A Developed Approximations for Reflectance and Transmittance of Asemicontinuous Percolated Metallic Films During Deposition

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A developed identities for the reflectance R and the transmittance T for thermally deposited percolated gold films of thickness ($D<<\lambda$) - at low deposition rate have been investigated at a definite wavelength near the IR-region of spectrum ($2.5 \geq \lambda \geq 1.5\ \mu m$) - taken into account the mechanism - of optical absorption caused by percolating conducting electrons and/or cluster modes as well as - of excitation of surface plasmons as a result of the granular effect of the investigated film. The calculated values of R and T are in accordance with published experimental - and calculated data.

Introduction

Semicontinuous metal films are normally prepared by thermal evaporation or sputtering of the metal on an insulating substrate. As the film grows further, the filling factor increases, so that irregularly shaped clusters are formed [1]. As more metal is evaporated, these clusters grow further and form fractal structures, the size of which diverges as the film approaches the percolation threshold. At that point a spanning or percolating cluster of metal is formed so that, there now exist continuous conducting paths from one end to the other end of the sample [1.2]. At higher surface coverage, the film is mostly metallic with voids of irregular shape and finally the film becomes continuous [1]. The aim of the present article is to develop approximations for R and T of granular metallic films, in the near IR-region at nearly normal incidence and to compare them with published data.

Theory:

We now deal to obtain a developed identities for R and T, for thin granular gold films.

In this case when radiation flux is incident upon a surface, three processes can occur: absorption, reflection and transmission. Absorptance A is the fraction of incident flux that is absorbed. The reflectance R is the fraction of incident flux which is reflected. The transmittance T is the ratio of the transmitted to the incident flux [3].

Assuming a negligible non specular scattering of the incident radiation waves on the investigated metal film. Hence from the conservation law of energy:

$$R+T+A= 1 \qquad (1)$$

$$A=1—R—T \qquad (2)$$

Since for a semicontinuous gold film - its dielectric const ($\varepsilon = \varepsilon_1 + I\, \varepsilon_2$) in the near - infrared region ($2.5 \geq \lambda \geq 1.5$ μm). A, R and T are weakly wavelength dependent along the investigated δD range (δD is the normalized film thickness) specially in the vicinity of percolation threshold — around D — We have then considered our calculations at λ= 1.7 μm [1,2,4]. D_c : is the critical thickness at which the film begins to conduct electrically [1,2,5]. It has been observed by [2] that near the percolation threshold $\varepsilon_1$has to be changed from a positive value at δD<o (insulator — like) to a negative one at δD >0(metal like).

Moreover the condition for the propagation of the surface Plasmon wave $\varepsilon_1 < -1$ –the region of attenuation of electromagnetic waves -[6] which is satisfied at the region δD> o whereas an increase of $I\varepsilon_1 I$ with the growth of δD must be expected [2], which must be accompanied with a sharp increase of R corresponds to a drop of T and A [1,2]. Moreover in the continuous insulator regime (δD< o) a slight increase of R corresponds to a drop of T must be caused by a pronounced increase of A [1,2].

In this case the propagated surface Plasmon wave along the surface boundary Au/vacuum are localized waves transport no energy away from the boundary — the fields of the surface waves are highly concentrated at the surface boundary and decay exponentially inside and outside the plasma [7,8,9,10].

Consequently R must depend on the term exp (1.15 δD) as well as T on the term exp (-1.1 δD).

Taking into account the optical absorption mechanism caused by percolating conducting electrons and / or cluster modes [2,4]. In which the optical loss function (ε_2/λ) must be considered.

Hence from the above demonstrations
R or T = f(ε_1, ε_2, λ, δD)

$$R = \left(\frac{\varepsilon_2}{\lambda}.\frac{I}{|\varepsilon_1|}\right)^{2\beta}.\exp(1.15\,\delta D) \quad (3)$$

$$I = 1\ \mu m \quad (4)$$

$$T = \left(\frac{\lambda}{\varepsilon_2}.\frac{|\varepsilon_1|}{I}\right)^{2n}.\exp(-1.1\,\delta D)$$

β & n : critical exponents related to the microgeometry of the formed cluster path [4,11] as will be demonstrated. The above equations must be restrected by

$-1 \le \delta D \le 1$ $\quad$ $1.5 \le \lambda \le 2.5\ \mu m$
$-0.887 \le \beta \le 0.920$ $\quad$ $-0.669 \le n \le 0.503$ [1,2,4,11]
$\delta D = (D-D_c)/D_c$

The film thickness D must be much smaller than the incident radiation wavelength λ [1,2,4].

In addition over a wide range of filling factors around the percolation threshold P_c – in which irregularly shaped clusters are formed [1] – the optical properties are assumed to be demonstrated by fluctuations [1,2,4]. In this case when $\delta D < 0$ the cluster has a fractal rather than a homogeneous integer – dimensional geometry [11]. Whilst at $\delta D > 0$ a nonlinearity of the conductivity of percolating electrons as a function of δD must be expected [4].

This circumstance has the consequence that a fluctuated variations of the exponents β, n against δ Dmust be expected and are shown in Fig.(1) with the fractal restriction:

$-0.887 \le \beta \le 0.920$, $-0.669 \le n \le 0.503$ [4,11]

Consequently the exponents β, n may be related to certain details of the micro geometry of the extending cluster path [11].

The calculated values of R, T using equations 3,4 as well as that of A using equation 2 are illustrated in Figs. (2,3) as a function of δD – respectively. The values of ε_1, ε_2 are obtained from [2]

It is observed that our calculated values of R. T and A are in accordance with the measured values by [1] as well as with the calculated values by [4] indicating that our suggested eqs (3,4) are useful and physically meaningful.

We now deal to calculate the surface coverage filling factor P* corresponding to maximum absorptance [11,12]. By considering our absorptance curve illustrated in Fig. (3) a central absorption peak is slightly asymmetric w.r.t. the origin ($D=D_c$). which may be attributed to that. close to D_c. the variation of percolating electrons conductivity is no longer linear but ~ $(P-P_c)^{1.3}$ [4].

Since $\delta D. = \dfrac{D - D_c}{D_c} = \dfrac{P^* - P_c}{P_c}$ [1,2]

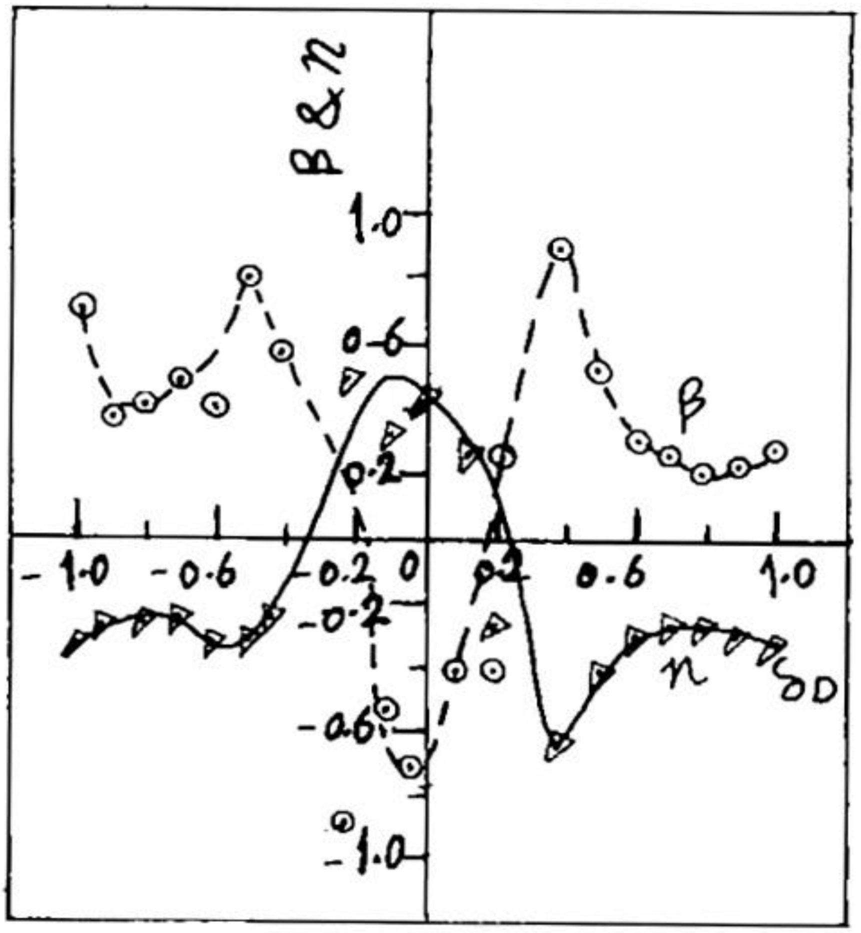

Fig.(1): The variation of the exponents β,n against the normalized film thickness δD

For the gold film. D = 73 A° which corresponds to $P_c = 0.65$ [2]
From our results shown in Fig. (2), P* corresponds to δD = 0.12

$$\therefore \frac{P^* - P_c}{P_c} = 0.12 \rightarrow \frac{P^* - 0.65}{0.65} = 0.12 \quad \therefore P^* = 0.728$$

In agreement with the observation of [1,2] in which P* = 0.74 as well as – the absorptance A is a continuously decreasing function for P >P* [1,2,3] .

From the above demonstrations eqs (3,4) are useful tool for investigating the predicted variations of R and T as well as of A (by using eq. 2) for granular gold films (formed by thermal evaporation) for the transition from a continuous — metal regime to a continuous — insulator regime.

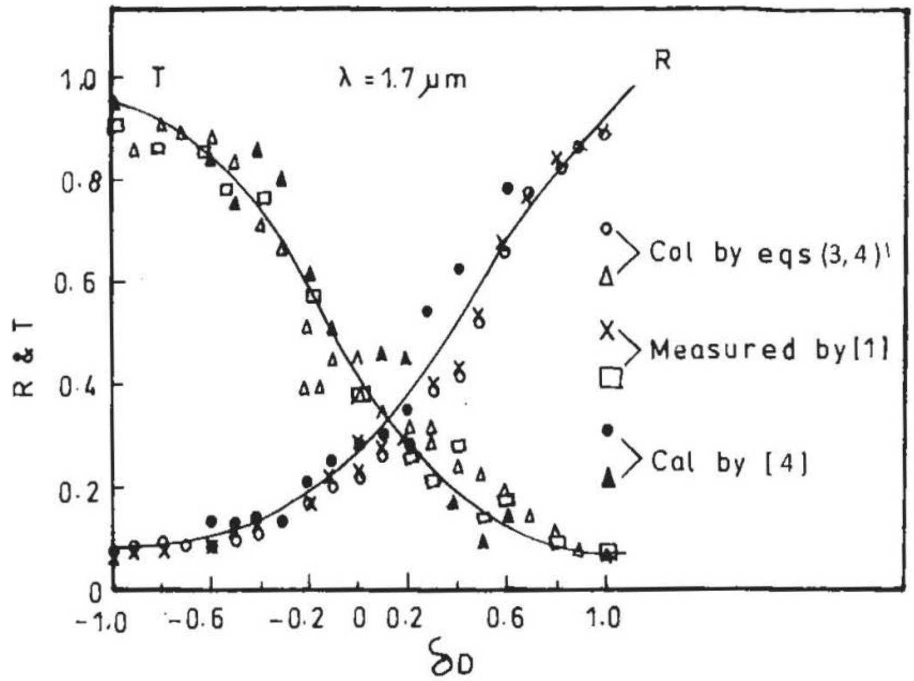

Fig.(2): The variation of the reflectance R & transmittance T against δD

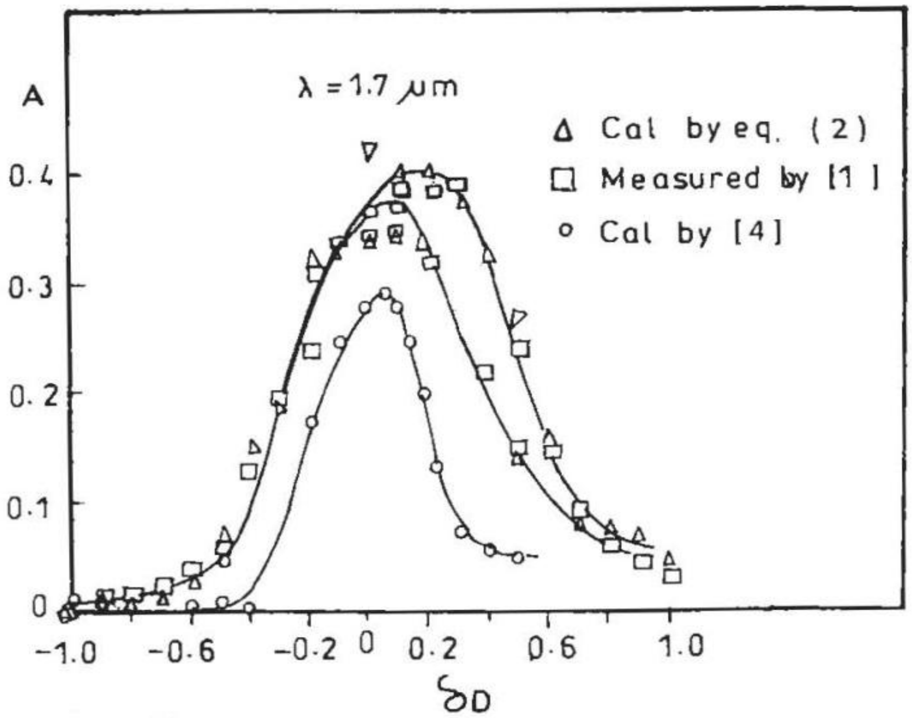

Fig.(3): The variation of the absorptance A against δD

Conclusion

A developed approximations of R and T for granular metal films have been treated in which R or T = F (ε_1, ε_2 , λ, δD)

Acknowledgement

The author is grateful to Prof. Dr. H. Talaat. Ain Shams University. for fruitful discussions and critical reading of the manuscript.

References

1. Y. Yagil, M. Yosefin, D.J. Bergman, G. Deutscher and P. Gadenne, *Phys. Rev. B, Vol*. **43**. 11342 (1991).

2. P. Gadenne. Y. Yagil and G. Deutscher, *J. Appi. Phys, Vol*. **66**, 3019 (1989).

3. W.G. Driscoll, W. Vaughon, *Handbook of Optics McGraw-Hill Book Company*, New York. p. (1-29) (1978).

4. F. Brouers, J.P, Clerc. 0. Giraud. J.M. Laugier and Z.A. Randriamantany, *Phys. Rev*. B, Vol. **47**, 666 (1993).

5. GB. Smith, GA. Nikiasson, J.S.E.M. Svensson and C.G. Granqvist, *J. Appi. Phys*. Vol. **59**, 571 (1986).

6. A.S. Barker. *AJP*, Vol. **42**, 1123 (1974).

7. C. Kittel, *Introduction to Solid State Physics*, Published by V.R. Damodaron for Wiley Eastern Limited. 483 5/24 Ansari Road. Darya Ganj. New Delhi 1 10002. p. 285 (1977).

8. H. Raether, *in physics of thin films*, **9**, 145 (1977).

9. A. Otto, Sektion Physik der Universitat Munchen, Germany Festkorperprobleme XIV. page 1-36 (1974).

10. M.J. Jory, G.W. Bradberry, P.S. Cairn and J.R. Sambles, *Measurements Science and Technology*, **6 [8]**, 1193 (1995).

11. R. S. Koss and D. Stround , *Physical. Rev* .B, vol. **35**, No 17, 9004 (1987)

12. F. Brouers. J.P. Clerc and 6. Giraud, *Phys. Rev*. B Vol. **44**, 5299(1991).