Study of reflection power and surface roughness of Cu nanolayers thin film with respect to various deposition rates of sputtering

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Abstract: Copper thin films have been deposited on glass substrate, by dc magnetron sputtering, then Reflection power and surface roughness of them with respect to deposition parameters have been investigated. For these purposes discharge current was changed in (0.2-1) A and gas pressure (Ar) range of (0.02-0.1) mbar was used. Due to these variations voltage differs from 320 to 395 V and deposition rate of (0.4-2.5) nm/sec were obtained. In different coating condition while thickness of produced thin films was constant (250 nm), reflection power and roughness of them were investigated by a double beam spectrophotometer and AFM respectively. These parameters for some thin films which were produced in the same conditions but have different thicknesses have been investigated too.

1. Introduction

Copper thin films have different applications in various technologies. Since Cu thin films have a high reflection power in red and infrared region of spectrum, these kind of thin films have many usage in optics and laser science, [1] although copper has been widely used in thin film and nanotechnology and plenty works have been reported, but there could be still a lot of values in studies which can link microstructure of copper to macroscopic properties. All these characteristics depend on the method of deposition and formation and also growth condition of Cu thin films. In our previous works on copper thin films residual stress with respect to substrate temperature and electrical characteristics of Cu with sputtering parameter have been reported. [2-4].

One of the most important properties of thin films that affect many other behaviors of them like adhesion, friction, electrical properties, reflection or scattering and adsorption and etc is surface roughness, which depends on deposition condition (substrate temperature, deposition method, thickness or deposition time …). Surface roughness can appear to be quite different depending on the scale which one investigates it. [5-9]. Usually roughness is defined by root mean square (rms) of heights, which is calculated in different scales by various analyzes such SEM, SPM(AFM, STM) but it is possible to calculate roughness by scattering or reflection power as well. [9]

Height fluctuation and roughness of copper thin film on glass and Si, has been reported [10, 11], but evaporation has been used to deposit Cu, but no physical relationship between surface roughness and coating parameters was given. Since dc magnetron sputtering is very clean, fast (high rate) and more controllable way to produce thin films, this method has been employed [13].
2. Experimental details

To deposit Cu thin films on glass substrate under various conditions, a vacuum system that could provide base pressure of $10^{-7}$ m.bar (Hind High Vacuum, H.H.V) was employed, thus background pressure ($p_r$) prior to Cu deposition was around this value. A disc of pure Cu with 3 mm in thickness and 125 mm diameter was used as target (cathode). Cu thin films were produced in research grade Ar atmosphere which was used for plasma formation. Ar pressure ($P$) range was changed from 0.02 to 0.1 m.bar. Discharge current ($i$) varied from 0.2 A to 1 A, and to sustain discharge in different conditions voltage ($V$) was varied from 320-395 V due to these changes (pressure and current changes).

Circular glass substrate with 20 mm diameter and 1 mm thickness was used. Just before using these glasses they were cleaned in heated acetone and then by isopropyl in ultrasonic bath. Substrate temperature was monitored during deposition by a digital thermocouple which was placed on substrate holder, since period of coating for each sample was relatively short, so substrate temperature did not change during deposition. For measuring deposition rate and thickness of Cu thin films vibrating quartz crystal thickness monitor as well as exact balance (10$^{-4}$ gr) were employed. Deposition rate ($\dot{R}$) for various conditions was 0.4-0.25 nm/sec.

A double beam spectrophotometer (model: camspec 350) was used for optical measurements; it can investigate reflection power of thin film against wavelength range of 200-1100 nm. X-ray diffraction (XRD) measurement was obtained after deposition. AFM measurements of these samples were carried out and by means of some data which exported from these analyzes surface roughness (interface width ($W$)) were calculated and relation between them and coating parameter were obtained.

3. Results

To study the effect of discharge current, voltage and gas pressure on deposition rate, at first Ar pressure was fixed at 0.02 m.bar and current was changed from 0.2 A to 1 A. These results are given in table 1.

\[ \dot{R} \text{ variation against electrical power } (P_e) \text{ (current times voltage)} \text{ in this situation is given in figure1, which shows a linear behavior and an equation in form of:} \]

\[ \dot{R} = 0.006 P_e \] (1)

Show good agreement with experimental results. Table 1 gives information about different samples which were produced under different experimental conditions.

By these results one can find an empirical relationship, which is given below:

\[ \dot{R} = 0.003 \frac{i \cdot V}{P^{0.19}} = 0.003 \frac{P_e}{P^{0.19}} \] (2)

To study effect of deposition rate and thickness on reflection power and roughness, three types of samples were produced. Information of these samples are shown in table 1. Fig 2 shows XRD of one of the Cu thin film which has been produced.

Reflection power ($R$) of samples is measured by a double beam spectrophotometer. In figure 3 (a), 3(b) variation of $R$ for samples of series 1 and 2 are shown respectively. In figure 4 variation of $R$ versus wavelength is shown for third series of samples, which have different thicknesses but were produced under the same deposition conditions.

AFM measurements of these samples were carried out, when deposition rate is low, surface roughness ($W$) does not vary that much, but when deposition rate gets higher, surface roughness also rises, and it doesn't depend on how deposition rate changes (by change of $P$ or $i$). This changes are shown in figure 5 and figure 6, by curve fitting equation (3) was found, which shows the relation between $W$ and deposition rate ($\dot{R}$) (samples of series 1 and 2)

\[ W = 3.5 + 0.32 (\dot{R}^{2.5}) \] (3)
Figure 1. Shows changes of deposition rate vs electrical power.

Figure 2. XRD pattern of Cu thin film

Table 1. Information of Cu thin film samples produced in various experimental conditions.

| Sample number | \( P(mbar) \) | \( V(V) \) | \( i(A) \) | \( \dot{R}(nm/sec) \) | \( t(sec) \) | \( T(nm) \) |
|---------------|---------------|------------|------------|----------------|------------|----------|
| 1-A           | 0.02          | 320        | 0.2        | 0.4            | 555        | 250 ± 30 |
| 1-B           | 0.02          | 345        | 0.4        | 0.8            | 300        | 250 ± 20 |
| 1-C           | 0.02          | 365        | 0.6        | 1.4            | 176        | 250 ± 20 |
| 1-D           | 0.02          | 395        | 1          | 2.5            | 100        | 250 ± 20 |
| 2-A           | 0.02          | 395        | 1          | 2.5            | 100        | 250 ± 20 |
| 2-B           | 0.05          | 350        | 1          | 1.9            | 133        | 250 ± 20 |
| 2-C           | 0.1           | 325        | 1          | 1.4            | 176        | 250 ± 20 |
| 3-A           | 0.02          | 400        | 1          | 2.5            | 50         | 125 ± 10 |
| 3-B           | 0.02          | 400        | 1          | 2.5            | 100        | 250 ± 20 |
| 3-C           | 0.02          | 400        | 1          | 2.5            | 250        | 625 ± 40 |
| 3-D           | 0.02          | 400        | 1          | 2.5            | 400        | 1000 ± 60 |

Figure 3(a). Exhibits reflection power of samples series 1.

Figure 3(b). Shows reflection power of second series of samples.
Figure 4. Reflection power of third series of samples.

Figure 5. Variation of W against deposition while current was changed.

Figure 6. Changes of W with respect to deposition rate while pressure was varied mean tolerance from equation (3) is 0.

Figure 7 Variation of roughness against Cu films thickness.

Variation of roughness against thickness is shown in figure 7 and it is obvious that rises of thickness cause an increase of roughness and then start to saturate.

Figures 8 and 9 show AFM surface image of 3-A and 3-D respectively.

Figure 8. 2D AFM image of 3-A.

Figure 9. 2D AFM image of 3-D.
4. Summary and conclusion
When Ar pressure was kept constant, deposition rate shows a linear behaviour with electrical power, as it is expected.

Surface roughness (interface width) in low deposition rate, remain roughly constant, but as rate increases, roughness of surface rise and it dose not matter whether this increasement of deposition rate is by reduction of Ar pressure or rise of discharge current has caused it.

Roughness of surface of Cu thin film increasement with film thickness of period of coating when deposition rate is kept constant, this increasement continue up to a certain point (thickness or time) then roughness start to show saturate behavior or remains roughly constant.

Reflection power of the Cu thin film become higher when film thickness is more, when deposition rate was constant, and also amount of this parameter for higher wavelength is more than visible region, which is copper characteristic. In higher deposition rate condition while film thickness was fixed, reflection power of Cu thin film is little more than low deposition rate condition, which can be due to higher pacing density of Cu atoms in copper thin film.

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