Photometric methods for determining the optical constants and the thicknesses of thin absorbing films: criteria for precise and unambiguous determination of $n$, $k$, and $d$ in a wide spectral range

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The application of error analysis within a certain algorithm for the most accurate and unambiguous determination of refractive index $n$, absorption coefficient $k$, and thickness $d$ of thin absorbing films in a wide spectral range is illustrated with three examples. Thin films of a dye, Ag, and Au are selected because their optical constants (~small $n$ for Ag and Au and considerable variations of $n$ and $k$ for the dye films) along with their thinness make investigating these thin films difficult. The important steps of the algorithm that ensure reliable isolation of the physically correct solutions and maximum accuracy of $n$ and $k$ in the spectral range investigated are also demonstrated. © 2001 Optical Society of America

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1. Introduction

In the previous part of the present study we analyzed the possible combinations of two and three photometric quantities by comparing the maximum absolute errors in refractive index $n$, absorption coefficient $k$, and thickness $d$ of thin films. The error analysis proved that the double ($TR$, $TR_m$, $TR_p^{70}$), and ($TR_m^{70}$) and the triple ($TRR_m$, $TRR_p^{70}$), ($TRR_m^{70}$), ($TRR_p^{70}$), and ($TR_mR_p^{70}$) combinations are the best methods. $T$ and $R$ denote transmission and reflection, respectively; the subscripts $m$ and $p$ denote an opaque substrate (metal) and $p$-polarized light, respectively; and the superscript number is the angle of incidence of the light. The absence of subscript $p$ and superscript number implies measurements with nonpolarized light at normal incidence, and the absence of subscript $m$ implies the presence of a nonabsorbing substrate.

We have shown that, at equal experimental errors $\Delta R$ and $\Delta T$, the methods selected make possible the determination of the optical constants and of the thickness with different degrees of accuracy, depending on the values of $n$, $k$, and $d/\lambda$ ($\lambda$ is wavelength). Hence, for the most accurate determination of $n$ and $k$ (and $d$), more combinations, preferably all, should be applied, and the errors should be evaluated as criteria for the best combination.

It is known that the major difficulty inherent in the inverse problem when one is extracting a film's optical constants and thickness is that the problem has multiple solutions. This poses another problem, that of reliable identification of the physically correct solutions.

In this study we illustrate with three examples the application of error analysis for possibly the most accurate determination of film thickness as well as of $n$ and $k$ in wide spectral range. We also demonstrate the algorithm for unambiguous selection of the physically correct solutions of $n$ and $k$.

2. Sample Preparation and Spectrophotometric Measurements

A. Thin-Film Preparation

Thin films of Ag and Au were prepared by thermal and e-beam evaporation, respectively, in a vacuum of better than $10^{-4}$ Pa, by simultaneous condensation upon glass substrates (BK-7) and Si wafers. For measurements of oblique incidence reflection, the rear surfaces of the glass substrates were matted.