[6]. During the last decade, GaN alloys have been shown to be excellent materials for the development of optoelectronic devices working in the UV range[7,8].

In the field of photodetector technology, AlGaN/GaN structures are of particular interest for fabrication of solar blind detectors operating in the UV spectrum[9]. AlGaN/GaN structures are also attracting attention as heterostructure field effect transistors (HFETs)[2,10~13] and heterostructure high electron mobility transistors (HEMTs)[14,15]. As an essential process for these AlGaN/GaN heterostructure devices, ohmic contacts determine many major parameters of the devices. So research into the AlGaN/GaN ohmic contact is of great importance to improve these devices' performance.

In order to achieve the AlGaN solar-blind UV detectors, the aluminum fraction needs to be improved. It was found that contact resistivity increased with Al fraction in the AlGaN layer[2]. For AlGaN with a high Al fraction, there are few reports on its contact resistivities. In this paper, ohmic contacts of Ti/Al/Ni/Au multi-layer metal on $Al_{0.27}Ga_{0.73}N$/GaN heterostructures are fabricated. Specific contact resistances are measured by LTLM and CTLM, respectively. $Al_{0.27}Ga_{0.73}N$/GaN photoconductor UV photodetectors are prepared and the *I-V* characteristics of the photodetectors without illumination are measured.

2　Experiment

The AlGaN/GaN heterostructure material was grown on one side polished (0001) sapphire substrates by the metal-organic chemical vapor deposition (MOCVD) technique. The epitaxial structure consists of the following layers: an 8nm-thick AlN nucleation

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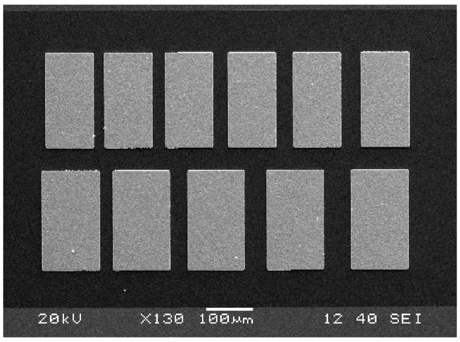

Fig.1 SEM photograph of TLM test pattern

layer, a 1μm-thick unintentionally doped GaN layer, and a 20nm-thick n-$Al_{0.27}Ga_{0.73}N$ ($1.0\times10^{18}\sim2.0\times10^{18}cm^{-3}$) layer for ohmic contact.

The wafer was sequentially ultrasonically cleaned in trichloroethane, acetone, ethanol, and soaked in a solution of HCl : H_2O = 1 : 1 for 2~3min to remove sample surface impurities. It was rinsed in high-grade deionized water several times and blow-dried immediately using dry N_2 to remove native oxides. Prior to the fabrication of the LTLM patterns, Si_3N_4 (100nm) was deposited on the surface of water by using electron beam evaporation, and the structures were patterned by mesa isolation using dry etching. LTLM and CTLM patterns were defined by standard photolithography. A layer structure consisting of Ti (10nm)/Al(100nm)/Ni(40nm)/Au(100nm) was deposited on the AlGaN/GaN by electron beam evaporation. After the deposition, the photoresist was lifted off. Samples were then rapid annealed at 650℃ for 30s in a high-purity N_2 ambient. A Si_3N_4 (250nm) passivation layer was deposited on the surface of the wafer using electron beam evaporation.

The surface morphology of the contacts metal was observed by SEM after the sample had been prepared. Figure 1 shows the SEM photograph of the LTLM test patterns. There are two types of pads in the TLM. The size of the first kinds of pads was 100μm×200μm and the spacing between the pads was 25, 30, 35, 40, and 45μm, respectively. The size of the second kind of pads was 120μm×210μm and the spacing between the pads was 30, 40, 50, and 60μm, respectively. It was found that the surface morphology of the contact metal is good. The SEM photograph of the CTLM test patterns is shown in Fig. 2. The radius of the inner circle is 50μm and the spacing between the inner and the outer contacts was 10, 20, 30, 40, and 50μm, respectively. AlGaN/GaN photoconductors UV detectors was also prepared on the same wafer. Figure 3 shows the SEM photograph of the photoconductors UV photodetector. The finger width of the interdigital metal electrode is 8μm and the finger spacing is 10μm.

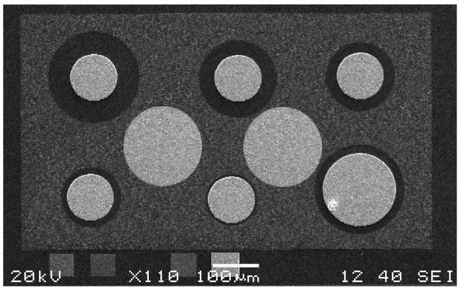

Fig.2 SEM photograph of CTLM test pattern

3 Results and discussion

The preparation of the LTLM test pattern is complex because a surface etching is required, but that of the CTLM pattern is simple. In order to precisely study the ohmic contacts, LTLM and CTLM test structures were fabricated.

The specific contact resistivities were derived from the LTLM and CTLM test structure, respectively. For the LTLM test structure, by assuming that the length of each contact is long enough, the total resistance between each contact R_T and the specific contact resistances ρ_c can be given as

$$R_T = 2R_c + \frac{R_{sh}d}{W} \tag{1}$$

$$\rho_c = \frac{(R_c W)^2}{R_{sh}} \tag{2}$$

where W is the width of the contacts, d is the spacing between pads, R_{sh} is the sheet resistance, and $2R_c$ is the y-interception of the fitting linear curve.

Figure 4 shows the variations of the total resistance R_T between adjacent LTLM pads as a function of the spacing d between the pads. The values of R_c, R_{sh} can be obtained by fitting this curve by means of Eq. (1). As seen in Fig. 4 (a), for devices, $2R_c$ = 17.9Ω, R_{sh} = 1212Ω/□, the value of the specific contact resistivity of Ti/Al/Ni/Au on AlGaN/GaN heterostructure is about $2.64\times10^{-5}\Omega\cdot cm^2$. For Fig. 4 (b), $2R_c$ = 17.4Ω, R_{sh} = 1035.3Ω/□, the value of specific contact resistivity ρ_c is about $3.22\times10^{-5}\Omega\cdot cm^2$.

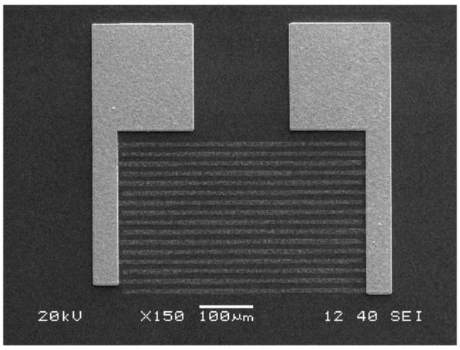

Fig.3 SEM photograph of the photoconductors UV photodetector

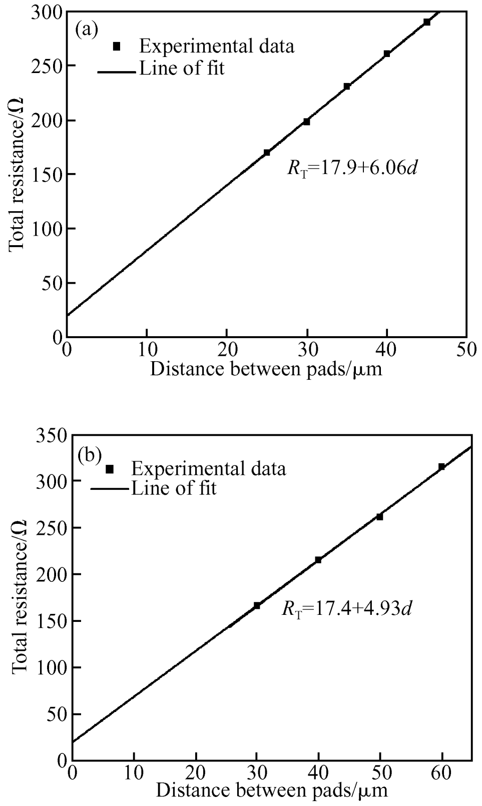

Fig. 4　Relationship between the resistance and the spacing between the pads　(a) $W = 200\mu m$, $d = 25, 30, 35, 40$ and $45\mu m$, respectively; (b) $W = 210\mu m$, $d = 30, 40, 50$ and $60\mu m$, respectively

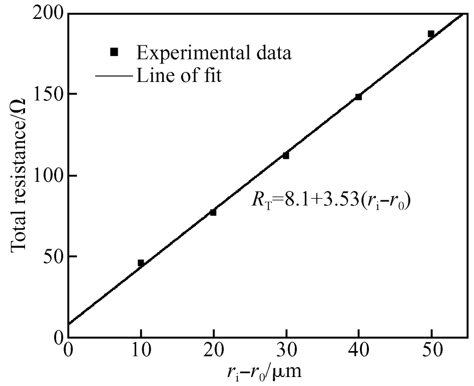

Fig. 5　Relationship between resistance and the spacing between the inner and the outer pads ($r_0 = 50\mu m$, $r_i - r_0 = 10, 20, 30, 40$ and $50\mu m$, respectively)

For the CTLM test structure, the total resistance between the internal and the external contacts can be approximated by

$$R_T = \frac{R_{sh}}{2\pi}\left[\ln\frac{r_i}{r_0} + L_T\left(\frac{1}{r_i} + \frac{1}{r_0}\right)\right] \qquad (3)$$

where R_{sh} is the sheet resistance, and r_0 and r_i are the inner and outer radius of each pad, respectively.

The relationship between the sheet resistance R_{sh} and the contact resistivity ρ_c can be expressed as

$$L_T = \sqrt{\rho_c / R_{sh}} \qquad (4)$$

where L_T is the transmission length. For $r_i \gg r_0 - r_i$, Equation (3) simplifies to

$$R_T = \frac{R_{sh}}{2\pi r_0}\left[(r_i - r_0) + 2L_T\right] \qquad (5)$$

Figure 5 shows the variation of the total resistance with the spacing $r_i - r_0$ between the inner and the outer contacts. All the inner radii of the pads were $50\mu m$. The values of R_{sh} and L_T can be obtained by fitting this curve with Eq. (5). The value of specific contact resistivity ρ_c can be obtained from Eq. (4). Values measured for the ohmic contact of Ti/Al/Ni/Au on AlGaN/GaN heterostructure were $R_{sh} = 1108.4\Omega/\square$, $L_T = 1.15\mu m$. So the value of specific contact resistivity ρ_c is about $1.46 \times 10^{-5}\Omega \cdot cm^2$. The specific contact resistivity from experiment is lower than the $1.70 \times 10^{-5}\Omega \cdot cm^2$ obtained by annealing for 30s at 750℃[16], for the same Ti/Al/Ni/Au contacts on $Al_{0.27}Ga_{0.73}N$/GaN heterostructures.

The dark current of $Al_{0.27}Ga_{0.73}N$/GaN photoconductor UV photodetectors was measured at room temperature by means of a KEITHLEY measure unit. Figure 6 shows the *I*-*V* characteristics of photodetectors without illumination. It was found that the *I*-*V* curve was linear with the changes of bias, indicating good electrical behavior for the ohmic contact on the AlGaN/GaN heterostructure.

Yang *et al*.[16] proposed that the ohmic contact had not yet formed after 650℃ annealing and that the *I*-*V* curve showed rectifier characteristics by experiment. However, the above experiment and calculation results show that good ohmic contact has been obtained by evaporating a Ti(10nm)/Al(100nm)/Ni(40nm)/Au(100nm) multilayer and annealing for 30s at 650℃ in ultra-high purity N_2 ambient.

Ti/Al/Ni/Au multi-layer metal on AlGaN/GaN heterostructures shows excellent ohmic characteristics. This result may be due to the fact that TiN formed at the Ti/AlGaN interface[12,17~19] after annealing at high temperatures, which may facilitate the electronic tunneling interface and formation of a

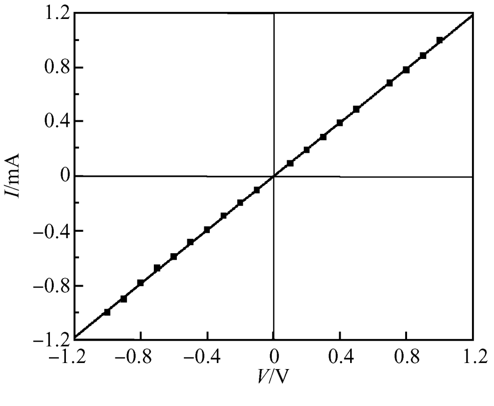

Fig. 6　*I*-*V* characteristics of AlGaN/GaN photoconductors UV photodetectors without illumination

good ohmic contact. At the same time, Ti/Al are combined into an alloy and Ni/Au form cermet-like matter after annealing, which prevents the oxidation of the contact layer and Au diffusion to the surface of the semiconductor[20,21].

4 Conclusion

In summary, ohmic contacts of Ti/Al/Ni/Au multi-layer metal on $Al_{0.27}Ga_{0.73}N$/GaN heterostructures were fabricated. Specific contact resistivities were measured by LTLM and CTLM, respectively. A minimum specific contact resistivity of $2.64\times10^{-5}\Omega\cdot cm^2$ was obtained using the LTLM, and a specific contact resistivity of $1.46\times10^{-5}\Omega\cdot cm^2$ was obtained using the CTLM. $Al_{0.27}Ga_{0.73}N$/GaN photoconductor UV detectors were prepared and the *I-V* characteristics of the detectors without illumination were measured. The result shows that the *I-V* curve was linear, indicating good electrical behavior of the ohmic contact on AlGaN/GaN heterostructure. Experimental results indicate that a good ohmic contact is obtained by evaporating a Ti(10nm)/Al(100nm)/Ni(40nm)/Au(100nm) multilayer and annealing for 30s at 650℃ in ultra-high purity N_2 ambient. This can be applied in high-performance AlGaN/GaN UV photodetector fabrications.

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用于紫外探测器的 AlGaN/GaN 异质结构的 Ti/Al/Ni/Au 欧姆接触特性*

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摘要： 采用 Ti/Al/Ni/Au 多层金属体系在 $Al_{0.27}Ga_{0.73}N$/GaN 异质结构上制备了欧姆接触.分别采用线性传输线方法（LTLM）和圆形传输线方法（CTLM）对其电阻率进行了测试.当 Ti(10nm)/Al(100nm)/Ni(40nm)/Au(100nm)金属体系在 650℃ 高纯 N_2 气氛中退火 30s 时，测量得到的最小比接触电阻率为 $1.46\times10^{-5}\Omega\cdot cm^2$.并制备了 $Al_{0.27}Ga_{0.73}N$/GaN 光导型紫外探测器，通过测试发现探测器的暗电流-电压曲线呈线性分布.实验结果表明在 $Al_{0.27}Ga_{0.73}N$/GaN 异质结构上获得了好的欧姆接触，能够满足制备高性能 AlGaN/GaN 紫外探测器的要求.

关键词： AlGaN/GaN；欧姆接触；比接触电阻；传输线法；Ti/Al/Ni/Au；紫外探测器

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