

## SOME OPTICAL PROPERTIES OF THIN CHROMIUM FILMS

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The optical properties of thin chromium films were investigated in the spectral range 0.1—5 eV. The results were compared with those obtained elsewhere on various chromium samples. The optical constants were calculated and three absorption peaks were observed at 0.17 eV, 2 eV and 3.3 eV.

### *1. Introduction*

Chromium exhibits an interesting type of magnetic ordering which has been studied by a variety of techniques<sup>1)</sup>. Anomalies appear in the transport properties as one passes through the Neel temperature<sup>2,3)</sup> ( $T_N = 312$  K). A number of other physical properties change upon magnetic ordering. Neutron diffraction measurements have shown that the ordering is indeed antiferromagnetic<sup>4)</sup>. Overhauser<sup>5)</sup> had proved that spin-density waves exist in chromium and it is an itinerant electron antiferromagnet, where the spins which align below 312 K belong to the mobile conduction electrons which provide the electrical conductivity.

Lomer<sup>6)</sup> had pointed out that the important area of the Fermi surface of chromium in (100) plane: the flat octahedral faces of the electron jack centered at  $\Gamma$  and the faces of the hole octahedron centered at  $H$ , have almost identical shapes, thereby enhancing the density-of-state factor in any coupling interaction. This area is responsible for the existence of the spin density waves in chromium, where the coupling of the surfaces is provided by the Coulomb attraction of the electrons and holes.

Several studies<sup>7-14)</sup> were carried out on the extra optical absorption caused by electron transitions across the first-order antiferromagnetic gap between the two electron and hole bands, which goes through the center of the flat section of the electron jack and through the center of the flat section of the hole jack, and an absorption peak was observed in the infrared spectrum of chromium single crystal and polycrystalline samples. However, there is a lack of information about the optical properties of thin chromium films.

The aim of the present contribution is to investigate the optical properties of thin chromium films, prepared by thermal evaporation in vacuum, in the infrared, visible and ultraviolet ranges.

## 2. Experimental

Chromium films of different thicknesses (20—160 nm) were prepared by thermal evaporation of highly pure chromium (99.999%) in a vacuum of  $\sim 10^{-4}$  Pa at an evaporation rate of about 2.5 nm/s., using a helical tungsten wire as a filament for evaporation. Two types of substrates were used, KBr discs for infrared measurements and fused silica plates for visible and UV measurements. The film thickness was measured by Tolansky interference method<sup>15)</sup> and confirmed by the weight of evaporated chromium sample. Transmission measurements were carried out at room temperature 293 K, using recording double beam infrared spectrophotometer\* type Beckmann 4220 and visible-UV spectrophotometer\* type Beckmann 5203, both give transmission values accurate to about  $\pm 1\%$ .

## 3. Results and discussion

Fig. 1 shows the spectral dependence of the transmission of chromium films of different thicknesses in the infrared range. The transmission decreases strongly with film thickness and for thickness  $> 200$  nm the film becomes opaque.

The problem of a plane electromagnetic wave of wavelength  $\lambda$  passing at normal incidence from vacuum into a homogenous plane parallel film of index  $n - ik$  and thickness  $d$ , on a substrate of index  $n_1$ , was treated by classical electromagnetic theory. For thick absorbing film ( $4\pi k d > \lambda$ ), the equations for the reflected and transmitted intensities are

$$R = \frac{(n - 1)^2 + k^2}{(n + 1)^2 + k^2} \quad (1)$$

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and

$$T = \frac{16n_1(n^2 + k^2)}{[(n + 1)^2 + k^2][(n_1 + n)^2 + k^2]} \exp - \left( \frac{4\pi kd}{\lambda} \right). \quad (2)$$

Eq. 2 allows to calculate the value of the extinction coefficient  $k$  and the refractive index  $n$  can be estimated from the preexponential factor by using the experimental values of  $T$ ,  $d$ ,  $n_1$  and  $k$ .

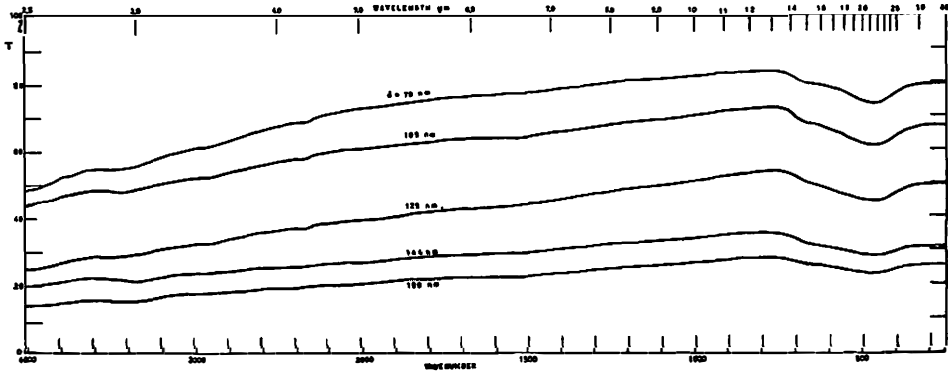


Fig. 1. Spectral dependence of the transmission of chromium films in the infrared range.

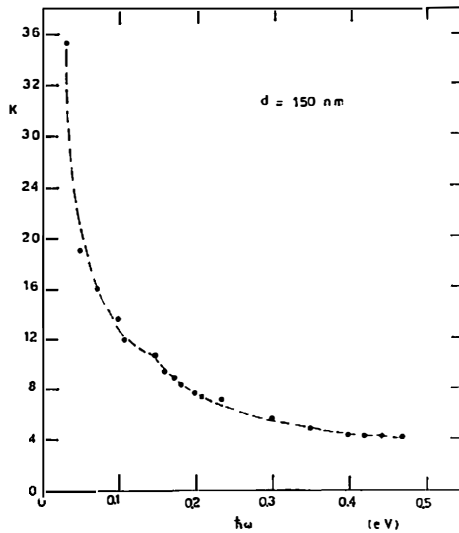


Fig. 2. The dependence of the extinction coefficient  $k$  on the photon energy in the infrared range.

Fig. 2 shows the variation of the calculated values of the extinction coefficient  $k$ , in the infrared range, with the photon energy. As shown the values of  $k$  decreases with the photon energy. The dependence of the absorption coefficient  $\alpha = 4\pi k/\lambda$

on photon energy (for 150 nm film) is shown in Fig. 3. A weak absorption peak is observed at 0.17 eV. In the same figure the results are compared with the absorptivity data of Bos and Lynch<sup>12)</sup>, measured by a calorimetric technique on a single crystal sample, whose surface is chemically etched and electropolished, the absorptivity peak is observed at 0.13 eV and is attributed to the antiferromagnetic gap.

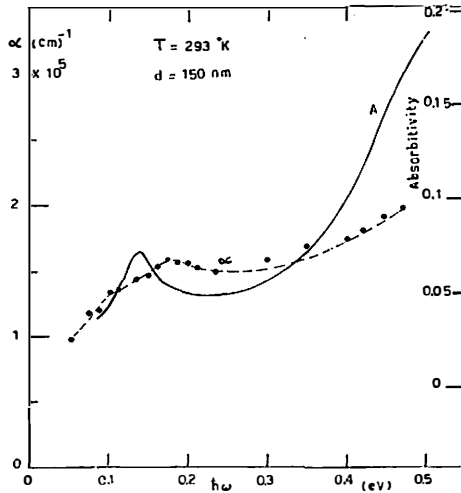


Fig. 3. The dependence of the absorption coefficient  $\alpha$  on the photon energy in the infrared range.

Theoretical model used by Fedders and Martin<sup>7)</sup> for the extra optical absorption across the antiferromagnetic gap predicts an optical conductivity whose real part is given by

$$\sigma(\omega) = \frac{4 e^2 k_F^2 \Delta^2 \tanh(\hbar\omega/kT)}{3\pi m \hbar \omega^2 [(\hbar\omega)^2 - 4\Delta^2]^{1/2}}, \text{ for } \hbar\omega > 2\Delta \quad (3)$$

where the energy gap at  $T = 0$  K is given by  $2\Delta = 3.5 kT_N = 0.094$  eV, and  $k_F$  is the radius of the electron and hole Fermi spheres. Recent calculations<sup>8)</sup> shows that electron-phonon interaction causes the gap energy to increase to  $2\Delta = 5.1 kT_N = 0.137$  eV. Evaporated chromium films have a structure different from that of bulk chromium and the weak absorption peak observed at 0.17 eV may be attributed to the gap smeared out because of the film structure and size effect.

Fig. 4 shows the spectral dependence of the transmissions for chromium films in the visible and UV ranges. The variation of the calculated values of the optical constants  $n$  and  $k$  with the photon energy is shown in Fig. 5. The values of  $n$  and  $k$  decrease with photon energy, and the value of  $n$  is found to be thickness dependent for  $d < 3000$  nm in the spectral range  $< 4$  eV and decreases on increasing thickness. The large values of  $n$  at small thicknesses are qualitatively predicted by the

Maxwell-Garnett theory<sup>16)</sup>. The optical constants  $n$  and  $k$  are compared with the data of Barker and Ditzenberger<sup>8)</sup> for electroetched single crystal samples and the data of Johnson and Christy<sup>17)</sup> for an evaporated Cr layer 45 nm thick (where a

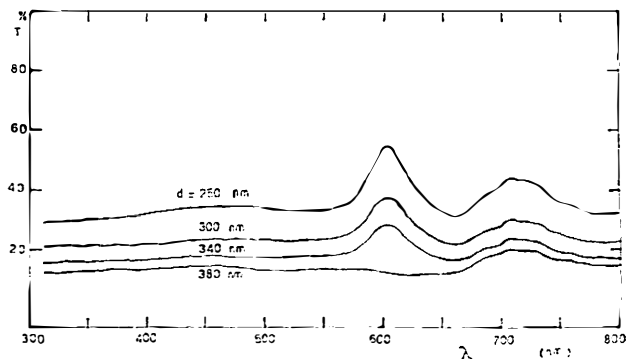


Fig. 4. Spectral dependence of the transmission of chromium films in the visible and UV range.

technique of inverting reflection and transmission measurements is used to calculate  $n$  and  $k$ ). The values of  $k$  are close to that of Johnson and Christy<sup>17)</sup> and lower than that of Barker and Ditzenberger. This may be attributed to the difference in quality of the surface of the samples, since electroetching affects the flatness of the surface.

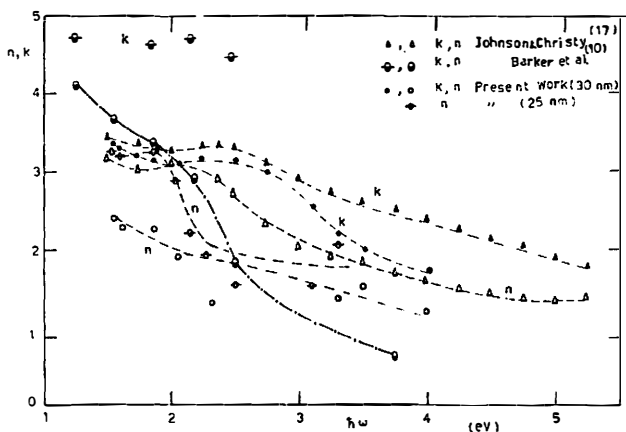


Fig. 5. The dependence of the extinction coefficient  $k$  and the refractive index  $n$  on the photon energy.

Fig. 6 shows the variation of  $\epsilon_1$  with photon energy, and the dependence of the optical conductivity  $\sigma_1 = \epsilon_2\omega/4\pi$  on the photon energy is shown in Fig. 7, compared with the data of Graves and Lenham<sup>13)</sup> for mechanically polished chromium using modified reflectance technique, the data of Lenham<sup>14)</sup> for mechanically polished chromium using ellipsometric technique and the data of Johnson

and Christy<sup>17)</sup>. It is readily seen that the results differ considerably from each other, however the results for 30 nm film is close to that of Johnson and Christy. These differences can be attributed to the difference in surface structure. Mechanical polishing and electroetching produce a surface layer of different structure, while evaporated films have a structure different from that of bulk chromium. Moreover, ellipsometric measurements are very sensitive to the quality of the surface.

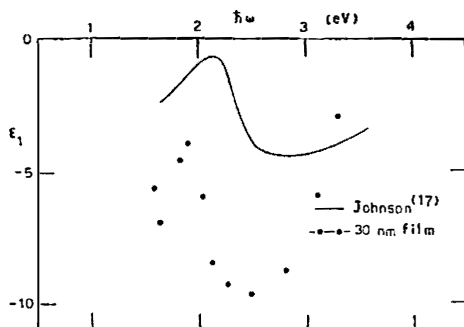


Fig. 6. The variation of the real dielectric constant with photon energy.

The optical conductivity curve shows two absorption peaks at 2 eV and 3.3 eV. This agrees with the observations of Graves and Lenham<sup>13)</sup>, where a large absorption peak at 2.1 eV and a weak one at 3.3 eV were observed.

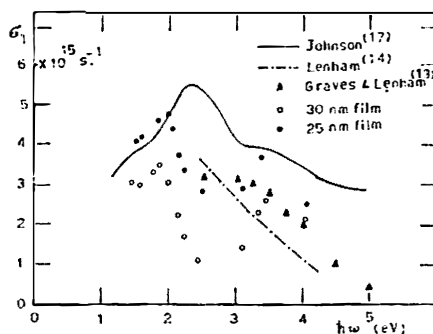


Fig. 7. The dependence of the optical conductivity on the photon energy.

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## NEKA OPTIČKA SVOJSTVA TANKIH FILMOVA KROMA

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Originalni znanstveni rad

Istraživana su optička svojstva tankih filmova kroma u spektralnom području od 0.1 do 5 eV. Dobiveni rezultati se uspoređuju sa rezultatima drugih autora dobivenim na sličnim uzorcima. Izračunate su optičke konstante i nađena su tri apsorpcijska vrha na energijama fotona od 0.17 eV, 2, eV i 3.3 eV.