GaN MSM photodetectors with TiW transparent electrodes

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Abstract

TiW films were deposited onto glass substrates and GaN epitaxial layers by RF magnetron sputtering. It was found that TiW film deposited with a 300 W RF power could provide us a high transmittance and a low resistivity. GaN-based ultraviolet metal–semiconductor–metal (MSM) photodetectors were also fabricated. It was found that photocurrent to dark current contrast ratios were 4.35, 4.6 \times 10^2 and 5.7 \times 10^4 for the photodetectors with ITO, TiN, and TiW electrodes, respectively. The large photocurrent to dark current contrast ratio could be attributed mainly to the fact that TiW can form a high Schottky barrier height on the surface of u-GaN epitaxial layers.

Keywords: GaN; TiW; ITO; TiN; UV; Photodetectors; MSM

1. Introduction

Light detection in the ultraviolet (UV) spectral range has drawn much attention in the recent years. UV photodetectors are useful in various fields such as biological and chemical applications. Until very recently, the primary means of UV light detecting was the use of silicon photodiodes. However, the most sensitive wavelength of Si photodiodes is not located in the UV region since room temperature bandgap energy of Si is only 1.2 eV. Thus, the responsivity of Si photodiodes is low in the UV region. To maximize the detector responsivity in the UV spectral region, one should choose wide bandgap materials, such as SiC, GaN and ZnSe, for the fabrication of solid state UV detectors. Among these wide bandgap materials, GaN has a direct bandgap and a high saturation velocity. These properties make GaN a promising candidate for UV detector applications [1–4]. In the past few years, various types of GaN-based photodetectors have been proposed, such as p–n junction diode [5], p–i–n diode [6–10], p–n–n diode [11], Schottky barrier detector [12–15] and metal–semiconductor–metal (MSM) photodetector [16–19]. Among these structures, MSM photodetector is easy to fabricate. However, responsivity of normal MSM photodetectors is limited by the presence of the opaque metal contact electrodes in general. Although back-side illumination can be used to solve this problem, it will also create critical problems in optical lithography alignment, device processing and chip packaging. Previously, it has been shown that one can use transparent contact electrodes to solve this problem. GaN-based UV MSM photodetectors with transparent titanium nitride (TiN) and indium tin oxide (ITO) Schottky contact electrodes have also been demonstrated [20,21]. In this paper, we deposited titanium tungsten (TiW) onto the surfaces of GaN layers by RF magnetron sputtering with various deposition conditions. The physical, optical and electrical properties of the deposited TiW films were then characterized. GaN-based UV MSM photodetectors with transparent TiW Schottky contact electrodes were also fabricated. The performances of the fabricated photodetectors were also evaluated.

2. Experiments

Prior to TiW deposition, GaN epitaxial layers were grown on c-face sapphire substrates by metalorganic chemical
vapor deposition (MOCVD) [22–24]. Trimethylgallium (TMGa) and ammonia (NH₃) were used as the source materials of gallium and nitrogen, respectively. We first deposited a 30 nm-thick 560 °C-grown GaN buffer layer on sapphire substrates followed by a 3 μm-thick 1050 °C-grown unintentionally doped GaN epitaxial layer. Typical room temperature carrier concentration of the unintentionally doped GaN epitaxial layers was ~10¹⁷ cm⁻³. The as-grown GaN wafers were then dipped in a diluted hydrochloric acid water solution (HCl:H₂O = 1:1) for 3 min to remove the native oxide of the samples. The TiW transparent electrodes were subsequently deposited onto the u-GaN epitaxial layers by RF magnetron sputtering with argon (Ar) gas at various deposition conditions. The TiW target was then used to measure the current–voltage (I–V) characteristics of these photodetectors in dark and under illumination. For photocurrent measurements, a 150 W deuterium lamp illuminating from the front side of GaN MSM photodetectors was used as the light source.

### 3. Results and discussion

Measured deposition rate of the TiW layers deposited at various conditions by RF magnetron sputtering shows that TiW deposition rate increases almost linearly as the RF power increases. Such a result indicated that the limiting factor of TiW deposition rate was the sputter energy and the amount of Ar atoms to bombard the target. In Fig. 1, X-ray diffraction (XRD) patterns show that the deposited TiW films were oriented in the (1 1 0) direction. The small 1.33° full-width-half-maximum (FWHM) of the TiW(1 1 0) XRD peak also suggests that quality of the deposited TiW films with 300 W RF power is reasonably good. Fig. 2 shows normalized transmission spectra for the TiW films deposited at various sputtering powers. In this figure, we kept Ar flow rate and chamber pressure at 10 sccm and 10 mTorr, respectively, during TiW deposition. The TiW thickness was kept at 10 nm. It should be noted that the transmittance of each film was normalized with respect to the transmittance of the glass substrate. In this figure, the transmittance of each film was normalized with respect to the transmittance of the glass substrate. With an incident light wavelength of 400 nm, it was found that the transmittances of the TiW films deposited with 200, 250, 300 and 350 W RF powers were 70.2, 74.8, 78.1, and 77.8%, respectively. As shown in the inset of this figure, it was found that measured resistivities of the TiW films deposited with 200, 250, 300 and 350 W RF power were 3.1 × 10⁻³, 2.5 × 10⁻³, 1.7 × 10⁻³ and 2.0 × 10⁻³ Ω cm, respectively. Fig. 3(a)–(d) shows surface electron microscopic (SEM) images of the TiW films deposited with 200, 250, 300 and 350 W RF powers, respectively. Among these four samples, it was found that we could achieve regular grains with the smallest average grain size from the TiW film deposited with 300 W RF power. Such a result agrees well with those observed from Figs. 1 and 2. It also indicates that TiW film deposited with a 300 W RF power could provide us a high transmittance and a low resistivity.

ITO and TiN films were also deposited onto glass substrates by RF magnetron sputtering for comparison. Fig. 4 shows normalized transmission spectra for the ITO, TiN and TiW films. With an incident light wavelength of 400 nm, it was found that the transmittances of ITO, TiN and TiW were
94, 57.5 and 78.1%, respectively. On the other hand, it was found that measured resistivities of ITO, TiN and TiW films were $1.71 \times 10^{-4}$, $3.49 \times 10^{-2}$ and $1.7 \times 10^{-3}$ Ω cm, respectively. In other words, ITO can provide us the highest transmittance and the lowest resistivity among the three materials. On the other hand, the transmittance and the resistivity of TiW are reasonably good, as compared to the properties of TiN.

To successfully apply these transparent materials onto GaN-based UV MSM photodetectors, the interfacial properties are also important. Fig. 5 shows dark $I-V$ characteristics of the GaN-based UV MSM photodetectors with these electrodes.

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Fig. 3. The SEM images of the TiW films with different RF power.

Fig. 4. The transmittance and resistivity of ITO, TiN, and TiW transparent electrodes.

Fig. 5. Measured dark currents of GaN MSM photodetectors with ITO, TiN, and TiW electrodes.
transparent electrodes. Under low applied bias (i.e. <4 V), it was found that dark current of the GaN-based UV MSM photodetector with TiW electrodes was much lower than those observed from the GaN-based UV MSM photodetectors with either ITO or TiN electrodes. Such a small dark current suggests TiW could form a high Schottky barrier height on the surface of u-GaN epitaxial layers. Fig. 6 shows I–V characteristics of the three MSM photodetectors under illumination. It was found that photocurrent observed from the photodetector with ITO electrodes was the largest, followed by the photodetector with TiW electrodes. On the other hand, photocurrent observed from photodetector with TiN electrodes was the smallest. The large photocurrent observed from the photodetector with ITO electrodes could be attributed mainly to the fact that TiW can form a high Schottky barrier on the surface of u-GaN epitaxial layers. Fig. 6 shows that photocurrent to dark current contrast ratios were 4.35, 4.6 \times 10^2 and 5.7 \times 10^4 for the photodetectors with ITO, TiN and TiW electrodes, respectively. The large photocurrent to dark current contrast ratio could be attributed mainly to the fact that TiW can form a high Schottky barrier height on the surface of u-GaN epitaxial layers.

### 4. Summary

In summary, TiW films were deposited onto glass substrates and GaN epitaxial layers by RF magnetron sputtering. It was found that TiW film deposited with a 300 W RF power could provide us a high transmittance and a low resistivity. GaN-based UV MSM photodetectors were also fabricated. It was found that photocurrent to dark current contrast ratios were 4.35, 4.6 \times 10^2 and 5.7 \times 10^4 for the photodetectors with ITO, TiN and TiW electrodes, respectively. The large photocurrent to dark current contrast ratio could be attributed mainly to the fact that TiW can form a high Schottky barrier height on the surface of u-GaN epitaxial layers.

### References