SPECTRAL CHARACTERISTICS OF ANTIREFLECTIVE OPTICAL COATINGS WITH COMPLEX REFRACTIVE INDEX

R.A. KARAMALIYEV
Baku State University, Z. Khalilov str., 23, AZ-1148,Baku, Azerbaijan

R.M. KASIMOV
*Institute of Chemical problems of National Academy of Sciences,
H.Javid av., 29, AZ-1143,Baku,Azerbaijan*

Spectral characteristics of reflection of optical waves by system an absorbing coat-metal at the selective thickness of coating corresponding requirements of a total absorption of incident radiation in it are considered.

1. Introduction

Last years the optics of antireflecting coatings represents the significant practical interest. The problem of the full suppression of reflection of optical waves from absorbing coatings is especially actual one. However, known computational methods of antireflecting coatings are valid only when optical media are completely transparent. As is known, in this case refractive indices of all media can have only real values [1-3].

One of the interesting problems in thin-film coatings optics is that of analysis of the spectral characteristics of a multilayer whose optical constants and thickness are known. For microwave region of spectrum the effect of reflectionless absorption in layered system an absorbing dielectric-metal both theoretically and experimentally was investigated in [4,5]. This method of investigation was extended to include optical wavelengths in [6].

In the present paper we have developed the research technique of antireflective absorbing optical coatings presented in [6] for to investigate their spectral characteristics.

2. Reflection characteristics of a two-layer dielectric-metal structure

In order to find a formula for the reflectance of a two-layer dielectric-metal structure illuminated by a parallel beam of light at wavelength λ, we must consider the multiple reflections of light at each surface of the structure and perform a multiple beam summation. Incident light is considered normally and plane polarized. The reflected complex amplitude R^* is given by

$$R^* = \frac{r_1 e^{i\varphi_1} + r_2 e^{i\varphi_2 - 2ikl}}{1 + r_1 r_2 e^{i(\varphi_1+\varphi_2)-2ikl}} \qquad (1)$$

where l is the thickness of the absorbing coating; r_1,r_2, φ_1, φ_2 are modules and phases of reflection coefficients for first and second surfaces of the layer, respectively; k is complex wave number and for materials with complex refractive index equals

$$k = \frac{2\pi(n - i\chi)}{\lambda} \qquad (2)$$

where n is the refractive index of the layer material, χ is the extinction coefficient of the material. Modules and phases of reflection coefficients are given

$$r_1 = \sqrt{\frac{(1-n)^2+\chi^2}{(1+n)^2+\chi^2}},\quad \varphi_1 = \pi - arctg\frac{2\chi}{1-n^2-\chi^2},\ r_2 = 1,\ \varphi_2 = \pi . \qquad (3)$$

The expression for energy reflectance may be obtained from equation (1)

$$R^2 = \frac{\left(r_1 - r_2 e^{-\frac{4\pi\chi l}{\lambda}}\right)^2 + 4r_1r_2e^{-\frac{4\pi\chi l}{\lambda}}\cos^2\left(\frac{2\pi nl}{\lambda}+\frac{\varphi_1-\varphi_2}{2}\right)}{\left(1 - r_1r_2 e^{-\frac{4\pi\chi l}{\lambda}}\right)^2 + 4r_1r_2e^{-\frac{4\pi\chi l}{\lambda}}\cos^2\left(\frac{2\pi nl}{\lambda}-\frac{\varphi_1+\varphi_2}{2}\right)} \qquad (4)$$

We shall introduce the suggestion that the specified zero minimum of function *R(l)* is realized at thickness of a layer of the absorbing substance a little differing from quantities of multiple $\lambda/4n$

$$\frac{l}{\lambda} = \frac{1}{n}\left(\frac{2N-1}{4} + \Delta\right) \qquad (5)$$

where N is ordinal number of the minimum of *R(l)* dependence corresponding to the antireflective absorption, Δ is the quantity to be determined by optical parameters of absorbing coating material.

One can see from equation (1) that the condition $R=0$ will be realized if we get

$$\ln\frac{r_2}{r_1}=\frac{\chi}{n}\left[\pi(2N-1)+\varphi_2-\varphi_1\right] \qquad (6)$$

$$\frac{l}{\lambda}=\frac{1}{n}\left(\frac{2N-1}{4}+\frac{\varphi_2-\varphi_1}{4\pi}\right) \qquad (7)$$

$$\Delta=\frac{\varphi_2-\varphi_1}{4\pi} \qquad (8)$$

From equations (6)-(8) one can see that to obtain non-reflective absorption on the coating layer for the selective wavelength, layer thickness and its optical parameters are required.

The dispersion theory gives us the connection between optical parameters n, χ and complex dielectric constant ε. The real ε' and imaginary ε'' parts of ε may be expressed by relations

$$\varepsilon'=n^2-\chi^2\ ,\ \varepsilon''=2n\chi \qquad (9)$$

In the first approximation we can obtain the next relation between ε' and ε''

$$\left(\varepsilon'-n_\infty{}^2\right)^2+(\varepsilon''-b)^2=b^2 \qquad (10)$$

where

$$b=\frac{2\pi q^2N_0}{m\gamma\omega_1}.\quad \omega_1{}^2=\omega_0{}^2-\frac{4\pi q^2N_0}{m} \qquad (11)$$

n_∞ is refractive index far from the resonance frequency ; q, m are charge and mass of electron , N_0 is concentration, γ is damping coefficient, ω_0 and ω_1 are frequencies.

In this approximation the frequency ω which the effect of non-reflective absorption takes place may be determined from the next equation

$$\frac{\varepsilon''}{\varepsilon'-n_\infty{}^2}=\frac{\gamma}{2(\omega_1-\omega)} \qquad (12)$$

Let us illustrate the results of this approach for dye solution of rhodamine. The absorption spectrum of rhodamine presented in fig.1.

Using optical parameters of dye solution γ, N_0 , ω_1, n_∞ we can calculate layer thickness l_0, refractive index n and extinction coefficient χ for a given incident optical wavelength. The Table of these selective parameters was presented in [6].

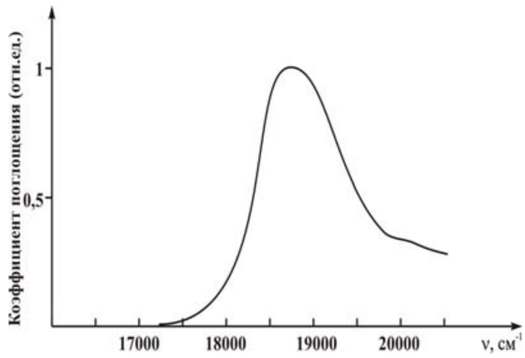

Fig.1. The absorption spectrum of rhodamine.

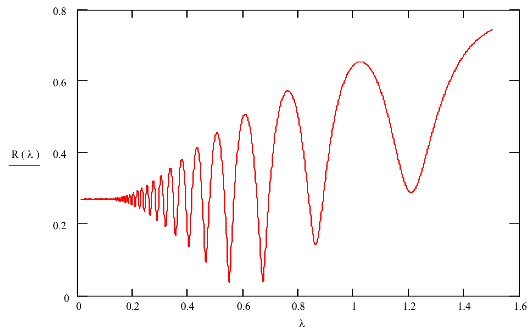

Fig.2. Absolute value of reflection coefficient R vs. of wavelength in the two-layer dielectric-metal structure: layer thickness $l$and wavelength λ is given in mcm, r_2=1, χ=0.08,n=1.7, l=0.68..

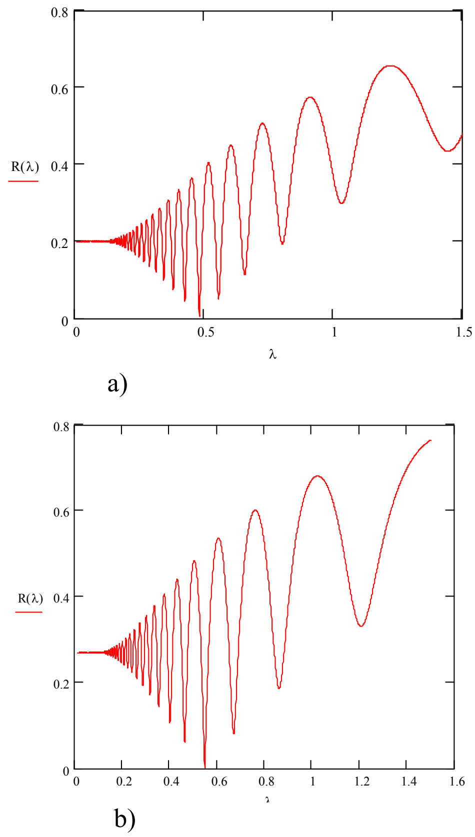

Fig.3. Absolute values of reflection coefficient R vs. of wavelength in the two-layer dielectric-metal structure: layer thickness l and wavelength λ is given in mcm, r_2=1, a)χ=0.08*;* n=.1.73*;* l=0.724*;* N=5 ; b) χ=0.07*;* n=.1.72*;* l=0.884*;* N=6

In fig.2 we represent dependence of reflection coefficient amplitude *R* on incident wavelength λ for non-selective values of optical parameters of the rhodamine. One can see that reflection coefficient R is an oscillating function of incident wavelength which asymptotically approaches its limit value *R*=1.There are two regions in the *R(λ)* dependence which differ by character of changing of extrema in increasing of wavelength of incident light. In the left domain decreasing of wavelength lead to a decreasing maxima and increasing minima of function R up to the complete coincidence of these parameters with limit *R* at large value of layer thickness. Unlike this case, in the right domain of function *R(l)* we observe increasing both maxima and minima of function R which approaches to 1. It is clear that a proper choice of dielectric properties of the optical coating, the boundary of the left and right regions may coincide with one of the minima of function *R(l)* taking zero value. It follows from this that existence conditions for this so-called zero minimum of function *R* will determine conditions for the total (non-reflective) absorption of the optical radiation by the coating-metal structure under study.

The method of computation of selective values of *l*, *n* and χ for to arise non-reflective absorption in the optical coating was presented in [6]. Using these optical parameters calculated for dye solution of rhodamine we have obtained spectral characteristics of this optical coating (fig.3a,b). They are gained at thickness of a layer *l*= 0.724(a) and *l* = 0.884mkm (b) corresponding to the fifth and sixth zero minimums of function *R(l)*. To these specified selective values of layer thickness of a coating correspond selective values of optical coefficients of a coating n=1.73, χ=0.08 (a) and n=1.72, χ=0.07 (b).

3. Conclusion

As follows from the analysis of the gained spectral characteristics of the rhodamine a total or non-reflective absorption of optical radiation may be observed for a frequency band where the wave dispersion of this substance takes place. Thus, the total absorption may be realized at the infinite number of discrete values of a layer thickness of a coating.

---

[1] *L.M. Brehovskih.* Waves in layered media, M., 1957(Russian)

[2] *M. Born, E.Volf.* Principles of optics, M., 1970.

[3] *Sh.A. Furman, A.V. Tikhonravov*. Basics of Optics of Multilayer Systems, Editions Frontieres, *Gif – sur – Yvette*, France, 1992

[4] *R.M. Kasimov, M.A. Kalafi, Ch.O. Kajar, E.R. Kasimov.* J. Engineering-physics, v.71, 2, 1998, pp.282-285 (Russian)

[5] *R.M. Kasimov, M.A. Kalafi, E.R. Kasimov etc*. J. Technical physics,v.66, №5,1996, pp.167-171 (Russian)

[6] *R.M. Kasimov, R.A. Karamaliyev, V.M. Salmanov.* Trans.of Acad.of Science of Azerb., ser. of phys-tech. and math.sciences v.26,№5,2006,pp.118-123 (Russian)

R.Ə. Kərəməliyev, R.M. Qasımov

KOMPLEKS SINDIRMA ƏMSALLI ƏKS ETDİRMƏYƏN OPTİK ÖRTÜKLƏRİN SPEKTRAL XARAKTERİSTİKALARI

Udan örtük-metal sistemində düşən şüalanmanın örtükdə tam udulması şərtlərinə uyğun seçilmiş qalınlıqları üçün optik dalğaların əks olunmasının spektral xarakteristikaları öyrənilmişdir.

Р.А.Карамалиев, Р.М.Касимов

СПЕКТРАЛЬНЫЕ ХАРАКТЕРИСТИКИ АНТИОТРАЖАЮЩИХ ОПТИЧЕСКИХ ПОКРЫТИЙ С КОМПЛЕКСНЫМ ПОКАЗАТЕЛЕМ ПРЕЛОМЛЕНИЯ

Рассмотрены спектральные характеристики отражения оптических волн системой поглощающее покрытие-металл при избирательных толщинах покрытия, соответствующих условиям полного поглощения в нем падающего излучения.

Received: 09.09.07