Features of photoelectric characteristics of CdS:Fe samples obtained using various technologies

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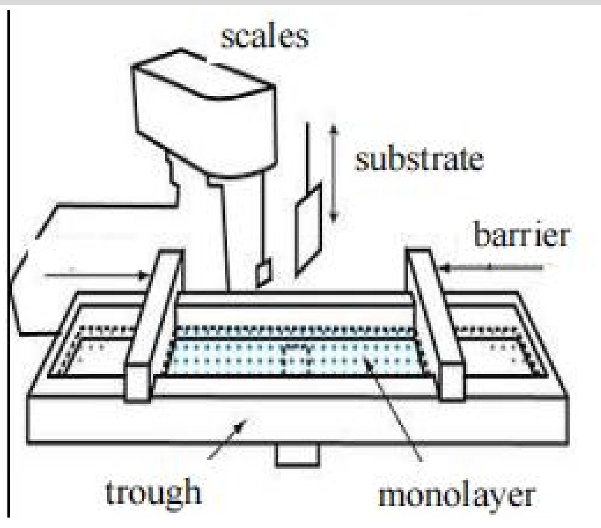
Relevance and purpose

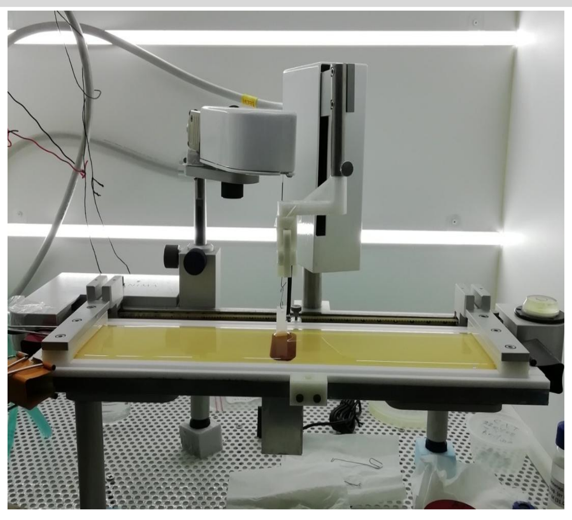
Semimagnetic solid solutions based on photosensitive semiconductors, in which the metal atoms of the base material are partially replaced by dopant atoms (e.g., Ga, In, Mn, Ni, and Fe), have become the subject of intensive experimental and theoretical research. Interest in studying such materials stems from the potential for significant changes in the electrical and optical properties of these materials in response to magnetic fields and illumination. To successfully predict changes in magnetic and photoelectric properties, the distribution of the dopant metal atoms in the semiconductor is of great importance. Therefore, it is important to pay attention to the technology and methods for producing such structures, highlighting the advantages of each technological approach. In this study, we investigated CdS-based structures doped with iron atoms, obtained using various technologies (thermal evaporation in a vacuum and Langmuir-Blodgett technology). Fe atoms diffuse from the metallized coating into CdS during high-temperature annealing, forming a solid solution of $Cd_xFe_{1-x}S$. However, due to the limited solubility of Fe in CdS, several competing processes—precipitation, diffusion, and surface oxidation—occur, leading to the formation of several phases unevenly distributed on the surface and in the bulk. [*Applied Physics, No. 5, 66 (2020), Semiconductors, 7, 2023*]

Production technology (*Langmuir-Blodgett technology*)

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

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.





Transfer of the obtained film to the surface of a semiconductor substrate (CdS)

4. Substrate - single crystal CdS.
5. Film transfer - Langmuir-Schaeffer method.
6. Number of transferred monolayers - 25.

High-temperature annealing (Fe diffusion into CdS)

7. The CdS/ArchFe structures were annealed at T=545±5 °C for 60 min. During annealing, Fe atoms diffuse into the CdS sample to form a solid substitution solution $Cd_xFe_{1-x}S$.

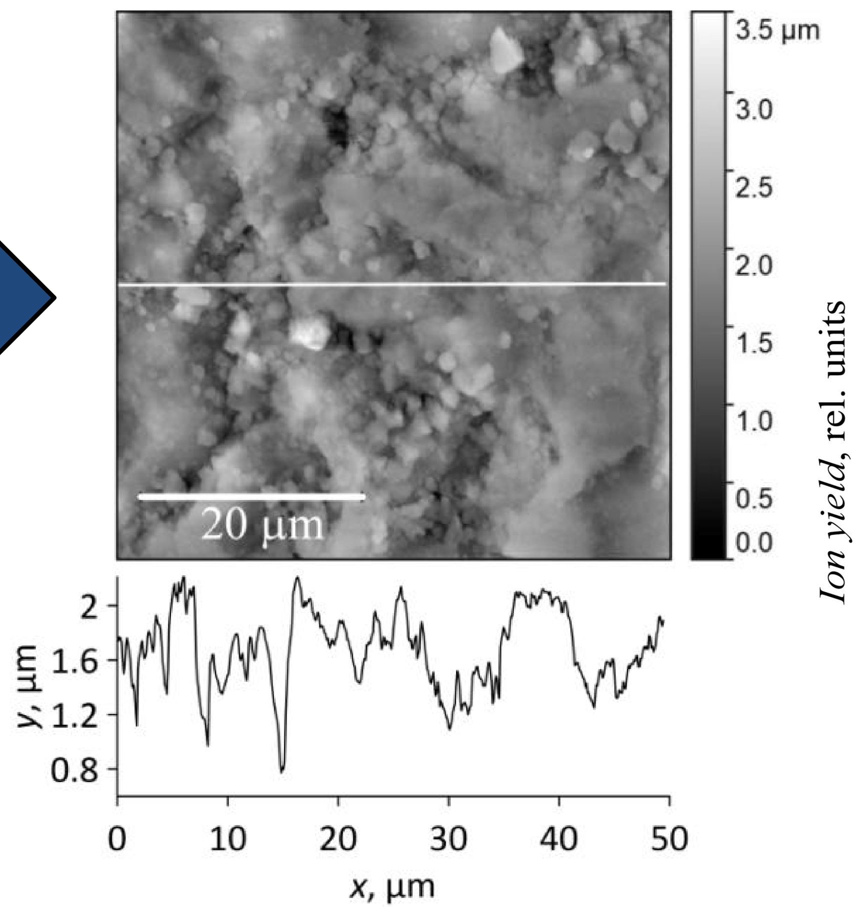


Fig. 1. AFM images of the surface and line profiles for CdS:Fe (after annealing of CdS/ArchFe)

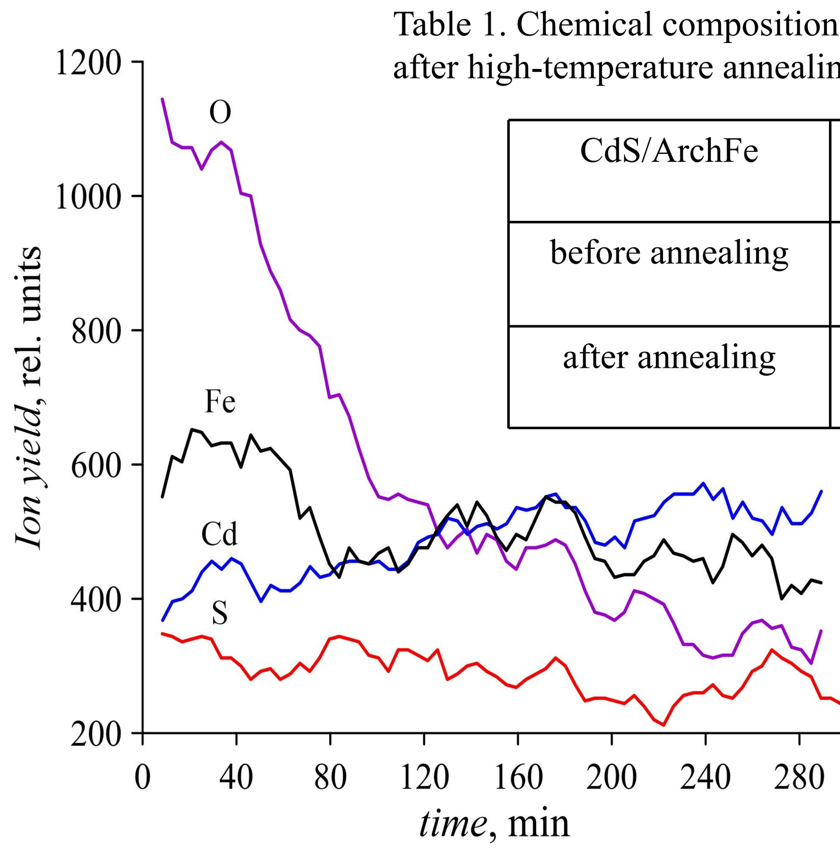


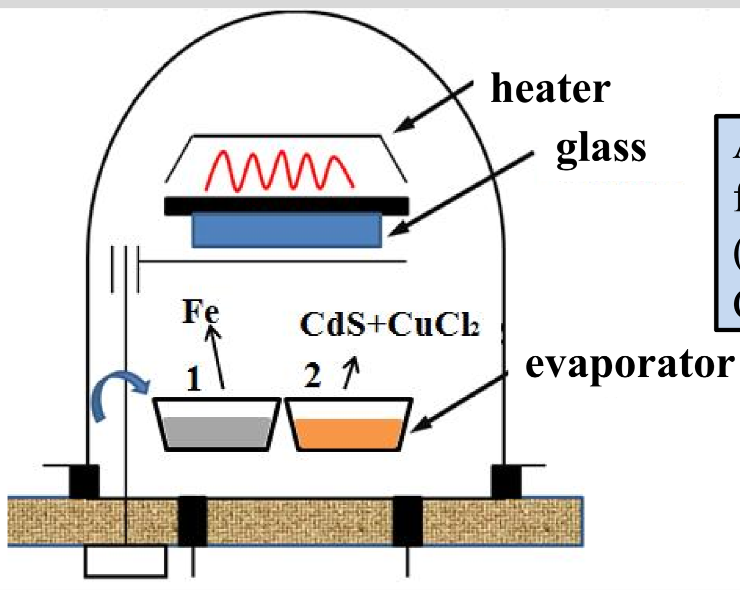
Fig. 2. Distribution profiles of chemical elements in CdS:Fe samples after high-temperature annealing

Table 1. Chemical composition of the surface of the CdS/ArchFe structure before and after high-temperature annealing

CdS/ArchFe	O, at. %	S, at. %	Fe, at. %	Cd, at. %
before annealing	25.51	37.05	4.41	33.03
after annealing	42.09	18.59	0.55	38.77

The obtained samples were studied before and after high-temperature annealing by scanning two sections of the sample measuring 50 by 50 µm at an accelerating voltage of primary electrons of 15 keV using a scanning electron microscope MIRA 2 LMU (Tescan).

Production technology (*Thermal evaporation in a vacuum*)



Annealing at 450°C for 15 minutes (diffusion of Fe into CdS)

1. Deposition of Fe with a thickness of 30-50 nm.
2. Deposition of CdS with a thickness of 0.6-0.8 µm

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 $Cd_xFe_{1-x}S$ solid solution with Fe_2O_3 and CdO inclusions on the sample surface.

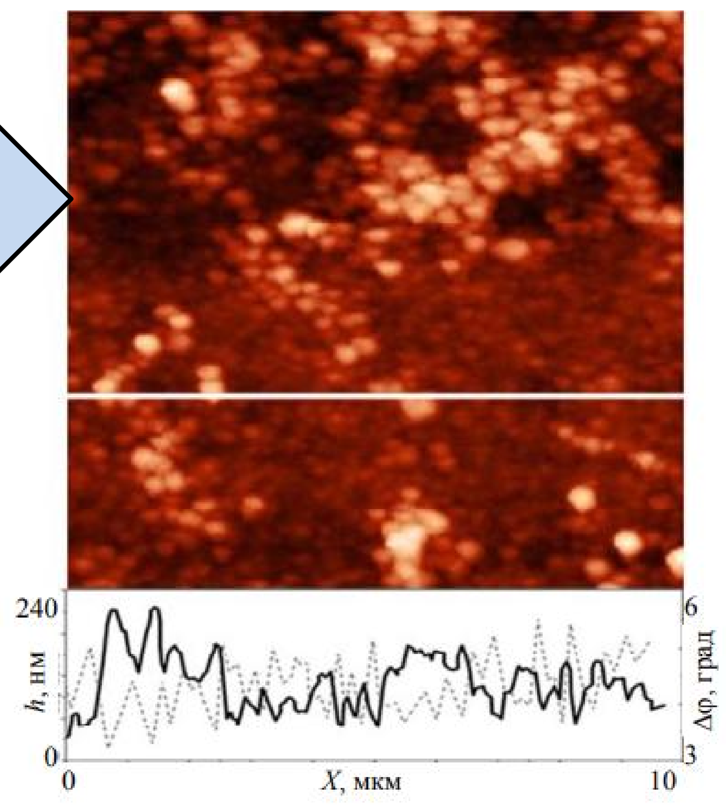


Fig. 3. AFM images of the surface and line profiles for CdS:Fe (after annealing)

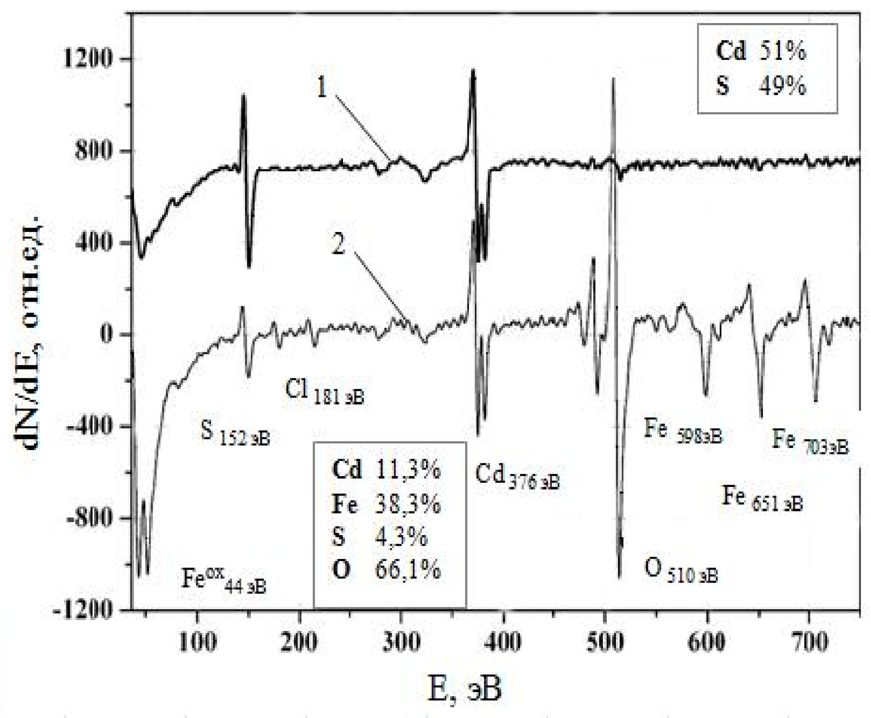


Fig.4. Auger spectra and comparison of surface composition of unannealed (1) and annealed (2) samples of heterogeneous material based on the solid solution $Cd_xFe_{1-x}S$.

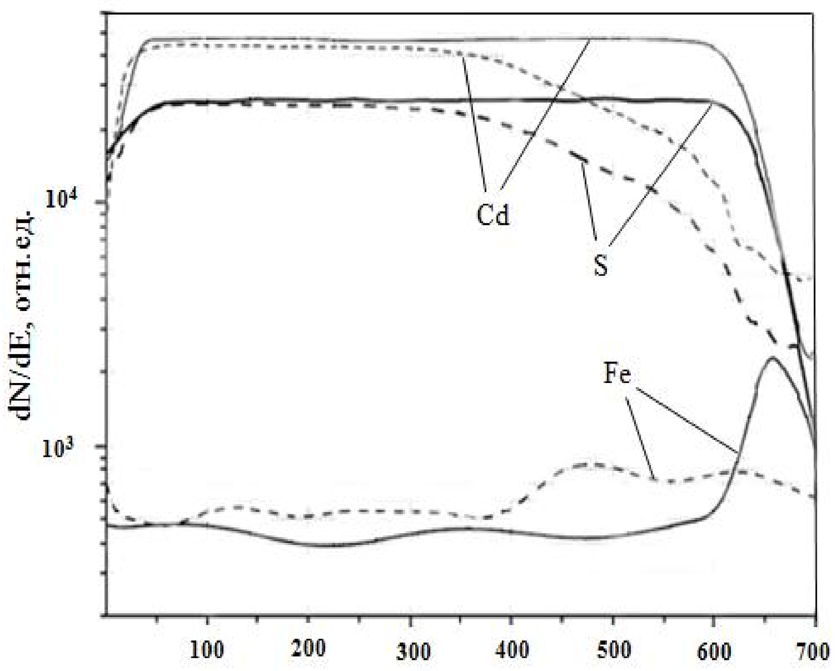


Fig.5. Distribution profiles of S, Cd and Fe in CdS:Fe samples before (solid lines) and after (dashed lines) high-temperature annealing.

Photoelectric characteristics of the studied samples

Langmuir-Blodgett technology

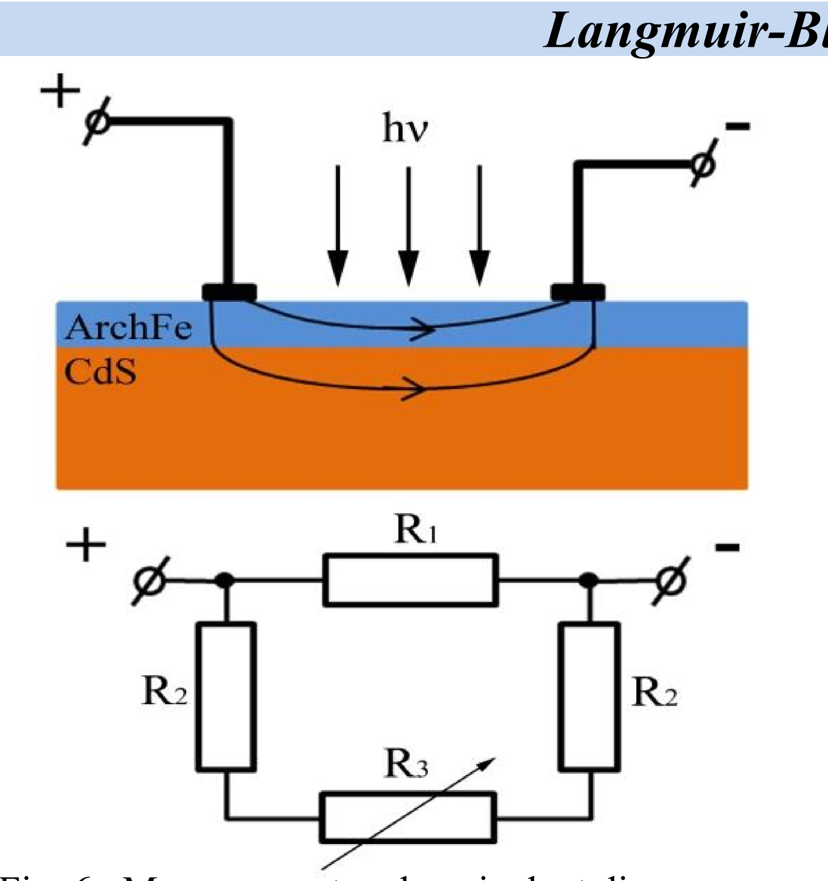


Fig. 6. Measurement and equivalent diagrams illustrating the transverse photoconductivity mode, where
R1 — resistance along the film ArchFe,
R2 — resistance across the film ArchFe,
R3 — photosensitive resistance of CdS.

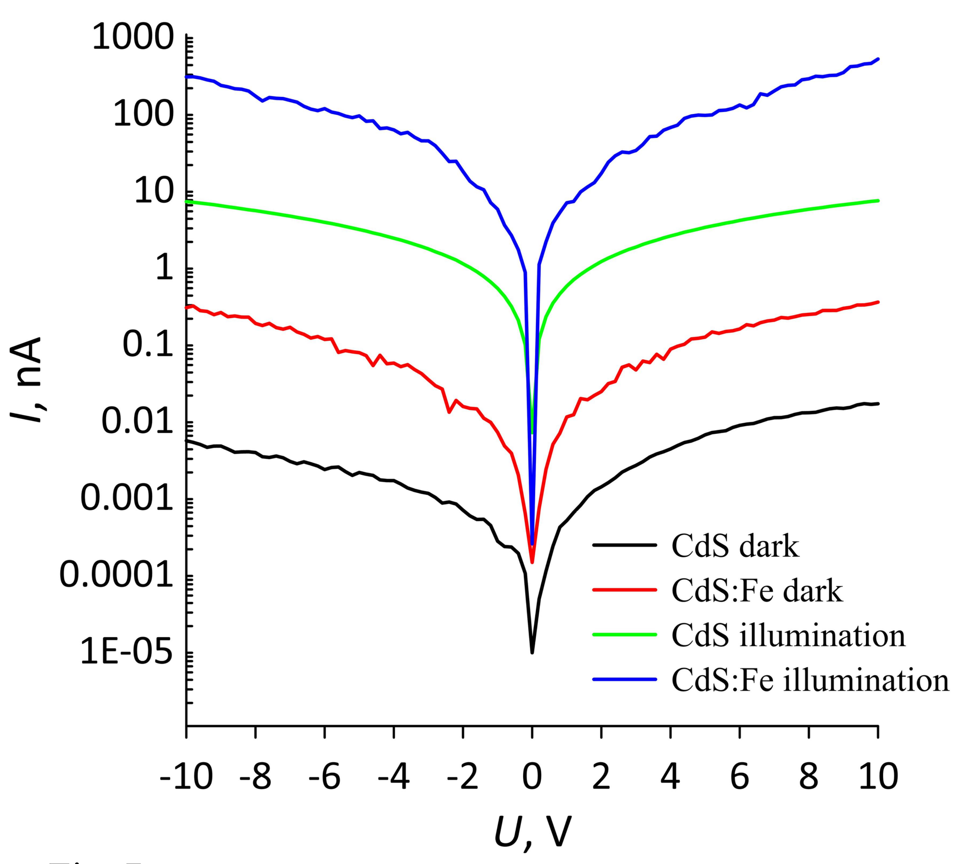


Fig. 7.Current-voltage characteristics plotted on a semi-logarithmic scale for samples of "pure" CdS and heterophase material CdS:Fe, measured in the dark and under illumination. ***Langmuir-Blodget technology***

Thermal evaporation in a vacuum

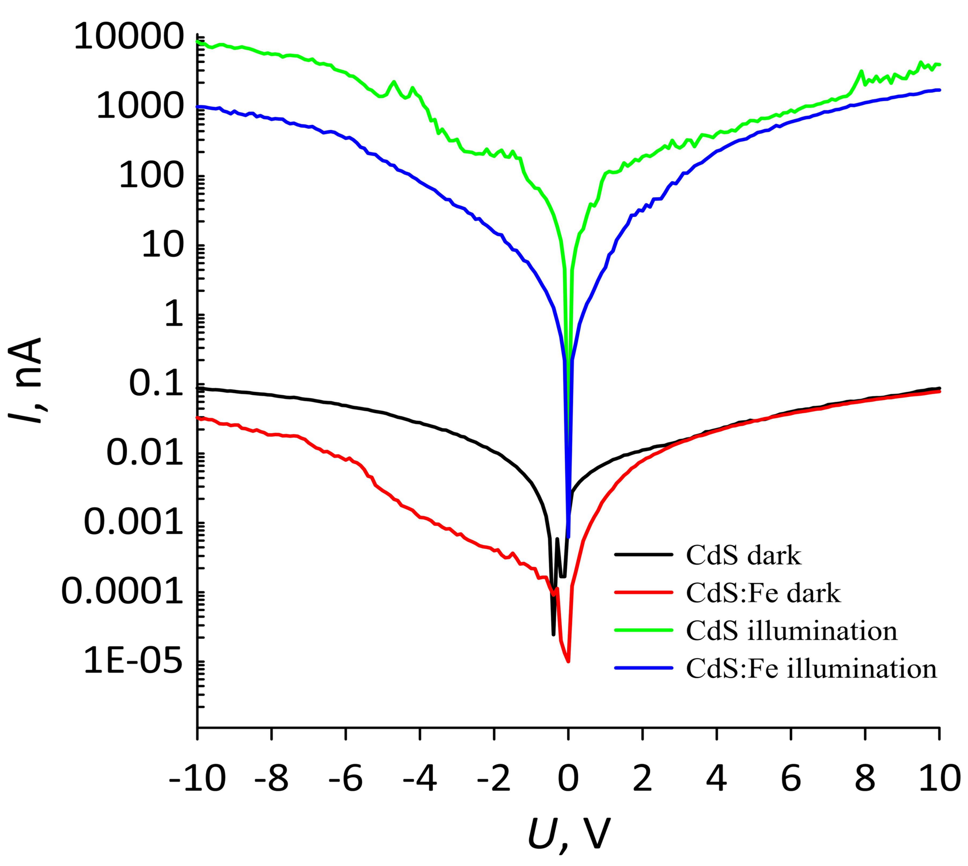


Fig. 8.Current-voltage characteristics plotted on a semi-logarithmic scale for samples of "pure" CdS and heterophase material CdS:Fe, measured in the dark and under illumination. ***Thermal evaporation in a vacuum***

Conclusion

A comparison of the photoelectric parameters of CdS:Fe samples obtained by different methods revealed that both batches of samples are photosensitive in the visible spectrum. The observed differences in dark resistance and the resistance change rate upon illumination are explained by the different location, thickness, and composition of the iron-containing layer relative to the front (illuminated) surface of the sample. As a result of diffusion from these sources, in the first case (Langmuir-Blodgett technology), the largest nanoscale FeS precipitates form near the illuminated surface, while in the second case (thermal evaporation in vacuum), they form closer to the substrate. Moreover, in the first case (Langmuir-Blodgett technology), the Fe located on the surface of the sample annealed in air oxidizes more strongly, forming Fe_2O_3; in the second case (thermal evaporation in vacuum), cadmium oxide predominates.