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Improved Electrical Properties of Cr/ITO Ohmic Contact Using RF Sputtering System

ELAHEH AKBARNEJAD,[1,*] EBRAHIM ASL SOLEIMANI,[2] AND ZOHREH GHORANNEVIS[3]

[1]Plasma Physics Research Centre, Science and Research Branch, Islamic Azad University, Tehran, Iran
[2]Thin film laboratory, ECE Department, University of Tehran, Tehran, Iran
[3]Department of Physics, College of Basic Sciences, Karaj Branch, Islamic Azad University, Alborz, Iran

In order to obtain a suitable ohmic contact with the lowest resistivity, chromium (Cr) thin films were deposited on a transparent conductive oxide (TCO) Indium Tin Oxide (ITO) by radio frequency (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 different thicknesses of 150, 300, and 600 nm at constant Ar gas flow of 30 SCCM. Results showed 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 for a 600 nm thickness Cr sample, which showed the lowest contact resistivity. On the other hand Cr/ITO has been studied for different flows of argon gas 10, 30, 50 and 70 SCCM, during the deposition with constant thickness of 600 nm Cr thin films. Our experimental results suggest that the best specific contact resistance was achieved at RF power of 150W, which was 4.7×10^{-6} Ωm^2*. The best specific contact for Cr/ITO has been obtained* 4.5×10^{-6} Ωm^2 *at argon gas flow 10 SCCM with 600 nm thickness.*

Keywords Chromium: FESEM; ITO: RF sputtering

1. 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 [1]. Especially stainless steel foils with a potential as low-cost substrates were tested [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

*Address correspondence to Elahe Akbarnejad, Plasma Physics Research Centre, Science and Research Branch, Islamic Azad University, Tehran, Iran. E-mail: elahe.akbarnejad@gmail.com

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Table 1. Sputtering condition for preparation of chromium thin films

Initial vacuum	8×10^{-6} Torr
RF power	300 W
Sputtering pressure	27 mtorr
Sputtering temperature	Room temp
Pre-sputtering time	10 min
Argon gas flow	30 sccm

solar cells [3]. If monolithically integration of the cells is desired to realize solar modules on electrically conducting substrates, the deposition of a dielectric barrier is necessary [4]. Thin Cr layers [5] as well as dielectric layers like Al_2O_3 [6] or SiO_2 deposited by sputtering or sol–gel-techniques have been used as diffusion barriers. Tin-doped indium oxide In_2O_3: Sn (ITO) is a highly degenerate n-type Wide gap (band-gap$\sim$3.7 eV) semiconductor and belongs to the class of transparent conductive oxides (TCO) which is important for photovoltaic applications. ITO film has high transmittance, high infrared reflectance, good electrical conductivity, excellent substrate adherence and hardness [7]. Because of its unique properties, it has found extensive application in solar cells [8], flat panel displays [9], heat reflecting mirrors [10], LEDs [11] and so on. In this study, the suitability of ohmic contact between Chromium layers as diffusion barriers in various terms of deposition condition with ITO was investigated. 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.

2. Experimental

2.1. Chromium Deposition in Different Thicknesses

Cr coating were deposited by means of the RF sputtering technique from a metallic Chromium target of 99.99% purity and using argon as a sputtering gas. The deposition

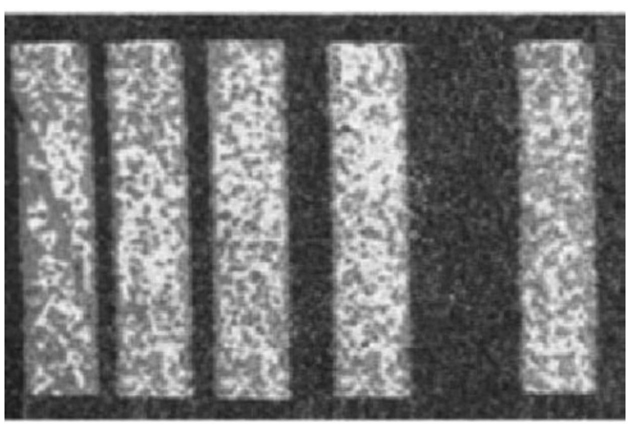

Figure 1. SEM image of TLM pattern.

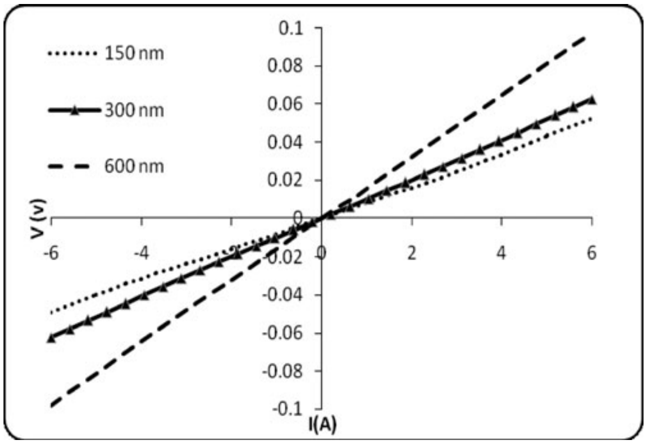

Figure 2. I-V characteristic of Cr 150, 300 and 600 nm contact to ITO.

chamber was initially pumped to a base pressure of 8×10^{-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 depositions. The gas flow rate of argon fixed at 30 sccm and RF power fixed at 300 W, respectively. The target to substrate distance was kept constant at 2.5 cm for each deposition. The thickness of Cr films varied to 150 nm, 300 nm, and 600 nm.

The sputtering conditions are summarized in Table 1:

After every deposition the thicknesses of the Cr films were measured using an alpha-step (Decktak500). The contact resistance between deposited metal films and ITO film is measured by transfer length method (TLM). 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 resistance of semiconductor and contact resistance between metal and semiconductor. If the distance between metal fingers are very small (d→0), we can approximate $R_T \rightarrow 2R_C$, now it is possible to calculate R_C. Fig. 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 with keithley 2361 system. 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 vs. the spacing between the TLM pads. The specific contact resistance was determined at Table 2 for the 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 in various thicknesses are compared. By extrapolation the line equations, the value of R_T obtained. Half the value of R_T will result R_C.

Table 2. Specific contact resistivity of Cr/ITO in different thicknesses of Cr thin films

Thickness (nm)	150	300	600
ρ_C (Ωm^2)	1.5×10^{-5}	1.1×10^{-5}	5.5×10^{-6}

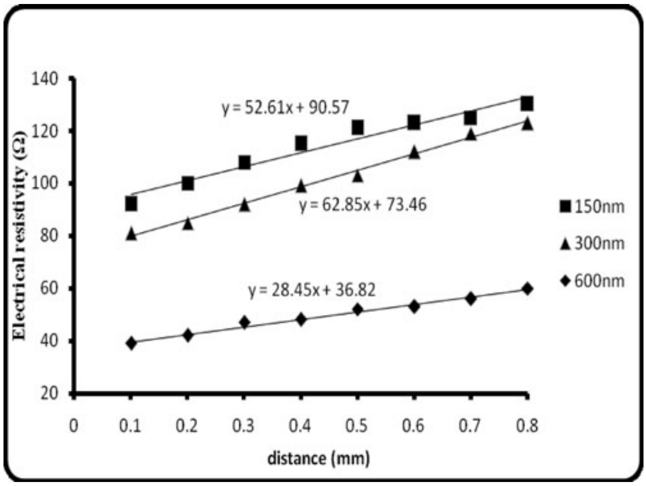

Figure 3. Cr/ITO contact resistivity in 150, 300 and 600 nm thicknesses with keithley 2361 system.

Table 3. Resistivity of Cr thin film in 150, 300 and 600 nm thicknesses

Thickness (nm)	150	300	600
ρ_s (Ωm)	8.4×10^{-5}	4.6×10^{-5}	1.0×10^{-5}

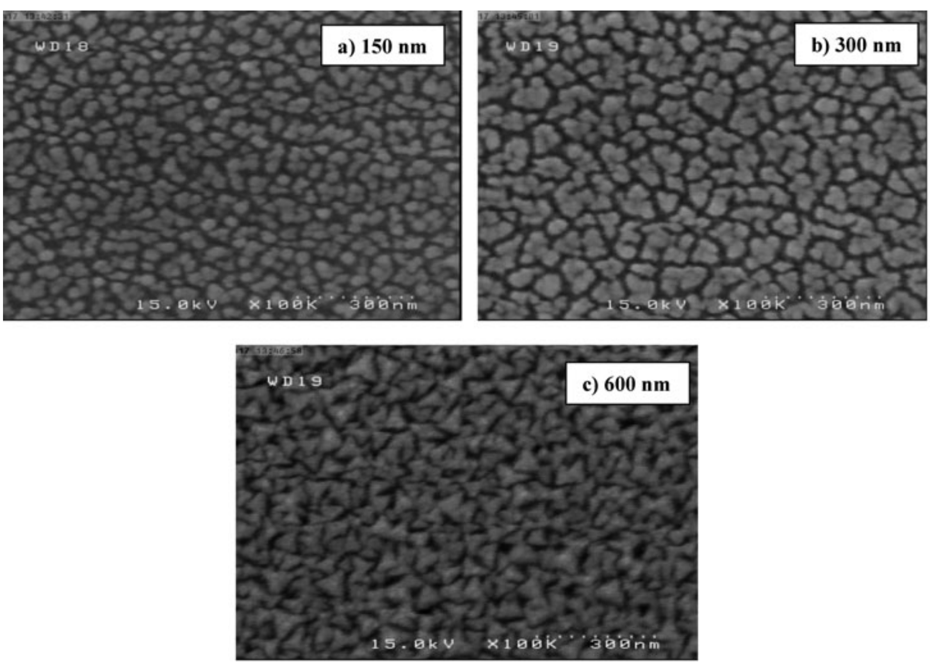

Figure 4. SEM images of chromium thin films in different thicknesses: (a) 150 nm, (b) 300 nm, (c) 600 nm.

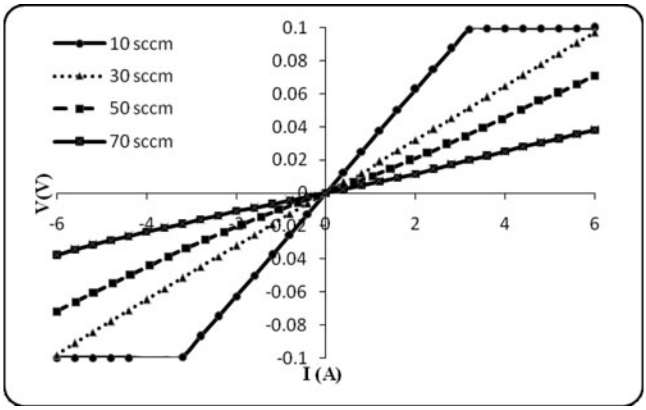

Figure 5. I-V characteristic of Cr 10, 30, 50 and 70 SCCM contact to ITO.

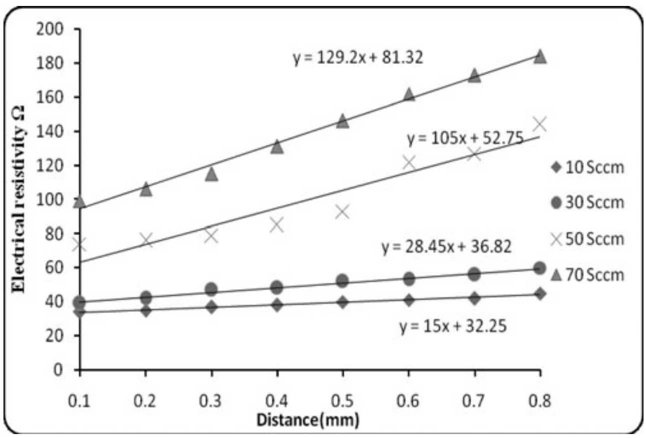

Figure 6. Cr/ITO contact resistivity in 10, 30, 50 and 70 SCCM flows of argon gas with keithley 2361 system.

Table 4. Specific contact resistivity of Cr/ITO in different flows of argon gas

Flow(sccm)	10	30	50	70
$\rho_c(\Omega m^2)$	4.5×10^{-6}	5.5×10^{-6}	8.5×10^{-6}	1.5×10^{-5}

Table 5. Resistivity of Cr thin film in various flows of argon gas

Flow(sccm)	10	30	50	70
ρ_s (Ωm)	1.5×10^{-6}	1.0×10^{-5}	1.3×10^{-5}	1.5×10^{-5}

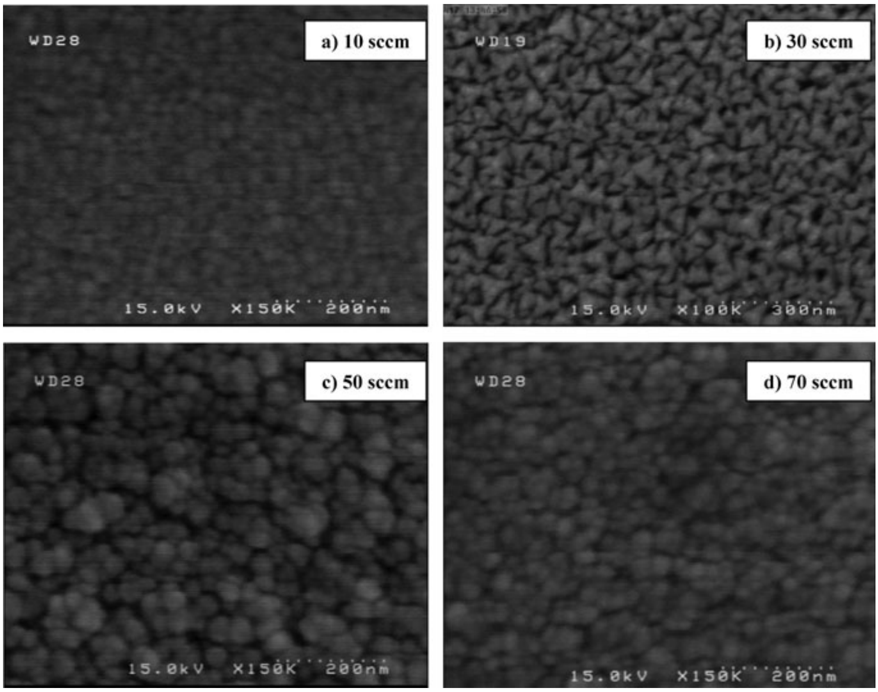

Figure 7. SEM images of chromium thin films in various flows of argon gas: (a) 10 SCCM, (b) 30 SCCM, (c) 50 SCCM, (d) 70 SCCM.

With specific contact relation equation:

$$\rho_c = R_c A_c$$

And by extrapolation the graph, specific contact resistances were calculated and as you can observe in Table 2, the lowest contact resistivity has been obtained in 600 nm thickness of Cr thin film.

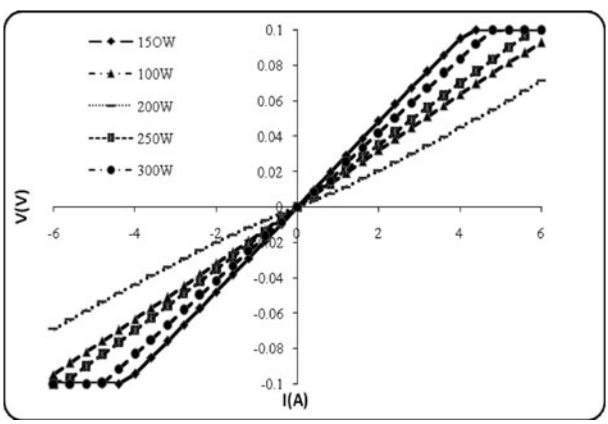

Figure 8. I-V characteristic of Cr 100, 150, 200, 250 and 300 WATT contact to ITO.

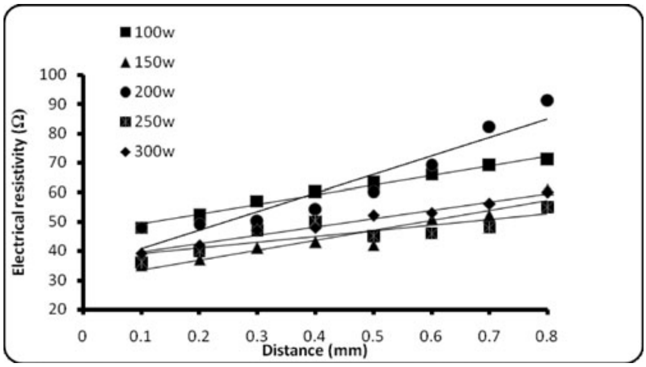

Figure 9. Cr/ITO contact resistivity in different RF powers of sputtering with keithley 2361 system.

Table 3. Indicates the value of sheet resistivity of chromium thin films layer deposited by RF sputtering method. Sheet resistivity's 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 1.0×10^{-5} Ωm.

Surface morphology of chromium thin films deposited by RF sputtering on ITO substrate in different thicknesses are shown in Fig. 4. In this image growing trend of the crystalline grains of chromium thin films can be observed.

2.2. Chromium Deposition in Various Flows of Argon Gas

According to the results, the lowest specific contact resistance is given in 600 nm thickness of Cr thin film. Therefore at this stage of the experiments, we will examine the effect of argon gas flow in sputtering system with maintaining constant thickness at 600 nm. Deposition have been performed four times in different flow 10, 30, 50, and 70 SCCM with constant thickness of Cr layer in similar condition as before.

I–V characteristic of the contact of chromium thin films at different argon gas flows 10, 30, 50 and 70 SCCM to ITO are given at Fig. 5.

Fig. 6 depicts comparison of ohmic contact in various argon gas flows during deposition by sputtering system.

And like the previous time by extrapolation the graph the specific contact resistances calculated and are shown in Table 4.

Resistivities of Cr thin films in different flows of argon gas are given in below Table 5. As we could see the chromium thin film is deposited in flow of argon gas 10 SCCM in comparison with other layer has a lower value.

Table 6. Resistivity of Cr thin film in different RF power of system

RF power (WATT)	100	150	200	250	300
ρ_c (Ωm^2)	7.3×10^{-6}	4.7×10^{-6}	5.5×10^{-6}	5.9×10^{-6}	5.8×10^{-6}

Table 7. Sheet resistivity of Cr thin film in different RF power of sputtering

RF power(WATT)	100	150	200	250	300
ρ_s (Ωm)	1.1×10^{-5}	1.1×10^{-5}	7.2×10^{-6}	7.9×10^{-6}	1.0×10^{-5}

The SEM images of Fig. 7 represent the structure of chromium thin films deposited in different flow of argon gas.

As we could see at flow of argon gas 10 SCCM the grains of Cr thin film are smaller and smoother in comparison with other flows. The worst results are achieved at flow of 50 and 70 SCCM which due to unequal grains of Cr, it's predictable.

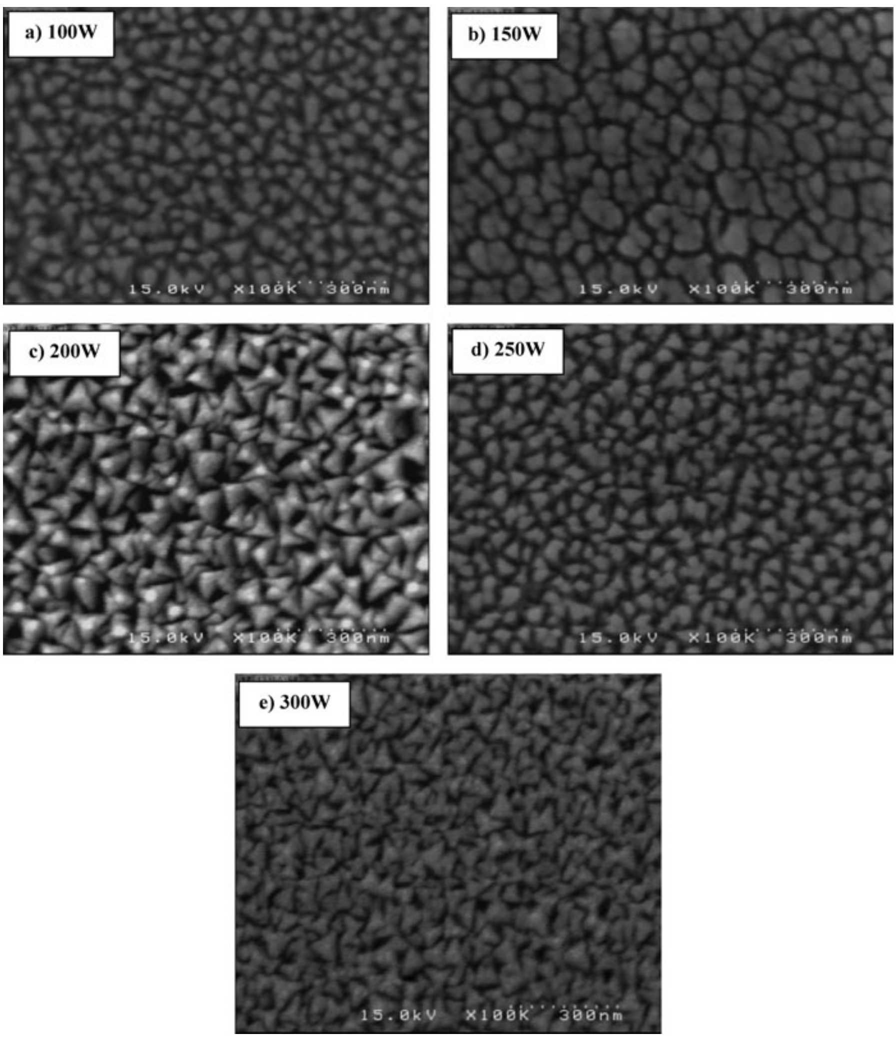

Figure 10. SEM images of chromium thin films in different sputtering RF power: (a) 100 W, (b) 150 W, (c) 200 W, (d) 250 W, (e) 300 W.

2.3. Chromium Deposition in Different Sputtering RF Powers

Results showed 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 for a 600 nm thickness Cr sample, which showed the lowest contact resistivity.

I–V characteristic of the contact of chromium thin films at different sputtering RF powers to ITO are given at Fig. 8.

Fig. 9 depicts comparison of ohmic contact in different RF powers of sputtering system.

The specific contact resistances calculated and are shown in Table. 6.

Sheet resistivity of Cr thin films in different RF power of sputtering are given in Table 7.

The SEM images of the samples, which were grown at different RF powers, are shown in Fig. 10, which represents growing trend of Chromium grain size while increasing RF power of sputtering. As can be seen from Fig. 10 this trend goes towards the crystallization seeds.

3. Conclusion

Best result occurs as the flow rate of Ar reached 10 SCCM at Cr thickness of 600 nm and RF power of 300 W, which is probably happening according to the SEM images due to the grains of Cr which have more chance to deposited on the substrate and fill the boundaries of the crystalline plate.

Chromium thin films of thicknesses 150, 300, and 600 nm are deposited on ITO substrates using RF sputter deposition techniques. The electrical resistivities of the as-deposited films are determined by the four-point probe and keithley 2361 systems. As expected, the specific contact and resistivity decrease with increasing thicknesses in the case of as-deposited films on ITO substrates. As an experimental result, the lowest specific contact resistivity of chromium thin films layer deposited on ITO substrate obtained about 5.5×10^{-6} Ωm^2 at 600 nm thickness in RF power of 300 W and Ar flow of 30 SCCM resistivity of 1.0×10^{-7} Ωm.

The optimal deposition RF power for chromium thin film was found to be 150 W in order to minimize the effect of ion bombardment and/or atomic peening that caused too much stress. Best result 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 4.7×10^{-6} Ωm^2 and specific sheet resistance of 1.1×10^{-5} Ωm.

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