SHORT COMMUNICATION

Variations of Thin Metallic Zinc Film Resistances with Sputtering Rate

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Variations of resistance of evaporated or sputtered films during deposition have been studied for deposition times lower than five minutes and for resistances higher than 100 \( \Omega \) sq\(^{-1}\). As our main objective is to study the conduction mechanisms in sputtered films over the thickness range from 200 to 1500 Å (i.e. in the 10 to 100 \( \Omega \) sq\(^{-1}\) sheet resistance range), we report in this note our investigations about the electrical resistance \( R(T) \) of zinc films for deposition time, \( T \) greater than two minutes and for four average deposition rates.

Preparation of films has been described in a previous paper; they are deposited by d.c. diode sputtering of a zinc target (99.9% purity) in an atmosphere of \( U \) grade argon. As broken sputtering is equivalent to continuous deposition, sputtering was stopped every minute to measure the resistance \( R \) with a multimeter. The average sputtering rate was determined from the deposition time and the film thickness measured by an optical method; this method is adequate for we have observed very slight anisotropic effects, which seem more important for higher sputtering rates; it varied with the intensity \( I_e \) of the glow discharge current, the voltage \( U_e \) remaining constant (curves 1, 2, 3 on Figure 2). Variations of the deposition rate as a function of the intensity \( I_e \) of glow discharge current for a voltage equal to 1500 V are shown in Figure 1. This curve is in good agreement with the results of Laville Saint-Martin who established that sputtering rate \( v \) is given by

\[
v = I_e U_e \exp\{-A U_e^{-1} - B U_e\}
\]

where \( A, B \) are constants.

For high voltage values in the range 1000 to 1750 V, eq. (1) may be expressed as

\[
v \propto I_e
\]

Variations of zinc film resistance \( R(T) \) versus deposition time \( T \) are plotted in Figure 2. Attempts have been made to fit these experimental variations to an empirical equation in the form

\[
R(T) = R_\infty \exp \left( \frac{1}{K_1 + K_2 T} \right)
\]

where \( R_\infty \) is the limiting value of \( R(T) \) when \( T \) is large and \( K_1, K_2 \) are constants.

As we have established that films thicker than 5000 Å exhibit bulk properties, their resistance \( R_b \approx 2.5 \, \Omega \) sq\(^{-1}\) is assumed equal to \( R_\infty \). Substituting for \( R_\infty \) in Eq. 3, this yields

\[
R(T) = R_b \exp \left( \frac{1}{K_1 + K_2 T} \right)
\]
$K_1$ and $K_2$ are determined by plotting $1/Ln[R(T)/R_b]$ versus deposition time $T$ (Figure 3). The slopes of the best fit straight lines determine the values of $K_2$, while $K_1$ is calculated from the intercept with the vertical axis.

From Figure 3 it can be seen that $K_1$ is independent of the deposition rate as indicated by Eq. 4. Thus,

$$K_1 \approx 1/Ln[Ro/R]$$  \hspace{1cm} (5)

where $Ro$ is the substrate resistance.

However the value of $Ro$ calculated from the experimental value of $K_1$ is low (about 6 kΩ). As quasi-linear growth occurs only above the first critical thickness we assume that this value corresponds to a smaller thickness for which the granular structure consists of a large number of empty channels distributed throughout the film. It has been shown that the value of the resistance of such a film depends essentially on the geometrical arrangement of the sputtering chamber which remained unchanged in our experiments.

Calculations allow one to determine suitable values of $K_2$, leading to a good agreement between the experimental and theoretical curves (Figure 2) in the resistance range 10 to 100 Ω sq$^{-1}$. A discrepancy of less than 10% is observed except for the lower sputtering rate but experimental accuracy is low in this case (15%).

The observed slight departures from the theoretical resistance at low $R$ values occur at low sputtering rates, whereas considerable departures have previously been observed by Laville Saint-Martin for higher sputtering rate.

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**FIGURE 2** Experimental (dotted lines) and theoretical (full lines) variations of zinc film resistance $R$, with sputtering rate $v$, equal to: (1) 80 A mn$^{-1}$, (2) 110 A mn$^{-1}$, (3) 130 A mn$^{-1}$, (4) 550 A mn$^{-1}$.

**FIGURE 3** $1/Ln[R(T)/R_b]$ versus $T$ (deposition time) with sputtering rate, $v$, equal to (1) 80 A mn$^{-1}$, (2) 110 A mn$^{-1}$, (3) 130 A mn$^{-1}$, (4) 550 A mn$^{-1}$.
We observe (Figure 4) that the magnitude of constant $K_2$ differs markedly for different deposition rates. Constant $K_2$ has been defined as a velocity constant related to the sputtering rate $v$ and may be given approximately by

$$K_2 \approx \alpha v \quad \text{with} \quad \alpha = 5 \times 10^{-4} \text{ Å}^{-1}$$

It may be concluded that in these experimental conditions the measured resistance fits the theoretical formulae obtained with the deposition rate as a parameter in the range 80 Å mn$^{-1}$ to 600 Å mn$^{-1}$; a simple way to predetermine thin film resistances is thus available.

REFERENCES

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