Measurement of plasma parameters in Ar/O_2 magnetron sputtering Zn plasma using Langmuir probe

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Abstract: Reactive sputtering technique using Zn metal target represents one of the simplest and most effective technique which has been used by many researchers. In the present work, we investigate the properties of reactive magnetron sputtering plasma using Zn target. The magnetron sputtering plasmas were produced using radio frequency (rf) power supply in Ar and Ar+O_2 as ambient gas. A Langmuir probe was used to collect the current from the plasma. From the current intensity, the electron density and electron temperature were calculated. The properties of reactive magnetron Zn sputtering plasma at various discharge conditions were studied. Basically, at rf power of 100 W, the electron density and electron temperature in Ar ambient gas (at 20 mTorr gas pressure) were 10^{10} cm^{-3} and 2 eV, respectively. In addition, the plasma properties changed drastically when the Ar+O_2 gas was used in magnetron sputtering plasma. The density evaluated from the electron saturation region showed the decrease from 10^{10} to 10^9 cm^{-3}.

Keywords: reactive magnetron sputtering, zinc oxide thin film, Langmuir probe analysis.

1. Introduction

Zinc oxide (ZnO) is a promising material which has been investigated for many applications such as photovoltaic and photosensor. The applications of ZnO thin film is due to several unique material properties where it is a II-IV semiconductor with a wide direct bandgap of 3.2 eV at room temperature, which is almost similar to Titanium Dioxide (TiO_2) material. In many research, ZnO thin films have been grown by various deposition technique, such as reactive sputtering, chemical bath deposition, pulsed laser deposition, and thermal chemical vapor deposition. In such options, the reactive sputtering technique using Zn metal target represents one of the simplest and most effective techniques which have been used by many researchers.[1-3]

Researchers have studied and showed the influence of deposition recipe to properties of deposited film. However, very few researchers investigated the details of the Ar and Ar+O_2 magnetron sputtering plasma properties employing Zn target. [4] Thus, in the present work, we investigate the properties of magnetron sputtering plasma using Zn target and its deposited Zn thin film. The magnetron sputtering plasmas were produced using radio frequency (rf) power supply in Ar and Ar+O_2 as ambient gas. A Langmuir probe was used to collect the ion and electron currents from the plasma. From the current intensity, the plasma or electron density and electron temperature were calculated. The properties of reactive magnetron Zn sputtering plasma at various discharge conditions were studied.

2. Experimental setup

The schematic of our magnetron sputtering chamber with a 3 inches diameter Zn target is shown in Fig.1. The background pressure was less than 2×10^{-6} Torr. It was achieved from a vacuum turbo molecular pump and backed by rotary mechanical pump. A Langmuir probe (Hiden Epsion) was used to measure the plasma parameters as shown in Fig.1. The Probe tips was placed at the center of the substrate holder and approximately 11 cm from the target surface. The Probe tips was made of tungsten with diameter of 0.15 mm and length of 10 mm. The tungsten tip is connected to a ceramic insulator to protect it from the plasma. Ar gas was introduced in the chamber for the discharge. Its flow rate was fixed at 45 sccm. The rf power was varied from 50 W to 200 W in 50 W increments. The total pressure inside the chamber was maintained at 20 mTorr during the data acquisition. For the reactive discharge study, oxygen was introduced in the Ar plasma, and the flow rate was fixed at 10 sccm.

Hiden's ESPsoft software was used to analyze the different plasma parameters. Briefly, the electron temperature, the plasma potential, the electron density and the ion density was calculated using the orbital motion limited (OML) theory.[5] Then, to calculate the electron energy distribution function (EEDF), the Druyvesten method was used.[6] This method uses the second derivative of the electron current with respect to the voltage. The probe tips was cleaned manually and by applying biased -60 V before each data acquisition or when needed. Five I-V characteristics curve were acquired and averaged for each condition to calculate the plasma parameters using semiautomatic data analysis option.

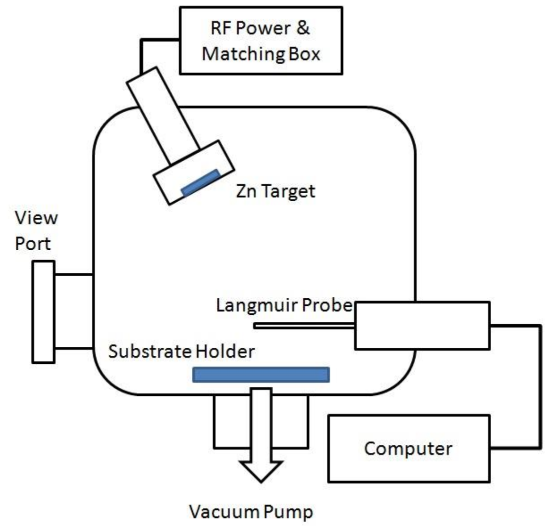

Figure 1. Schematic of experimental setup.

3. Results and discussions

Fig. 2 shows the I-V curves obtained directly from the Langmuir probe at 20 mTorr Ar discharge and 50 W to 200 W rf power. This curve represents the electron density current as a function of probe bias. The region where there is no net current is known as floating potential or plasma potential. Generally, the I-V characteristic curve is divided into three regions to calculate different plasma parameters. There are ion saturation region, transition region and electron saturation region. The ion saturation region the region where the probe only collects the positive ions. The electron saturation region is where it collects only electrons. The transition region is used to calculate the electron temperature and plasma potential. In the present paper, we only focus on the electron saturation region and transition region for the plasma parameters analysis.

From Fig. 2, we can directly understood that the plasma potential were about 15 V to 22 V, depends on the discharge rf power. The plasma potential increased with the discharge rf power. On the other hand, Fig. 3 is the I-V curves obtained directly from the Langmuir probe at 20 mTorr Ar+O_2 discharge and 50 W to 200 W rf power. The flow rate of Ar and O_2 were 45 and 10 sccm, respectively. Although the electron saturation region decrease drastically, the plasma potential was almost unchanged at 15 V to 22 V, depends on the discharge rf power.

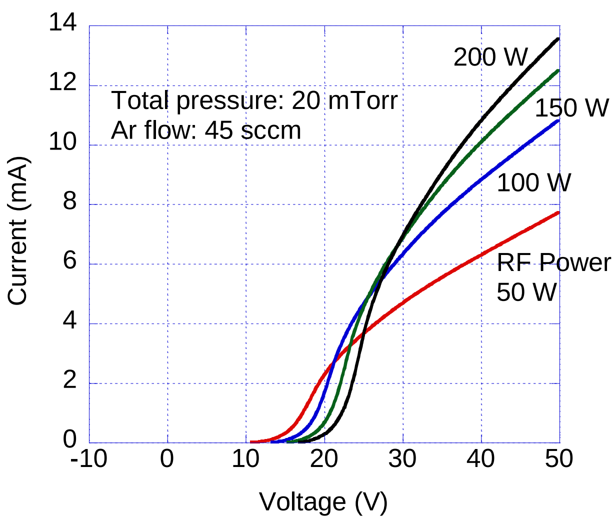

Figure 2. I-V characteristics obtained by the Langmuir probe for Ar plasma.

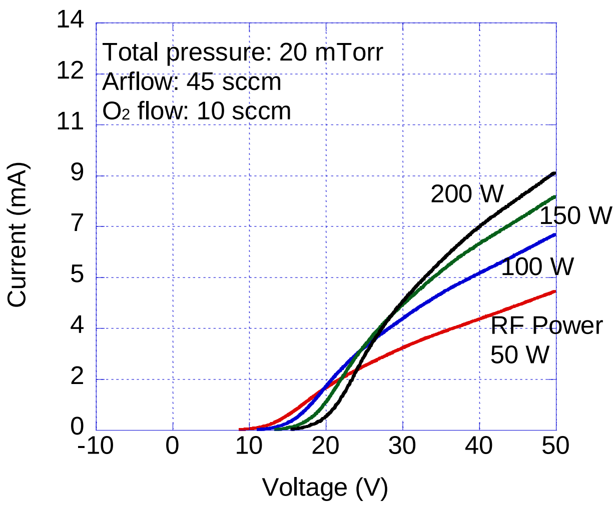

Figure 3. I-V characteristics obtained by the Langmuir probe for Ar+O_2 plasma.

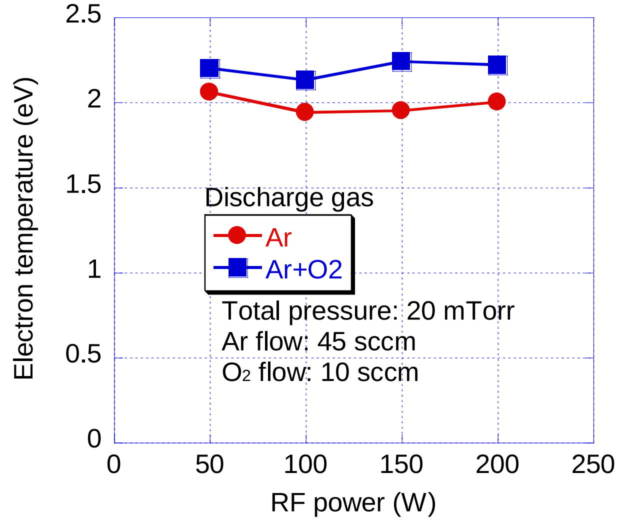

Figure 4. Electron temperature in Ar and Ar+O_2 plasmas as function of discharge rf power.

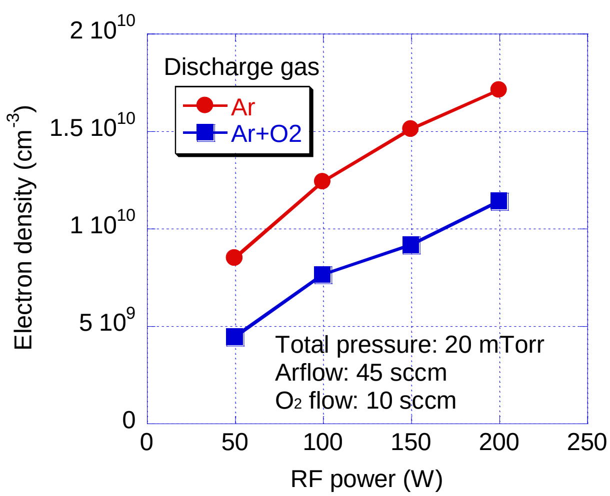

Figure 5. Electron density in Ar and Ar+O_2 plasmas as function of discharge rf power.

As mentioned previously, the electron temperature can be evaluated from the I-V curve transition region, in which the slope (gradient) of the curve is in inverse number of the electron temperature, T_e.

$$\frac{\Delta V}{\Delta(\ln I)} = \frac{1}{T_e} \tag{1}$$

Fig. 4 shows the electron temperature in Ar and Ar+O_2 plasma as a function of discharge rf power. The electron temperature was constant with the discharge rf power. It increased slightly from 2 eV in Ar plasma to 2.25 eV in $Ar+O_2$ plasma. The electron temperature increases due to the decrease in the energy loss by the electrons during ionizing collision with O_2 molecules as the ionization cross-section for O_2 is smaller than that of Ar.

Fig. 5 shows the electron density in Ar and $Ar+O_2$ plasma as a function of discharge rf power. The electron density increased from 8×10^{9} cm^{-3} at 50 W to 1.8×10^{10} cm^{-3} at 200 W. However, with the addition of O_2 in the ambient gas, the electron density decreased drastically. As shown in Fig. 5, the electron density at 200 W in $Ar+O_2$ plasma is 1.2×10^{10} cm^{-3}, which is 33% lower than that in Ar only plasma.

The phenomenon is explained by the change of the target surface where it is covered with ZnO layer in reactive discharge. This corresponds to a transition from a metal mode to oxide mode by oxidation of the metal target. This phenomenon was confirmed from the optical emission spectroscopy analysis where we found the drastic drop in Zn atom emission with the addition of O_2 in the ambient gas. In addition, the electron temperature is not much changed by the addition of O_2 as shown in Fig. 4.

4. Conclusion

Langmuir probe study was carried to investigate the effect of O_2 and rf discharge power in magnetron sputtering plasma. The results revealed that the electron density decreased with the addition of O_2. The electron density increase with the discharge rf power. However, the electron temperature was almost unchanged with the discharge rf power. The similar experimental parameter will be use for the growth of ZnO thin film and its correlation will be studied.

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