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Chromium thin film deposition on ITO substrate by RF sputtering

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Abstract To obtain a suitable ohmic contact with the lowest resistivity, chromium (Cr) thin films were deposited on transparent conductive oxide indium tin oxide (ITO) by RF sputtering method in argon atmosphere and its electrical properties were optimized. The deposition of Cr thin film has been performed for the layers with thickness of 150, 300 and 600 nm in constant Ar gas flow of 30 SCCM. Results show that the lowest contact resistivity belongs to the layer with 600 nm thickness. Furthermore, Cr/ITO has been studied for five different RF powers of 100, 150, 200, 250 and 300 W. Experimental results show that specific contact resistance of Cr/ITO contact decreases in condition of depositing chromium thin films on ITO at higher RF powers. Analysis of SEM has been performed on the samples. The SEM micrographs show Cr thin films have smaller grains at RF power of 150 W, in comparison with other RF powers. The lowest specific contact resistivity for Cr/ITO has been obtained $4.7 \times 10^{-2} \Omega \text{ cm}^2$ at RF power of 150 W with 600 nm thickness of chromium thin films.

Keywords Chromium · ITO · RF sputtering · FESEM · Ohmic contact

Introduction

Interesting and novel applications in photovoltaic are expected from thin and flexible solar modules, especially in the fields of space, aeronautic, and mobile applications. Within the past years, the development of flexible and lightweight Cu (In,Ga)Se₂(CIGS) modules has intensified. These activities were encouraged by the relatively high small-area cell efficiencies obtained on polymer as well as on metallic substrates. The most interesting substrates are metal foils, since they can be coated in a roll-to-roll process at high temperatures of up to 600 °C and in a Se atmosphere. Especially stainless steel foils with a potential as low-cost substrates were tested [1, 2]. Nevertheless, cell and module efficiencies were lower than on glass substrates. The preparation of highly efficient solar cells requires the deposition of a barrier layer to reduce the diffusion of impurities from the metal substrate into the solar cells [3, 5]. If monolithical integration of the cells is desired to realize solar modules on electrically conducting substrates, the deposition of a dielectric barrier is necessary [4, 5]. Thin Cr layers [3–8] as well as dielectric layers like Al₂O₃ [4, 6] or SiO₂ [6] deposited by sputtering or sol-gel techniques have been used as diffusion barriers. One of the factors affecting the performance of these devices is the choice of ohmic low resistance and reliable contact materials. Most groups use transparent conducting oxide of indium tin oxide (ITO) as front contact. ITO is an n-type semiconductor with a band gap of 3.5 eV and electron affinity of 4 eV. ITO film has high transmittance, high infrared reflectance, good electrical conductivity, excellent substrate adherence and hardness [9]. Because of its unique properties, it has found extensive application in solar cells [10], flat panel displays [11], heat reflecting mirrors [12], LEDs [13, 15] and so on.

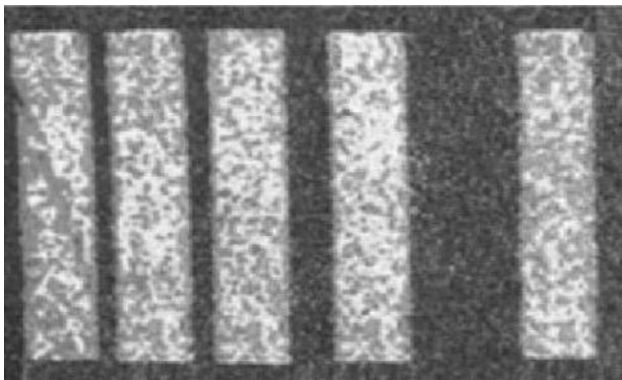
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Table 1 Experimental conditions for chromium thin films deposition

Initial vacuum	8×10^{-6} Torr
RF power	300 W
Sputtering pressure	27 m Torr
Sputtering temperature	Room temperature (RT)
Pre-sputtering time	10 min
Argon gas flow	30 SCCM

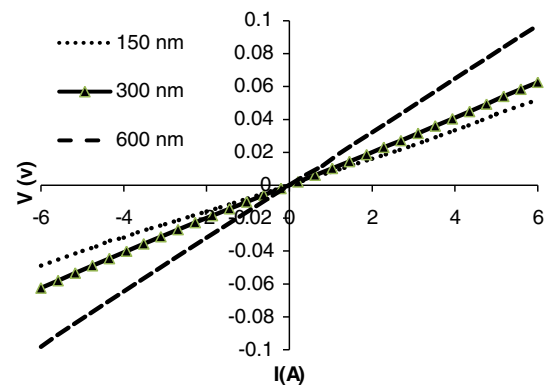
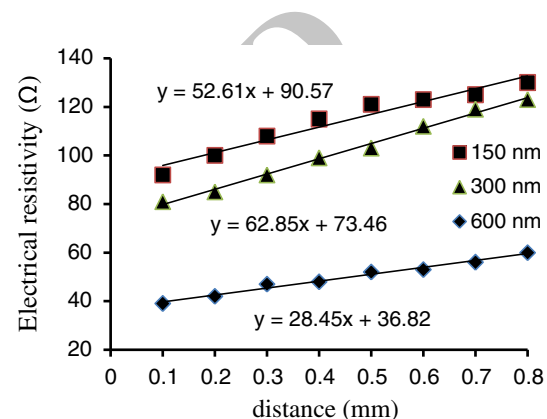
**Fig. 1** SEM image of TLM pattern

Generally the contact between metal and semiconductor can behave ohmic if the Schottky barrier height is zero or even smaller. Usually, the work function of metals is smaller than 5 eV, so the main issue is to choose and design a contacting system which has lower resistance and behaves ohmic [16, 17].

In the present investigation, we report the influence of process parameters on the comparisons of the Cr/ITO ohmic contact properties, the deposition rate, and the structure and properties of Cr coatings deposited by RF sputtering of a metal Cr target in an Ar atmosphere.

Chromium deposition with different thicknesses

Cr coating was done by means of the RF sputtering technique from a metallic Chromium target of 99.99 % purity using argon as a sputtering gas. The deposition chamber was initially pumped to a base pressure of 8.0×10^{-6} Torr and then back filled with Ar (99.999 % purity) to a process pressure of 27 mT. The ITO/glass substrates were ultrasonically cleaned in an acetone and deionized water before each deposition. The gas flow rate of argon was fixed at 30 SCCM and RF power was fixed at 300 W, respectively. The thicknesses of the Cr thin films were varied by different deposition times to 150, 300 and 600 nm. The sputtering conditions are summarized in Table 1.

**Fig. 2** I–V characteristic of Cr 150, 300 and 600 nm contacts on ITO**Fig. 3** Graph of Cr/ITO contact resistivity for 150, 300 and 600 nm Cr film thicknesses measured with Keithley 2361 system

After every deposition, the thicknesses of the Cr films were measured using an alpha-step (Decktak500). The thicknesses of the Cr films were varied from 150 to 600 nm depending on the experimental conditions. To measure the contact resistance of the deposited films, transfer length method (TLM) was used. The total resistance (R_T) of the metal/semiconductor contacting system is $R_T = 2R_C + 2R_M + R_{Sem}$, where R_M is the resistance of metal, which can be neglected; R_{Sem} and R_C are the resistances of the semiconductor and the contact resistance between metal and semiconductor. If the distance between metal fingers is very small ($d \rightarrow 0$), we can approximate $R_T \rightarrow 2R_C$, and calculate the R_C . Figure 1 shows SEM image of TLM pattern used in our measurement.

Figure 2 shows the current–voltage (I–V) characteristics of the Cr/ITO contact layers, measured between ohmic pads. The Cr/ITO contacts exhibited a linear ohmic behavior in the voltage range of -6 to 6 V. The specific contact resistance was calculated from the graph of the measured resistances versus the spacing between the TLM pads. The specific contact resistance was determined to be 1.4×10^{-1} , 1.1×10^{-1} and $5.8 \times 10^{-2} \Omega \text{ cm}^2$ for the

Table 2 Specific contact resistivity of Cr/ITO for different thicknesses of Cr films

Thickness (nm)	150	300	600
ρ_c ($\Omega \text{ cm}^2$)	1.4×10^{-1}	1.1×10^{-1}	5.8×10^{-2}

Table 3 Specific sheet resistivity of Cr thin film in 150, 300 and 600 nm thicknesses

Thickness (nm)	150	300	600
ρ_s ($\Omega \text{ cm}$)	8.4×10^{-4}	4.6×10^{-4}	1.0×10^{-4}

Cr/ITO contacts by Chromium films with different thickness, respectively, indicating that the Cr layer is a suitable ohmic layer for an ITO contact scheme.

In Fig. 3, ohmic contact resistance between Cr/ITO with three different thicknesses of 150, 300 and 600 nm is compared and the value of R_T was obtained by extrapolation of the line equations. Note that R_C is the $R_T/2$. Contact resistances were calculated using specific contact relation equation given below [18]:

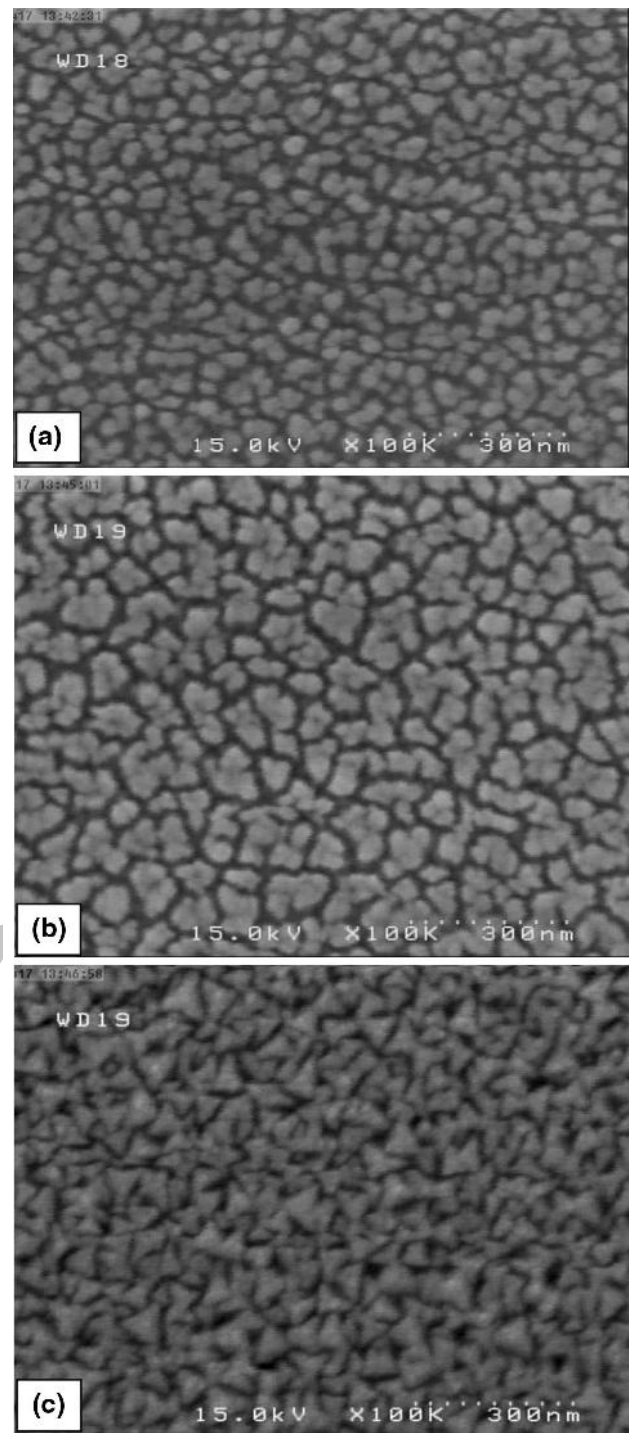
By extrapolating the graph, specific contact resistances were calculated and the lowest contact resistivity has been obtained, which is given in Table 2.

Table 3 indicates the value of sheet resistivity of Chromium thin film layer deposited by RF sputtering method. Sheet resistivities of prepared samples were measured by four point probe. In this experiment, the sheet resistance of Cr/ITO contacts as function of Chromium thin film thicknesses decreased by increasing thickness to $1.0 \times 10^{-4} \Omega \text{ cm}$.

Figure 4 shows the SEM images of the deposited films on glass with different thicknesses. The power was kept at 300 W in these samples. Surface morphology of Chromium thin films deposited by RF sputtering on ITO substrate is shown. In these images growing trend of the crystalline grains of Chromium thin films can be observed. However, the surface morphology in these images indicated different feature sizes which could be due to different crystal orientations.

Chromium deposition at different sputtering RF powers

To study the effect of RF power of sputtering system on the resistance of the films, the sample with 600 nm thicknesses was used, which showed the lowest specific contact resistance according to our results. Therefore, samples were prepared at different RF powers of 100, 150, 200, 250 and 300 W using 600 nm Cr thickness at the same experimental conditions, which were used in our previous experiments. The I–V characteristics of the contact

**Fig. 4** SEM images of Chromium thin films with different thicknesses: **a** 150 nm, **b** 300 nm, **c** 600 nm

Chromium thin films at different RF powers of 100, 150, 200, 250 and 300 W are given in Fig. 5.

I–V characteristics of the contact of Chromium thin films at different RF powers of 100, 150, 200, 250, and 300 W to ITO are given in Fig. 5. It shows the current–voltage (I–V) characteristics for Cr/ITO contacts. The

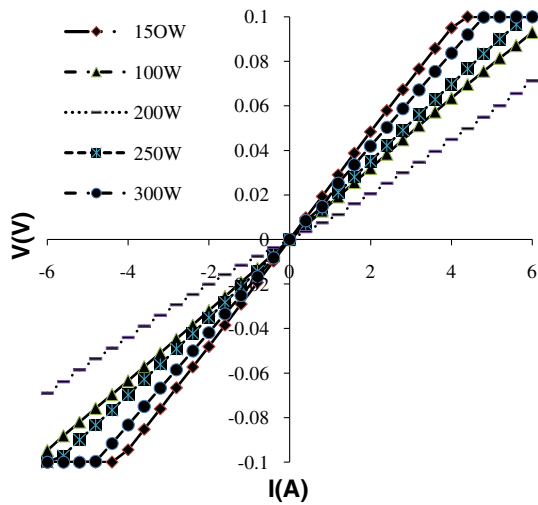


Fig. 5 I–V characteristic of Cr/ITO ohmic contact at different RF powers of Cr films deposition

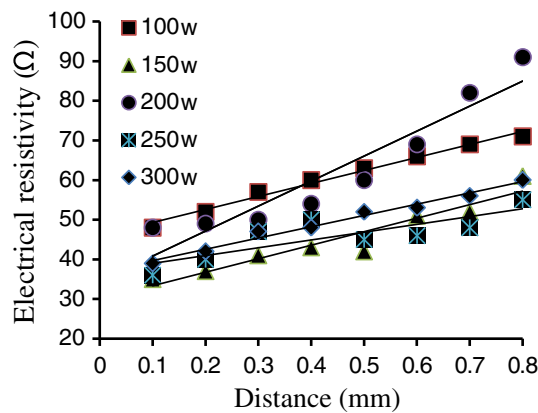


Fig. 6 Cr/ITO contact resistivity in 100, 150, 200, 250 and 300 W RF power of sputtering system with Keithley 2361 system

Table 4 Specific contact resistivity of Cr/ITO at various RF power

Power (W)	ρ_c ($\Omega \text{ cm}^2$)
100	7.3×10^{-2}
150	4.7×10^{-2}
200	5.5×10^{-2}
250	5.9×10^{-2}
300	5.8×10^{-2}

results show that the contacts growth in 150 W has superior contact resistivities, as compared to the contacts in 100, 200, 250 and 300 W. All of the ohmic contacts show linear and symmetrical I–V characteristics in investigated range of argon gas flow.

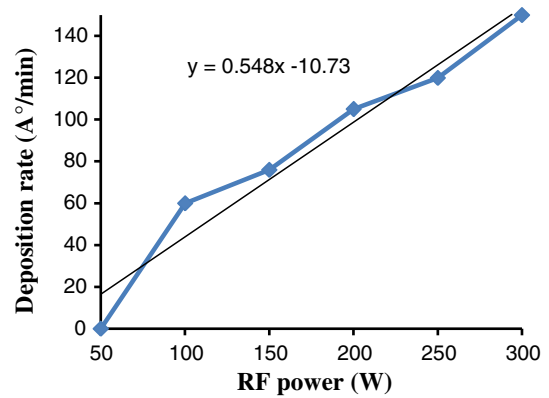


Fig. 7 Deposition rate as functions of the RF power

Figure 6 depicts comparison of ohmic contact in various RF power depositions by sputtering system. As mentioned before, by extrapolating the line equations, the value of R_T was obtained. Half the value of R_T will result in R_C .

The specific contact resistances also were calculated using the extrapolation method, which was mentioned in previous section. The calculated specific contact resistances are given in Table 4.

According to the above table, deposited Cr thin film at 100 W RF power gives a higher contact resistance in comparison with the other samples, which were prepared at 150, 200, 250 and 300 W RF powers and samples prepared at these powers did not show any significant changes in ρ_c amount. The lowest specific contact resistance was achieved for Cr thin film deposited at 150 W RF power. On the other hand, specific sheet resistance of the thin Chromium film deposited at 150 W RF power was $1.1 \times 10^{-3} \Omega \text{ cm}$, which was measured with four point probe system. It is worth noting that the deposition rate is one of the most important factors in developing a physical vapor deposition (PVD) technique alternative to Cr electroplating. The deposition rate of Cr is thought to depend upon many sputtering process parameters such as RF power, pressure, substrate temperature, gas flow rate of Ar, and the target-to-substrate distance. The dependences of the deposition rate on the RF powers are shown in Fig. 7.

The SEM images in Fig. 8 represent the structure of Chromium thin films deposited at different RF power. Growing trend of Chromium grain size while increasing RF power of sputtering can be observed. As it can be seen from the images this trend goes towards the crystallization seeds. At 150 W RF power the grains of Cr thin film are smaller and smoother in comparison with layer deposited in other RF powers. In these pictures, Chromium grain size as function of RF power is shown.

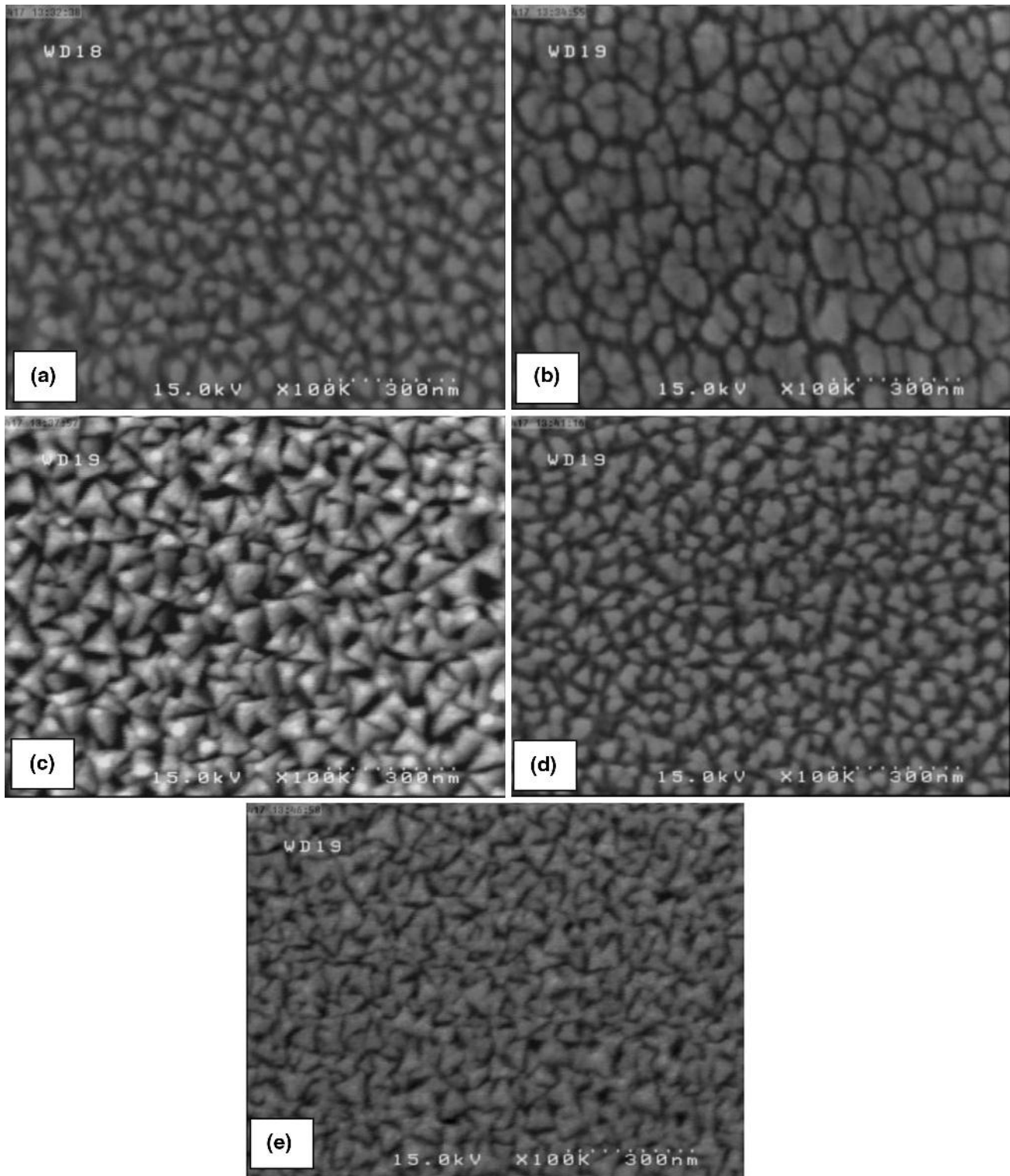


Fig. 8 SEM images of Chromium thin films deposited in different RF powers of sputtering: **a** 100 W, **b** 150 W, **c** 200 W, **d** 250 W and **e** 300 W

Conclusions

In summary, Chromium thin films of 150, 300 and 600 nm thicknesses are deposited on ITO substrates using RF

sputter deposition techniques. We investigated the characteristics of the ohmic contact between Cr/ITO for various thicknesses of Chromium 150, 300 and 600 nm and for various RF powers from 100 to 300 W. As expected, the

specific contact and resistivity decrease with increasing thicknesses in the case of as-deposited films on ITO substrates. The specific contact resistivity of Cr (600 nm)/ITO (300 nm) films showed a minimum value of $5.8 \times 10^{-2} \Omega \text{ cm}^2$ which is a reliable ohmic contact for device applications such as back contact in solar systems and LEDs as it was reported by K. M. Kang et al. [14]. The sheet resistance was lower than $1.0 \times 10^{-4} \Omega \text{ cm}$.

The optimal deposition RF power for Chromium thin film was found to be 150 W to minimize the effect of ion bombardment and/or atomic peening that caused too much stress. Best result was occurred as the flow rate of Ar reached 30 SCCM at Cr thickness of 600 nm and RF power of 150 W, which is probably happening due to the larger grain size of Cr morphology in comparison to the other samples prepared with different RF powers according to the SEM images with specific contact resistance of $4.7 \times 10^{-2} \Omega \text{ cm}^2$.

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