

Study and Calculation Electrical Properties of Silver Thin Layers by Four-Point Probe Method

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Abstract

In this research Ag thin layers on silicon p-type substrate with crystal orientation (100) and 300, 360 and 400 nm thicknesses by thermal evaporation was deposited. Four-point probe and XRD analysis of surface layers consequently for study electrical properties included of sheet resistance, conductivity, resistivity and investigation of Ag phase formed, was done. As result XRD was shown that at 400 nm the best state of silver face-central cubic (FCC) structure with crystal orientation (200) was formed and by Deby-Scherrer formula distance between successive plates was calculated 8.94 nm. Four-point illustrated that sheet resistance and electrical resistivity with increase thickness, decreases while conductance increases. At 400 nm thickness Ag layer has the most conductivity and the lowest resistance.

Keywords: FCC lattice; Thickness; Sheet Resistance; Conductivity

Introduction

Physics of thin layer to study material that one those dimension than two other dimension is small [1]. A layer with thickness between 0.1 nm till several microns was called thin layers [2]. Mostly three methods for formation thin layer depending on intensity of interaction between layer atoms in plant and substrate atoms exist [3]. In mostly cases layer are in three dimensioned core formed, constitution, growth and conjoin islands. Fundamentally three various groups of thin layers exist; amouf, polycrystalline and mono crystal [4-6]. Entirely thin layers attribute (electrical, optical, magnetic, thermal and mechanical) was divided in two groups; inherent and extrinsic [7] that was affected of special manner of generation and geometric condition of deposition, type of material layer, quality and physical condition of substrate that was included crystal structure, orientation and roughness [8,9].

Inherent and extrinsic properties consequently were related to low thickness and layer preparation method [10]. For example one of the inherent properties is layer specific resistance that decreases opposite its thickness while also it depends on layer's crystalline grain size and thin layer preparation method [11]. Vacuum evaporation is one of the general methods of provision very pure silver layers and under condition was rather controlled [12]. This method has properties involve of possibility use of various metal target, high rate deposition and good cohesion layer to substrate [13]. In this research, silver thin layers on silicon substrate by physical vapor deposition (PVD) were made. Electrical and structural properties via four-point probe and XRD analysis were probed.

Sample Preparation

For preparation silver thin layer by physical evaporation method [14] at first the substrate has been chemically cleaned and then rinsed in de-ionized water and dried in air. Then tungsten metal with silver was laid in deposition device furnace until tungsten metal by reason very high melting point in comparison with silver was heat transfer and evaporation silver.

Three Ag layers on p-type silicon with (100) orientation and 1 cm × 1 cm dimension in 6.5×10^{-5} mbar vacuum and 300, 360 and 400 nm thickness with 0.4 nm/s deposition rate, were deposited. For eliminate pollutions on silicon surface and more cohesion silver on substrate,

temperature until 100°C was raised. Measuring thickness moment deposition was used of Edvard STM device. Thus that with changing frequency of thickness meter as the result of silver deposition on crystal near of silicon wafer, this frequency changing value was converted to thickness size. For study layers crystal structure and electrical properties consequently was used XRD analysis (PHLIPS-PW3710) and four-point probe meter.

Pay attention to data given relation between structure layers with electrical properties characterized.

Theory of Four-Point Probe Resistance Meter

For measuring electrical resistivity of semiconductor material, four-point probe device was used [15]. By helping this analysis also can measure sheet resistance of thin and thick layers. This device is included of four probes with equal distances from tungsten metal that direct current applied between outside probe and voltage was measured between inside probe. At the end of each probe for lessen damage to sample in the time of analysis coils was devised. So by the values obtained for voltages and currents, conductivity and sheet resistance can measured. Schematic plot of device was shown in Figure 1.

For calculation relations in thin layers, it was supposed that metal probe was very small and at sample width direction is semi-infinity. So in local that thickness layer; t was very smaller than distance between probes; s ($t \ll s$) loops current are circle form that originate of outer probe tip.

$$\Delta R = \rho \left(\frac{dx}{A} \right) \quad (1)$$

Which R is resistance, ρ is resistivity, A is current crossing section

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Received February 23, 2017; **Accepted** March 13, 2017; **Published** March 31, 2017

Citation: Askari MB, Shahryari M, Nanekarany S (2017) Study and Calculation Electrical Properties of Silver Thin Layers by Four-Point Probe Method. J Laser Opt Photonics 4: 150. doi: [10.4172/2469-410X.1000150](https://doi.org/10.4172/2469-410X.1000150)

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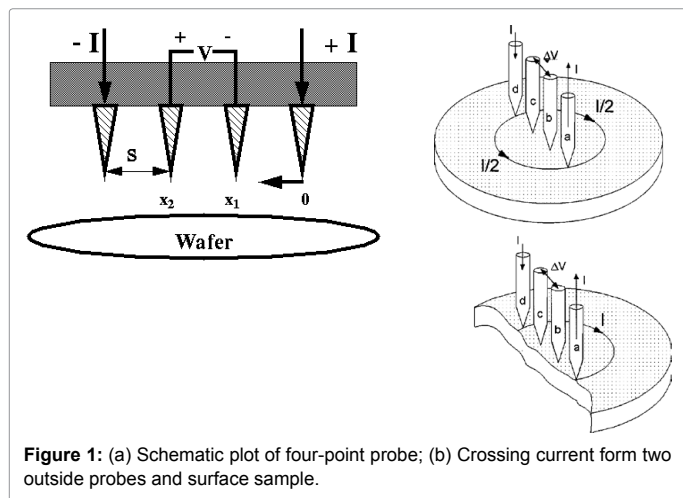


Figure 1: (a) Schematic plot of four-point probe; (b) Crossing current form two outside probes and surface sample.

in layer and dx is part of current way on layer between two outside probe. Pay attention to assumption that current is cricoid, in relation surface was expressed in form $2\pi xt$. With replace relation become as bellow:

$$R = \int_{x_1}^{x_2} \rho \frac{dX}{2\pi Xt} = \int_s^{2s} \frac{\rho}{2\pi t} \frac{dX}{X} = \frac{\rho}{2\pi t} \text{Ln}2 \quad (2)$$

And with notice to current relation in two outside probes; $R = \frac{V}{2I}$ resistivity for one thin layer eventuates in form relation 3:

$$\rho = \frac{\pi t}{\text{Ln}2} \left(\frac{V}{I} \right) \quad (3)$$

Figure 1

It should be look after that relation 3 is independent of distance between probes; s . Also this relation was used for study properties of semiconductor thin layers. In general sheet resistance relation of thin layers was in form; $R_s = \frac{\rho}{t}$ that was shown below:

$$R_s = \frac{\pi}{\text{Ln}2} \left(\frac{V}{I} \right) \quad (4)$$

Finally conductivity by use of relation; $\sigma = \frac{1}{\rho}$ was calculated [16].

Result and Discussion

For study the effect of thickness on electrical properties of sample, four-point probe analysis uses. Sheet resistance, electrical resistivity and conductance by use of relations 3 and 4 were calculated. Amounts of parameters that measured were mentioned in Table 1. As was observed by increases thickness layer, electrical resistivity and sheet resistance decreases but conductance increases (Table 1).

On the hand for study silver phases formed after deposition of with 400 nm thickness under 0-90 degree diffraction angle, done XRD analysis. As in Figure 2 was shown silver peak with crystal orientation (200) at $2\theta=38.250$ degree was formed. With uses of Deby-Scherrer formula, grain size formed was calculated as [17]:

$$t = \frac{0.9\lambda}{B\cos\theta_B} \quad (5)$$

In this relation t is grain size, λ is wave length of irradiative ray, and B is full width at half maximum (FWHM) and θ_B is the angle that the maximum height of peak was observed. Finally distances between silver successive plates in (200) orientation equal to 8.94 nm was calculated (Figure 2).

| Conductivity ($\frac{1}{\Omega-cm}$) | Sheet Resistance (cm^2) | Resistivity ($\Omega.cm$) | Using amperage (mA) | Using voltage (mV) | Thickness layer (nm) |
|---|--------------------------------|--------------------------------|------------------------|-----------------------|-------------------------|
| 0.187×10^3 | 0.177 | 5.31×10^{-6} | 100 | 3.9 | 300 |
| 0.227×10^3 | 0.122 | 4.39×10^{-6} | 100 | 2.7 | 360 |
| 0.290×10^3 | 0.086 | 3.44×10^{-6} | 100 | 1.9 | 400 |

Table 1: Results of four-point probe analysis.

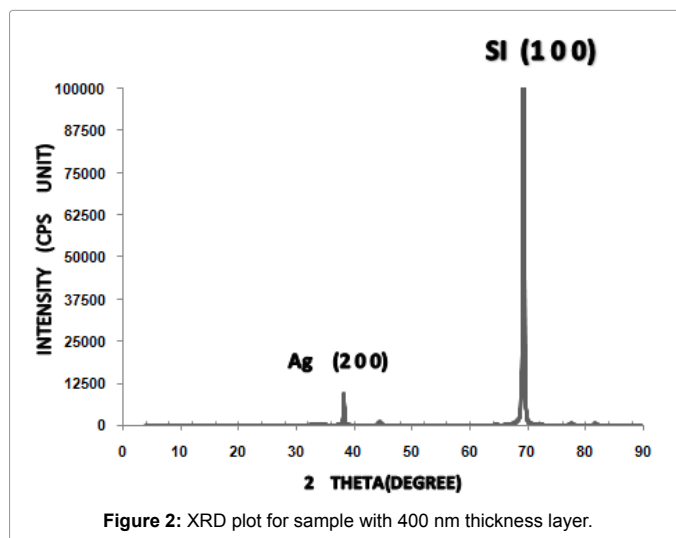


Figure 2: XRD plot for sample with 400 nm thickness layer.

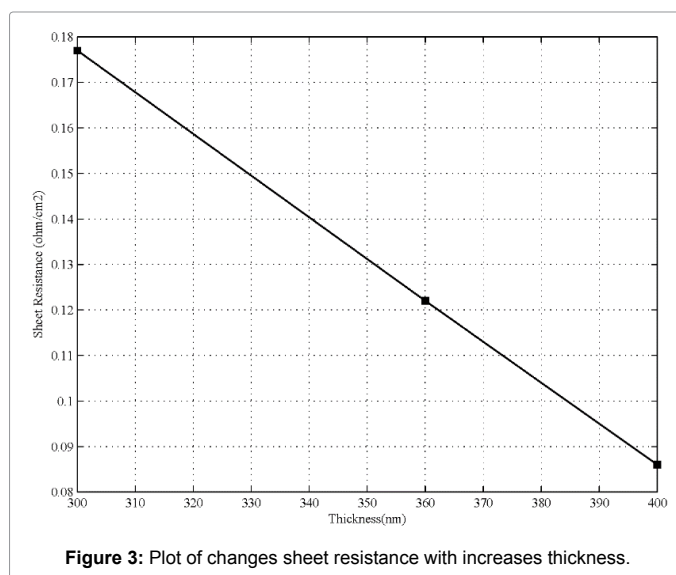


Figure 3: Plot of changes sheet resistance with increases thickness.

Since in this thickness no another peak was not observed, as result absolutely at beginning silver layer with different crystal orientation was started to forming on silicon wafer. Until at 400 nm thickness as was shown in fig 2 the idealist itself orientation at (200) was formed and other crystal orientations was omitted. So it was shown in fig 3, 4 resistances and conductance at first has low quantity and with increase thickness, sheet resistance decreases and conductance increases.

In other words for the reason that Ag in crystalize state has face-center cubic structure (FCC) although the FCC structure was formed but doesn't have specific arrangement however simultaneously with increase thickness FCC structure was better and in 400 nm the arrangement was formed (Figure 3).

Conclusion

Pay attention to Bravais Lattice and coordination number that was expressed instance property of lattice. FCC structure has maximum coordination number, 12. In other words this structure is the densest cubic Bravais Lattice. Also by comparing packing fraction of these lattices was cleared that FCC structure has maximum value, 0.74. As result absolutely silver layer through its structure shows good conduction itself.

Science increases thickness layer consequently was made that structure be more arrangement and enhances crystal plates in one specific orientation. Forming such regular crystal was accompanied with more electrons mobility on surface.

As result this mobility was made that with increase thickness, sheet resistance and resistivity decreases and conductivity increases.

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