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Design and Performance Studies of the Scanning Magnetron in Terms of V-I Characteristics, Dependence of V-I Characteristics on Scanning Speed, Deposition Rate and Substrate Temperature

N.S. Panwar[1], A.S. Pharswan[2]

Department of USIC, Hemwati Nandan Bahuguna Garhwal University, Srinagar Garhwal 246174, India

Abstract: ***A scanning magnetron target in fig1 is designed in the present study in this system the target is scanned by the magnetic field of a moving magnet fitted in a boat shaped magnet holder on the cathode plate . The scanning of the target by the magnet holder initiates ejection of material from scanned target surface towards the substrate leading there by to a uniform erosion and deposition of a uniform film over a wide substrate area V-I characteristic in fig2 of the currently developed scanning magnetron is studied at different T.S.D.5,8,11cm and pressure $5x10^{-3}$, $1x10^{-3}$,$8x10^{-4}$,$6x10^{-4}$,$4x10^{-4}$ m bar .V-I characteristics in fig3 of the scanning magnetron is measured for different scanning speed viz 14cm/sec , 8cm/sec, and 3cm/sec at Ar pressure of $5x10^{-3}$mbar$1x10^{-3}$mbar$4x10^{-4}$mbar with 11 cm T.S.D., Stylus dektak is used to determine thickness and thus deposition rate in fig4, at T.S.D. 5,8,and 11cm for 400ma ion current at $5x10^{-4}$ m bar Ar pressure. The substrate temperature was measured in fig 5 using platinum constantan thermocouple at ion current 200ma ,400ma, 600ma and at Ar pressure $5x10^{-4}$m bar, $1x10^{-3}$mbar and $5x10^{-3}$mbar in .In view of the above studies performance of the scanning magnetron is obtained.***

1. Introduction

In magnetron sputtering electron acceleration in the magnetic field takes the helical path this principal is used in the cold cathode ionization guage , is useful to enhance ionization in the sputtering system .The secondary electrons coming out of the cathode will be confined by the magnetic line of force running parallel to the cathode. .This causes high ionization probability and hence more sputtering rate because of this the thickness of the cathode dark space reduces and the operating pressure can be as low as 10^{-4} torr. With an additional advantage that the number of electrons that escape from the magnetic field is very low to heat the substrate. Thus high deposition rate low pressure operation and low substrate heating are obtained in this process.

The transverse electric field is effective in bending the electrons and thus enhancing the ionization and making cathode dark space shorter .This enables one to obtain the discharge at lower pressure and prevent back diffusion of ejected particles to the cathode surface .Studying the various types of magnetron like cylindrical post cathode, planer and other configuration Thornton[1-3] has confirmed current voltage relation I ά V^n where n is constant representing the electron trapping in the plasma.

However Westwood[4] showed that the current voltage characteristics of magnetron discharge follow a quadratic law,

$$I=k(V- V_0)^2$$

Where V_0 is the threshold voltage necessary for maintaining discharge which strongly depends on pressure. The effect of magnetic field strength from 50 -300 G was described by Thornton[5] in his work on cylindrical magnetron copper deposition.

Design of Scanning Magnetrron:

Main aim in designing a scanning magnetron sputtering target fig-1 is to obtain good efficiency in terms of uniform erosion over the full target surface a uniform thin film deposition and high deposition rate, low target heating, low substrate heating. In view of this a system is designed to scan large area .Cathode plate made of nonmagnetic stainless steel with dimensions of 300mmx200mmx12mm is designed .A rectangular cavity with dimension 274mmx174mmx9mm with 5mm water inlet 5mm water outlet is designed on the cathode plate .A target of titanium with dimension 2oommx120mmx3mm is screwed on the other side of cathode plate . A magnet holder with dimension100mmx80mm at the bottom and 80mmx20mm at the top , 50 mm height 3mm thick all around with slant faces made of soft iron and boat shaped is designed. The magnet holder is fitted with two magnet one inside and other on the top out side coupled through 3mm thick holder plate placed back to back 1.5 k gauss each. This magnet holder makes magnetic lines of field parallel to the cathode plate and screened off the magnetic lines of field with grater curvature at the poles and around null point of the magnet .For the batter composition of eroded material target is kept cool using continuous supply of water in rectangular cavity during sputtering .Top plate with 457mm diameter and 10mm thick and with a rectangular thorough hole wih 274mmx174mm around the centre is designed. This top plate sits over the opening of vacuum chamber couples with neoprene 0 ring. Teflon sheet with outer dimension 300mmx200mmx5mm and with inner dimension 274mmx174mm is designed and placed between top plate and cathode plate for electric isolation. Cathode plate is screwed with top plate using Teflon bushes (3mm inner diameter ,5mm outer diameter) for electric isolation Neoprene O ring with sectional diameter 6.985mm ring is fitted in the designed groove on the cathode plate and coupled with Teflon sheet to get vacuum sealing. Motor selection is done for the linear motion of 300 gm weight magnet holder. A step motor 50 Newton cm torque, 51cm length is selected for the linear motion of the magnet holder. Electronic circuitry is designed to give smooth rotational motion and to control rotational motion of step motor shaft also electronic circuitry is designed to indicate speed and faulty motion .To convert rotational motion into uniform linear motion two pulleys (25mm diameter each) timer belt (32 inch circumference) and two guide rod made of hard steel (6mm diameter 280 mm length) system is designed. Step motor and pulley belt system are attached with step motor holder and pulley holder on two different brass flanges with dimension (100mmx55mmx24mm) and (100mmx60mmx24mm). Belt is screwed on guide nut 44mmx17mmx10mm placed at the magnet on the top of magnet holder and passes through pulley on one brass flange and pulley attached on the motor shaft on other brass flange. Two guide rods passing through two linear motion bearing(6.38mmx12.7mmx19.5mm) fitted in guide nut 2mm apart are made to rest on vertically moving (in mm) two different aluminum flanges . Each flange is made of two flange with same dimension 30mmx30mmx5mm, two vertical slot of 3mm diameter 10mm length are designed on each flange , two small aluminum flanges are then coupled through two 3mm screws and bolt thus forms one vertically moving flange, similarly another vertically moving flange is designed. These vertically moving aluminum flanges are screwed on the middle of shorter side of water cavity edge. The other two brass flanges are fixed on the top plate on the opposite site in the line of aluminum flange.

Scanning motion of the magnet holder is achieved along the guide rods with the help of pulley belt system and motor derive. Scanning magnetron assembly thus designed is fixed on the top plate. It is distance between the target and magnet holder and magnetic field strength below target speed of the motor which control sputtering process along with other parameter.

2. Experimental Method

The present system is a sophistication[6] of a D.C. sputtering unit having a combination of 300 lit /sec diffusion pump with a 200lit /min rotary vacuum pump the system gives an ultimate vacuum of $5x10^{-6}$ milli bar. The pressure monitoring is done by using pirani and penning gauge combination. The vacuum chamber is a 300mm diameter S.S cylinder opened at both ends. The scanning magnetron target (200mm × 120mmx3mm) is mounted on the cathode plate which is scanned by magnetic field with different speed of magnet holder , using pulley belt, step motor derive. Deposition is carried out in sputter down mode magnetic field strength below the target was found 800 gauss, however it has been reported that magnetic field can be varied up to 80 gauss. The substrate holder fixed to the base plate Iolar- 2 grade argon (99.999%) has been used as sputtering gas, flow of which is controlled by combination of two needle valve in series. A variable power supply of high voltage type ,with15 Kv and 10A rating was used . The substrate temperature was measured using a platinum constantan thermocouple, thickness of the deposited films was measured by a stylus Dektak .

3.1 V-I Characteristics: In fig 2 (a), (b), (c).

It has been observed that with decreasing pressure a slightly higher voltage is required at the cathode then required at higher pressure for the same value of the current. This gives directly the indication that at higher pressures more ionization takes place i.e. collision probability of electron increases. The electron trapping efficiency , from these characteristics by fitting them with the formula[7] $I=KV^n$ has been calculated .The electron trapping efficiency n was found increasing with increasing pressure and varying from 10 to 91 and even more in some observations, in the observed pressure range .Earlier reports[8-9] show n varying between 3.5 and 7. It is observed that at larger target substrate distances current variation is almost linear and it showed diode like characteristics at small T.S.D. The values of the current are larger at larger T.S.D at particular voltage. This can be thought in terms of ionization probability i.e. more in the case of more T.S.D. (more volume)

In the normal D.C. sputtering the operating pressure are high and resulting cathode currents are low even at high cathode potential at a pressure of $10 x10^{-3}$ torr to achieve a cathode current of 90 mA the cathode voltage must be kept very high about 2000 volts[10] .Same current has been observed in the present magnetron at a cathode potential of 365 volt and that too at $3x10^{-4}$ m bar and at lower substrate distance 11cm The scattering of the sputtered atoms reduces in the magnetron due to its low pressure operation , which results into the formation of high adhesive films than that obtained from the D.C. sputtering which operates at higher pressures. It is observed that an increase in cathode potential up to a critical value increases cathode current and thereafter current falls. This has been explained as to be due to the escape of high energy electrons and hence drop in ionization efficiency. The critical voltage was found to be varying with magnetic field.

3.2 Dependence of V-I Characteristics on Scanning Speed:

In fig3 (a), (b), (c), it is observed that the V-I characteristics of the scanning magnetron do not depend significantly on the scanning speed in the measured range.

The cathode voltage and current were observed slightly fluctuating during scanning when the magnet reaches the target end. At the end small magnetization of the top plate may disturb the magnetic field lines and hence the discharge under the target at the end causes fluctuations in the cathode current and voltage but this effect can be reduced by using nonmagnetic top plate. Some effect of argon pressure variation can also be attributed to this behavior during the discharge i.e. fluctuations in the argon pressure due to ionization when the magnet is in the centre, ionization takes place there and these ions are directed towards cathode creating low pressure zone at the end of the target and there is not sufficient gas atoms to maintain the discharge.

The slight fluctuations in the I-V values when the magnet is not at the extreme position may be due to non uniformity in the cathode plate, is that due to variation in the magnetic field reaching the target surface during scanning.

3.3 Deposition Rate and Temperature Rise of Substrate

Though the uniform thickness area increases with increasing T.S.D., the deposition rate decreases with increasing T.S.D. In figure 4 (a)(b)(c) this can be thought due to the fact that when target substrate separation is increased the scattering of the eroded atoms and gas molecules increases due to more volume which leads to decrease in the deposition rate and increase in the area of uniform thickness. It is observed that deposition rate increases with increasing current at each Ar pressure, up to the discharge current of 400 ma. in figure 4 (a)(b)(c). Which indicates increase in ejection of target atoms with ionization current, is that Ar ions. At these currents (<=400 ma) only the bombarding gas ions contribute to cathode current and not the electrons, as electrons are trapped by the magnetic field. For higher current, is that for 600 ma deposition rate was observed decreased at each Ar pressure, higher voltage is required for higher current, which increases the strength of electric field. This increase of electric field seems to lead escaping of the electrons trapped by the magnetic field near the target and reduces the ionization and hence the deposition rate. However these escaping electrons add to the cathode current. It is also observed in figure 4(a)(b)(c) that deposition rate increases with decreasing Ar pressure, at each current value. This is due to the fact that at higher pressure the collision between the sputtered material and gas molecules increases and hence prevent the former to sit directly on to the substrate and thus reducing the deposition rate. The highest deposition rate for titanium (Ti) was observed 1755, 1053 and 742 A^0 /min at the T.S.D. 5, 8 and 11 cm, respectively for 400 ma at 5 X 10^{-4} m bar Ar pressure. At the same time the rise in temperature of the substrate decreases with increasing target substrate separation at each current and Ar pressure value, figure 5 (a)(b)(c). Thus to get a large uniform deposition area the rise in temperature is not a problem since increasing T.S.D. leads large uniform deposition area and reduced substrate temperature rise.

3. Conclusion

The observed I-V values at different Argon pressures for target substrate separation 5,8and11cm in the vacuum chamber are shown in fig 2 (a)(b)(C).It is observed, at smaller T.S.D.,5 and 8cm it shows diode like characteristics, at larger target substrate distance (T.S.D.) 11cm current variation is linear within certain limits of voltages and pressures. It is observed that current usually begins to flow at low voltages and low pressure, it is appreciable at 240 volt and at pressure of $5x10^{-3}$ m.bar. The lowest pressure at which the discharge is observed in the present system is about $3x10^{-4}$ m bar at 345 and 360 volt for T.S.D,5 and 11 cm. The scattering of the sputtered atoms reduces in the Magnetron due to its low pressure operation which results into the formation of high adhesive films then that obtained from the d.c. sputtering, which operates at higher pressure. The variation of cathode current with voltage for different scanning speeds and at different argon pressures at T.S.D. 11 Cm is shown in fig 3 (a)(b)(c) It is observed that the I-V variations of the scanning magnetron do not depend significantly on the scanning speed in the measured range .The slight fluctuation in the IV values when the magnet is not in the extreme position may be due to non uniformity in the cathode plate i.e. due to variation in magnetic field reaching the target surface during scanning . The highest deposition rate in fig 4(a)(b)(c) for titanium (Ti) was observed 1755,1053and 742 A^0/min at the T.S.D. 5,8 and 11 cm respectively for 400 ma at $5x10^{-4}$ m bar Ar pressure. At the same time the rise in temperature in fig5(a)(b)(c) of the substrate decreases with increasing T.S.D. at each current of 200,400,600 ma and increasing Ar pressure value of $5x10^4$, $1x10^{-3}$, $5x10^{-3}$ m bar. These studies show that the scanning magnetron has many advantages, like high ionization efficiency, low pressure operation, low substrate heating, formation of good adhesive films low voltage operation, uniform erosion (~100%) over the scanning area of the target and larger uniform thickness films .This offers a good scope of the development of sputtering technology for large area uniform target erosion, large area uniform thickness thin film deposition and etching of the surfaces

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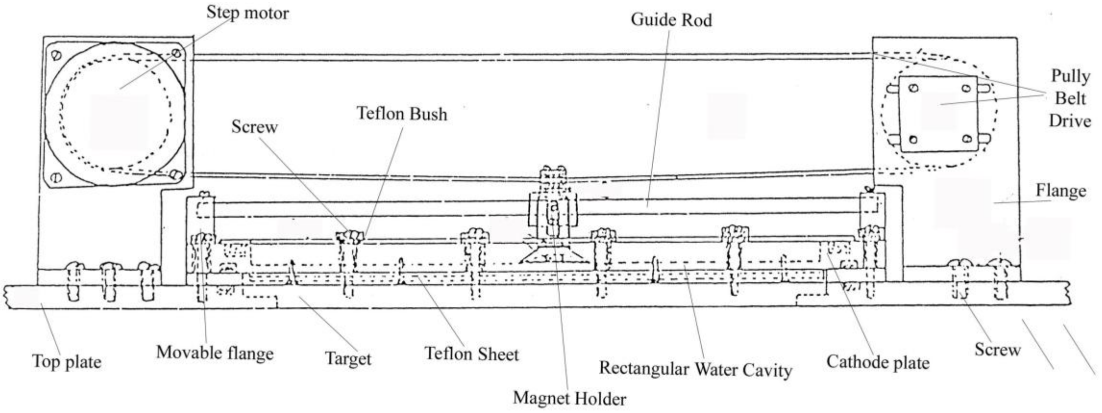


Figure 1: Assembly diagram of scanning magnetron (front view)

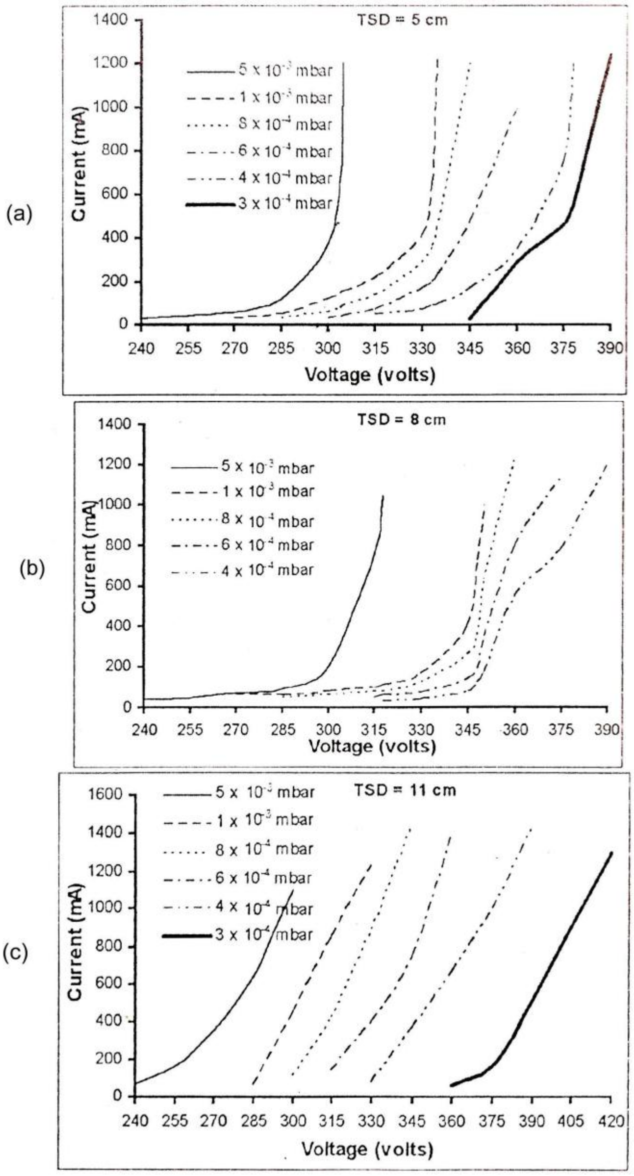


Figure 2 (a) (b) (c): i-v characteristics of scanning magnetron at different T.S.D. and pressures

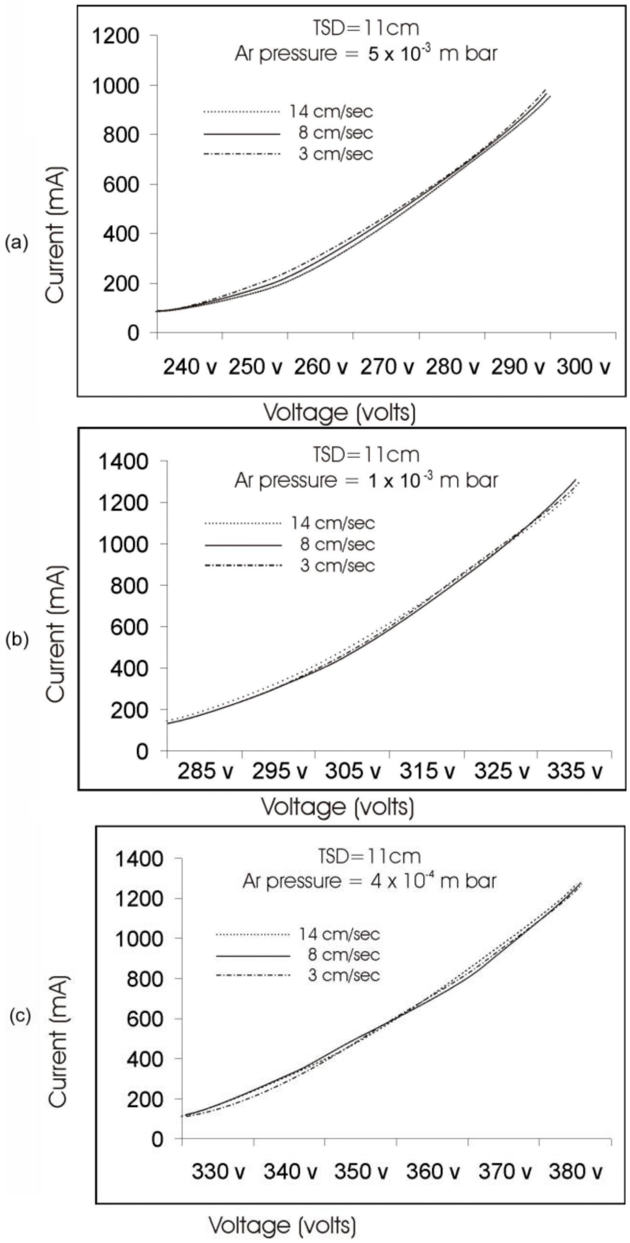


Figure 3 (a) (b) (c): i-v characteristics of the scanning magnetron system, at different scanning speed at different pressures

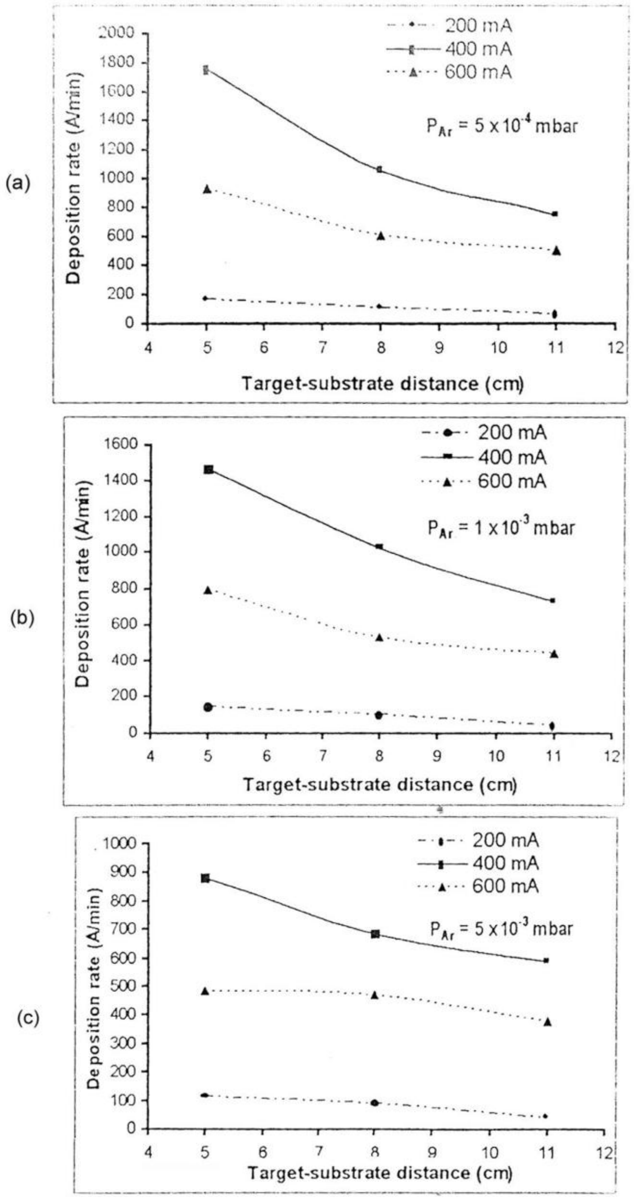
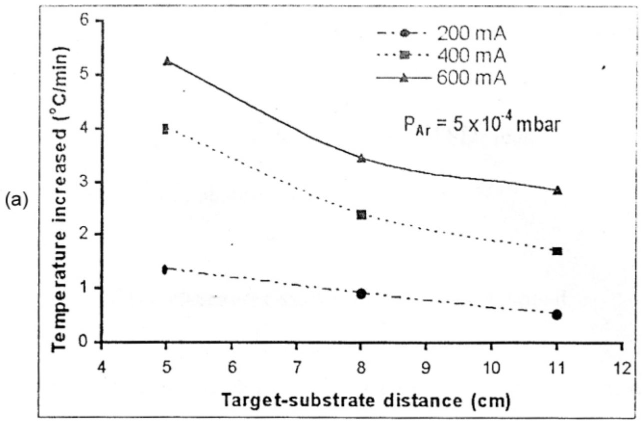


Figure 4 (a) (b) (c): Variation of deposition rate with target substrate distance (T.S.D.), at different pressures



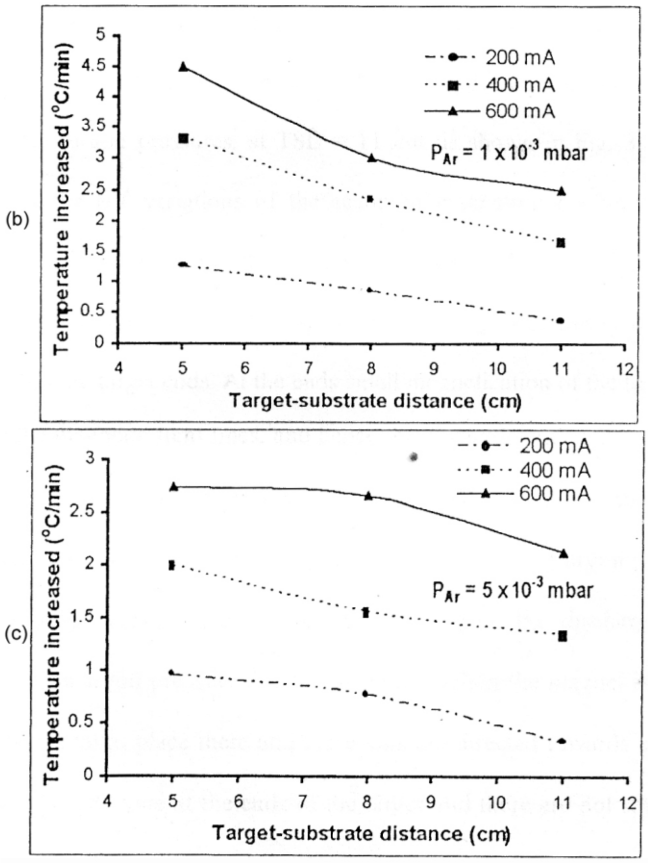


Figure 5 (a) (b) (c): Variation of temperature rise with T.S.D. at different pressures and different discharge current

Figure Captions

Fig 1 Assembly diagram of scanning magnetron (Front View)
Fig 2 (a) (b) (c) i-v characteristics of magnetron at different T.S.D. and pressures
Fig 3 (a) (b) (c) I-v Characteristics of the scanning magnetron system, at different scanning speed
Fig 4 (a) (b) (c) Variation of deposition rate with target substrate distance (T.S.D.) ,At different pressure
Fig 5 (a)(b) (C) Variation of temperature rise with T.S.D. at different pressures and different discharge rate