A STUDY OF MOLYBDENUM THIN FILM CONTACT TO MULTI CRYSTALLINE SILICON IN SOLAR CELLS

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1. Abstract

To obtain a suitable ohmic contact with low specific contact and sheet resistance athin film of Mo~1µm is deposited on n-type multi crystalline Si wafer by RF sputtering in Argon atmosphere. The ohmic characterization of Molybdenum contact was investigated by the Keithley2361 and the sheet resistance was measured by the four point probe. Two sets of experiments were carried out to study the resulting deposition of Molybdenum thin film. In the first experiment, during the deposition process, the RF power was varied at constant 100, 200 and 300 Watts and in the second experiment RF power was kept at a constant 300 W while the Ar gas flow was varied at constant 10, 30 and 50Sccm.The specific contact resistance was not affected by varying the RF power of deposition; it remained at about $1\times10^{-3}\Omega m^2$. However, the sheet resistivity reduced to $1.6\times10^{-5}\Omega m$. Although varying the RF power did not impact the resistivity of the contact by much, the XRD spectra of the samples show that there was an increase in the crystalline structure as the RF power was increased. The best result was achieved with the lowest Ar gas flow with the specific contact resistance of $8\times10^{-4}\Omega m^2$ and the sheet resistivity of $3.3\times10^{-6}\Omega m$.The low Ar gas flow not only yielded the sample with the lowest specific contact and sheet resistivity, it also produced the sample with the most orderly deposited molybdenum grains; as observed with the SEM.

2. Introduction

Thin film solar cell technologies were developed to provide high production capacity at reduce material consumption and energy input in fabrication process, and integration in the structure of modules by the deposition process and consequently cost reduction for large scale terrestrial application [Razykov et al, 2011]. Low resistive ohmic contacts are crucial for both device applications and the study of fundamental physics [Takada et al, 2010]. The most important parameter for ohmic contacts is the contact resistance, which depends on the metal and substrate [Gambino and Colgan, 1997].

Molybdenum, a chemical element, can provide the electrical properties of an ohmic contact [Martinez, Guillen, 2003]. It has a very high melting point (2610℃) [Khan, Labbe, 1997] and is able to withstand extreme temperatures without thermal expansion or softening. It also exhibits excellent corrosion resistance, weld-ability, and thermal and electrical conductivity [http://www.evanstechnology.com/molybdenum.html]. Sputtering is the most widely used method for deposition [King et al, 1998, 1999]. Sputtered Molybdenum coating used in the production of solar cells and thin film flat panel displays is one of the emerging applications of the material. It is generally accepted that the work function for Molybdenum in device applications is dependent upon the conditions of its deposition and subsequent processing. This material has a high work function of 4.6–4.9eV [Yun and Rhee, 2008].

In this work, Molybdenum films were used as the back contact layers for the silicon based solar cells. This study is composed of two main experiments; in the first experiment the RF power of the sputtering system was varied and in the second experiment the flow of sputter gas was varied. The conductivity and the contact resistivity of the resulting Mo/Si contacts were studied. Furthermore, the Molybdenum films were studied using X-ray diffraction in order to determine the influence of the various RF power on crystallographic properties and the a scanning electron microscope (SEM) was used to distinguish the changes in various Ar gas flow.

3. Experiment

3.1. Sample Preparation

The multi crystalline silicon (mc-Si) wafers were cut into 1cm × 1.5cm pieces by DICER system. In order to remove all foreign matter from the surface of the Si wafers (dirt, scum, silicon dust, etc.) prior to processing, the silicon substrates were cleaned chemically using a modified-RCA process. The chemicals used in this process were comprised of ammoniac, hydrogen peroxide, and DI water by the volume ratio of 1:1:5.

The Molybdenum film was deposited on Si substrates using a RF sputtering system in the Argon atmosphere from a Mo target with a purity of (99.9%). The sputtering system conditions for both experiments are given in Tab.1. In the first experiment Molybdenum was deposited using three RF power depositions: 100, 200 and 300 watt and Ar gas flow kept at 30Sccm. In the second experiment the RF power was kept at 300 watts and three Ar gas flow were used: 10, 30 and 50 Sccm. Finally, the thickness of the Molybdenum films was measured using the DEKTAK profiler.

Tab.1: Optimized sputtering condition for preparing Mo thin films

Initial vacuum	8×10^{-6} Torr
Sputtering pressure	3.7×10^{-2} Torr
Sputtering temperature	Room.temp.
Film thickness	1 µm

The photolithography proccess was used to pattern the samples. The thicknesses of the Molybdenum films were determined using the DEKTAK profiler and the I-V curves of the contacts were attained by utilizing the Keithley 2361. Moreover, a four point probe was used to determine the sheet resistivity of the Mo film.

For the first part of the study, the fabricated samples were studied using an X-ray diffraction (XRD) to determine the samples' predominant crystal faces. For the second part of the study, the samples were imaged under a scanning electron microscope (SEM) in order to study their morphology.

3.2. Resistivity measurement

This study focuses on the contact resistivity ρ_c, since it is the best parameter that characterizes the quality of an ohmic contact [Musa et al, 1983]. The contact resistance of Mo to Si was determined using the Transmission Line Method (TLM) [Scrooder, 1990]. Fig.1 shows a TLM structure and a schematic of a patterend sample which was prepared by photolithography and etched in Molybdenum etching solution. The distance between each pad wasvaried from 0.8mm to 0.1mm by 0.1 decrements. The area of each pad is 0.4mm × 0.8mm.

The TLM was used to measure the contact resistance between deposited metal films and Si. The total resistance R_T of the metal/semiconductor contacting system is:

$$R_T = \rho_s \frac{d}{Z} + 2R_C \qquad \text{(eq.1)}$$

Where ρ_s is the resistivity of semiconductor, d is the distance between each two pads and the R_C the resistance of metal/semiconductor contact. If the distance between metal pads is minute (d→0), we can approximate $R_T \rightarrow 2R_C$. The total electrical resistance as a function of the distance between each two pads is displayed in a graph in Fig.1. By extrapolating the points displayed in each chart the total resistance was calculated.

For anohmic contact, the specific contact is defined as[Fahrenbruch, 1992]:

$$\rho_C = \left.\frac{dV}{dJ}\right|_{V=0} = R_C A_C (\Omega\text{cm}^2) \qquad \text{(eq.2)}$$

Where ρ_C is the specific contact resistivity and the A_C is the area of a pad. Once the contact resistivity of pads and semiconductor were measured by the Keithley2361 the specific resistance was attained by utilizing eq.2.

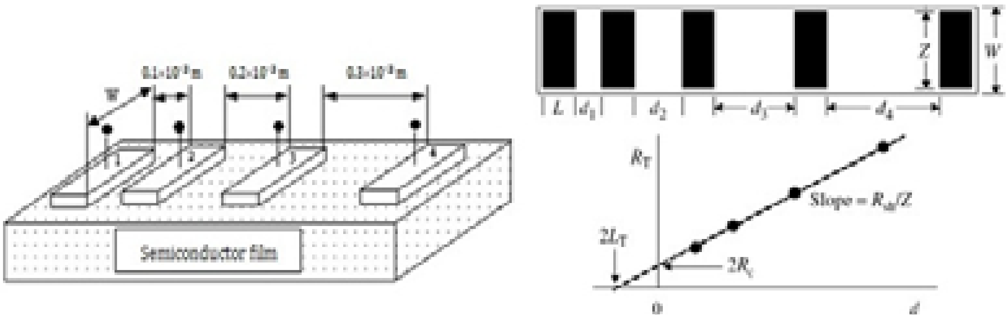

Fig.1: TLM structure and the extrapolation of a plot of electrical resistance as a function of contact spacing d, to find the total contact resistance

For understanding the changes of sheet resistivity experiment and the effect of the parameters in each the Four Point Probe was used.

4. Results and discussion

4.1. Effects of various RF powers

In this part of the experiment, the RF power was varied and the flow of Ar gas was kept fixed at 30Sccm. The RF power depositions of 100, 200 and 300 W were used. The I-V characteristic of the contact of the Mo to Si is illustrated in Fig. 2.The linear behavior of the I-V curves confirms Molybdenum's ohmic property.

By extrapolating the points were measured with two probes of Keithley2361 which are shown in fig. 3 charts the total resistance achieved and according to 3.2 the specific contact resistivity could be figured out.

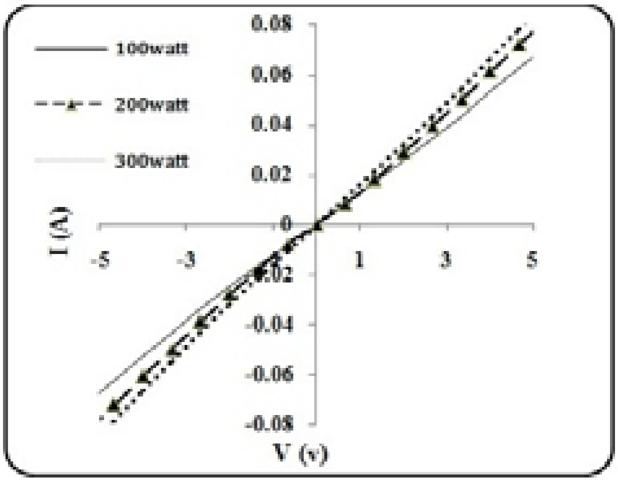

Fig.2: I-V characteristics to show the ohmic contact

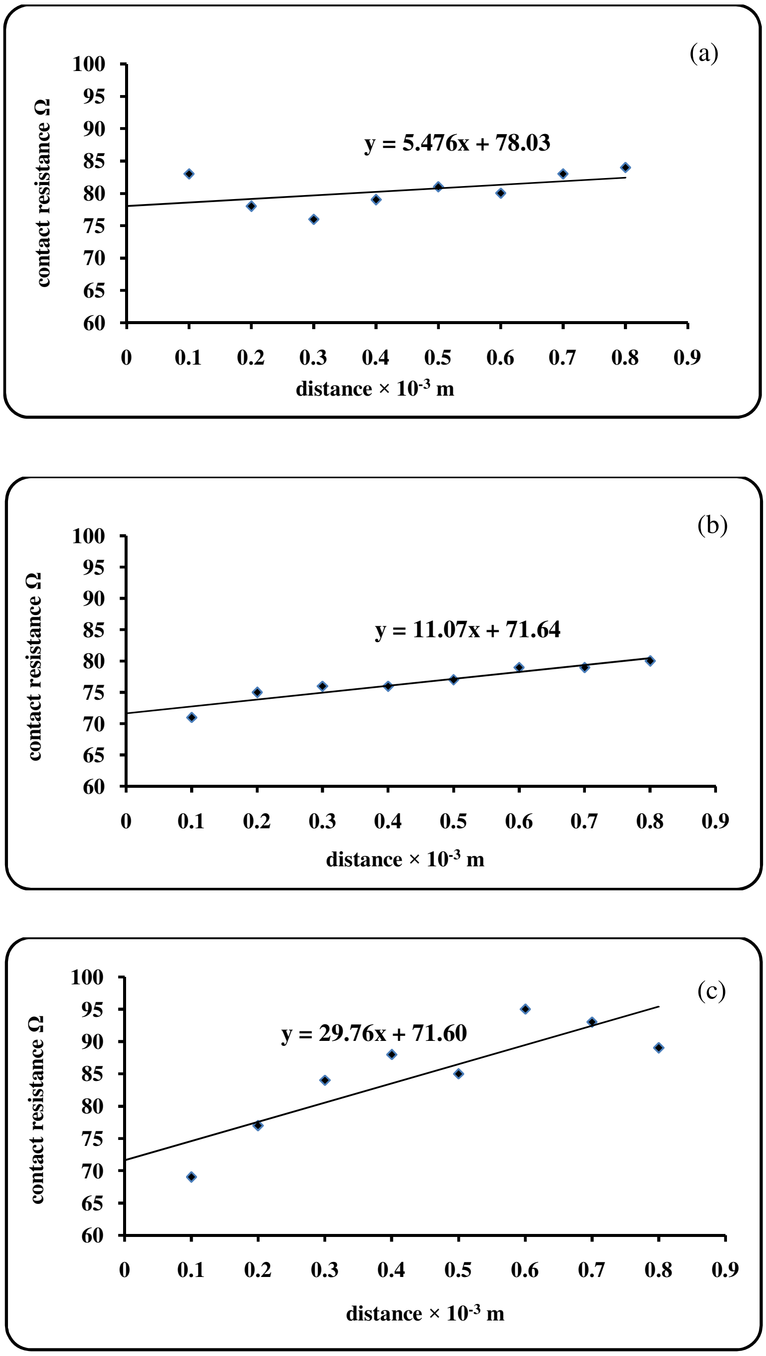

Fig.3: The plot of electrical resistance for (a)100 (b)200 (c)300 watt RF power deposition with extrapolation of it

The results of specific contact and sheet resistivity for the samples in three various RF power depositions are recorded in Tab.2. According to the results, although increasing the power of deposition reduces the sheet resistivity to 1.6×10^{-5}Ωm, it does not have much effect on the specific contact resistance, which remains around 1.1×10^{-3} Ωm^2.

Tab.2: specific contact resistivity and sheet resistivity

P (watt)	100	200	300
$\rho_c(\Omega m^2)$	1.2×10^{-3}	1.1×10^{-3}	1.1×10^{-3}
$\rho_s(\Omega m)$	3×10^{-5}	2.5×10^{-5}	1.6×10^{-5}

The XRD spectra depicted in Fig. 4 displays the crystallographic orientation of the Mo films. Results not only, indicate that at high power deposition, the Mo films grow with preferential orientation along the (1 1 0), but also that by increasing the RF power the Mo films become more oriented so that the samples deposited by the RF power greater than 200W exhibits preferential growth along the (2 1 1) plane.

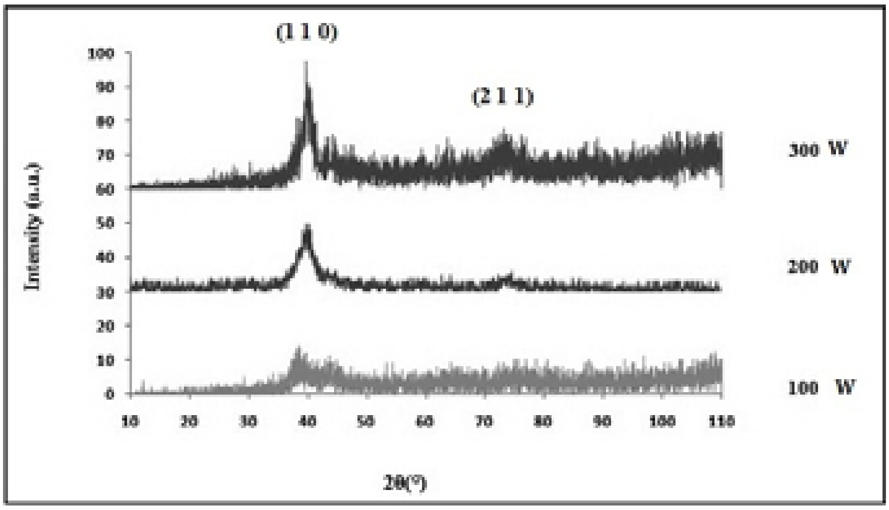

Fig.4: XRD spectra of the three Mo films deposited on Si in power of deposition 100, 200 and 300 W

4.2. Effects of various gas flows

In this part of the experiment, the flow of Ar gas was varied while the RF power was kept constant. Three different flows of gas were used 10, 30 and 50Sccm and the RF power was kept at 300Watt. Then the specific contact and sheet resistivity resulted in each deposition process was measured, and each deposition sample was imaged under a scanning electron microscope (SEM) in order to observe its surface texture.

As the results are shown in Tab.3, the lowest specific contact and sheet resistivity have been gained in the lowest Ar gas flow. There are two reasons for this result. Firstly, in the lower Ar gas flow deposition, fewer Argon molecules absorbed the same RF power; hence each Argon molecule carried more energy.

Tab.3: The specific contact resistivity and sheet resistivity as a function of gas flow

Flow(sccm)	**10**	**30**	**50**
$\rho_c(\Omega m^2)$	8×10^{-4}	1.1×10^{-3}	1.3×10^{-3}
$\rho_s(\Omega m)$	3.3×10^{-6}	1.6×10^{-5}	3.5×10^{-5}

Secondly, by comparing the images from the SEM in Fig. 5, it can be observed that the deposition with the lower gas flow resulted in a more ordered surface. This is in turn, due to the fact that the low gas flow provided the grains of molybdenum with more opportunity to deposit on the substrate and fill the boundaries of the crystalline plates.

Finally, it is important to note that, deposition using a lower gas flow not only results in better specific contact and sheet resistivity, but also it is more economical because less gas is wasted.

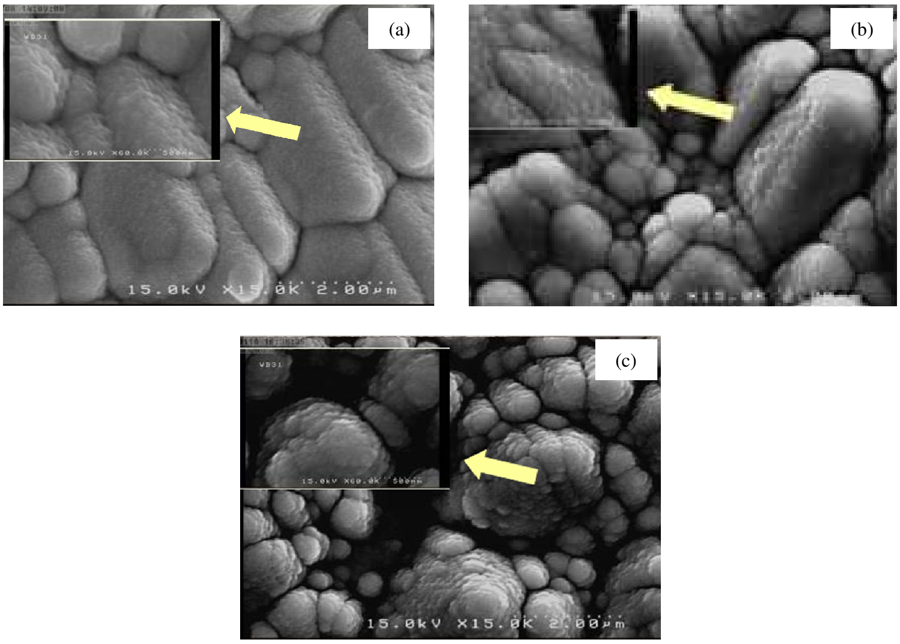

Fig.5: The SEM micrographs of the as-deposited Mo inflow of Ar (a) 10 sccm (b) 30 scm (c) 50 sccm

5. Conclusion

In order to effectively adopt the Molybdenum back contact for polycrystalline silicon, we studied the effects of various RF powers and various Ar gas flows while Molybdenum was deposited. In the first part of the study, we showed that the influence of the RF power over the electrical properties of the Molybdenum is weak and the sheet resistivity of the resulting films were almost unaffected by the variations in the RF power. In The second part of the study we have shown that the flow of the Ar gas during the deposition process impacts the specific contact and sheet resistivity. The lowest Ar gas flow resulted in the lowest sheet resistivity and the most ordered sample surface.

6. References

Fahrenbruch, A.L., Bube, R.H., Fundamentals of Solar Cells, Academic press, New York, 1992

Gambino, J.P., Colgan, E.G, 1997, Siicides and ohmic contacts, J. Material Chemistry and Physics, 52, 99-146

Khan, A., Labbe, J., 1997, Luminum nitride-molybdenum ceramic matrix composition, J. European ceramic society, 17, 1885-1890

King, T.J*et al.*, 1999, Novel Materials and Processes for MOS Devices, MICRO Project 98-071

Martinez, M.A., Guillen, C., 2003. Comparison between large area dc-magnetron sputtered and e-beam evaporated molybdenum as thin film electrical contacts, J. Materials Processing Technology. 143-144, 326-331

Musa, A. et al., 1983, J. Appl. Phys, 54, 3260

Razykov, T.M., Ferekides, C.S., Morel, D., Stefanakos, E., Ullal, H.S., Upadhyaya, H.M., 2011, Solarphotovoltaeic electricity: Current status and future prospects, J. SOLAR ENERGY, article in press.

Schrooder, K., 1990, semiconductor material and device characterization, third ed. John Wieleys & Sons, New Jersey

Takada, Y., Muraguchi, M., Edhan, T., Nomora, S., Shiraish, K., 2010, proposal of a new physical model for ohmic contacts, J. Physica E, 42, 2837-2840

Yun, D, Rhee, S., 2008, Effect of molybdenum electrode annealing on the interface properties between metal and pentacene, J. Organic Electronics, 9, 551-556

http://www.evanstechnology.com/molybdenum.html