

Electrical and structural properties of the Ta/Ag thin films prepared by DC magnetron sputtering

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Abstract. Tantalum on silver (Ta/Ag) thin films have quickly increased into high research for applied science with the promise of suitable for high temperatures environments and micro-systems for electronics applications. Ag and Ta/Ag thin films were deposited on silicon substrates by dc magnetron sputtering method. We choose the dc magnetron sputtering method because it has many advantages, such as high growth rate, the possibility of large area deposition, and low cost. X-ray diffraction (XRD) analysis and four point probe (FPP) were used for determining the prepared samples. For Ag thin film deposited in room temperature, there are no peaks corresponding to Ag in the XRD pattern which demonstrates amorphous structure. Also, the XRD pattern of Ta/Ag thin film illustrates that the peak of Ta has grown to the crystal direction (002), which shows that the structure of deposited Ta layer on Ag thin film becomes a crystalline state from amorphous state. The relationship between thin film resistivity and Ta/Ag film thicknesses are investigated in this paper.

1. Introduction

The electrical and structural properties of thin metal films can be effected by a large number of parameters such as time, surface, thickness and different kind of substrates. A composition of two or more thin metal film phases can improve the structural, electrical and optical properties. The wide use of tantalum thin films is in the knowledge of microelectronics, capacitors and transistors, because of their excellent physical and electrical properties [1-3]. Silver has many interesting attributes, like excellent high frequently virtues, highest electrical conductivity, low resistivity, and a rather high melting point [4]. The inset of Ag particles into thin films cans enhancement film conductivity [5].

With numerous studying the articles and the books, is reached this conclusion that Ta/Ag has been almost reviewed seldom. With these descriptions, the most papers existing in such a research field, are reviewing the electrical properties of Ag/Ta layers. Mardani et al. prepared Ag/Ta and Ag/TaN thin films using a DC magnetron sputtering method. They studied the thermal stability of Ag on SiO₂ with layer of Ta or TaN as a diffusion barrier. They found that Ag on Ta can be used permanent high-temperature metallization [5]. Thus, we predict that the professional applications of Ta/Ag layer are more practical in electrical devices.

In this work, we applied our research investigated the electrical and structural properties of Ta and Ta/Ag thin films that prepared by DC magnetron sputtering method. Eventually, we prepare a summary of our results and present some inferences.



2. Materials and methods

The substrates used in the experiments were (100) p-type silicon wafers. Ag thin films with 20, 30, 40 and 50 nm thicknesses were deposited on silicon (Si) substrate by DC magnetron sputtering of pure Ag in a room temperature. Substrates were cleaned, ultrasonically, in ethanol and acetone for 15 min each and blown dry using N₂ gas before being introduced into the chamber. Thicknesses of prepared samples were controlled by a quartz crystal mass monitor in the chamber. The deposition parameters of Ag and Ta/Ag layers are shown in table 1.

Table 1. Deposition parameters of Ag and Ta/Ag layers.

Samples condition	Base pressure (mbar)	Work pressure (mbar)	Voltage (V)	Current (mA)	Deposition time (s)	Deposition rate (nm/s)	Thickness (nm)
Ag	4×10^{-5}	5×10^{-2}	70	15	100, 150, 200, 250	0.2	20, 30, 40, 50
Ta/Ag	5×10^{-5}	5×10^{-2}	105	65	420	0.48	20

Then the phase and crystalline structure of the prepared samples were characterized by using X-ray diffraction (XRD; Philips pw 1800) analyses using Cu K α X-rays ($\lambda = 0.154$). Conventional four-point probe (FPP5000) resistivity measurements investigated the electrical properties of Ag and Ta/Ag films. The structural and resistivity of thin films will be briefly discussed.

3. Results and discussion

There are no peaks corresponding to Ag in the XRD pattern of the Ag thin film deposited on the Si substrate by 20 nm thickness in room temperature. The XRD pattern demonstrates amorphous structure for all Ag thin films. It is probably due to two reasons that no peaks are seen in Ag samples. Since the thickness of Ag is very low, so the X-ray easily penetrates into the substrate and effects on it. Just the peak of the silicon substrate can be observed in this spectrum. The second reason could be due to an adsorption between the substrate surface and Ag atoms. An adsorption phenomenon occurs because of the properties on the surface of the silicon substrate [6]. These properties have two origins. First, the discontinuity phenomenon which means that the properties of substrate surface are different from the properties of the rest of the substrate points and in fact, the surface atoms are different from the bulk atoms. Second, the unsaturated solid surface atoms which have created a surface bond with neighboring atoms below the surface of solid atoms, but at the level of atoms of the above are free and have the ability to create bonds with other atoms [7-8]. So there is a desire to reach a state of saturation in the molecules of the surface.

The XRD pattern of the Ta/Ag thin film deposited on the Si substrate is shown in 'figure 1'. As can be seen, The peak of the substrate observed at $2\theta = 69.41^\circ$, in addition at $2\theta = 33.11^\circ$, the peak of Ta has grown to the crystal direction (002), which shows that the structure of deposited Ta layer on Ag thin film becomes a crystalline state from amorphous state. So as it was mentioned above, the free Ag atoms have bonded to Ta atoms.

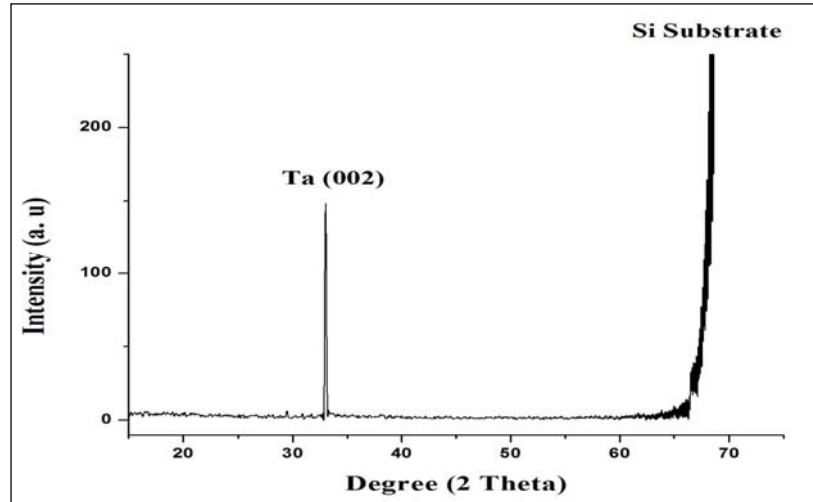


Figure 1. XRD pattern of Ta/Ag thin film.

The electrical properties of Ag and Ta/Ag thin metal films with different thicknesses of Ag from 20 to 50 nm were investigated by FPP method. The result shows the dependence of the Ag films resistivity on thickness. As can be seen, all the Ag thin films had amorphous structure, thus certain changes were not observed in their resistivity. The resistivity of thin films (ρ) can be expressed as [9]

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

Where ρ_p , ρ_m , ρ_r , ρ_i and ρ_s represents the resistivity caused by photon, impurity, defects, grain boundary and the surface scattering, respectively. The photon can be assumed to have the same influence on resistivity. The resistivity caused by impurity and the defects should be the same under the same deposition conditions except varying deposition time [2, 10]. Also, the resistivity due to surface scattering should not play its role in the decreasing resistivity trend in our experiment due to film thicknesses of our Ag films ranging from 20 to 50 nm are much higher than the electron mean free path of Ag [2, 10]. 'Figure 2' shows the dependence of the Ta/Ag films resistivity on Ag films thickness. So, the Ta/Ag thin films resistivity decreases with increasing Ag film thickness to 50 nm, in which the decreasing trend can be attributed to the inverse linear dependence of film resistivity increase on grain size.

Orientation of atoms in crystalline structures is very important. The materials have different crystalline orientation that shows they have different properties. In this project, crystalline orientation of Ta/Ag thin film is very significant for studied electrical and structural properties.

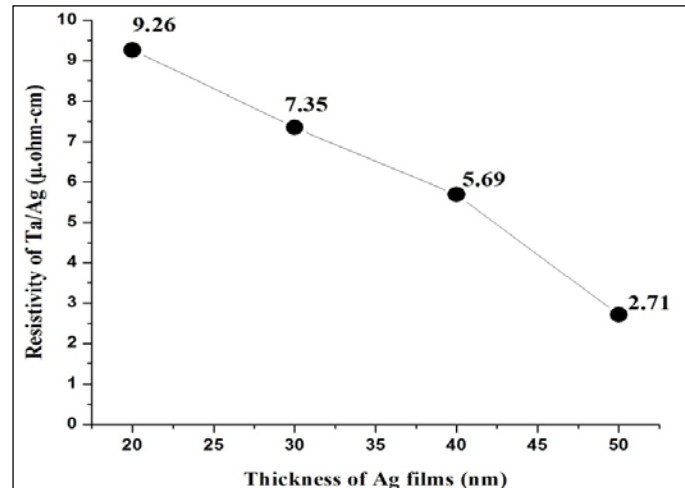


Figure 2. Dependence of the Ta/Ag resistivity on the Ag films thickness.

4. Conclusion

Ag and Ta/Ag thin metal films were deposited on Si substrates by DC magnetron sputtering method and studied in order to understand the influence of Ag thickness and Ta layer on electrical and structural properties. The results show the Ta layer effectively decreased the Ag agglomeration that's improvement in crystallinity. As the Ag thin films thicknesses increased, Ta/Ag thin films resistivity decreased, which illustrated that the Ta/Ag thin films are good choices in microelectronics devices, compared to Ag thin films.

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