Some Geometrical Considerations Connected with the Planetary Movement of the Substrate During Sputtering

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***Abstract* –Thin solid films produced by vacuum deposition have to be uniform in respect of their thickness. One has to pay attention to the geometrical arrangement of substrate and source in the vacuum chamber. Often rotation of the substrate holder around the evaporator is used for getting uniform films. In the present work we describe geometrically the rotation of the substrate plane around an arbitrary axis.**

***Key words* – coordinate systems, rotation, transformation of coordinates, magnetron sputtering**

I. INTRODUCTION

In modern vacuum machines great attention [1,2] is paid to the arrangement of all parts built in the vacuum chamber in order to get an uniform thickness distribution of the thin film over the substrates. In most cases the lather are plain: some are circular (Si wafers), other are rectangular (ceramics, glass). To develop a theoretical model of evaporation and afterwards a program for calculation the thickness of the film, one has to know the kind of evaporation source used and the configuration in the chamber. We can get the amount of condensed atoms (thickness of the film) in one certain point of the substrate if we know (in first approximation) for how long and under what flux of evaporated particles this point is exposed. The flux is determined by the space distribution of evaporation and the power of the source. These are technical characteristics of the source equipment.

The time of stay of a chosen point in the particle flux depends on the arrangement: source – substrate and the kind of motion the substrate performs. The substrate motion should ensure best thickness uniformity.

Every vacuum equipment is individual. We have a magnetron sputtering system consisting of 4 cathodes ordered in equal distances one from other and laying in one plane. The substrates are disposed on a plain plate (substrate holder). The target plain is motionless, while the substrate holder is rotating around its own axis and around the plain, where the targets lay. We need to know in every moment of this planetary movement of the substrate the position of every chosen point on it [3].

The aim of this work is to describe in geometrical terms the planetary movement of one plane around another.

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II. ROTATION OF A PLANE AROUND AN ARBITRARY AXIS

We consider a rotation of a plain with a coordinate system bound to it around an axis of a fixed coordinate system.

Let's have the coordinate system $K(O,x,y,z)$. Around the Oz axis a plain σ is rotating. σ is in distance R from the point O has an angle α with the plane Oxy (Fig.1).

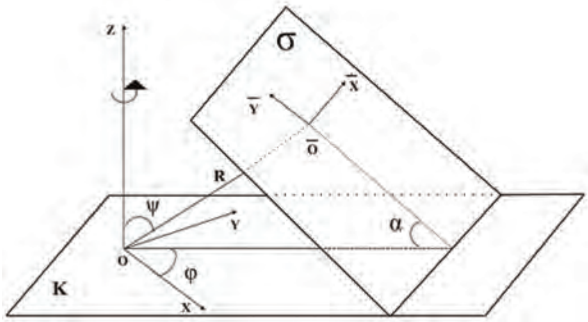

Fig. 1. Coordinate system K with a rotating plane σ

$\overline{O}$ is the orthogonal projection of the point O in σ. We chose in the same plane σ a local coordinate system $\overline{K}(\overline{O},\overline{x},\overline{y},\overline{z})$ with origin of coordinates point $\overline{O}$, so that $\overline{x}$ is parallel to Oxy and $O\overline{y}$ lays in σ. We denote the fixed angle between Oz and $O\overline{O}$ with ψ, and the varied angle between Ox and the projection of $O\overline{O}$ in the Oxy plane with φ. Using these notations the $\overline{O}$ coordinates in the coordinate system $K(O,x,y,z)$ are:

$$x= R\sin\psi.\cos\varphi;\quad y=R\sin\psi.\sin\varphi\ (1);\quad z=R\cos\varphi \qquad (1)$$

If the angle velocity of σ around Oz is ω, it is obviously, that $\varphi = \omega.t$. Let's have an arbitrary point S from σ with coordinates in in $\overline{K}$ - $\bar{x},\bar{y}$ (Fig. 2).

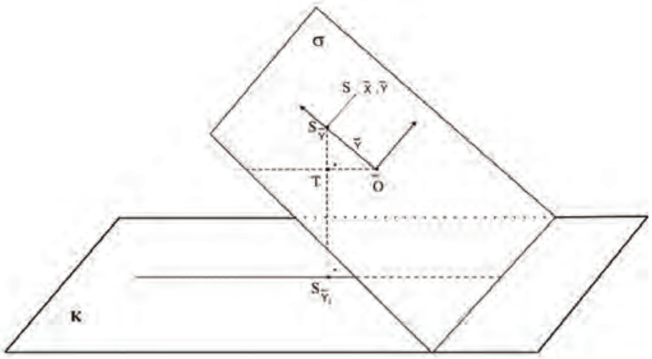

Fig. 2. Point S from σ and its projection in K

$S_{\bar y}$ is its projection on the axis $\bar{O}\bar{y}$. $S_{\bar y_1}$ is the projection of $S_{\bar y}$ in O,x,y plane. Let's T be a projection of $\bar{O}$ over $S_{\bar y}S_{\bar y_1}$, then $\angle S_{\bar y}\bar{O}T = \alpha$ and $S_{\bar y}T = \bar{y}.\sin\alpha$, $\bar{O}T = \bar{y}.\cos\alpha$.

$Z_{S_{\bar y}} = Z_S$ becauce of that, that $SS_{\bar y}$ is parallel to Oxy. Besides that:

$$Z_{S_{\bar y}} = TS_{\bar y_1} + Z_{\bar O} + \bar{y}.\sin\alpha = R\cos\psi + \bar{y}.\sin\alpha \quad (2)$$

To find out S_x and S_y we project σ over the plane O,x,y. The projections of the different elements we denote with an additional index "1" (Fig.3).

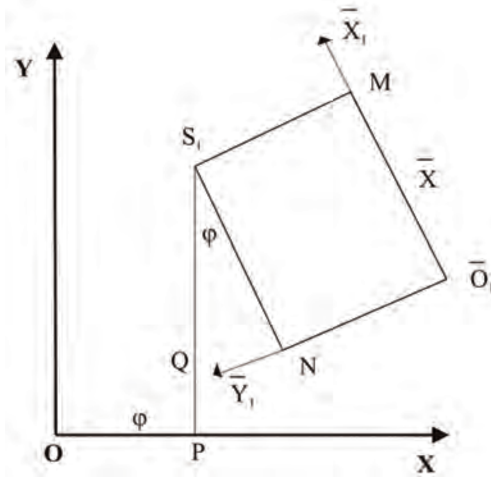

Fig. 3. Some points and segments in the plane O,x,y

Because $O\bar{O}$ is perpendicular to σ and $\bar{x} \parallel O$xy it follows, that $O\bar{O}_1 \perp \bar{O}_1\bar{x}_1$. From $\bar{O}\bar{y} \perp \bar{O}\bar{x}$ follows, that $\bar{O}_1\bar{y}_1 \perp \bar{O}_1\bar{x}_1$. We denote the projections of S_1 on the axes $\bar{O}_1\bar{x}_1$, $\bar{O}_1\bar{y}_1$ O,x with M, N and P respectively. From the fact, that $\bar{O}\bar{x}$ is parallel to O,x,y follows that, the distances along this axis remain the same when projected, this means $\bar{O}_1M = \bar{x}_s = \bar{x}$. From the other side $\angle NS_1P = \angle \bar{O}_1OP = \varphi$. The coordinated of S_1 we search are the lengths of the segments OP and S_1P. As can be seen from Fig.2 $\bar{O}_1N = \bar{y}.\cos\alpha$. Further $S_1Q = \bar{x}/\cos\varphi$ and $NQ = \bar{x}.\mathrm{tg}\,\varphi$.

The projection of $O\bar{O}$ over Oxy is $O\bar{O}_1$ and has the length R sin α. From here follows:

$$OQ = O\bar{O}_1 - \bar{O}_1N - NQ = R\sin\alpha - \bar{y}.\cos\alpha - \bar{x}.\mathrm{tg}\,\varphi \quad (3)$$

Therefore:

$$x_s = x_{s_1} = OP = OQ\cos\varphi = R\sin\alpha\cos\varphi - \bar{y}.\cos\alpha\cos\varphi - \bar{x}\sin\varphi \quad (4)$$

$$y_s = y_{s_1} = S_1P = S_1Q + QP = \bar{x}/\cos\varphi + OQ\sin\varphi = \bar{x}/\cos\varphi + (R\sin\alpha - \bar{y}.\cos\alpha - \bar{x}.\mathrm{tg}\,\varphi).\sin\varphi = \bar{x}\cos\varphi + R\sin\alpha\sin\varphi - \bar{y}.\cos\alpha\sin\varphi \quad (5)$$

Finally, when we know the coordinates of S toward $\overline{K(O,x,y,z)}$ in the plane σ, which has $\angle\alpha$ with Oxy ($\angle\psi = \angle\alpha$), the distance R from O with an angle φ between Ox and the projection $O\bar{O}$ in Oxy we get the following formulas for the coordinates of the point S in K:

$$x_s = R\sin\alpha\cos\varphi - \bar{y}\cos\alpha\cos\varphi - \bar{x}\sin\varphi = x_{\bar o} - \bar{y}\cos\alpha\cos\varphi - \bar{x}\sin\alpha \quad (6)$$

$$y_s = R\sin\alpha\sin\varphi - \bar{y}.\cos\alpha\sin\varphi + \bar{x}\cos\varphi = y_{\bar o} - \bar{y}.\cos\alpha\sin\varphi + \bar{x}\cos\varphi \quad (7)$$

$$z_s = R\cos\alpha + \bar{y}\sin\alpha = z_{\bar o} + \bar{y}\sin\alpha \quad (8)$$

III. Planetary Movement of the Substrate Plane

The planetary movement itself is a combination of two rotations of a body (plane): one rotation around its own axis and at the same time and independently from that around another central axis. The angular velocities of both rotations are in general different.

In our case (Fig. 4) the matter of interest is the rotation of σ, the plane, where the substrates are disposed (substrate plain) with an own angular velocity ϖ around an axis coincidental with the perpendicular R to σ and passing through $\bar{O}$. Besides that there is another independent movement around the Oz axis with an angular velocity ω.

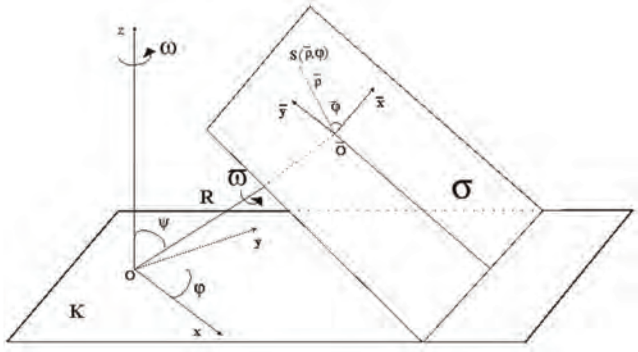

Fig. 4. Planetary rotation with two angle velocities ω and ϖ

The angle dependences by these two rotations are: $\bar{\varphi} = \bar{\varpi}.t$ и $\varphi = \omega.t$. To describe the whole motion (planetary rotation) it is convenient in this case to use polar coordinates in the σ plane: $\sigma = \sigma(\bar{\rho}, \bar{\sigma})$. Substituting in (6), (7) and (8) and having in mind, that R and α are parameters we can express x_s, y_s и z_s trough φ, $\bar{\rho}$, $\bar{\varphi}$.

These geometrical relationships give us in every moment the position of a chosen point of the substrate. This would be enough for creating the mathematical model of planetary rotation.

IV. Conclusions

We present in details a geometrical model for planetary rotation of a plane, consisting of a rotation around an arbitrary axis in the space and a rotation around another own axis. In the text there are schemes illustrating the transformations of coordinates of a chosen point from a moving coordinate system (substrate plane) to an fixed one.

The results will be used in a software program for predicting thickness distribution of the layer. The program will give an account not only to the particular geometrical conditions but also to the physical and technological parameters of our experimental equipment [4].

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