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The method of controlling the thickness of the deposited film on the basis of the surface plasmon resonance effect

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Abstract. New method, based on surface plasmon resonance, for thickness control of thin films deposition in vacuum is offered by authors. This method allows to determine with high accuracy thickness of nanoscale optical coatings. Numerical simulation of surface plasmon resonance conditions in Kretchman geometry and it's frequency changes during deposition of different thickness Ta_2O_5 films are presented. Modeling was given in WinSpall program.

1. Introduction

Different methods are used nowadays for control of thin film thikness during deposition in vacuum. Widely used two methods – quartz frequency change (mass change method) and photometric measurements (reflectance/transmission coefficient change). Both of them have limitations of usage in nanoscale film thikness control. This limitations are especially relevant for multilayer optical coatings task.

Authors offer method for film thikness detection prevented imperfection of quartz and photometric systems. Excitation of surface electromagnetic wave (SEW) in Kretchman geometry was taken as a base.

2. Surface electromagnetic waves

Surface electromagnetic waves or surface polaritons are special kind of electromagnetic waves, propagating along boundary matter surface. Field of this waves localized in near surface layer with dimention, as usual, about wave length. As a result of this localization, even insignificant dielectric permittivity changes take an effect on SEW excitation conditions [1–3].

Different dielectric permittivity sign of bordering matters is an indispensable condition for SEW exitation. Surface wave energy produced by electromagnetic field of falling light and a component linked to resonance properties of matter. It can be lattice mechanical oscillations (phonons), electron oscillations in metals (plasmon), excitons in semiconductors. Independently of quasi particle, taking part in SEW excitation – surface localization is typical for all of them [4].

Conversion of incident light in SEW by prism method is based on total internal reflection effect at falling of *p*-polorized light on sarface active layer (SAL) from matter with higher optical density. Propagation length of SEW along surface is strongly sensitive to processes in absorption layer, surface state and it's changes, adsorption layers presence, films, surface roughness and other. It provides possibility to analyse surfaces and matters boundary with SEW mechanism.

Angle of incidence is chosen by well-known in optics condition:

$$\theta > \left[\arcsin\left(\frac{\varepsilon_2}{\varepsilon_3}\right)\right]^{1/2};\ \varepsilon_2 < \varepsilon_3, \tag{1}$$

were ε_2 – dielectric permittivity of air; ε_3 – dielectric permittivity of prism material. Surface plasmon exitation method exist in two modifications: Otto (figure 1(a)) and Kretchman (figure 1(b)) geometry. Generally lasers are light sources for SEW exitation.

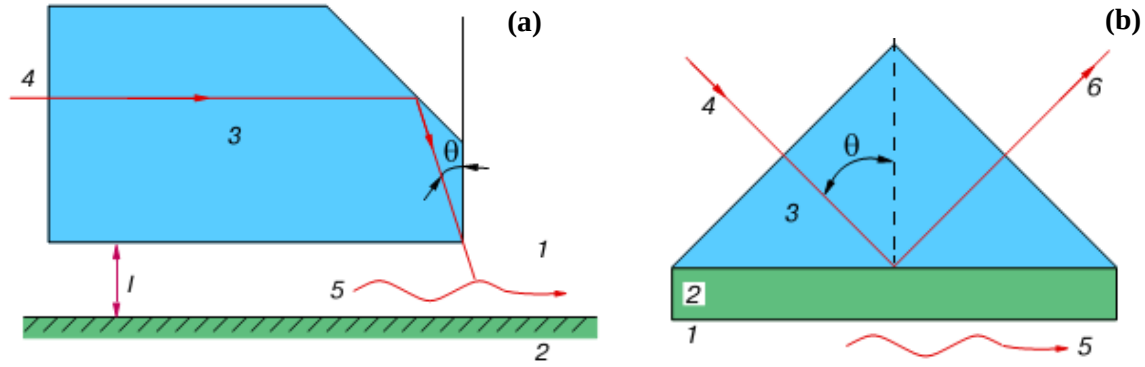

Figure 1. Exitation of SEW by light: **(a)** – prism method in Otto geometry; **(b)** – Kretchman geometry; *1* – dielectric (air); *2* – surface active layer; *3* – prism; *4* – incident light; *5* – surface electromagnetic wave; *6* – mirrored light.

Convertion effectiveness of incident light into SEW in Otto scheme, usualy applied for infrared radiation region, is about one tenth, while in Kretchan scheme, for visible region, reaches up to 1. But in last case taking out SEW from prism is embarrassed and SAL usualy deposite on prism facet as a thin film [4].

3. Film thikness control method

Thin film thickness detection method, proposed by authors, prevent from disadvantages of photometric and quartz resonator methods. As mentioned above, resonance exciting of electron gas oscillations (plasmons) by electromagnetic wave in thin layer of conductive matter, placed between materials with different refractive index, is called surface plasmon resonance (SPR) [1]. In most cases for SPR effect used system wich consists of opticaly transparent material with high refractive index (fused silica, for example [4]) and thin gold film, deposited on it's surface. High chemical inactivity makes gold mainly used material for SPR applications [4].

Layer of gold deposit on hypotenuse facet of the prism. According to numerical simulation and literature 50 nm film is optimal. At definite incidence angle (behind total reflection) of laser beam on gold surface (from prism side) SEW excites at gold/air boundary. Surface plasmon frequency depends on dielectric permittivity of gold ε_1 and contiguous matter ε_2 by dispersion ratio:

$$\frac{\omega_p}{k_{px}} = \frac{c\sqrt{\varepsilon_1 + \varepsilon_2}}{\sqrt{\varepsilon_1 \varepsilon_2}}, \tag{2}$$

were k_{px} – wave vector projection of *p*-polarized light on *x* axis.

If such system mount in vacuum chamber and start material deposition then on gold surface will growth thin film. This leads to ε_2 change and, correspondingly, change of surface plasmon frequency. Now resonance conditions will be corresponding to another incidence angle of laser beam.

Illuminating prism by laser beam with some aperture we will see resonance angle shifting during film deposition. Main advantage of proposed method is that system directly registrate dielectric permittivity change of material deposited on sensor surface. It allows calculate optical thickness of the layer in real time.

4. Modeling results

Results of modeling in WinSpall program are shown below. Light source is *p*-polarized He-Ne laser beam. Wave length is 632.8 nm. Dielectric permittivity of prism material is $\varepsilon_3 = 2.2952$. Dielectric permittivity of gold is $\varepsilon_1 = -12.033 + i1.1634$. Illuminating 50 nm thick gold film from prism side by laser beam with 40° aperture we will see on screen (or CCD) narrow strip of resonance at 43°.

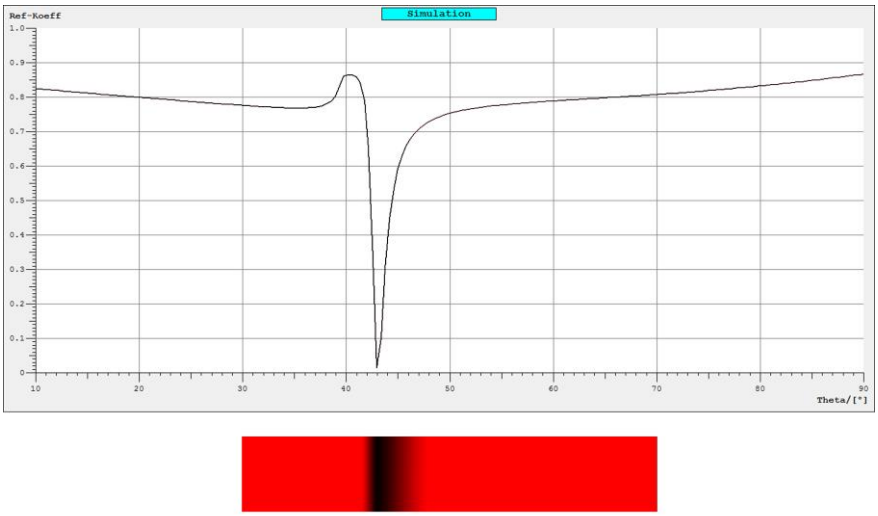

Figure 2. SEW excitation by He-Ne laser. Gold film thickness is 50 nm.

As mentioned above – growing film thickness can be determine by SPR angle shift. To show this, different thickness of Ta_2O_5 film, deposited on gold surface, ware simulated. Dielectric permittivity of Ta_2O_5 is $\varepsilon(Ta_2O_5) = 4.4958 + i0.0041967$. Shifting of signal minimum on screen (or CCD) allows to watch on resonance angle change.

Numerical simulation results for different thickness of Ta_2O_5 film (1; 5; 10; 15; 20; 25 and 30 nm) are shown on figure 3 and in table 1.

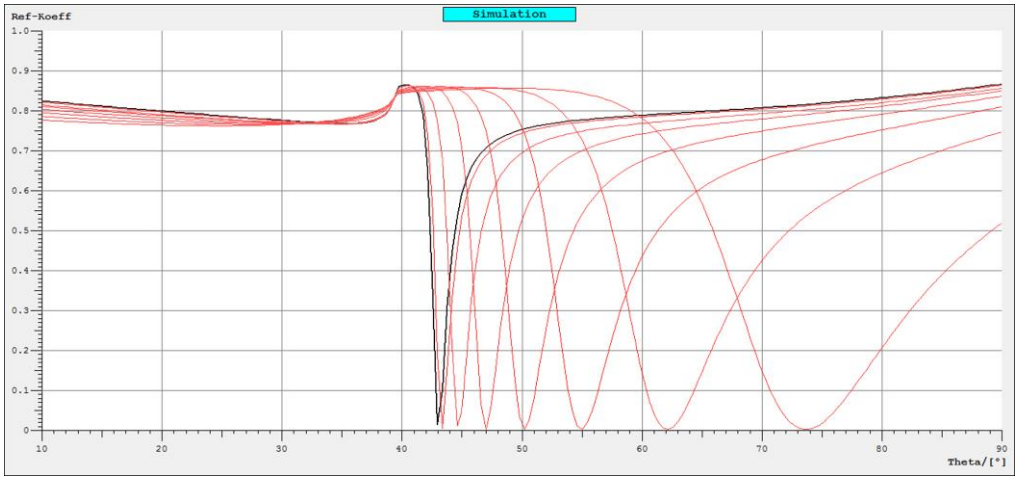

Figure 3. Numerical simulation results of SPR angle shift for different Ta_2O_5 film thickness. The values of thickness and angels are shown in table 1.

Table 1. Modeling results.

Ta_2O_5 thickness (nm)	0	1	5	10	15	20	25	30
Resonance angle (deg)	43.0	43.4	44.7	46.9	50.2	55.0	62.1	73.7

As it is seen from presented results – proposed method allows thickness measuring of nanoscale films with high accuracy. Now we are working on measuring system prototype, which will be mounted in vacuum material evaporation plant as a real time thickness detection system.

5. Conclusions

Computer modeling results shows operability of invention such thickness measuring system. Offered by authors method allows to calculate optical thickness of growing nanoscale film in real time, that is relevant task for optical coatings evaporation.

References

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