Calculating the Thickness of Thin Films, Produced by Different Kinds of Evaporators

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Abstract - **The thickness uniformity of thin films, deposited on different substrates is very important with a respect to the quality of the layers and the output of the technological process. It has to be proofed, when a new vacuum equipment is first set in operation. The present work predicts the thickness of the produced layers using some idealized models and shows the way for calculating it by a real sputtering process.**

Keywords – **cathode sputtering, mathematical models, NiCr, erosion profile.**

I. INTRODUCTION

A standard B-55 vacuum plant is supplied additionally with a magnetron sputtering system in order to produce NiCr resistive layers. We have to consider according to the new arrangement in the chamber and some technological parameter – for instance the sputtering rate some models, which are suitable for calculating the thickness distribution of the film over the substrate.

II.BASIC CONCEPTS AND QUANTITIES

We suggest a cos law of distribution for the sputtered atoms. They reach the substrate without hindrance and all of them condense there.

A basic concept in the models is the parallel disposition between the motionless substrate and target.

The main quantities we use in our considerations are shown on Fig.1. Here denote the symbols the following: dA_e – the elementary emitting surface, dA_r – the elementary surface on the substrate, φ - the sputtering angle, θ - the condense angle, α - the angle between the Y axis and the radius vector to dA_e, h – the distance target-substrate, s – radius, r – the distance between dA_e and dA_r, l – the distance between the centre of the substrate and the point, where the thickness d is calculated.

III.MODELS FOR CALCULATING LAYER'S THICKNESS

A.SMALL SURFACE EVAPORATOR

The thickness of the layer d_e from the small emitting surface dA_e on an infinite small surface dA_r of the substrates by randomly oriented to each other substrate and target is given with [1]:

$$d_e = \frac{m_1}{\pi.\rho}\frac{\cos\varphi.\cos\vartheta}{r^2}dA_e \qquad (1)$$

where ρ is the density of the sputtered material. The meaning of m_1 is the mass of the sputtered material, produced from one sputtered surface unit in one second, that is so to say the mass velocity (intensity) of sputtering.

Assuming a *plain substrate, planar to the emitting surface* of the target we get (Fig. 1):

$$\varphi = \theta,\ \cos\varphi = \cos\theta = \frac{h}{r},\quad dA_e = s.d\alpha.ds \qquad (2)$$

$$d_e = \frac{m_1}{\pi.\rho}\frac{h^2}{r^4}.s.ds.d\alpha \qquad (3)$$

We can get the distribution of the final thickness d of the layer over the substrate when we integrate (3):

$$d = \iiint_{t,s,\alpha} d_e = \iiint_{t,s,\alpha} s.\frac{m_1}{\pi.\rho}\frac{h^2}{r^4}.ds.d\alpha \qquad (4)$$

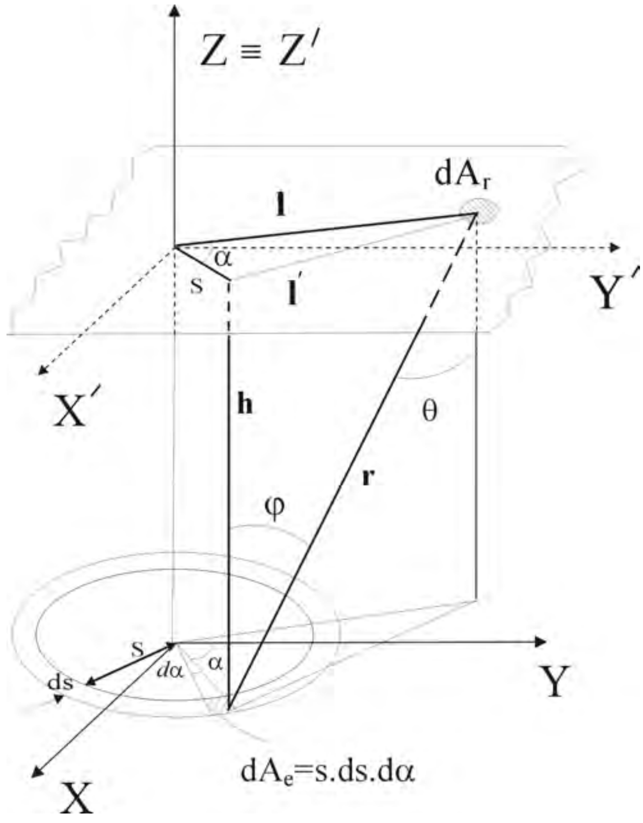

Fig.1: Geometric arrangement substrate-sputtering target

According to the relationships between the quantities on Fig.1 we get:

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$$r^2 = h^2 + l'^2 = h^2 + (l^2 + s^2 - 2l.s.\cos\alpha) \qquad (5)$$

Then:

$$d = \iint_{t,s} \frac{h^2 m_1}{\pi\rho}.s.ds.dt \int_{\alpha} \frac{d\alpha}{(h^2 + l^2 + s^2 - 2l.s.\cos\alpha)} =$$

$$= \frac{h^2}{\pi\rho} \iint_{t,s} m_1.s.ds.dt \int_{\alpha} \frac{d\alpha}{(h^2 + l^2 + s^2 - 2l.s.\cos\alpha)} =$$

$$= \frac{h^2}{\pi\rho} \iint_{t,s} m_1.s.ds.dt.\Im \qquad (6)$$

$\Im$ means here:

$$\Im = \int_0^{2\pi} \frac{d\alpha}{(h^2 + l^2 + s^2 - 2l.s.\cos\alpha)} \qquad (7)$$

Substituting:

$$b = h^2 + l^2 + s^2\ ;\ c = 2l.s\ ;\ a = \frac{c}{b} \qquad (8)$$

we get for $\Im$:

$$\Im = \frac{1}{b^2} \int_0^{2\pi} \frac{d\alpha}{(1 - a.\cos\alpha)^2} = \frac{1}{b^2}.I \qquad (9)$$

The integral I is a sum of four integrals, two of the kind $I' = \int_0^{\frac{\pi}{2}} \frac{dx}{(1 - a.\cos x)^2}$, the rest - $I'' = \int_0^{\frac{\pi}{2}} \frac{dx}{(1 + a.\cos x)^2}$.

We unite all them in one integral within the same limits and after some transformations we receive:

$$I = \frac{2\pi}{(1 - a^2)^{\frac{3}{2}}} \qquad (10)$$

Substituting (10) in (9) and using (8) we get for $\Im$:

$$\Im = 2\pi \frac{(h^2 + l^2 + s^2)}{\left[(h^2 + l^2 + s^2)^2 - 4.h^2.l^2\right]^{\frac{3}{2}}} \qquad (11),$$

and for d:

$$d = \frac{2h^2}{\rho} \iint_{t,s} m_1 \frac{(h^2 + l^2 + s^2)}{\left[(h^2 + l^2 + s^2)^2 - 4.h^2.s^2\right]^{\frac{3}{2}}} s.ds.dt \qquad (12)$$

The expression (12) is for the case of a small surface evaporator.

Further on the calculation for a certain point of the substrate of the full (final) thickness of the layer d depends on:

- The kind of the evaporating source
- The dependency $m_1 = m_1(s,t)$

B.THIN RING EVAPORATOR

An evaporator in the form of a thin ring with radius s is considered. Assuming m_1= const(t) and $m_1 \neq m_1(s)$, we receive from (12) after double integrating:

$$d = \frac{M_r}{\pi\rho h^2} \frac{1 + (l/h)^2 + (s/h)^2}{\left\{\left[1 + (l/h)^2 + (s/h)^2\right]^2 - 4(s/h)^2\right\}^{3/2}} \qquad (13)$$

M_r here means the total evaporated mass from the thin ring evaporator.

$$M_r = 2\pi s.ds \int_t m_1 dt = 2\pi s ds \tau \qquad (14)$$

C.DISK EVAPORATOR

The same procedure in the case of a disk evaporator by the same conditions (m_1= const(t) and $m_1 \neq m_1(s)$ gives for d the expression:

$$d = \frac{M_d}{2\pi\rho s^2} \left\{ 1 - \frac{1 + \left(\frac{l}{h}\right)^2 - \left(\frac{s}{h}\right)^2}{\sqrt{\left[1 + \left(\frac{l}{h}\right)^2 + \left(\frac{s}{h}\right)^2\right]^2 - 4\left(\frac{s}{h}\right)^2}} \right\} \qquad (15)$$

In (15) M_d stands for the total amount of the sputtered mass from the disk:

$$M_d = \pi s^2 \int_t m_1 dt = \pi s^2 m_1 \tau \qquad (16)$$

IV.REAL EXPERIMENTAL MODEL

The equations (14) and (16) show, that the sputtering rate m_1 is assumed to be invariable during the whole time of evaporation - τ . This is reasonable when we keep up a constant power of the generator. When we calculate d in the case of a thin ring evaporator (13) or a disk evaporator (15), *we regard m_1 as a constant over the whole surface* of evaporation as well. Otherwise m_1 would take part in the integration over s.

Actually m_1 varies over the surface of the evaporator. The real dependence $\mathbf{m_1 = m_1(s)}$ is connected with the concrete technological equipment and the kind of the target.

A good proof for the above mentioned are the *erosion profiles* of long used targets (cathodes). Their erosion surfaces repeat the dependence $m_1 = m_1(s)$ and are not ideal responding to the models *B* and *C*.

The main interest in our experiments was in the thickness of the deposited resistive films over the substrate. They were produced by sputtering a NiCr (Ni:Cr = 80:20) target. After a long time of sputtering the cathode looks like this shown in Fig. 2.

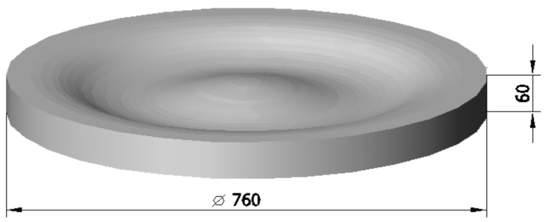

Fig. 2: The view of a NiCr target after a long use, mm.10

When new the target is a regular disk with ϕ = 76 mm, h = 6 mm.

The sputtering profile of NiCr target as a result of measurements and interpolation is shown as curve *1*on Fig. 3:

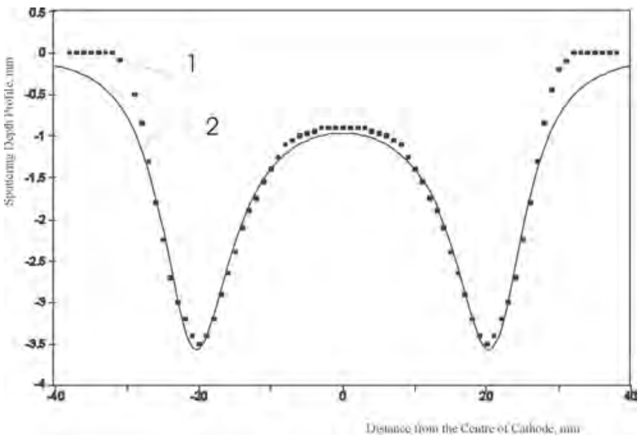

Fig. 3: Measured erosion profile – *1* and fitting curve to it – *2* of a long used NiCr target

It can be seen from Fig.3, that the profile is sharp with a minimum by distances $\pm$ 20 mm from the centre of the target. The edges of the target are practically not sputtered, but the centre is sputtered with some little rate.

The fitting curve (Fig. 3, curve *2*), witch corresponds best to the measured profile can be found with the help of an appropriate software program. We have used TableCurve2d program to reveal the analytical form of the dependence $m_1(s)$. So we got for m_1 a function of a kind:

$$m_1(s) = (a + b.s + c.s^2 + d.s^3 + e.s^4)^{-1} \qquad (17),$$

where:

$$a = -1.0284864,\ b = -1.715905.e^{-6},\ c = 0.0036083349,$$
$$d = 4.3724109.e^{-9},\ e = -4.3472891.e^{-6} \qquad (18)$$

The integral, which has to be solved in our case is:

$$d = \frac{2h^2\tau}{\rho}\int_{-38}^{38}\frac{m_1(s)(h^2+l^2+s^2)}{\left[\left(h^2+l^2+s^2\right)^2-4h^2.s^2\right]^{3/2}}\ s.ds \qquad (19)$$

In the last equation $m_1(s)$ comes from (17), the coefficients in it from (18), h and l are technological parameters. Equation (19) can be numerically calculated with a suitable program, for example with the mentioned TableCurve.

V.CONCLUSIONS

In the present work we consider some idealized models for calculating thickness of sputtered layers. In the reality we can't ignore the influence of the different rate of evaporation over the target on the thickness distribution. A model which takes into consideration this different sputtering rate is proposed.

A comparison between calculated and experimental results for the layer's thickness distribution over the substrate using different models will be a subject of an other work [2].

REFERENCES

[1] Leon I. Maissel and Reinhard Glang, *Handbook of Thin Film Technology*, McGRAW HILL COMPANY, 1970.
[2] D. Parashkevov, in preparation