Absorption of light by "drops" of the metallic phase near the semiconductor–metal phase transition in VO_2

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Absorption of light by "drop" of the metallic phase has been observed in a VO_2 film long before the temperature of the phase transition into the metallic state is reached.

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It is known that in crystals with first-order phase transition small inclusions of a new phase can be produced long before the phase-transition temperature T_c is reached. In[1] it was shown that in thin films of vanadium dioxide the smearing of the phase transition with respect to temperature, and particularly with respect to the optical properties, can actually be explained as being due to the coexistence of the metallic and semiconducting phases. The electric conductivity of such a two-phase system is described by percolation theory.[2]

The presence of minute "drops" of a metallic phase in the semiconducting region can manifest itself in the appearance of a unique resonant absorption. Using the Mie theory, we can represent the cross section for the absorption of light of frequency ν by metallic spheres whose dimensions are much less than the wavelength of the light in the form

$$Q_a - \nu \operatorname{Im}\left(\frac{1}{\epsilon_m/\epsilon_s + 2}\right), \tag{1}$$

where $\epsilon_m(\nu)$ and $\epsilon_s(\nu)$ are the dielectric constants of the metallic sphere and of the surrounding semiconducting medium. It is seen that expression (1) describes a band with a maximum frequency determined from the condition $\epsilon_m/\epsilon_s + 2 = 0$. We report here the observation, in the semiconducting phase of VO_2, of metallic drops whose absorption of light is well described by expression (1).

The optical spectra were measured on films 2000 Å thick deposited on glass of on an aluminum mirror. This variant is more convenient from the experimental point of view, since it gets around the difficulty that the chosen substrate transmits radiation with a broad spectrum, but what are actually determined in the reflection experiments are the singularities of the absorption by the film. In this case, by measuring the reflection coefficient R_0 of the film at room temperature and the reflection coefficient R_T at various temperatures in the vicinity of the phase transition, we can trace the variation of the absorption of the light as the phase-transition temperature $T_c \approx 340$ K is reached. The quantity $A = 1 - (R_0/R_T)$ determines the change of the light absorption in the film when the film is heated to the temperature T_c. Measurement of A in the temperature interval 273—373 K has shown that an absorption band with a maximum near 0.7 eV is observed already at 20° below T_c. With further increase of the

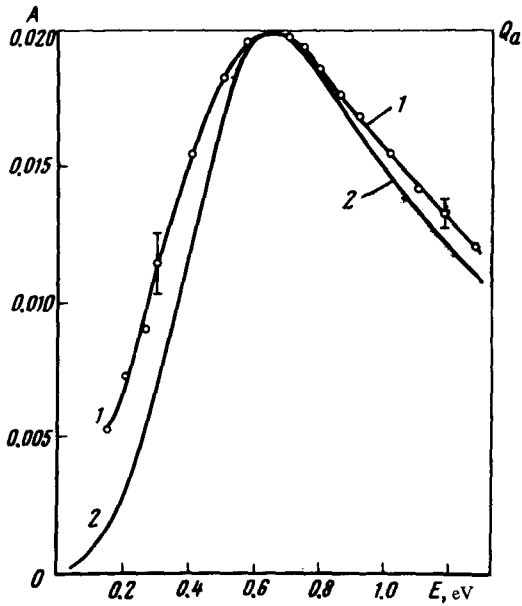

FIG. 1. Spectral dependences of the absorption of light by "drops" of the metallic phase of VO_2: 1—experimental spectrum, 2—spectrum of the absorption cross section Q_a calculated by the Mie theory.

temperature, this band increases in intensity and in width, and becomes completely "smeared out" at $T = T_c$.

Figure 1 shows the spectral behavior of A at a temperature 330 K, i.e., 10° below T_c. The same figure shows the cross section Q_a for the absorption of light by small metallic spheres, calculated from formula (1). The values of the dielectric constants of the metallic and semiconducting phases used in the calculation of Q_a were taken from[3].

The comparison of the calculated and experimental curves is quite good, thus confirming the idea of the onset of "drops" of the metallic phase long before the phase-transition temperature is reached.

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