*Elżbieta Idczak**

Optical Properties of Non-Transparent Chrome Layers

The dispersion of the dielectric constant $\varepsilon(\omega)$ for non-transparent chrome layers has been calculated in the spectral region 0.22–25 μm (0.05–5.6 eV). The plasma frequency Ω and the frequency of collisions γ of conduction electrons have been found on the basis of the dispersion $\varepsilon(\omega)$. The results thus obtained have been interpreted on the basis of data for energy bands in chrome.

1. Introduction

In the previous paper [1] the optical constants n and k for non-transparent chrome layers were determined in the wavelength region 0.22–25 μm. The knowledge of the constants n and k allows to determine the dispersion of the real $\varepsilon_1(\omega)$ and imaginary $\varepsilon_2(\omega)$ components of the dielectric constant and the optical high frequency conductivity $\sigma(\omega)$ of the layers in the studied spectral region. Optical measurements of the dispersion of the complex dielectric constant $\varepsilon = \varepsilon_1+i\varepsilon_2$ of metal within a broad wavelength region enable us to obtain some important characteristics of the conduct of electrons — plasma frequency Ω, the frequency of electron collisions γ, as well as to determine the spacing between energy bands in the region of allowable transitions in the momentum space.

The optical properties of bulk chrome were studied within the spectral region 0.25–18 μm [2].

Optical properties of non-transparent chrome layers in the spectral region 0.22–25 μm have been investigated for the first time in the present work.

In room temperature for transitional metals there exist conditions for a normal skin effect. In the spectral region in which both the inter-band and inner-band transitions play a role, (usually the visible part and the near infra-red) optical properties of those metals may be described as follows [3]

$$\varepsilon_1(\omega) = n^2-k^2 = 1+\tilde{\varepsilon}_1(\omega)-\frac{\Omega^2}{\omega^2+\gamma^2}, \tag{1}$$

$$\varepsilon_2(\omega) = 2nk = \tilde{\varepsilon}_2(\omega)+\frac{\Omega^2\gamma}{(\omega^2+\gamma^2)\omega}, \tag{2}$$

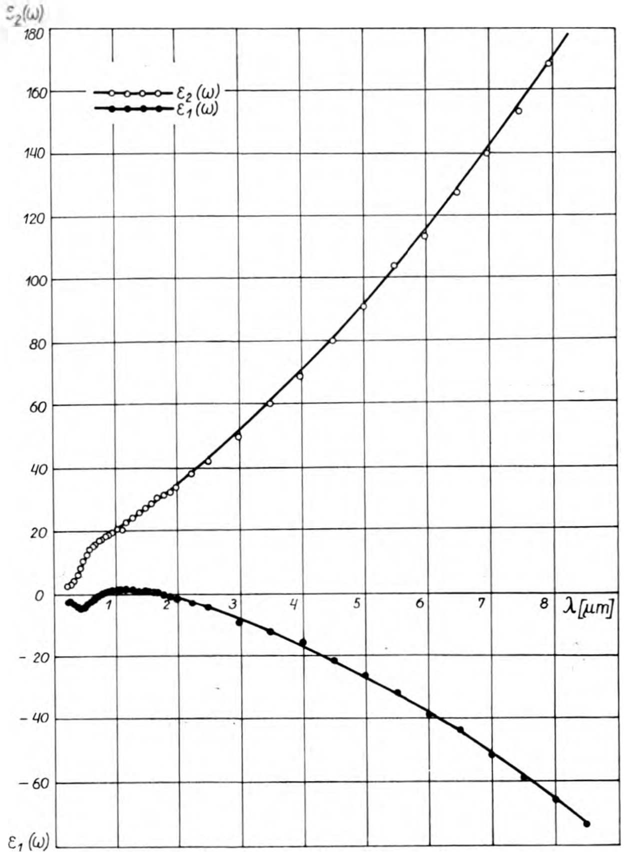

Fig. 1. Spectral dependence of the real $\varepsilon_1(\omega)$ and imaginary $\varepsilon_2(\omega)$ parts of the dielectric constant of non-transparent chrome layers

$$\sigma(\omega) = \frac{nk\omega}{2\pi} = \tilde{\sigma}(\omega)+\frac{\Omega^2\gamma}{(\omega^2+\gamma^2)4\pi}, \tag{3}$$

where:

$\varepsilon_1(\omega)$ and $\varepsilon_2(\omega)$ — real and imaginary parts of the dielectric constant,

$\sigma(\omega)$ — high frequency optical conductivity,

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*) Instytut Fizyki Technicznej Politechniki Wrocławskiej 50-377 Wrocław, Wybrzeże S. Wyspiańskiego 27, Poland.

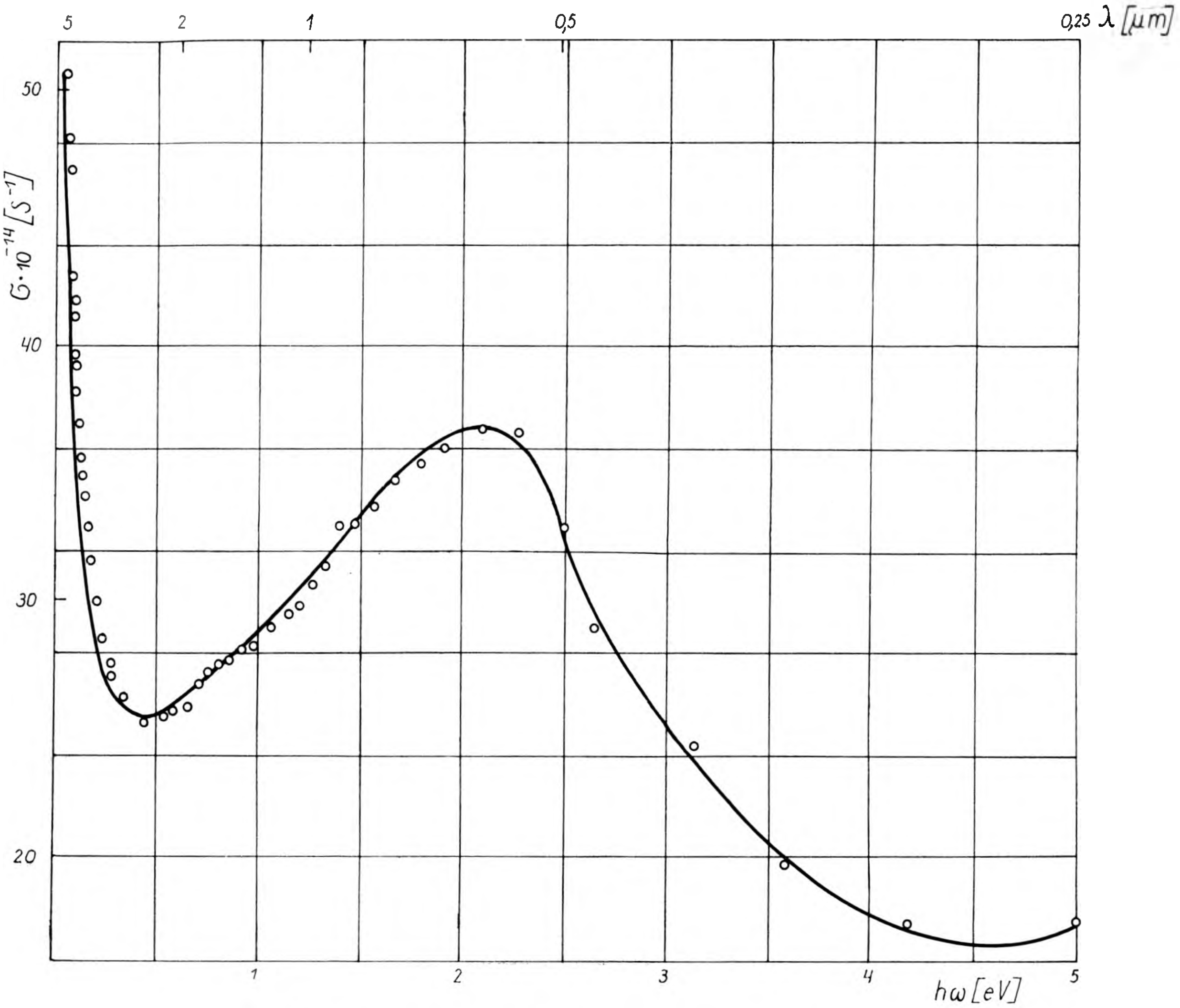

Fig. 2. Conductivity $\sigma(\omega) = nk\omega/2\pi$ of non-transparent chrome layers

$\tilde{\varepsilon}_1(\omega)$, $\tilde{\varepsilon}_2(\omega)$ and $\tilde{\sigma}(\omega)$ — contribution to the dielectric constant and conductivity due to the inter-band transitions of the conduction electrons,
n and k — optical constants of metal,
ω — angular frequency,
Ω — frequency of plasma vibrations,
γ — frequency of electron collisions.

As can be seen from formulae (1–3), the micro-characteristics of conduction electrons, the plasma frequency Ω and the frequency of electron collisions γ can be found on the basis of the metal optical constants n and k.

2. Results and discussion

On the basis of the optical constants n and k for non-transparent chrome layers, which are calculated in paper [1] the real $\varepsilon_1(\omega)$ and imaginary $\varepsilon_2(\omega)$ parts of the dielectric constant (fig. 1) together with the high frequency optical conductivity $\sigma(\omega)$ have been calculated (fig. 2), and the spectral dependence of the energy absorption coefficient A (fig. 3) given for the layers.

As follows from figs 1 and 2, the dielectric constant $\varepsilon_1(\omega)$ and $\varepsilon_2(\omega)$ and the optical conductivity $\sigma(\omega)$ of non-transparent chrome layers in the wavelegth region 3–25 μm increase monotonically with increasing light wavelength. It may, therefore be concluded that the optical properties of chrome layers in infrared (3–25 μm) are determined primarily by the mechanism of the inner-band transitions of conduction

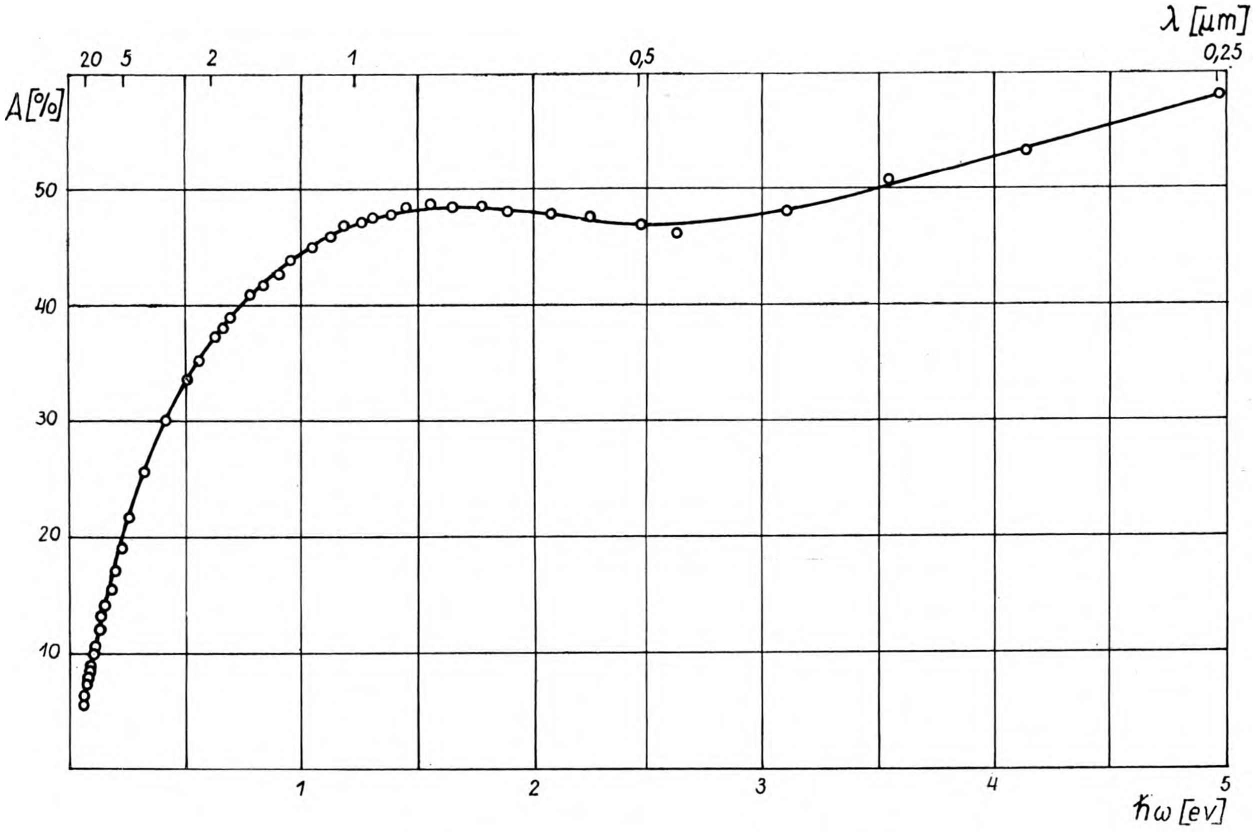

Fig. 3. Absorption of non-transparent chrome layers

electrons. Whereas, as can be seen from fig. 2, in the wavelength region 0.27–25 μm (4.5–0.5 eV) there is a strong absorption band for chrome with a maximum 2.12 eV (0.59 μm).

Let us consider the wavelength region 3–25 μm in which the inter-band transitions of conduction electrons can be neglected as regards chrome layers. The quantities $\varepsilon_1(\omega)$, $\varepsilon_2(\omega)$ and $\sigma(\omega)$ very monotonicly in this region with increasing light wavelength (figs 1 and 2). We can assume, therefore, that $\tilde{\varepsilon}_2(\omega) = 0$ and $\tilde{\varepsilon}_1(\omega) = P$ which is constant. The formulae determining the optical properties of metal become thus:

$$\varepsilon_1(\omega) = n^2 - k^2 = 1 + P - \frac{\Omega^2}{\omega^2+\gamma^2}, \tag{4}$$

$$\varepsilon_2(\omega) = 2nk = \frac{\Omega^2\gamma}{(\omega^2+\gamma^2)\omega}, \tag{5}$$

$$\sigma(\omega) = \frac{\Omega^2\gamma}{2\pi(\omega^2+\gamma^2)}. \tag{6}$$

Noskov in his paper [4] has supplied the method by which the frequency of electron collisions and plasma oscillation frequency can be calculated from formulae (4–6) for the region of inner-band electron transitions ($\tilde{\varepsilon}_2(\omega) = 0$ and $\tilde{\varepsilon}_1(\omega) = P$). As follows from formulae (4–5) in order to determine the frequency of electron collisions γ, the graph $\varepsilon_2\omega$ vs. $1-\varepsilon_1$ must be drawn. The slope of the line $\varepsilon_2\omega = f(1-\varepsilon_1)$ determines directly the frequency of electron collisions. Having obtained the frequency γ, one can determine the plasma frequency Ω from eqs. 4 and 5 by drawing the functions $1-\varepsilon_1$ vs. $(\omega^2+\gamma^2)^{-1}$ and $\varepsilon_2\omega$ vs. $(\omega^2+\gamma^2)^{-1}$. The frequency of plasma oscillations and the frequency of electron collision have thus been found for chrome layers. The dependence $\varepsilon_2\omega$ vs. $1-\varepsilon_1$ for chrome layers at wavelength region 3–25 μm has been drawn in fig. 4. As may be seen in fig. 4, $\varepsilon_2\omega$ changes linearly with $1-\varepsilon_1$ in this spectral region, allowing to determine the frequency of electron collisions from the slope of the line $\varepsilon_2\omega = f(1-\varepsilon_1)$, which was found to be $\gamma = 0.5\cdot 10^{14}\ \mathrm{s}^{-1}$. The dependences $1-\varepsilon_1$, and $\varepsilon_2\omega$ vs. $(\omega^2+\gamma^2)^{-1}$ for chrome layers, assuming $\gamma = 0.5\cdot 10^{14}\ \mathrm{s}^{-1}$, have been shown in fig. 5. From the slope of the line $1-\varepsilon_1 = f(\omega^2+\gamma^2)^{-1}$ the frequency of plasma oscillations was found to be $\Omega^2 = 4.77\cdot 10^{30}\ \mathrm{s}^{-2}$.

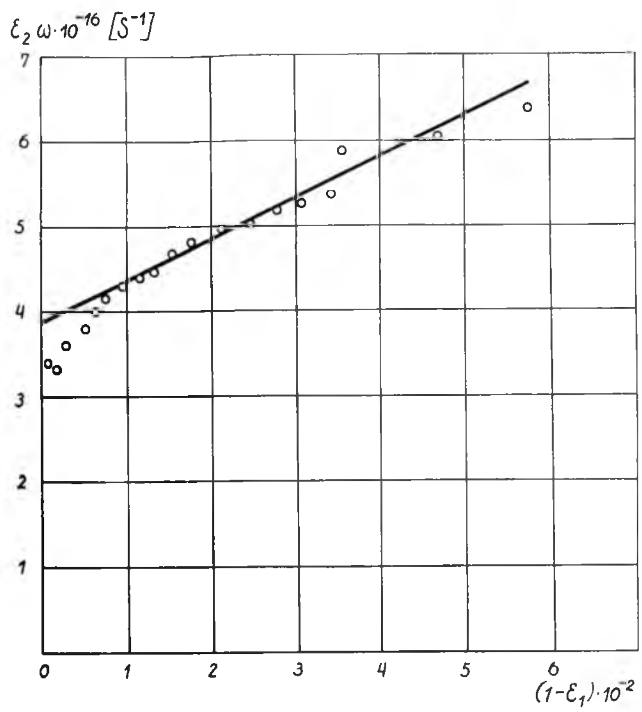

Fig. 4. Plot of $\varepsilon_2\omega$ vs. $(1-\varepsilon_1)$ for non-transparent chrome layers

A similar value for the plasma oscillation frequency results from the function $\varepsilon_2\omega = f(\omega^2+\gamma^2)^{-1}$, which is $\Omega^2 = 4.63\cdot 10^{30}$ s^{-2}. As follows from fig. 5, the straight line $\varepsilon_2\omega = f(\omega^2+\gamma^2)^{-1}$ bisects some constant value at the ordinate axis. As shown in paper [5], the presence of the non-dispersion contribution $\varepsilon_2(\omega)$ is a characteristic feature of practically all transitional metals 3d and 4d and indicates that the fast-relaxing electrons for which $\gamma^2 \gg \omega^2$ participate in conduction. These electrons do not contribute considerably to the dielectric constant $\varepsilon_1(\omega)$. As follows from paper [2] a kind of paramagnetic chrome in bulk has a strong absorption band for energies 0.4–4.5 eV. Maximum absorption for bulk chrome occurs at 2.25 eV. The frequency of plasma oscillations has the value $\Omega^2 = 4.4\cdot 10^{31}$ s^{-2}.

It follows from the above presented studies that for non-transparent chrome layers the absorption band is in the same energy region 0.4 – 4.5 eV, the maximum absorption occurs also at about the same energy value 2.12 eV. Whereas the frequency of plasma electrons oscillations (Ω) in chrome layer is considerably smaller $\Omega^2 = 4.7\cdot 10^{30}$ s^{-2} than in bulk chrome.

It follows from paper [6,7] that the frequency of plasma electrons oscillations Ω is proportional to Fermi's surface S_F and the mean electron velocity V_F, on this surface, and depends on the correlation effects between electrons. May be these effects cause decrease in the plasma frequency oscillations in chrome layers and not in bulk chrome. On the basis of results obtained in the reported work on non-

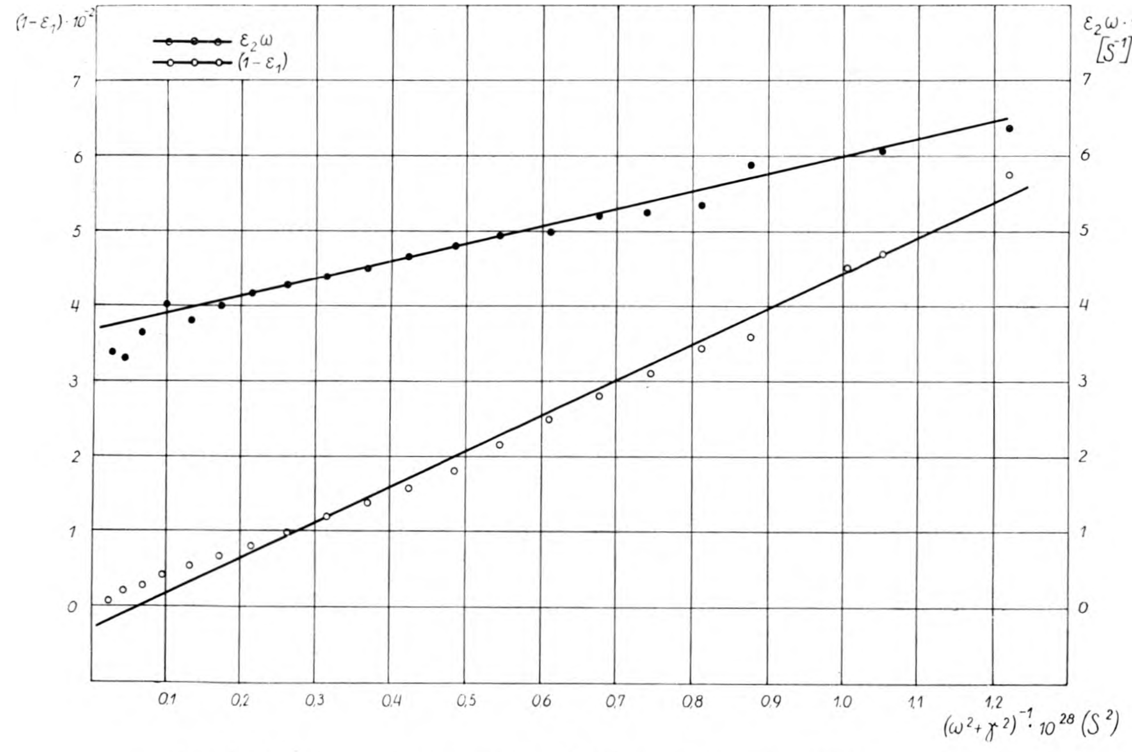

Fig. 5. Plot of $\varepsilon_2\omega$ and $(1-\varepsilon_1)$ vs. $(\omega^2+\gamma^2)^{-1}$ for non-transparent chrome layers

transparent chrome layers one may conclude that the structure of evaported chrome layers is similar to the structure of the bulk material.

The band structure of metals from the chrome group (W, Mo and Cr) was calculated by LOUCKS and MATTHEIS [8–9]. According to these calculations the structure of energy bands of W, Mo and paramagnetic Cr is very similar: the two lower energy bands are completely occupied, and the 3.4 and 5-th partialy occupied bands are the conduction bands. Fermi's surfaces of the metals have the same topology, and differ in the size of their parts. It follows from paper [8] that the presence of a strong absorption band for Mo within the energy region 0.75–5.15 eV agrees with energy differences for electron transitions between the energy bands: 3 and 4, 4 and 5, and 4 and 6. Since the spectral character of the absorption band of these metals and evaporated chrome layers are similar, it may be expected that the basic band develops similarly in chrome layers. The shift of this band in chrome layers in the direction of lower energies as compared with bulk chrome may be linked with a change in positions occupied by the energy bands.

It is my pleasure to thank Mrs. doc. C. Wesołowska for helping me in this work.

Оптические свойства непрозрачных плёнок хрома

В области спектра 0,23–0,25 мкм (0,05–5,6 эв) была расчитана дисперсия диэлектрической проницаемости $\varepsilon(\omega)$ непрозрачных плёнок хрома. На основе данных дисперсии $\varepsilon(\omega)$ расчитана была частота колебаний плазмы Ω^2 и частота столкновений γ электронов проводимости. Полученные результаты интепретировались на основе данных о структуре энергетической зоны в хроме.

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Received, March 17, 1972.