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VARIATION OF THE ELECTRICAL PROPERTIES OF MANGANESE THIN FILMS WITH DEPOSITION CONDITIONS

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ABSTRACT

The behaviour of the electrical properties of manganese thin films of different thickness (240 - 1500 Å) evaporated under different deposition conditions was studied. The effect of the rate of evaporation (1 - 7 Å/s), the residual gas pressure (10^{-5} - 10^{-6} Torr) and the type of residual gas (being air or pure argon) was investigated. Low deposition rates and/or high residual gas pressure resulted in higher resistance values. Using argon instead of air as residual gas enhanced the electrical conductivity.

INTRODUCTION

The properties of thin films are usually affected by the preparation conditions. The structure of thin films obtained by thermal evaporation is influenced by the evaporation parameters, such as the substrate material and temperature, residual gas type and pressure, rate of evaporation and film treatment (Thun, 1964, Maissel and Glang, 1970, Hunderi and Myers, 1973, McBreen and Moskovits, 1983 and Albano et al., 1985). The electrical resistance of metal films usually decreases with increasing film thickness, increasing evaporation rate and decreasing pressure (Baba et al., 1976, Romanowski and Kepinski, 1980, George and Joy, 1980, Renucci et al., 1982 and Reda et al., 1984).

Films prepared under vacuum, with argon as residual gas, normally show better properties. The structure of films obtained using argon resembled that obtained under ultra high vacuum (Gardiner and Stiddard, 1981 and Al-Houty et al., 1989).

The work on the properties of thin metal films is tremendous; nevertheless, the study on Mn films is not so extensive. Beynon and Olumekor investigated the

electrical properties of Mn films and their dependence on thickness (1974), evaporation rate (1977), residual gas type and pressure (1977) and film aging, both in air and in vacuum (1977). The optical phase properties, the electrical properties, the TCR and activation energy values and the structure of Mn films deposited on glass and mica substrates were studied (Al-Houty, 1978).

The optical constants of thick Mn films were also determined by Barakat et al. (Barakat et al., 1979). Also, the dependence of the resistivity of α - Mn on substrate temperature and residual gas pressure (Grassie and Boakye, 1979) and the TCR values of thin Mn films (Shivaprasad et al., 1980) were reported.

The aim of the present work is to provide some additional information about the electrical properties of thin manganese films and their dependence on deposition conditions.

EXPERIMENTAL

Manganese films of different thickness (240 - 1500 Å) were thermally evaporated in vacuum of 10^{-5} - 10^{-6} Torr, onto glass substrates held at room temperature. The vacuum system (Edwards 306) was flushed several times with pure argon gas before evaporation. The film thickness, as well as the evaporation rate, was monitored using a quartz crystal thickness monitor connected to a ratemeter (Edwards F.T.M. 2).

The film electrical resistance was measured in situ using a programmable digital multimeter (Keithley DMM 192). The output of the thickness monitor was connected to a keithley DMM 195. Both instruments were synchronized to log data on the film thickness and resistance simultaneously.

RESULTS AND DISCUSSIONS

Effect of evaporation rate

The experimental data obtained for the resistance of Mn films evaporated with different evaporation rates are tabulated in Table 1. The residual gas was argon of pressure 10^{-6} Torr. It is obvious that the resistance of Mn films is extremely sensitive to the evaporation rate. The film resistance decreased with increasing deposition rate which is in agreement with reported results for different metal films (Adamov et al., 1974, Angadi and Udachan, 1981 and Al-Houty et al., 1984 and 1989). It is, however, different from that reported for Mn films, where the resistivity was almost constant for deposition rate $<$ 8 Å/s, then it decreased as rate increased above 8 Å/s (Beynon and Olumekor, 1977).

Table 1.
Resistance values of Mn Films deposited in argon with different evaporation rates.

Thickness (Å)	Rate (Å/s)	Resistance (Ω)
240	1	1240
400		520
500		256
600		150
960		113
240	5	780
400		360
520		181
960		74
1600		51
240	7	350
400		270
520		112
960		62

The decrease in the resistance with increasing deposition rate is due to the decrease in grain size and increase in the nucleation rate (Thun, 1964). Hence, it is expected that smooth continous films will be formed at higher rates leading to lower resistivity values.

Effect of type and pressure of residual gas

The initial resistance of films evaporated in air were higher than those deposited in argon. Table 2 shows the results obtained for a 250 Å film deposited with an evaporation rate of 1 Å/s. This result is in agreement with that reported for a 500 Å Mn film deposited at 5 Å/s (Beynon and Olumekor, 1977). The resistance values dropped sharply when the films were prepared in argon. It is believed that such films might have better structure which could resemble that for films prepared under ultra high vacuum (Gardiner and Stiddard, 1981 and Al-Houty et al., 1989).

It was also observed that films prepared in argon were homogeneous and showed better adherence to the substrate. While films deposited in air at pressures higher than 5×10^{-5} Torr had shown poor adherence to the substrate. When such films were subjected to the atmosphere, numerous cracks were easily detected by means of a low power microscope. It was also found that their resistance increased steadily and in many cases in an erratic way.

Table 2.

Resistance values of 250 Å Mn Films deposited under different types and pressures of residual gas (evaporation rate = 1 Å/s).

Pressure (Torr)	Residual Gas	R(kΩ)
2×10^{-5}	Argon	1.9
	Air	4.6
10^{-5}	Argon	1.7
	Air	3.3
5×10^{-6}	Argon	1.3
	Air	2.7
2×10^{-6}	Argon	1.2
	Air	2.2
10^{-6}	Argon	1.1
	Air	2.0

The effect of the residual gas pressure is an increase in the film resistance as the pressure increases. Similar results were also reported for Mn films (Beynon and Olumekor, 1977 and Grassie and Boakye, 1979). Films prepared under pressure values of about 10^{-5} Torr in air exhibited very high resistance values. Since the resistivity is peculiarly sensitive to the pressure of hydrogen or oxygen in the sample (Grassie and Boakye, 1979), it is believed that absorbed gasses in the film are the cause of the observed high resistance values.

Effect of aging

By aging or isothermal annealing, the film is held at the deposition temperature for a period of time. The resistance of Mn films increased gradually with time approaching a constant value. The rate and amount of increase depended on the type and pressure of residual gas. It was found that the change in the film resistance is minimal when the residual gas was argon. Figure (1) shows an example of the obtained behaviour for a 240 Å Mn film deposited in argon. Though the film was deposited in vacuum of 10^{-5} Torr, it showed a stable state of order after about 30 minutes. The observed change in the film resistance after one hour was less than 5%.

It was found that well-prepared Mn films under appropriate conditions, such as inert residual gas, better vacuum and higher deposition rates, exhibit low resistance values and better stability. Further investigation of this result was made on $\sim$ 1000 Å films deposited in argon. The deposition rate was 5 Å/s and the pressure was about 10^{-6} Torr. The nominal values of the resistance was about 100 Ω. DC

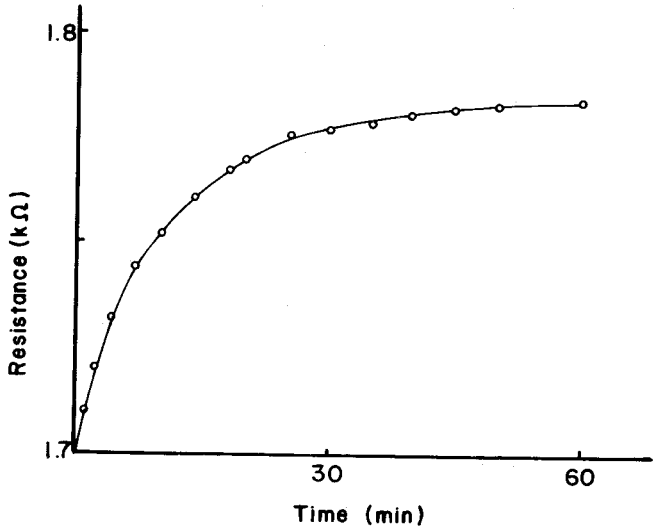

Fig. 1: Resistance variation of a 240Å Mn film with time.

electric current was passed through the films up to a value of 0.3 A. It was found that the film resistance was stable, showing only about 0.05% increase for dissipation of less than one watt. The results of this test are shown in Figure (2). As it is obvious from Figure (2) that powers exceeding one watt caused a decrease in the film resistance, it is believed that self-heating occurred in the film causing the decrease in the resistance as a result of annealing. Nevertheless, the change did not exceed 0.1% when powers of 10 watts were used.

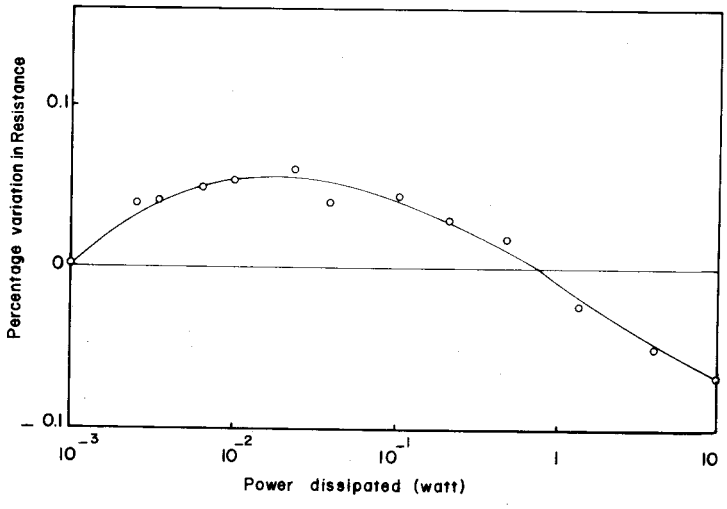

Fig. 2: Percentage change in resistance of 1000 Å well-aged Mn film with dissipated power.

CONCLUSION

Manganese films of different thicknesses were prepared under different deposition conditions. Low resistance values were obtained for films prepared under vacuum of about 10^{-6} Torr with deposition rate of about 7 Å/s. Films prepared in argon were reasonably stable and showed better adherence to the substrate. It is believed that Mn films, when properly prepared, can be used as stable thick-film resistors in the fast expanding electronic industry.

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تأثـــير ظـــروف التبخير
على الخواص الكهربية لأغطية رقيقة من المنجنيز

لطيفـــة إبـراهيم الحـــوطي

يهدف هذا البحث إلى دراسة تأثير ظروف التبخير على الخواص الكهربية لأغشية رقيقة من معدن المنجنيز ذات سمك يتراوح بين ٢٤٠ ـ ١٥٠٠ أنجستروم . تم تحضير تلـك الأغشية بطـريقة التبخيـر تحت ضغوط منخفضـة تتـراوح قيمتهـا بين $١٠^{-٥} - ١٠^{-٦}$مم زئبق حيث كان الوسط المحيط بالعينة عند التحضير إما هواء أو معبأ بغاز الأرجون (الخامل) . كما تم ترسيب تلك الأغشية على سطوح زجاجية بمعدلات تبخير مختلفة تتراوح ما بين ١ إلى ٧ أنجستروم/ث . ولقد بينت الدراسة أن المقاومة الكهربية لأغشية المنجنيز تقل مع زيادة معدل التبخير ومع تناقص الضغط الذي تم تحضيرها عنده . كما أن التبخير في وسط الأرجون يؤدي إلى إنخفاض في قيمة مقاومة الغشاء بالإضافة إلى تحسين خواص الغشاء بصفة عامة .