International Journal of Engineering & Technology, 7 (4.30) (2018) 326-329

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Characterization of Cr/Ag Bi-Layer thin Metal Contacts Sputter Deposited on *N*-Type Si Semiconductor

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Abstract

Good electrical conductivity of metal contacts on semiconductor are very crucial in determining quality of the energy conversion efficiency. This paper reports on the Cr/Ag thin metal contacts properties sputter deposited on n-type Si. The metal contacts were characterized based on the morphological and electrical properties. The surface morphology of metal contacts was characterized by using atomic force microscope (AFM) and resulted in increment of the surface roughness from 1.35 nm to 9.21 nm at the thickness of 20 nm to 100 nm. The electrical characteristics were characterized by using four-point probe system. From the measurement, the lowest electrical resistivity was measured as 1.19×10^{-6} Ω-cm at Ag thickness of 100 nm. Whereas the electrical conductivity of the thin metal contact was obtained as 8.40×10^{5} Ω-cm^{-1} at Ag thickness of 100 nm. From the analysis, it is clearly shown that as the Ag thin metal thickness gets thicker, the surface roughness gets rougher thus resulting in the improvement of the electrical characteristics of the Si/Cr/Ag contacts.

Keywords: *Cr/Ag; Metal contacts; thin films; Si semiconductor; sputter.*

1. Introduction

Metal material is a good electrical conductor especially gold (Au), copper (Cu), titanium (Ti), aluminium (Al), nickel (Ni) and argentum (Ag). The conductivity of each metal material is differed by their physical structure itself which is formed by the movement of the free electron of each metal material and thus affect the electrical conductivity when there is a presence of the potential energy through it. All of these metal material has their own unique properties such as Ni which is able to reduce the channel between the drain and source gate which will decreased the resistivity of the device and thus making this metal material to become important in complementary metal oxide semiconductor (CMOS) device industry [1]. While for Ti, is its grain refinement formation that produce the smoother surface of deposited thin film and also has a high resistance to the corrosion that enable the metal contact to be applied in high thermal energy device such as in the laser technology [2]. Then, for the Au metal material, it has high malleability, ductility, resistance to corrosion and also one of the good electrical conductor material and has been widely used in metal contact technology [3]. As for Ag, it will produce neutral color in the range of visible light spectrum and also make it as an ideal candidates for the low thermal emissivity that is reported by Ding *et al.*[4]. But after all, by comparing the electrical conductivity as well as their electrical resistivity, Ag offers as a good candidate to be used in metal contact technology due to its lowest electrical resistivity and highest electrical conductivity which are 1.59×10^{-8} Ω-m and 6.30×10^{7} (Ω-m)$^{-1}$ respectively among other materials.
The electrical and structural properties of thin metal films can be affected by a large number of parameters such as deposition time, surface morphological, thickness and type of substrates. Therefore, the composition of the two or more thin metal film phases may give benefits to the metal contact technology such as an improvement in morphological, optical and electrical properties of the deposited multilayers thin film. Many researchers have reported on the bi-layer metal contacts such as Au/Cu, and Ni/Cr, Cr-C/Ag and Ni/Ag [5], Ti/Al, Cr/Pd [6] and Ni/Au. For the Au/Cu bi-layer thin film which is both in the transition metal material, the bi-layer thin film increases the grain size during the increment of the thin film thickness and thus decreased in the electrical resistivity during the annealing treatment process. Their behavior tends to be stable which is reported by Novelo *et al.* [7]. For Ni/Cr bi-layer thin film, Cheng *et al.* [8] reported that the resistance of the thin films is non-linearly decreased with the increased of the deposition rate and had no apparent variations during the deposition time increment.

In electronics industry, multilayer thin film is used as metallic contacts or as a relays in micro-electrochemical systems (MEMS). The selection of the sub-layers sandwich depends on its MEMS application. Au, Ag and Cu are commonly used as a conduction layer while Cr, Ti and Pt are employed as an adhesion layer which is acted as a diffusion barrier for the electric charge particles. In the research reported by Bassiri [9], the performance in electrical and mechanical behavior of the contact relays also depends on the adhesion layer such as Ti or Cr. Between these two materials, Cr layer seems to be more favorable intermediate layer as compared to Ti due to the less increased in electrical resistivity. For Cr-C/Ag multilayer deposited thin film, Folkenant *et al.* [10] stated that the resistance of the deposited thin film decreased with the addition of Ag nanoparticles which enable the Cr-C/Ag thin films to be applied in the electric contact application. This metal carbide transition material is one of the potential candidates for the applications of high hardness, high wear resistances, low friction as well as high corrosion resistance conditions. Besides, it also gives better contact properties.

Deposition of metal contact semiconductor substrate can be done by various technique such as physical vapor deposition (PVD) and chemical vapor deposition (CVD). Mostly used PVD technique are thermal evaporation and sputtering, while the metal organic chemical vapor deposition is one example of the CVD technique. Thermal evaporation technique is the most simple and low cost technique to be used in deposition process, but it resulted poor adhesion contact while MOCVD technique is highly cost as compared to sputtering technique. In the other hand, sputtering technique is the most favorable deposition technique because this technique is easily to handle and the thickness of the metal deposition contact can be controlled which can improve the resistivity of the contact.

This paper reports on the properties of Cr/Ag thin metal contacts sputter deposited on n-type Si at different Ag thicknesses. The metal contacts were characterized based on the morphological and electrical properties.

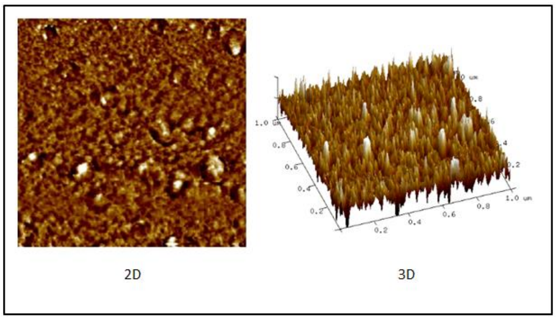
2. Methodology

In this study, n-type Si is chosen as a substrate as Si offers a good quality, low cost and vastly used in semiconductor optoelectronics industry. The Si wafer was cut into small pieces of 1.0×1.0 cm^2 and cleaned by using acetone, IPA and finished by DI water to remove surface contamination. After cleaning, very thin layer of intermediate layer of Cr (5 nm) was deposited on the Si substrate followed by Ag top layer at different thicknesses. The deposition process of the thin metal contact on the substrates were being done by using RF sputtering system. For the thickness of Ag metal with the purity of 99.99 %, it was varied at 20, 40, 60, 80, 100, and 120 nm each. The thickness of the deposited thin film was measured based on the sputtering rate of the sputtering system.

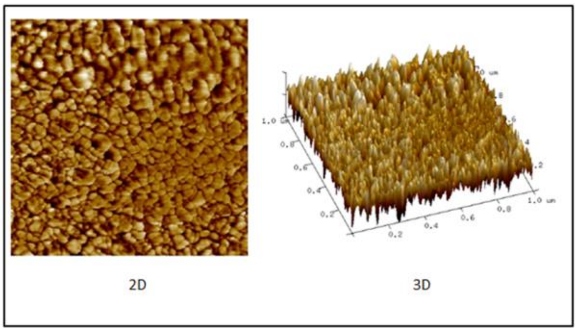
The surface morphological and electrical properties of the metal contacts were characterized by using atomic force microscopy (AFM) and four-point probe. The surface morphological characterization by AFM were scanned by using tapping mode. The metal contacts were characterized based on its electrical resistivity and sheet resistance by using four-point probe. The conductivity then was determined by calculating the reciprocal of the resistivity.

3. Results and Discussion

Surface morphological of the Cr/Ag metal contacts were characterized in 2D and 3D by using AFM as shown in Fig. 1. From the analysis, as the thickness of the thin film increases, the surface of the thin film becomes rougher from 1.35 to 9.21 nm at thickness of 20 and 100 nm respectively, as shown in Fig. 2. The formation of the coarse grain seems to be unavoidable as the thicker Ag metal material were deposited. But, it is significant to the research conducted by Loka and Lee [12] that stated the bi-layer surface was crystallized and forming a coarse grain resulted from the increment of the Ag metal material thickness. Thus, the morphological surface of the bi-layer thin film will be rougher. Besides that, Changwon *et al*. [13] also convinced that the additional roughness occurred is due to the dense wrinkles and bumps formation throughout the surface during the vacuum phase of the sputtering process that will deform the bi-layer thin film surface.



(a)



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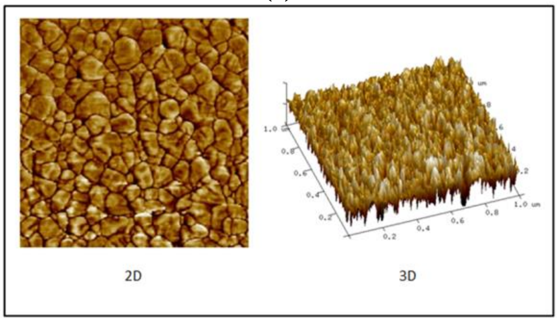
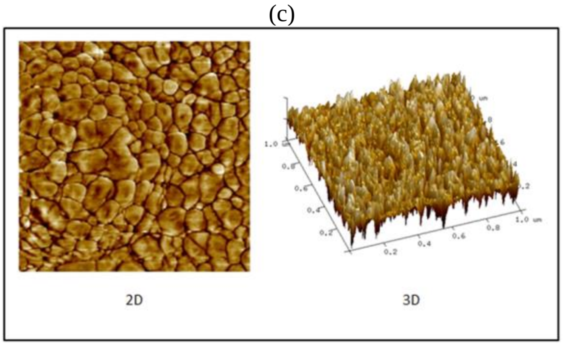
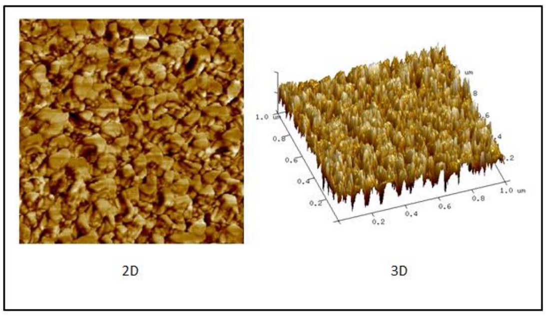


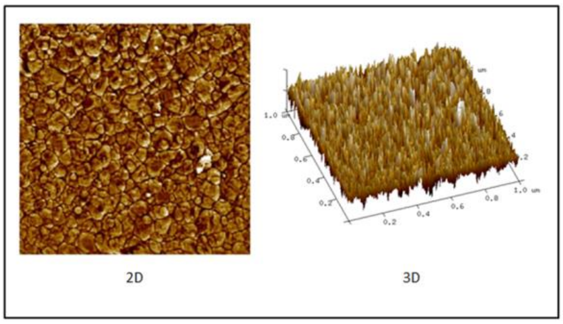
(c)



(d)



(e)



(f)

Fig. 1: Surface morphological of Cr/Ag thin metal contacts sputter deposited on n-type Si scan bay AFM in 2D and 3D (a) 20 nm (b) 40 nm (c) 60 nm (d) 80 nm (e) 100 nm (f) 120 nm.

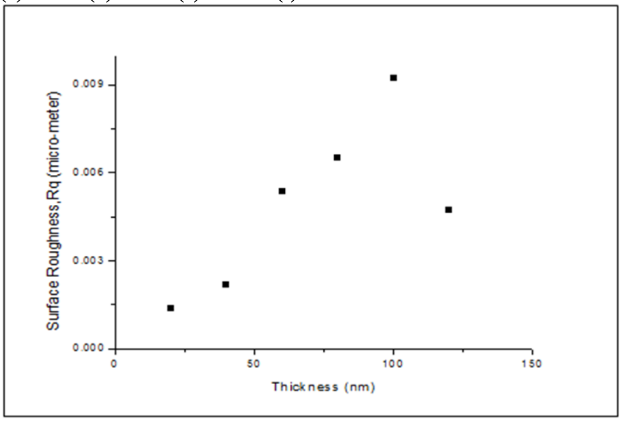


Fig. 2: Surface roughness, R_q at different Ag thickness.

The electrical characterization was performed by using four-point probe. Fig. 3 shows the relation between the resistivity of Ag thin metal film at different deposited thickness. It can be seen that, as the thickness increased from 20 to 100 nm, its electrical resistivity was continuously decreased which follows the theoretical data. However, the resistivity (ρ) of thin film is slightly increased at the thickness of 120 nm which is 2.82×10^{-6} Ω-cm. This may be due to the existence of the impurities that may increase the resistance to the electrical current to pass through its surface. Generally, the resistivity of the bulk Ag is the lowest as compared to other metal material which is 1.59×10^{-6} Ω-cm. From the experiment, after being deposited on Si/Cr, the lowest electrical resistivity of the thin film is 1.19×10^{-6} Ω-cm at 100 nm.

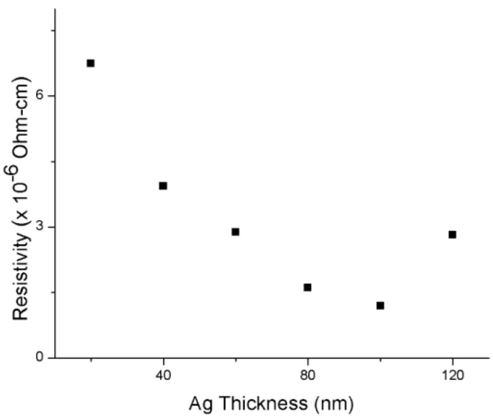


Fig. 3: Electrical resistivity of Cr/Ag metal thin films at different Ag thicknesses.

Further analysis shows the electrical conductivity of the Ag thin films at 100 nm is the highest of 8.40×10^5 (Ω-cm)$^{-1}$ as compared to other thickness, as shown in Fig. 4. The presence of the very thin deposited Cr under-layer between Si substrate and Ag top layer which act as a buffer layer as well as good adhesive to upper contact layer. This buffer layer will prevent the charge carrier from being ejected from the thin film surface and depleted. Thus, will increased the electrical conductivity as the resistivity of the metal thin films decreases.

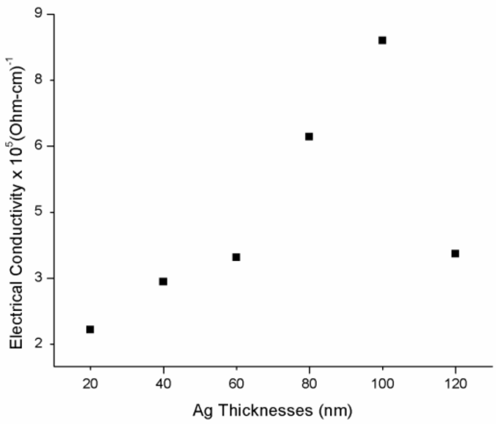


Fig. 4: Electrical conductivity of Cr/Ag sputter deposited on Si at different Ag thicknesses.

Fig. 5 shows the sheet resistance, R_s of the Si/Cr/Ag thin metal contacts against the different thickness of Ag material deposited on Si/Cr substrates. Similar to the electrical resistivity of the deposited thin film, the sheet resistivity, R_s of the thin film were decreased as the thickness of thin film increased. Based on the analysis, the highest sheet resistivity of Si/Cr/Ag thin film is at the thickness of 20 nm which is 3.37×10^{-1} Ω/sq while the lowest sheet resistivity, R_s was at the thickness 100 nm which is 1.19×10^{-1} Ω/sq.

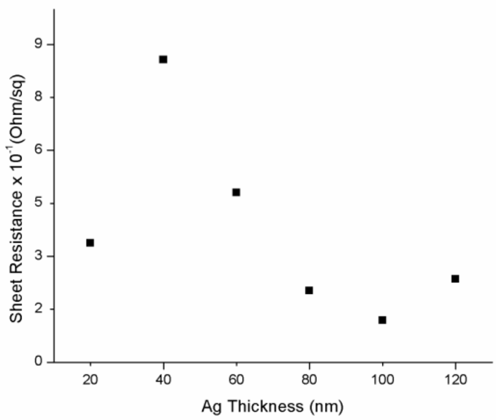


Fig. 5: Sheet resistance of the Si/Cr/Ag thin metal contacts.

Based on the electrical properties characterization, the electrical resistivity of the deposited thin film depends on the thickness of the metal contact. The electrical resistivity (ρ) can be expressed as

$$\rho = \rho_p + \rho_m + \rho_r + \rho_i + \rho_s \quad (1)$$

where ρ_p , ρ_m , ρ_r , ρ_i , ρ_s represents the electrical resistivity caused by photon, impurity, defects, grain boundary and the surface scattering effect, respectively. The resistivity caused by impurity and defects can be classified as the same deposition conditions except the deposition time. While, for the resistivity caused by the surface scattering should not play a role in this condition due to the lower of electron mean free path compared to the varied deposition thickness that ranging from 20, 40, 60, 80, 100 and 120 nm [9]. Experimentally, as the thickness of the thin film increased, the electrical resistivity is continuously decreased from 20 nm to 100 nm. This is due to an increment of the grain size that will reduce the grain boundary thus decreasing the electrical resistivity of the thin film. But, there were small increment of the electrical resistivity at the thickness of 120 nm. This may due to the present of the impurities that will decreased the charge carrier concentration. The electrical conductivity shows an increment as if it is inversely proportional to the electrical resistivity. While, the sheet resistance was decreased as the thickness of the thin film increased.

4. Conclusion

The Cr/Ag thin metal contacts show good surface morphological and electrical properties as the thicknesses increases. The surface roughness was become rougher which is 1.35 to 9.21 nm as the thickness increased from 20 nm to 100 nm respectively as well. The electrical resistivity depends on the thickness of the thin film and were decreased from 6.74×10^{-6} to 1.19×10^{-6} Ω-cm at the thickness of 20 and 100 nm, respectively. The electrical conductivity was increased from 1.83×10^{5} to 8.40×10^{5} $(\Omega\text{-cm})^{-1}$ as the Ag thickness increases to 100 nm. In addition, the sheet resistivity was decreased from 3.37×10^{-1} to 1.19×10^{-1} Ω/sq.

Acknowledgement

This research was funded by Fundamental Research Grant Scheme (FRGS) with grant No. 1600 from Malaysian Ministry of Higher Education and Incentive Grant Scheme for Publication (IGSP) with grant No. U670 by Universiti Tun Hussein Onn Malaysia. Thanks also to Physics Laboratory, Faculty of Applied Science and Technology, and Microelectronics & Nanotechnology-Shamsuddin Research Centre (MiNT-SRC) for the facilities provided.

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