Spectral and Photoelectric Properties of Ionic Liquid Crystals Tuned by Nanoparticles

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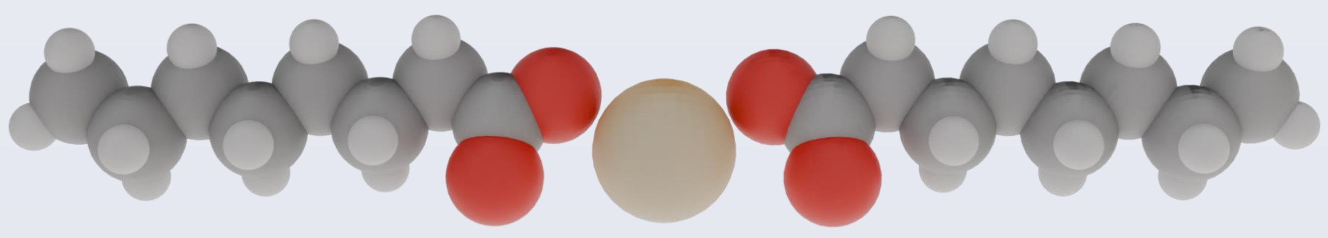
Abstract

We studied the cadmium octanoate $Cd^{+2}(C_7H_{15}COO^-)_2$ (abbreviation CdC_8) ionic liquid crystals with several types of NPs. A distinctive property of the CdC_8 matrix acting as a nanoreactor is the possibility to control the size and uniformity of NPs during the synthesis. Nanocomposite materials including semiconductor NPs in the CdC_8 matrix are investigated. The shape and size of NPs are measured using scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Obtained data are used to analyze the correlation between the structural characteristics of NPs and their optical properties. The photoelectric properties of these materials are studied using ultraviolet and visible range light sources of different intensities. The results demonstrate that synthesized nanomaterials have great potential for the design of photoelectric elements and optical sensors.

Material

Cadmium octanoate CdC_8 (Fig.1) material form glassy structures with smectic A ordering (Fig.2) during cooling. Chemically synthesizes NPs can be directly in the smectic A mesophase. This provides uniform NPs with a narrow size distribution within the glassy matrix and allows the development of nanocomposites with unique electrical and optical properties.

$$Cd^{2+}(NO_3)_2 + 2K(C_7H_{15}COO) \rightarrow Cd^{+2}(C_7H_{15}COO^-)_2 + 2KNO_3$$



$Cd^{+2}(C_7H_{15}COO-)_2$

Fig.1 Schematic illustration of the cadmium octanoate CdC_8 structure.

Structural properties

For study of the sizes of CdS and C NPs, we dissolved the nanocomposites CdC_8 + CdS NPs (Fig. 3) and CdC_8 + C NPs (Fig. 4) in Hexane - C_6H_{14}, then dropped 1 μl of the obtained substance onto the top of the carbon film supported by copper grid and let it dry. To analyze the samples, we used the LEO 1550 SEM and FEI Titan Tecnai G2 F20 TEM.

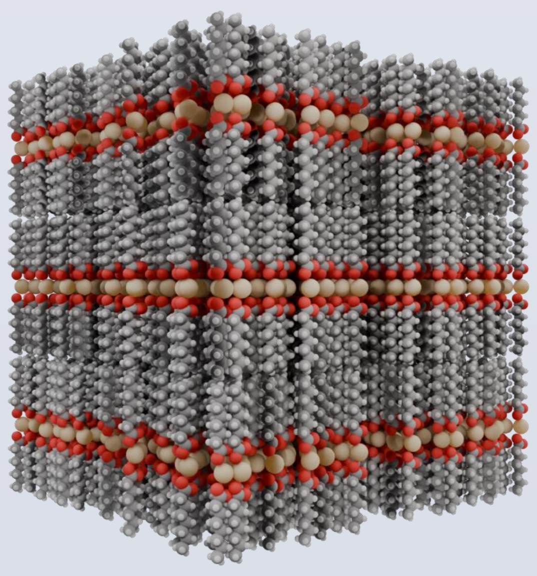


Fig. 2 Schematic illustration of the structure of CdC_8 matrix of smectic A ordering

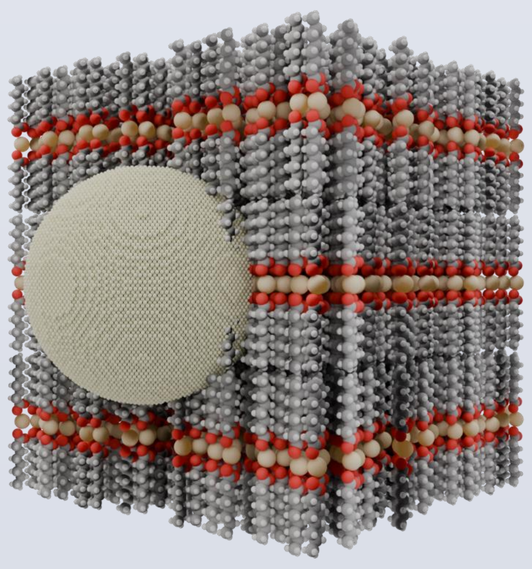


Fig. 3 Schematic illustration of CdC_8 matrix with CdS NPs

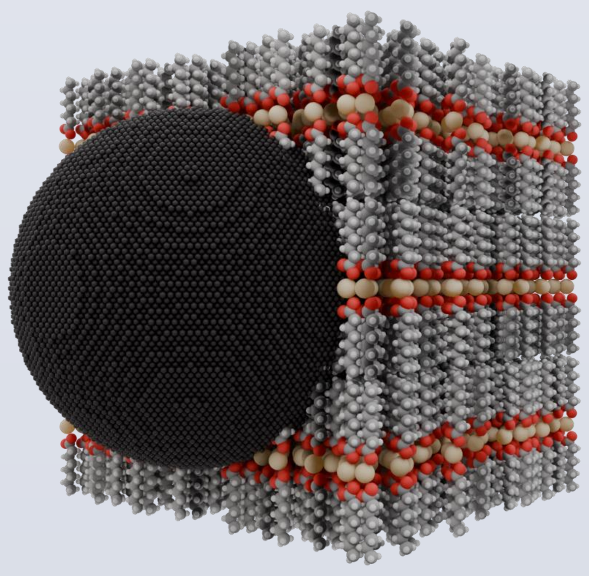


Fig. 4 Schematic illustration of CdC_8 matrix with C NPs

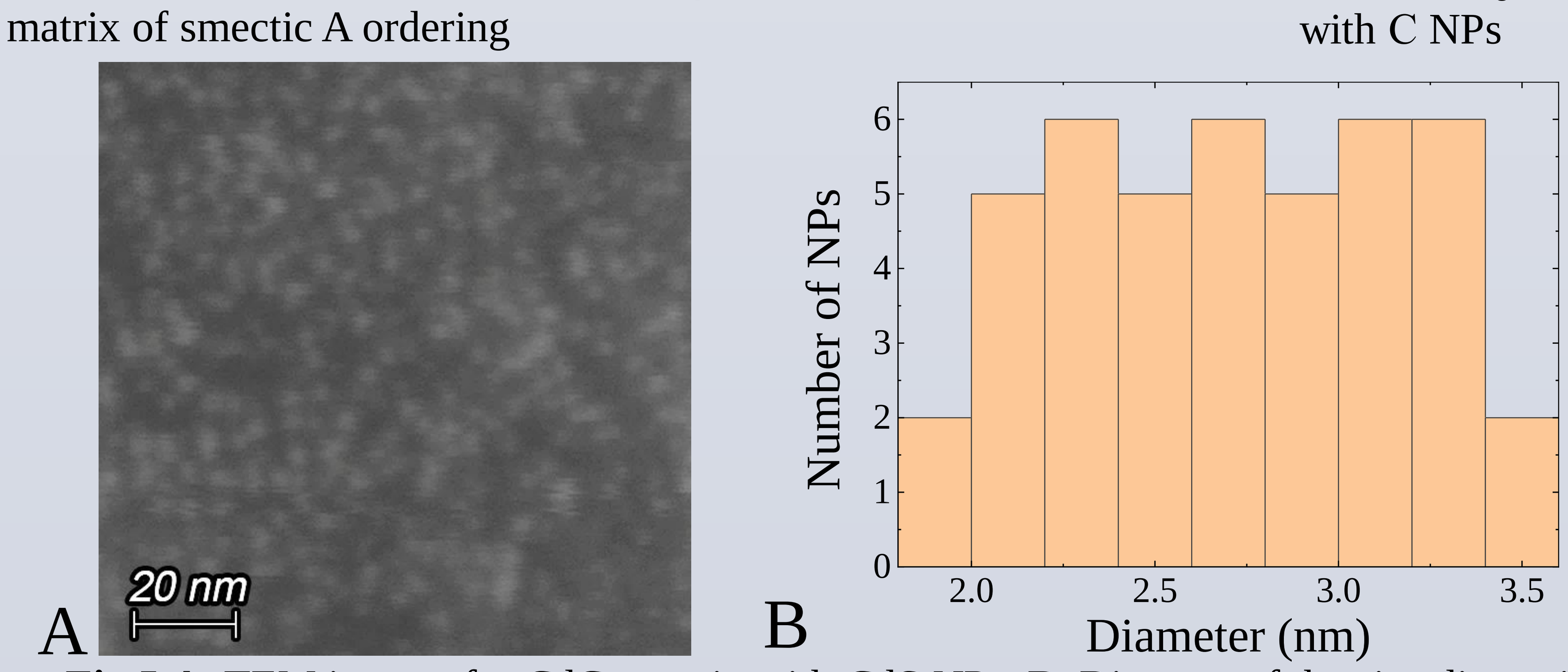


Fig.5 A. TEM images for CdC_8 matrix with CdS NPs. **B.** Diagram of the size dispersion calculated from the TEM image

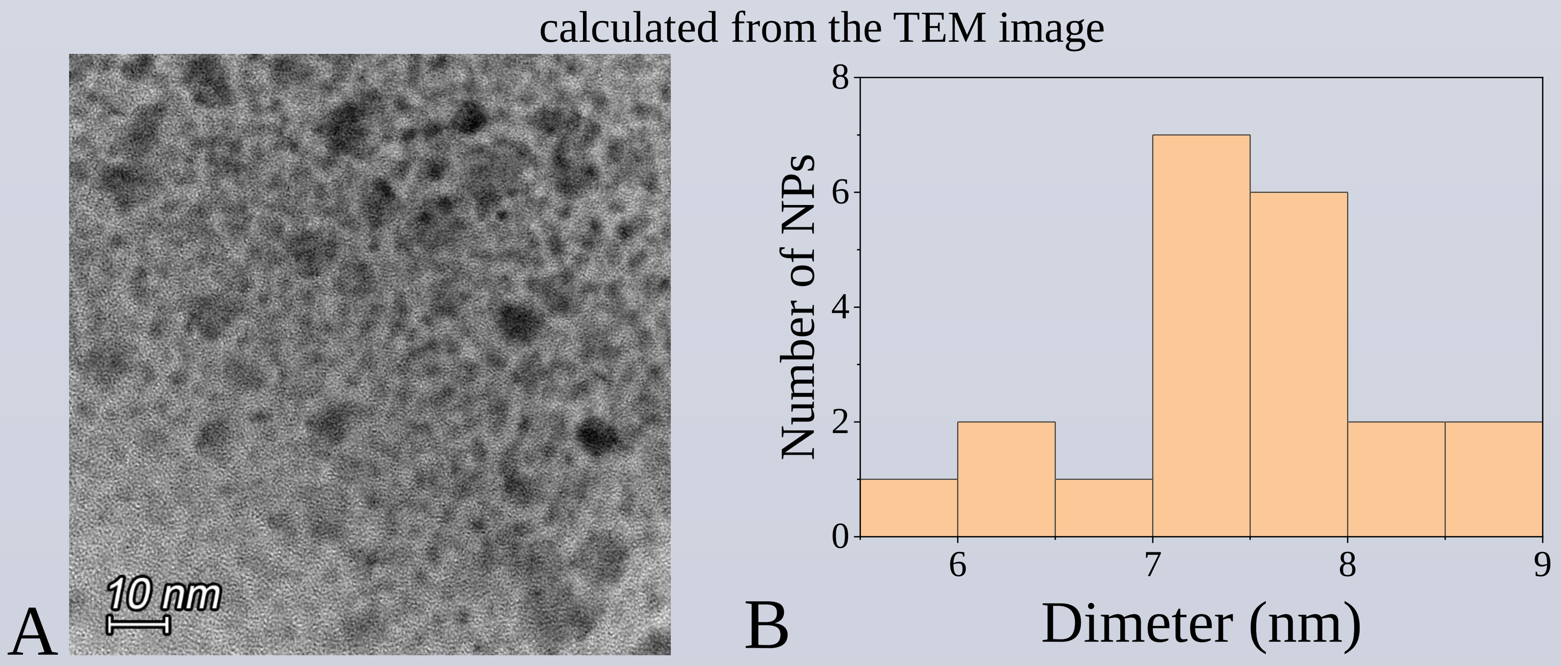


Fig.6 A. TEM images for CdC_8 matrix with C NPs. **B.** Diagram of the size dispersion calculated from the TEM image

Spectroscopy

Raman spectra revealing the molecular vibrations of the CdC_8 matrix shown in Fig. 7A. The optical spectra (Fig.7B) measured in UV and visible range revealed features of CdS and C NPs .

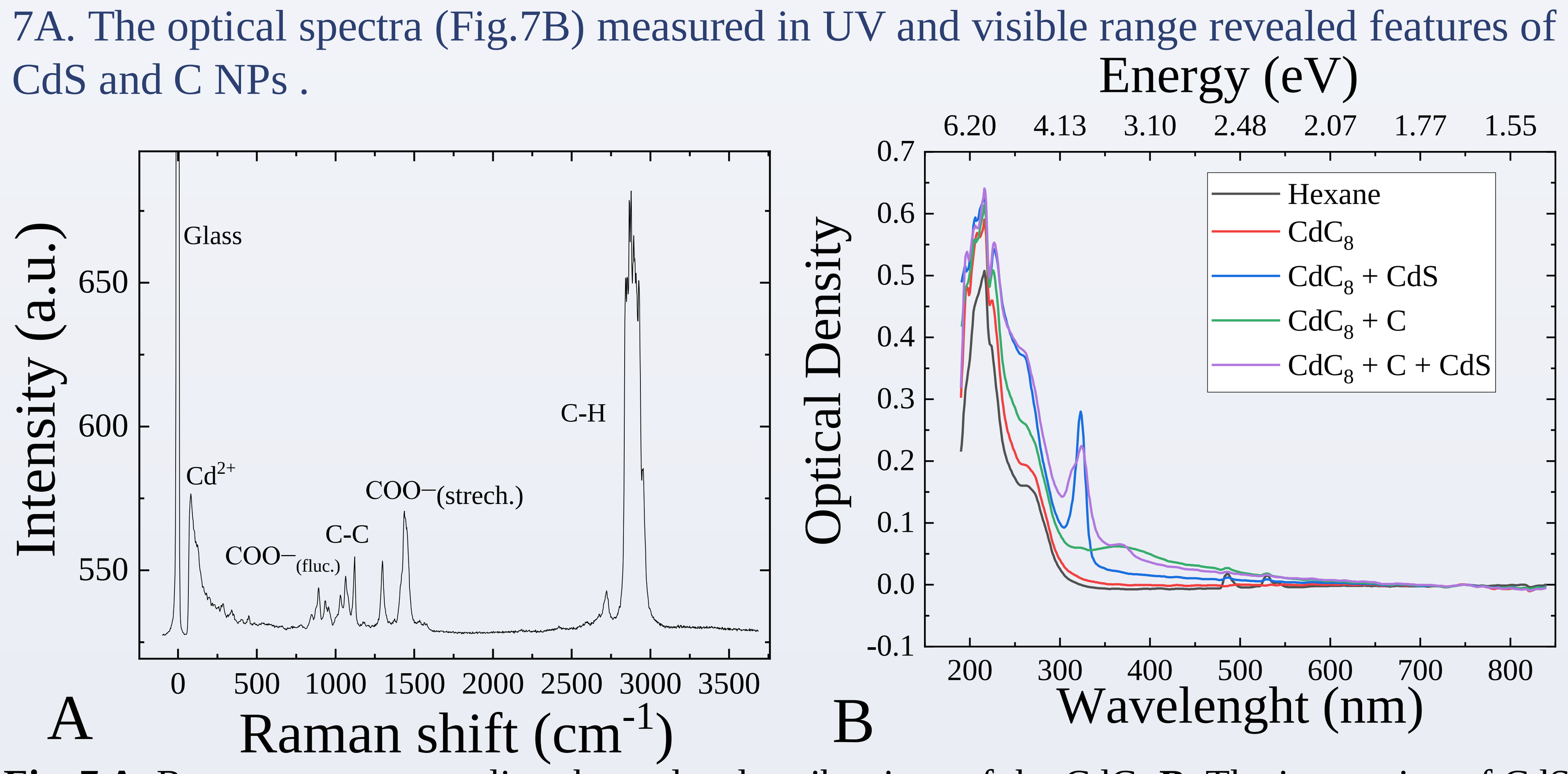


Fig. 7 A. Raman spectra revealing the molecular vibrations of the CdC_8 **B.** The interaction of CdS and C NPs with UV and visible light in hexane

The Brus equation (1) can be used to calculate the size of NPs using optical spectra data. Where $E_{gap\ NP}$ - band gap of NPs, $E_{gap\ B}$ - band gap of bulk material, R - the radius of NPs, h - Planck's constant, m_e - electron effective mass of NPs, m_h - hole effective mass of NPs. R can be found by the energy difference and the material factor NPs according to equation (2).

$$E_{gap_{NP}} = E_{gap_B} + \frac{h^2}{8R^2}\left(\frac{1}{m_{e*}} + \frac{1}{m_{h*}}\right) \quad (1)$$

$$R = \sqrt{\frac{h^2\left(\frac{1}{m_{e*}} + \frac{1}{m_{h*}}\right)}{8\,(E_{gap_{NP}} - E_{gap_B})}} \quad (2)$$

Theoretical calculations using the Brus equations allowed to estimate the size of CdS NPs to be about 2.8 nm and C NPs about 6.2 nm. These sizes are in good agreement with results obtained TEM image studies.

Photoelectric

Photoconductivity studies of the CdC_8 matrix are shown in Fig. 8 A and for the CdC_8 matrix with CdS NPs - in Fig. 8. B measured in a wide temperature range. The photocurrent exhibits nonlinear behavior in different mesophases of the nanocomposites. To explain the nonlinear current-voltage behavior, two types of near-electrode processes are considered, depending on the magnitude of the applied voltage.

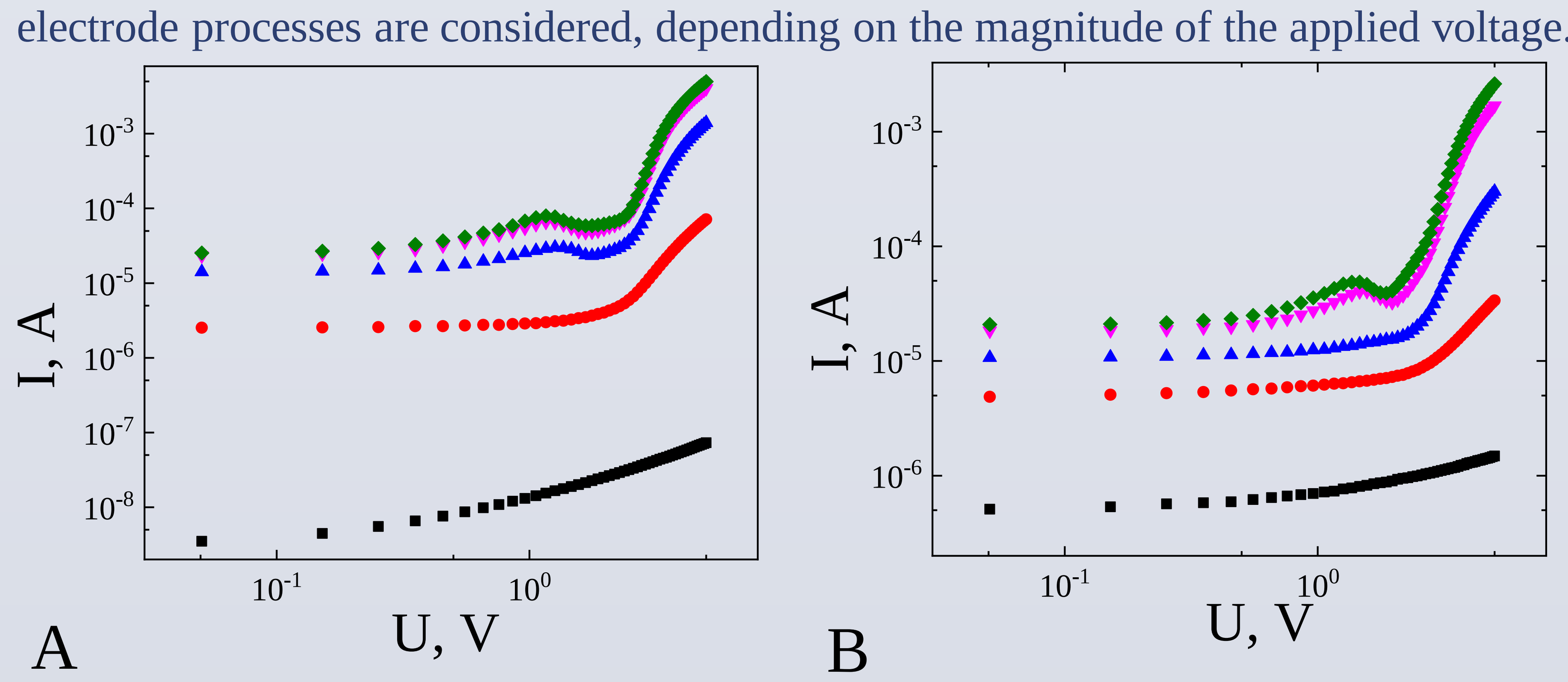


Fig. 8. Non-stationary I-V characterization using UV light **A.** CdC_8 matrix. **B.** CdC_8 matrix + CdS NPs at temperatures: 70 °C (black), 90 °C (red), 110 °C (blue), 130 °C (pink) and 150 °C (green).

Photovoltaic effects in CdC_8 matrix with 4 mol % CdS NPs (Fig. 9 A) and in CdC_8 with different concentrations of CdS NPs: 2 mol % and 4 mol % CdS (Fig. 9 B) was registered for the first time and studied as a function of temperature. The main mechanism of the photovoltaic effect can be related to the Dember effect, which appears due to the significant difference in the magnitude of the mobility of positive and negative charges (ions and electrons in our case).

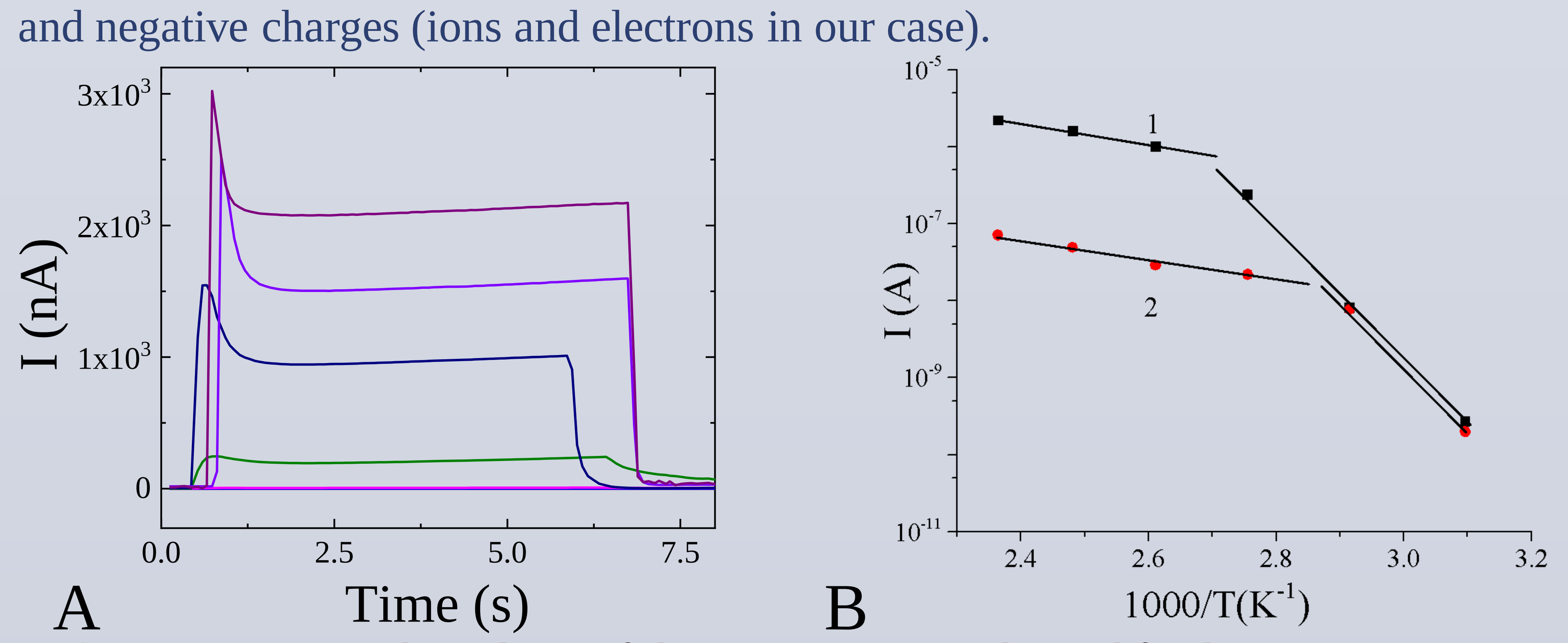


Fig. 9. Temperature dependence of short-circuit current obtained for the nanocomposite: **A.** CdC_8 + CdS 4 mol % CdS. **B.** CdC_8 with different concentration of CdS NPs: (1) 2 mol % CdS and (2) 4 mol % CdS.

Acknowledgements

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