

The effect of iron doping of cadmium sulfide on the optical and photoelectric characteristics of the material

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Relevance and purpose

Photoelectric and optical phenomena in semiconductors such as CdS play a pivotal role in modern optoelectronics. Research into CdS-based materials is driven by the potential to tailor their properties through doping and the creation of heterophase structures. The incorporation of Fe ions modifies the band structure of CdS, altering the bandgap, optical absorption coefficients, and photoconductivity compared to pure CdS. This offers additional opportunities to tune material parameters based on synthesis conditions and intended applications. The synthesis technique is a crucial factor determining the properties of the resulting samples. Various production methods—such as vacuum thermal evaporation and hybrid approaches employing the Langmuir–Blodgett technique—yield structures with distinct morphologies and phase compositions, which directly influence their photoelectric and optical properties.

Production technology

Thermal vacuum evaporation (TVE)

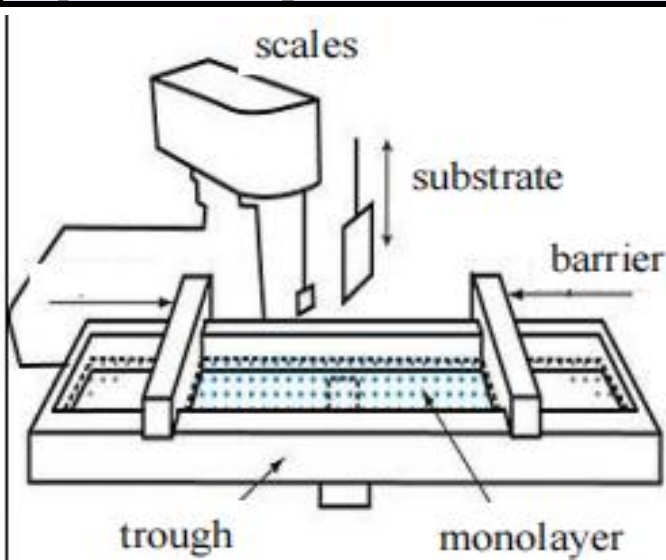
During annealing, Fe atoms diffuse throughout the entire thickness of the CdS sample. This process results in the formation of a heterogeneous material based on a $\text{Cd}_x\text{Fe}_{1-x}\text{S}$ solid solution with Fe_2O_3 inclusions on the sample surface.

Annealing (diffusion of Fe into CdS) at $T=545\pm 5$

Fig. 1. Schematic representation of samples obtained using the TVE method. Region I is the CdS:Fe solid solution region; region II is the region of FeS nano-inclusion precipitation

Hybrid method using Langmuir-Blodgett technology (TVE/LB)

Creation of a metallized ordered organic film on the surface of an aqueous subphase



Transfer of the obtained film to the surface of a CdS

1. Organic matrix - arachidic acid, $C=10^{-3}$ mol/l, $V=50$ μl .
2. Iron source - FeCl_3 , $C=10^{-3}$ mol/l.
3. pH of subphase -4.2 ± 0.05 .
4. Substrate - CdS (obtained by TVE).
5. Film transfer - Langmuir-Schaeffer method.

High-temperature annealing (Fe diffusion into CdS)

6. The CdS/ArchFe structures were annealed at $T=545\pm 5$ °C for 15 min. During annealing, Fe atoms diffuse into the CdS sample to form a solid substitution solution $\text{Cd}_x\text{Fe}_{1-x}\text{S}$.

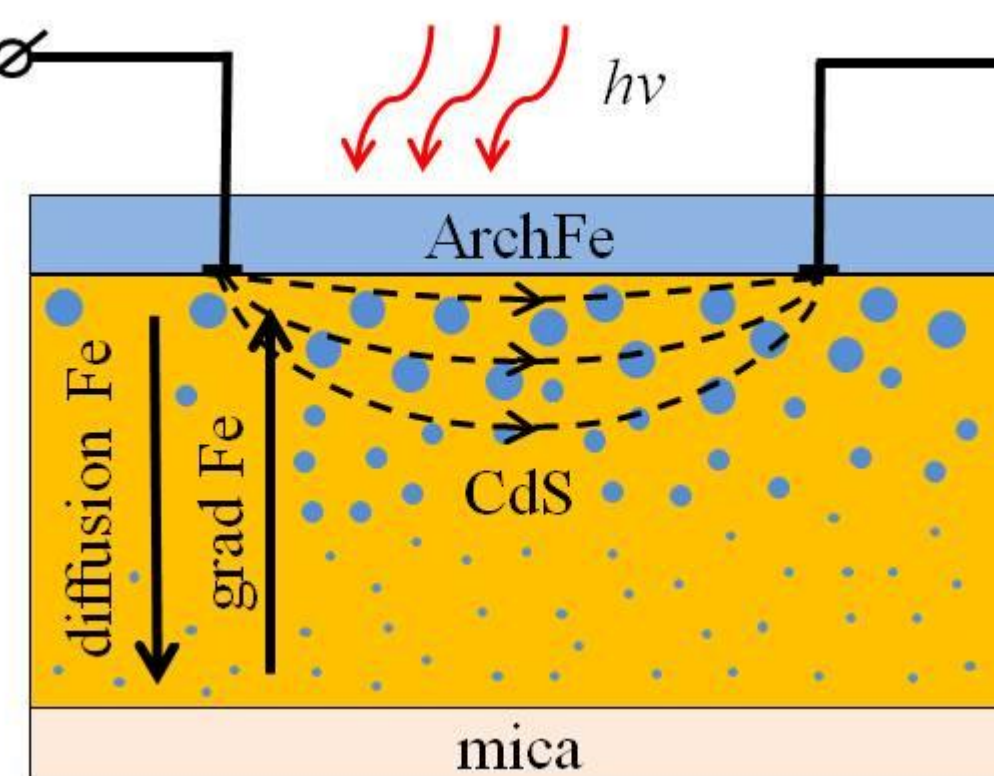
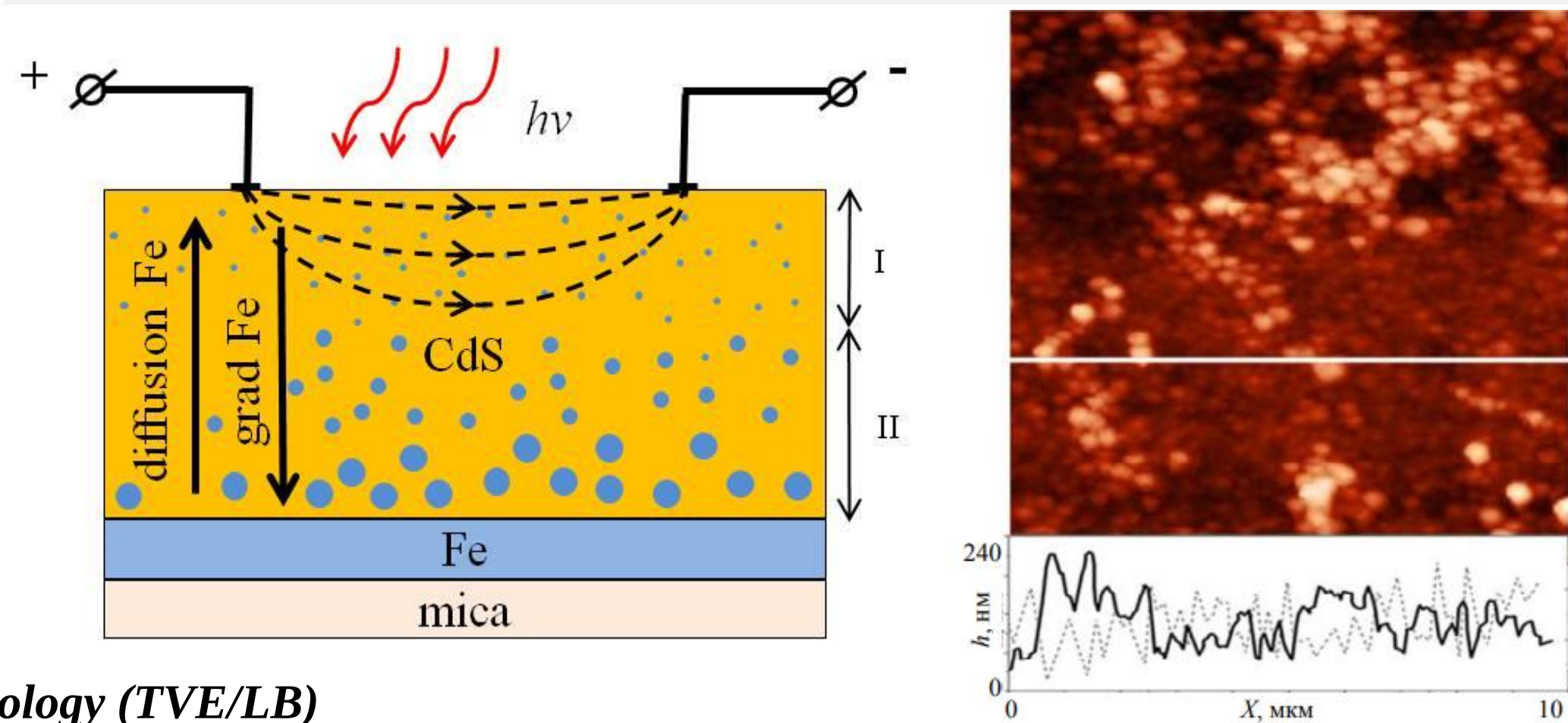


Fig. 2. Schematic representation of samples obtained using the TVE/LB method. Region I is the CdS:Fe solid solution region; region II is the region of FeS nano-inclusion precipitation

Photoelectric characteristics of the studied samples

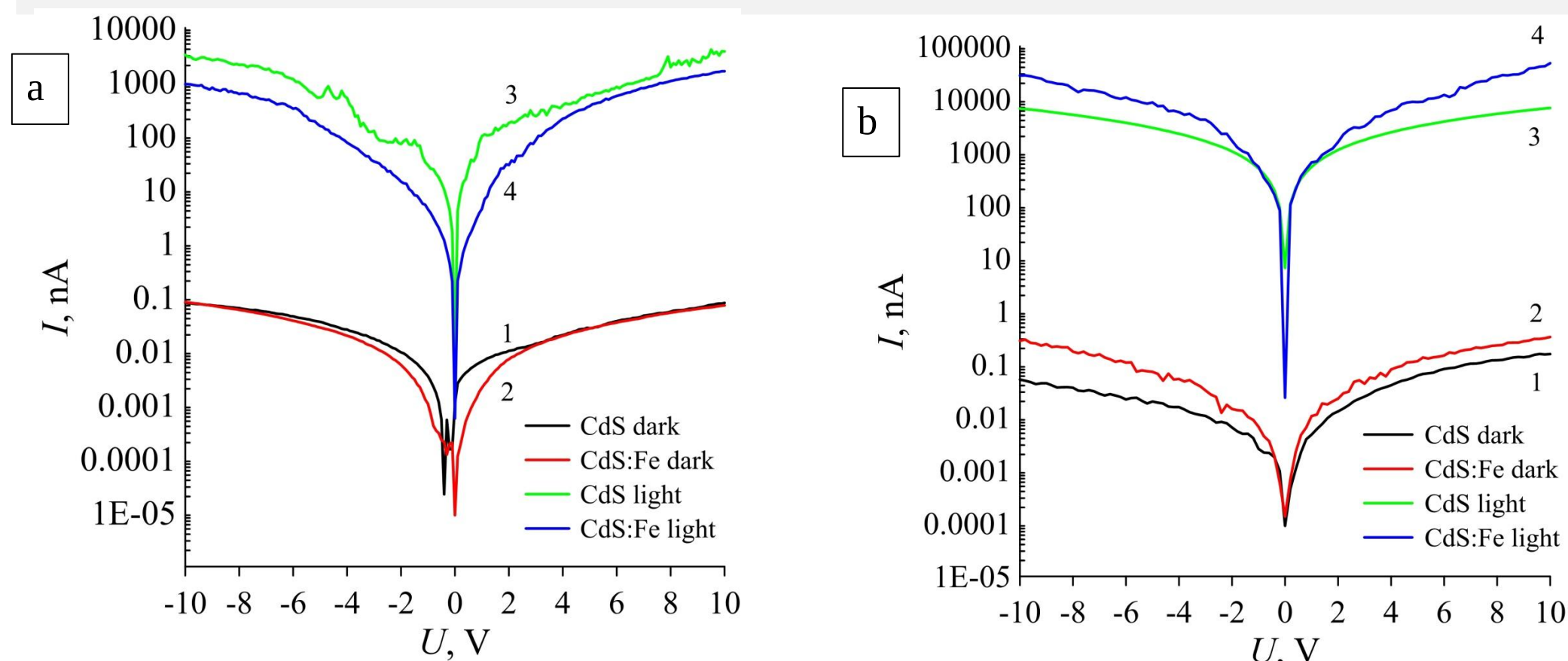


Fig. 3. Current-voltage curves measured in darkness (curves 1, 2) and under illumination (curves 3, 4) plotted in a semilogarithmic scale, for samples of "pure" CdS (curves 1,3) and CdS:Fe (curves 2, 4) obtained using: a — TVE technology; b — TVE/LB hybrid method.

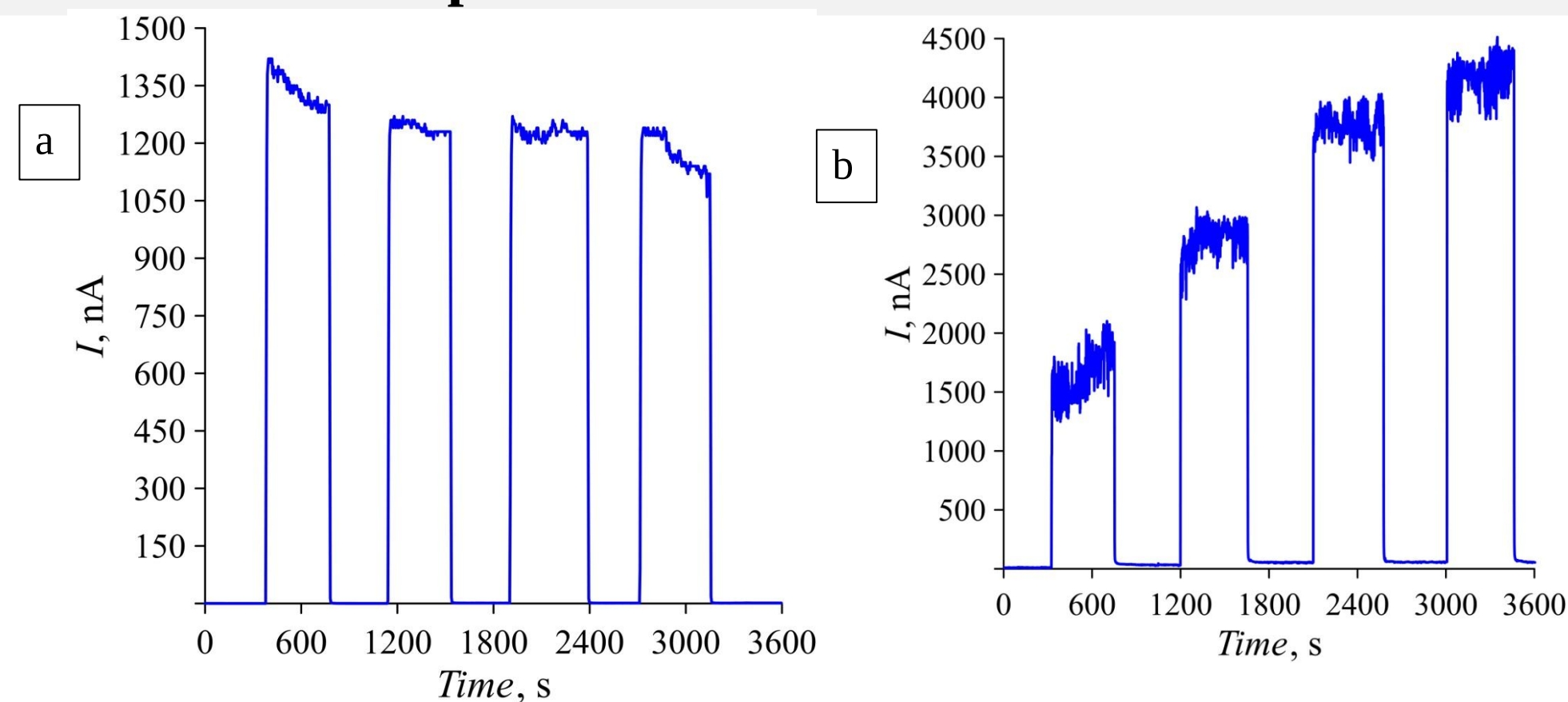


Fig. 4. Dependences of current on time during periodic switching on of illumination with the same intensity for CdS:Fe obtained: a — by the TVE method; b — by method using LB technology (TVE/LB).

A comparison of the photoelectric characteristics and parameters of CdS:Fe samples obtained by different methods showed that both batches of samples have photosensitivity in the visible region of the spectrum, but the nature of the change in currents is diametrically opposed: the dark currents and photocurrents of heterophase CdS:Fe samples fabricated by TVE method decline, while for the films obtained by hybrid technology they increase. Over time, under constant illumination, the sensitivity of CdS:Fe samples obtained using TVE method decreases slightly. For CdS:Fe samples obtained using the hybrid TVE/LB method, the phenomenon of negative photofatigue is observed in the kinetic dependences. The observed differences are explained by different location of the precipitation region of FeS nano-inclusions relative to the illuminated surface of the sample.

Optical characteristics of the studied samples

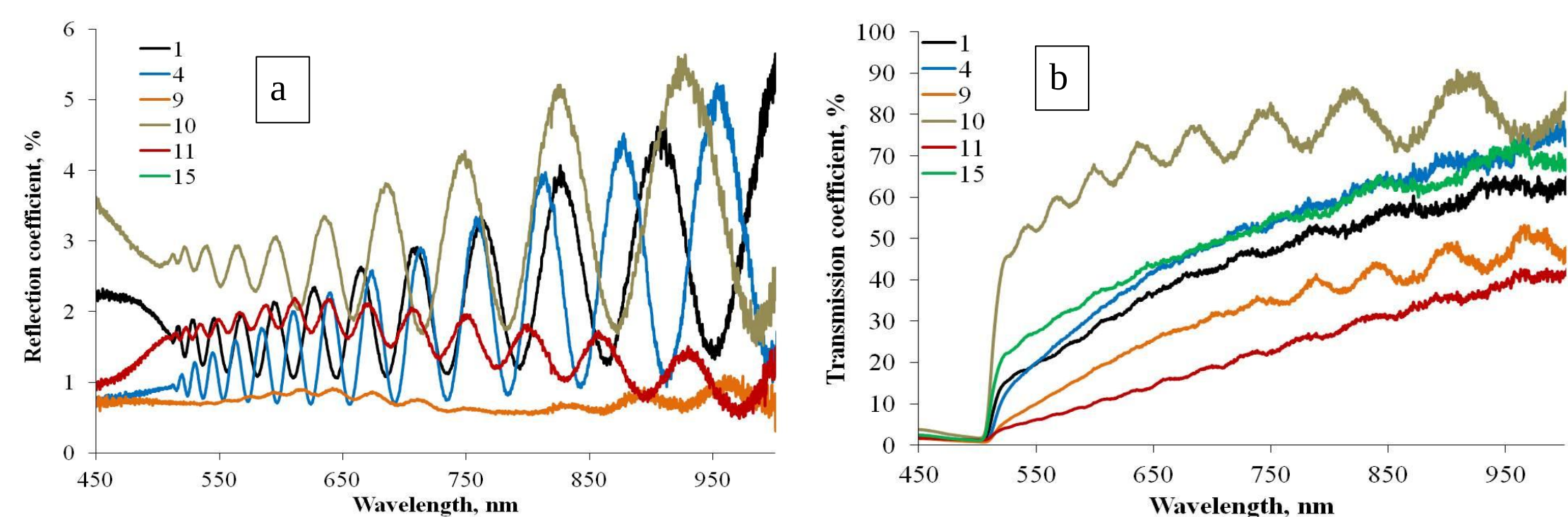


Fig. 5. Reflection (a) and transmission (b) spectra of the studied samples

Since the position of the fundamental absorption edge is sensitive to structural defects, impurity states, and film formation conditions, the optical band gap of the samples was determined using the Tauc formula:

$$(\alpha h\nu)^2 = A(h\nu - E_g),$$

где $h\nu$ — энергия фотона, E_g — ширина запрещенной зоны, A — коэффициент, зависящий от свойств материала.

$$\alpha \sim \ln(1/T)$$

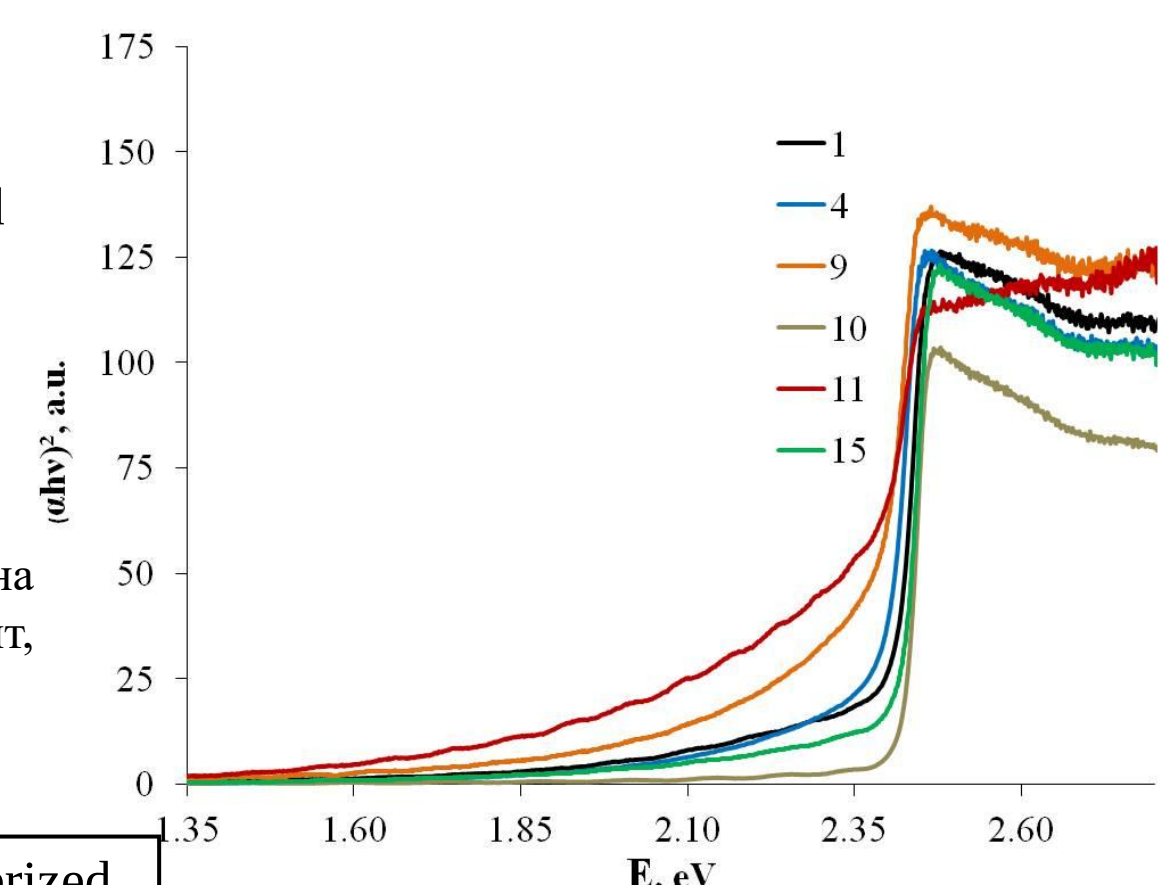


Fig. 6. Tauc plots for the studied samples

Sample	Composition	Method	Annealing
1,4	CdS (1 g) + CuCl ₂ (10 mg)	TVE	—
9	CdS (1 g) + CuCl ₂ (0,01 g) + Fe (35 mg)	TVE	+
10	CdS (1 g) + CuCl ₂ (10 mg) + Fe (20 mg),	TVE	—
11	CdS (1 g) + CuCl ₂ (0,1 mg) + Fe (15 mg)	TVE	+
15	CdS + Fe (deposited by the LB method onto CdS using ArchFe)	TVE/LB	+

Samples prepared by TVE without Fe addition are characterized by relatively high transmittance values and pronounced interference oscillations. The introduction of Fe leads to reduced film transparency, a blurring of the fundamental absorption edge, and a decrease in E_g values. This behavior may be attributed to the emergence of additional localized states within the band gap, as well as increased structural defect density and inhomogeneity.

Sample	1	4	9	10	11	15
E_g , eV	2,36	2,37	2,34	2,4	2,3	2,39