ABSTRACT.

The resistance, Hall voltage and the metrical thickness (\(t_{MBI}\)) measurements are made on evaporated thin-films of silver and gold. Puch-Sondheimer's theory is solved graphically for normalized conductivity, Hall coefficient and for normalized mean free path. From the intersection of theoretical and experimental curves, the film-thicknesses \(t_{Cond}\), \(t_{Hall}\), and \(t_{MFP}\) are determined. The results \(t_{Cond} \approx t_{Hall} \approx t_{MFP} / t_{MBI}\) are explained on the basis of "Island Structure Model" of evaporated film. The explanation suggests that "In the treatment of Puch-Sondheimer's theory the scattering probabilities of electrons within the film boundaries, should be taken into consideration".

INTRODUCTION.

Electrical resistance of metal arises from deviations of a perfect lattice caused by the thermal motions of the atoms and by the structural irregularities, such as impurity atoms and lattice defects. Using free electron theory of metals, considering a film structure as equivalent to bulk, and different scattering probabilities for like boundaries (mean free path effect), Puch-Sondheimer's (1, 2) treatment leads to the expression for normalized conductivity and isothermal Hall coefficient, as a function of the ratio of film-thickness to bulk mean free path. In 1964, Leonard and Ramey (3) gave mean
free path method for thin-film thickness determination from the theoretical expression for conductivity and isothermal Hall coefficient. This method is based on a result of classical relation for normalized conductivity and Hall coefficient. In 1965, Lucas (4) has given a more general treatment for the electrical conduction in thin-films, having unlike boundaries.

Film thickness is the principal parameter, on which the validity of thin-film theories stand. This paper deals with co-relation of thicknesses, obtained by various methods based on Fuchs-Sondheimer's theory, and their comparison with the material thickness. The scattering probability \( p \) for like boundaries is considered zero (completely diffuse scattering). Silver and gold are selected on account of their high surface mobility of electrons, less scattering of electrons from the film or substrate and less affinity for oxygen and other residual gases. The experimental results are explained on the basis of Neugebauer and Webb's (12, 14) "Island Structure Model" of thin-films.

**EXPERIMENTAL.**

Film preparation and its resistance measurement:- For thin-film preparation, an evaporation plant with provision for annealing the film, measuring its temperature and resistance under vacuum, is designed and constructed in the laboratory by Shahad...
by Shah and Naik (5). During the film growth, the influencing parameters such as purity of metal, cleanliness and geometry of glass substrate, temperature of substrate, rate of evaporation and annealing of deposited film, are controlled. The substrate is a 'gold seal' microspec slide kept 15 cms., above the evaporation Mo-boat. At a pressure of $10^{-2}$ torr, the cleaned substrate is ionically bombarded, degassed at $150^\circ$C, and the metal is degassed at $400^\circ$C. Films of spectrographically pure Ag and Au (Johnson & Matthey) are prepared under identical conditions at room temperature, at a pressure of $10^{-5}$ torr and at high evaporation rate (80 Å per sec). It is annealed for a fixed time under identical conditions. When a metal is evaporated on to a substrate, small islands of the metal are formed first. As deposition continues, the island grow, agglomerate and eventually form a continuous film. During the process of annealing, size of the film islands formed during evaporation increases at the cost of neighbouring small islands, resulting in further separation of islands. This process results in a consequent decrease of resistance, which makes the film less porous i.e. more homogeneous.

The homogeneity of the film is checked (within 4 per cent) by measuring percentage transmittivity at five different points, with the use of S.P. 500 Unicam spectrophotometer. In the case of annealed films, the investigations made by Shah and Naik (5) agree well with Vanr's theory, which suggests that the process anneals out the vacancies and defects resulting in lower resistance.
The resistance \( R \) of an annealed film is measured under vacuum to prevent the film surface from chemisorption and absorption of gas molecules, using a Kohlrausch bridge in conjunction with a sensitive galvanometer \( (10^{-6} \text{ amp/div.}) \).

**Hall voltage (d.c.) measurement:** The film is placed on a plastic holder and current and potential leads are soldered using indium metal. The electromagnet is energized by \( 110 \text{ volt (d.c.)} \) generator and is calibrated using bismuth spiral. The presence of misalignment voltage is eliminated by using the circuit as suggested by Davis (6). The presence of Ettinghausen effect is eliminated by using the current and potential leads of the same metal as the film. Thermomagnetic effects (viz., Nernst effect and Right-Leduc effect) are eliminated by taking four observations for a given current and field strength, as suggested by Cusack (7). Error due to Hall breadth is eliminated using the relation (8),

\[
\text{Correct Hall Voltage} = \frac{(\text{Observed Hall Voltage}) \cdot (\text{Sample width})}{(\text{Separation of Hall contacts})}
\]

Residual zero field potential is taken into account, which is added or subtracted from the developed potential. Knowing the polarity of the magnetic field, and the direction of the current in the film and in the potentiometer, the algebraic sign of the current and hence of Hall voltage is determined.
Keeping primary current \( I_x = 40 \text{ ma.} \), Hall voltage \( E_y \) is measured using PYE-potentiometer \( 0.5 \text{ mV} \) in conjunction with dead beat PYE-galvanometer \( 0.3 \text{ mV/div} \), for various magnetic fields ranging from 1.4 to 19.9 kilogauss.

**Film-thickness measurement.** Tolansky's \(^{(2)}\) method, based on the principle of Fizeau fringes, involves measurement of fringe displacement. This method gives directly the metrical thickness \( t_{MRF} \); and compared to its experimental simplicity, the method is capable of high accuracy \( \pm 10 \text{ Å} \).

**RESULTS AND DISCUSSIONS**

Using Fuchs-Sondheimer's theoretical expressions \(^{(2)}\), the values of normalized conductivity, Hall coefficient and of mean free path are computed for various values of \( k \) in the range 0.05 to 5.0, where \( k \) is the ratio of film thickness to bulk mean free path. Using these values, theoretical curves are drawn and are represented in Figs. 1-3 (solid line).

Using bulk constants, observed data and the below mentioned classical relations for arbitrary values of \( k \), the values of normalized conductivity, Hall coefficient or of normalized mean free path are calculated for corresponding value of \( k \), for a particular method. Using these values, the experimental curve is drawn for a particular film (Figs. 1-3) (dotted line).
Classical relations for

1) Normalized conductivity:
\[
\frac{\sigma_F}{\sigma_B} = \frac{L}{W} \cdot \frac{1}{R} \cdot \frac{1}{\sigma_B} \cdot \frac{1}{\lambda_B} \cdot \frac{1}{k}.
\]

2) Normalized Hall coefficient:
\[
\frac{H_F}{H_B} = \frac{1}{I_x} \cdot \left( \frac{E_y}{H_Z} \right) \cdot \frac{\lambda_B}{H_B} \cdot k.
\]

3) Normalized Mean Free Path:
\[
\frac{\lambda_F}{\lambda_B} = \frac{L}{W} \cdot \frac{1}{R} \cdot \frac{\lambda_B^{-1/3}}{\sigma_B} \cdot \left( \frac{E_y}{I_x \cdot H_Z} \cdot \frac{1}{H_B} \right)^{2/3} \cdot k^{-1/3}.
\]

where \( \sigma_F, \sigma_B, H_F, H_B, \lambda_F, \lambda_B \) are respectively the conductivity, Hall coefficient and the mean free path for film and for bulk metal respectively. \( L, W \) and \( R \) are respectively length, breadth and resistance of a film. \( I_x \) and \( \frac{E_y}{H_Z} \) are respectively primary current and the ratio of Hall voltage to magnetic field (graphically determined).

From the intersection of theoretical and experimental curve, corresponding value of \( k \) (as shown by arrow in Figs. 1-3) and then the film-thickness is determined by a particular method, viz., Conductivity method (Fig. 1, \( t_{\text{cond}} \)), Hall coefficient method (Fig. 2, \( t_{\text{Hall}} \)) and Mean Free Path method (Fig. 3, \( t_{\text{MFP}} \)).

The results for five films, each for Ag and Au (Table 1) can be explained in the following way:

According to Steinberg (10), the variation of Hall
voltage versus magnetic field is linear. For silver and gold films, our results verify the same in the field range 1.4 to 19.9 kilo-gauss.

The physical properties of films are due to several causes, the most important factors are probably: (1) size effect or geometrical effect for the film and (2) island structure of the film.

(1) Geometrical effect: If the thickness \( t \) of a film is made comparable to mean free path of electron \( \lambda_b \) in bulk metal (viz., \( t \ll \lambda_b \)), then the mean free path of electron \( \lambda_f \) within the film reduces \( \lambda_f < \lambda_b \). The reduction of mean free path will result in enhanced resistivity value, several times higher than the value for bulk metal. Sondheimer has considered the resistivity \( \rho_g \), due to geometrical effect for the film, by considering different scattering probabilities of electrons at like boundaries (viz., \( Z = 0 \) and \( Z = t \)).

(2) Island structure of the film: Theoretically, a thin film is an isotropic, plane-parallel sided solid without structural irregularities i.e. film density is same as that of bulk metal. Practically it is impossible to have such an ideal film. Therefore the experimental results will not agree with the theory. Electron microscopy has enabled informations to be obtained directly regarding the aggregation in thin-films. A vacuum evaporated thin-film contains aggregates of crystallites. According to Piccard
and Duffendack (16) and Levenstein (17), the island structure of the film is in a somewhat disordered state. This low state of order disturbs the periodicity of lattice vibrations creating incoherent scattering of electrons in the film. This results in the reduction of electronic mean free path for the film. As the mean free path of electron decreases ( viz., as film thickness decreases ), the resistivity and Hall coefficient of the film also increases ( as shown in Figs. 1, 2, 3). Therefore the measurement of data which are based on conduction of electrons ( i.e. Resistance and Hall voltage ) would certainly be higher than that expected theoretically. This gives lower value of thickness by each method. Therefore,

\[ t_{MFP} \lt t, \text{ due to lower value of } \lambda_p \text{ for the island film} \]
\[ t_{Cond} \lt t, \text{ due to higher value of resistivity of the island film} \]
\[ t_{Hall} \lt t, \text{ due to higher value of Hall coefficient of the island film} \]
\[ t_{MBI} \gt t, \text{ due to less dense structure of the island film} \]

Where \( t \) is the thickness that can be inferred theoretically. This indicates that \( t_{Cond}, t_{Hall}, t_{MFP} \) are remarkably smaller than \( t_{MBI} \) due to reduction in the electronic mean free path ( \( \lambda_p \) ) for the experimental film. However, for Cu, Ag, Au films Leonard and Ramey's (3, 11) results show that \( t_{MFP} \ll t_{MBI} \) due to the reduction in the electronic mean free path ( \( \lambda_b \) ) for bulk metal.

As all methods are based on one theory, the values
obtained for $t_{\text{Cond}}$, $t_{\text{Hall}}$, $t_{\text{MFP}}$ are nearly same for one film. For gold film, the data reported by Jeppensen, Flagg and Rancount (15) verifies our results $t_{\text{Cond}} \approx t_{\text{Hall}} \approx t_{\text{MFP}} < t_{\text{MBI}}$ for Ag and Au films.

In the case of island structure film, the resistivity is attributed to the contractions which typically exist at the interface between grains. The resistivities $\zeta_s$, $\zeta_d$ depend on the size of the island and the distance between islands respectively i.e. $\zeta_s$, $\zeta_d$ depend on the process of film growth. Considering these factors, Neugebaur and Webb (14) have given recently "Island structure model".

This modifies Mittheissen's rule for film resistivity as under:

$$\zeta_F = \zeta_i + \zeta_T + \zeta_d + \zeta_s + \zeta_d$$

Where $\zeta_i$ = Temperature independent resistivity due to impurity and imperfections of atoms.

$\zeta_T$ = Temperature dependent resistivity due to lattice vibrations. In this case, imperfections remain present even after efficient annealing (residual resistivity), which also contribute to the film resistivity.

$\zeta_d$ = Resistivity due to size effect for the film.
The results (Table 1) show that percentage deviation of $t_m$ from $t_{MBI}$ are nearly of the same order (30 per cent), where:

$$t_m = \frac{t_{Cond} + t_{Hall} + t_{MFP}}{3}$$

This may be due to the reason that residual resistivitities $\sigma_s, \sigma_d$ are not considered in the basic assumptions of Sondheimer's theory. Finally the present investigations indicate that in the treatment of Fuchs-Sondheimer's theory, the scattering probabilities of electrons within the film boundaries should also be taken into consideration.
# Table I

RESULTS FOR VACUUM EVAPORATED THIN FILMS OF SILVER AND GOLD:

<table>
<thead>
<tr>
<th>Metal and Film No.</th>
<th>Resistance of an annealed film in ohms. $R_{\text{ohms}}$</th>
<th>Graphically determined (E_y/\text{Hz} \times 10^{-9}) Volt. gauss (E_y)</th>
<th>Film thickness in Å.U.</th>
<th>Percentage deviation of (t_m) from (t_{\text{MBI}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag 1</td>
<td>11.94</td>
<td>-38.80</td>
<td>165</td>
<td>107</td>
</tr>
<tr>
<td>Ag 2</td>
<td>6.09</td>
<td>-23.60</td>
<td>238</td>
<td>168</td>
</tr>
<tr>
<td>Ag 3</td>
<td>4.29</td>
<td>-17.40</td>
<td>307</td>
<td>220</td>
</tr>
<tr>
<td>Ag 4</td>
<td>2.34</td>
<td>-14.60</td>
<td>385</td>
<td>278</td>
</tr>
<tr>
<td>Ag 5</td>
<td>1.86</td>
<td>-96.94</td>
<td>493</td>
<td>383</td>
</tr>
<tr>
<td>Au 1</td>
<td>16.34</td>
<td>-33.60</td>
<td>145</td>
<td>94</td>
</tr>
<tr>
<td>Au 2</td>
<td>7.24</td>
<td>-17.90</td>
<td>233</td>
<td>157</td>
</tr>
<tr>
<td>Au 3</td>
<td>3.96</td>
<td>-11.85</td>
<td>335</td>
<td>238</td>
</tr>
<tr>
<td>Au 4</td>
<td>3.53</td>
<td>-11.00</td>
<td>368</td>
<td>254</td>
</tr>
<tr>
<td>Au 5</td>
<td>2.55</td>
<td>-8.50</td>
<td>454</td>
<td>316</td>
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</tbody>
</table>
REFERENCES


CAPTIONS FOR THE FIGURES

FILM-THICKNESS DETERMINATION

BY THE METHODS BASED ON FUCHS - SONDEIMER'S THEORY

Fig. 1. The intersection of theoretical curve for metals \( \frac{\sigma_F}{\sigma_B} \) versus \( k \), solid line, with the plot of experimental data (dotted curve, \( \Theta \) Ag,) illustrates the film thickness determination by conductivity method.

Fig. 2. The intersection of theoretical curve for metals \( \frac{\lambda_F/\lambda_B}{\lambda_F} \) versus \( k \), solid line, with the plot of experimental data (dotted curve, \( \Theta \) Ag) illustrates the film thickness determination by Hall Coefficient method.

Fig. 3. The intersection of theoretical curve for metals \( \frac{\lambda_F/\lambda_B}{\lambda_B} \) versus \( k \), solid line, with the plot of experimental data (dotted curve, \( \Theta \) Ag, \( \times \) Au), illustrates the film thickness determination by Mean Free Path method.
Figure 2
ABSTRACT

Murnmann-Fosterling's theoretical expression is solved graphically for optical constants. Using optical constants ($n, k$), film-thickness ($t$), the percentage transmittance are calculated for wavelengths 4348 Å, 5085 Å, 5461 Å, 5790 Å. The results so obtained are compared with the values of $\% T$ observed using spectrophotometer. This suggests that the theory is valid in the longer wavelength region for silver films. The value of calculated $\% T$ depends much more sensibly on $k$ than on $n$. Spectral transmittance behaviour of gold film shows a peak at wavelength 5100 Å.

INTRODUCTION

For studying, mechanical, dielectric, electrical, magnetic, optical, magneto-optical, and alloying properties of metals in a pure state, thin evaporated films are found to be most useful and very convenient. Wide variations have been observed between the physical properties of matter in thin-film state and those of the bulk materials. One may establish an exceptional rule: There are four states of matter, all with very different properties viz; gas, liquid, solid & thin-film.
Semi-transparent metallic films are used for controlling the intensity of light into its reflected and transmitted parts in a desired ratio. By use of a method as described by Geffohen (1), evaporated thin-films are also used for preparing interference filters. The transmittance of light through metals can be measured only by use of thin-films.

The theories given below, enable us to determine the optical constants of thin metallic films by measuring the polarisation of reflected light, and film-thickness. In general, the values of refractive index \( n \) and absorption coefficient \( k \) cannot be derived explicitly, in terms of the measured quantities. So that one has necessarily to calculate \( \Psi \) and \( \Delta \) from a given range of \( n \) and \( k \). Where \( \Psi \) and \( \Delta \) are respectively, an azimuth and phase difference between the two amplitudes of a reflected elliptically polarised light.

The two theories are as under (1) :-

1) Murmann–Fösterling's theory (1933): In the basic assumptions of the theory; the amplitudes of light waves, reflected or transmitted by the dielectric-metal boundary are considered real.

2) Vasichek's theory: In the basic assumptions of the theory, " the amplitudes of light waves, reflected or transmitted by the dielectric-metal boundary are considered complex.
According to Vasicek(1), his theory gives better agreement with experimental results, in the case of semi-metallic(Sb, Bi) films. While M-F's theory gives better agreement with experimental results in the case of metallic films. In the present investigations, M-F theory is used.

This paper deals with study of the systematic variations in optical constants and transmittance of thin-films of silver and gold, with thicknesses and with wavelengths.

The films are studied in the thickness range 100 Å to 500 Å. The selected wavelengths are 4348 Å, 5085 Å, 5481 Å, 5790 Å.

The investigations are summarised by comparing the calculated (using M-F theory) and observed (using spectrophotometer) percentage transmittance. The results indicate that the theory may have better agreement with observed quantities in the longer wavelengths (red) region.

**EXPERIMENTAL**

For thin-film preparation, an evaporation plant with provision for annealing the film, measuring its temperature and its resistance inside vacuum, was designed and constructed in the laboratory by Shah & Naik(2). Electrical contacts on the films are made by coating thick silver films (1000 Å thick & 0.5 cm wide) on the same side and along both the shorter edges of the substrate. The substrate used is a 'gold seal' microscope slide.

Three plates are coated simultaneously in one evaporation, so as to coat them identically.
1) The glass plate of size $3.0 \text{ cm} \times 2.5 \text{ cm} \times 0.1 \text{ cm}$, for the use of transmittance measurements.

2) The glass plate of size $7.5 \text{ cm} \times 2.5 \text{ cm} \times 0.1 \text{ cm}$, which have electrical contacts at its two edges. This is to be used for resistance measurements during annealing, and for polarisation measurements.

3) A quartz piece (worked to $\lambda/5$), with half the surface exposed to the vapour beam and half covered with a mask. This plate is finally used for the thickness measurement.

These three plates are mounted on a specially constructed brass holder ($2$). The thick silver coatings of the plate $2$ are pressed mechanically between two brass plates. This provides electrical terminals for resistance measurements while annealing. According to the evaporation geometry of the substrate, the thickness tolerance is $\pm 0.3\%$.

The films are prepared at the rate of $80 \text{ A/sec}$, at a pressure of $10^{-5}$ torr, and at room temperature ($\approx 25^\circ \text{C}$). According to Frenkel theory of adsorption, "At room temperature, a deposited layer of atoms is covered by succeeding layers, before reaching tothermal equilibrium with the substrate." This results in many vacancies and crystal defects to be trapped in the deposit ($4, 5$). In the case of Cu, Ag and Au films, investigations made by Shah & Naik ($2$), show that the process of annealing the films under
vacuum (just after deposition) helps in removing mainly the point defects, so that in the repeated process of film preparation, one gets more or less identical films as regards their defect structure. Silver and gold films in the thickness range 100 Å to 500 Å are studied in the following manner.

For transmittance measurements specimen 1 and S.P. 500 Unicam spectrophotometer (accuracy ± 0.3 %) are used. Transmittivity of incident light through metal-glass boundary are recorded with respect to a clean glass plate, in the visible wavelength range 4000 Å to 10,000 Å (graph 1).

For polarisation measurements specimen 2 is used, and the measurements are carried out with an ellipsometer as described below.

1) A Leits monochromator with cadmium-mercury tube as light source, giving a broad beam.

2) A spectrometer with a specially mounted collimator and telescope arms, rotating in a horizontal plane. It has a scale on a large fixed circle having L.C. (Least count) = 1'.

3) A polariser and a quarter wave plate (for a wavelength at which the investigations are to be made) are mounted in a circular disc, fixed in the collimator arm. L.C., of a disc having polariser = 0.1', L.C., of a disc having λ/4 plate (mica) = 5'.
4) A photomultiplier tube (R.C.A 931 A), attached with the analyser. The tube is energized by a 900 V(d.c) stabilizer, and the output is measured with a multiflex galvanometer (10$^{-9}$ amp/div). L.C. of a disc having analyzer (Nicol)=0.6°.

To eliminate the out of phase reflections, a black paper is attached at the back of the specimen. For high accuracy, all measurements are made at the near principal angle of incidence (75°). The quantities $\psi$ and $\Delta$ are measured using the method as described by Menard (6), and they completely define the state of polarization of reflected light. From the knowledge of $\psi$ and $\Delta$, for a particular wavelength, and film thickness by an independent method (as described below), the optical constants are determined by the method as described in latter part.

For film-thickness measurements, specimen 3 and the multiple beam interference method based on the principles of Fizeau fringes (Z) are used. The method gives the metrical-thickness directly without the knowledge of the coated material. To fulfill the condition for high reflectivity, the half coated quartz is completely silvered with about 1000 $\AA$ thickness. The reference flat (worked to $\lambda/40$, Leitz Wetzler) is coated on one side by a semi-transparent silver film. The unevenness is eliminated by using optically flat (worked to the fraction of $\lambda$) plates viz; quartz and reference plate. To obtain sharpness of the fringes, the wedge angle
formed by two silvered surfaces is controlled using
differential screw arrangement. Compared to its experimental
simplicity, the method is of high accuracy (± 10 Å).

RESULTS & DISCUSSIONS

Determination of optical constants using ψ, Δ and Ψ :- The state of reflected ellipitically polarised light
at metal-film can be obtained in terms of optical constants
for a particular wavelength, thickness and angle of
incidence of light beam. Figure 2.1 is a sheet of ψ and Δ
versus Ψ, with k as parameter for Ψ = 0.3. From a suitable
sheet for a given Ψ, two values of k are read off,

1) k(ψ) corresponding to given (ψ, Ψ).
2) k(Δ) corresponding to given (Δ, Ψ).

Similarly, second and third pair of k(ψ) & k(Δ) are
read off for succeeding higher values of Ψ. The plot of k(ψ) &
k(Δ) versus Ψ, yields desired values of Ψ and k.

The procedure can best be illustrated by giving an example.

For using the curves, the angle of incidence and
substrate index should be 75° and 1.5 respectively. For a
silver film :

\[ t = 307 \text{ Å}, \quad \Psi = 39.05^\circ, \quad \Delta = 90^\circ 00, \quad \lambda = 5461 \text{ Å}, \]

Observed \% T = 21.6

\[ \Psi = 0.706, \quad \Delta = 0.682 \text{ rad.,} \quad \Psi = 1.571 \text{ radian.} \]

<table>
<thead>
<tr>
<th>Ψ</th>
<th>k(ψ)</th>
<th>k(Δ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>3.41</td>
<td>3.59</td>
</tr>
<tr>
<td>0.4</td>
<td>3.73</td>
<td>3.57</td>
</tr>
<tr>
<td>0.5</td>
<td>3.93</td>
<td>3.50</td>
</tr>
</tbody>
</table>
Figure 2.2 shows an intersection of $k(\psi)$ and $k(\Delta)$ curves at $n^* 0.345$ & $k=3.590$. It is obvious from the figure that in the comparative variation in $k(\psi)$ & $k(\Delta)$ as a function of $4\pi t/\lambda$, the variations of $k(\psi)$ with respect to $n$ are more sensitive than that of $k(\Delta)$. The optical constants are determined for various wavelengths and thicknesses for silver and gold films (fig. 3 & 4). The constants are converted to $n$ and $k(1)$, which are at normal angle of incidence, $\theta_o=0^\circ$. Knowing $n$, $k$, and $t_A$, the percentage transmittance can be calculated using M-F's expression for transmission. In the case of silver and gold films, variation of calculated $\% T$ and of observed $\% T$ with thicknesses at different wavelengths are shown in figure 5.

It is observed that the annealing temperature of the film, depends on the parent material, film-thickness, and

* For M-F theory, Tables of $X$, $n$ and $k$ versus $\psi$ and $\Delta$ are obtained using IBM 1620 and are represented graphically. A Comparative set of curves (42 SHEETS) are prepared for use. Each sheet gives $\psi$ and $\Delta$ versus $X = 4\pi t/\lambda$, for a range of $k$ and for one value of $n$. The values of $n$ and $k$ may be obtained accurately upto three decimals, between the values 0.0 to 5.0Angles $\psi$ and $\Delta$ are given in radians. The substrate index = 1.5, Angles of incidence = 75°.

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on the influencing parameters during the film growth. Annealed gold films possesses typical yellow colour of gold in the reflected light. The gold film appears greenish in transmitted white light.

According to Beer-Lambert's law \( T = \frac{k \cdot t}{\lambda} \). A light incident normally on the metallic film, will suffer absorption viz; undesirable less of light on transmitting through the film. For films, transmittance varies exponentially with wavelengths (figure 1). In the case of silver films, \%T drops exponentially with wavelengths, indicating a peak (extrapolated \( \approx 3400 \AA \)) in the ultraviolet wavelength region. The steepness of the curves increases with increase of thickness. In the case of gold films, \%T varies exponentially with wavelengths, giving a peak at \( \lambda = 5100 \AA \). The peak for maximum \( T \) becomes sharper (viz; the band-width decreases) with increase of film-thickness. Simultaneously the greatest transmittivity of the film also decreases.

For silver and gold films, at particular wavelength, the refractive index decreases with increase of thickness (in the case of gold films, only upto \( 350 \AA \), thickness). (Figure 3). As lower the value of \( n \), higher will be the reflectivity. Thus the reflectivity increases with increase of film-thickness. For a particular film, the refractive index decreases with increase of wavelengths.
For silver and gold films (figure 4), at a particular wavelength, \( k \) decreases up to minimum and then increases with increase of thickness. The value of \( k \) is minimum in the thickness range 225Å to 325Å. For a silver film, \( k \) decreases with increase of \( \lambda \). For a gold film, \( k \) increases up to maximum and then decreases with increase of \( \lambda \). The value of \( k \) is maximum at \( \lambda = 5085\text{Å} \). It can be seen from figure 5 that for gold films, the calculated \( \% T \) is minimum at \( \lambda = 5085\text{Å} \). Now comparing the variation of \( k \) with \( t \) and \( \lambda \), with the variation of \( \% T \) with \( t \) and \( \lambda \) (vis; figure 4 and 5), for silver and gold films it is apparent that, for a lower value of \( k \), the calculated \( \% T \) is higher and vice versa. Thus the dispersion of \( \% T \) with thickness and with wavelength is analogous to that of \( k \) with \( t \) and with \( \lambda \), viz; the value of calculated \( \% T \) depends much more sensibly on \( k \) than on \( n \).

From figure 5, it becomes clear that observed \( \% T \) and calculated \( \% T \) gives better agreement for longer wavelengths. This disagreement may be due to the reason that "according to the basic assumption of the theory, the material forming the film is evenly distributed over the surface of the substrate and have the same specific mass as the same bulk material. This means that the density of the metallic-film is the same as that of bulk material. While according to the study of thin film structure through electron microscope (8,9), an evaporated thin-film is having a microstructure vis; an"
Aggregated one*. The influence of microstructure of the film on the optical properties will be less with the increase of wavelengths. In the longer wavelength region (red), the optical properties may not be influenced by the film-structure. Thus the observed and calculated quantities should have good agreement in the red wavelength-region. The figure 5 illustrates that the determinations of the optical constants for silver films by using M.P.'s theory, are valid in the longer wavelength region (vis; more than $\lambda = 6000\text{ Å}$).

ACKNOWLEDGEMENT.

Thanks are due to Dr. V.V. Shah, Senior Scientific Officer, National Physical Laboratory, New Delhi-12, for valuable suggestions and discussions.

REFERENCES.


CAPTIONS FOR THE FIGURES

Paper:— "Optical properties of Evaporated Thin-Films of Silver & Gold.

Figure 1:— Variation of observed transmittance with wavelengths, for different thicknesses of silver and gold films.

Figure 2.1. Theoretical dependence of $\Psi$ with $4\pi t/\lambda$
for $k = 1.5(0.5)5.0$ for $n = 0.3$ (Solid curves),
Theoretical dependence of $\Delta$ with $4\pi t/\lambda$
for $k = 1.5(0.5)5.0$ for $n = 0.3$ (Dotted curves).
□ corresponds to $k(\Psi) = 3.41$ for $\Psi = 0.682$, & $x = 0.706$.
○ Corresponds to $k(\Delta) = 3.59$ for $\Delta = 1.571$, & $x = 0.706$.

Figure 2.2. Illustrates the determination of $n$ & $k$ from the intersection of $k(\Psi)$ & $k(\Delta)$.

Figure 3. log $n$ versus log $X$, for various wavelengths.

Figure 4. log $k$ versus log $X$, for various wavelengths.
Figure 5. Variation of observed $\% T$ (using spectrophotometer) with film-thicknesses, for various wavelengths (solid curves).

Variation of calculated (using M.F. Theory, $\overline{n}, \overline{k}$ & $\overline{t}$) $\% T$ with film-thicknesses for various wavelengths (Dotted curves).
Figure 1
Silver

Gold

\(\lambda, \text{nm}\)
Figure 3

Graph showing data for Gold with different wavelengths (\(5085 \text{ Å}, 5461 \text{ Å}, 4341 \text{ Å}, 5790 \text{ Å}\)) plotted on a log-log scale.

Axes:
- Y-axis: \(\log \tau\)
- X-axis: \(\log \chi\)