Synthesis of carbon and gold nanoparticles in metal-alkanoate matrix: a study of structural properties and electrical behavior

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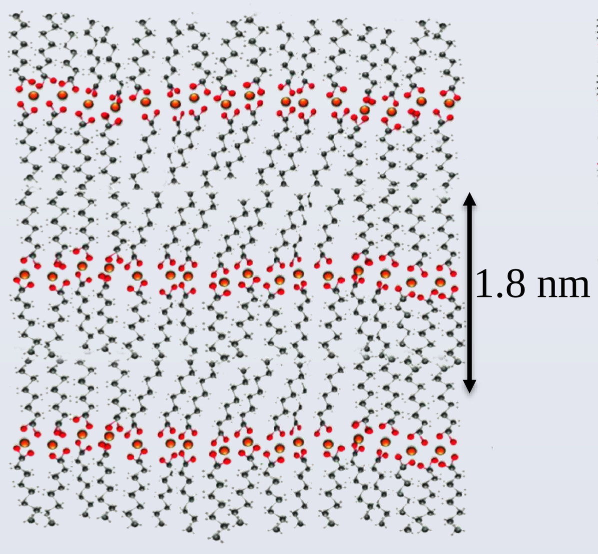
Abstract

The focus of this work is on studying the structural and electrical properties of ionic metal-alkanoate composites consisting of a cadmium octanoate matrix in combination with carbon and gold nanoparticles (NPs). Specifically, this NPs were chemically synthesized within the smectic A phase of $(Cd^{+2}(C_7H_{15}COO)^{-2}$, brief - CdC_8), which served as a well-ordered nanoreactor. The size and shape of the NPs were precisely controlled during the synthesis, resulting in highly stable and organized nanocomposites. The structural properties of these nanocomposites were studied using the transmission electron microscopy technique, which allows an understanding of the NPs locations and estimation of the sizes and dispersion of the synthesized NPs.

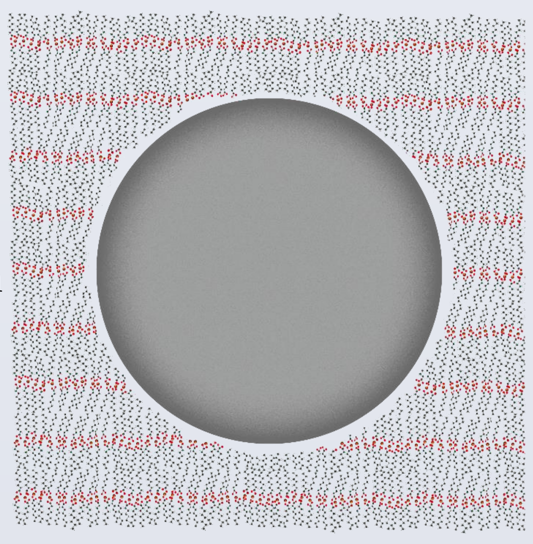
The electrical characteristics were studied at different temperatures corresponding to different phases of the material. We compared the electrical properties of both pure matrix and nanocomposites with gold and carbon nanoparticles to find out their role.

Materials preparation

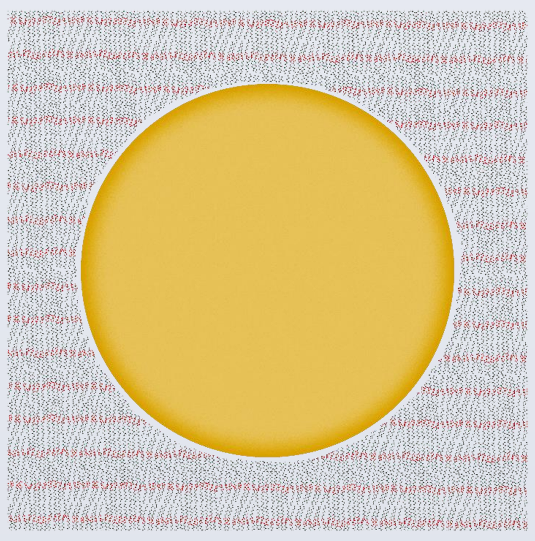
The metal-alkanoate nanocomposites are prepared on the base on the metal-alkanoates, namely either on the CdC_8. These materials exist in the form of polycrystalline powders at room temperature. When heating these powders to the temperature range 98 - 180°C, the metal alkanoates get the smectic A mesophase, where they can used as the nanoreactor for the chemical synthesis of C and Au NPs. A schematic representation of the sizes of C and Au NPs synthesized in a CdC_8 matrix with the preservation of scale is shown below.



Pure matrix CdC_8
layer size ≈ 1.8 nm



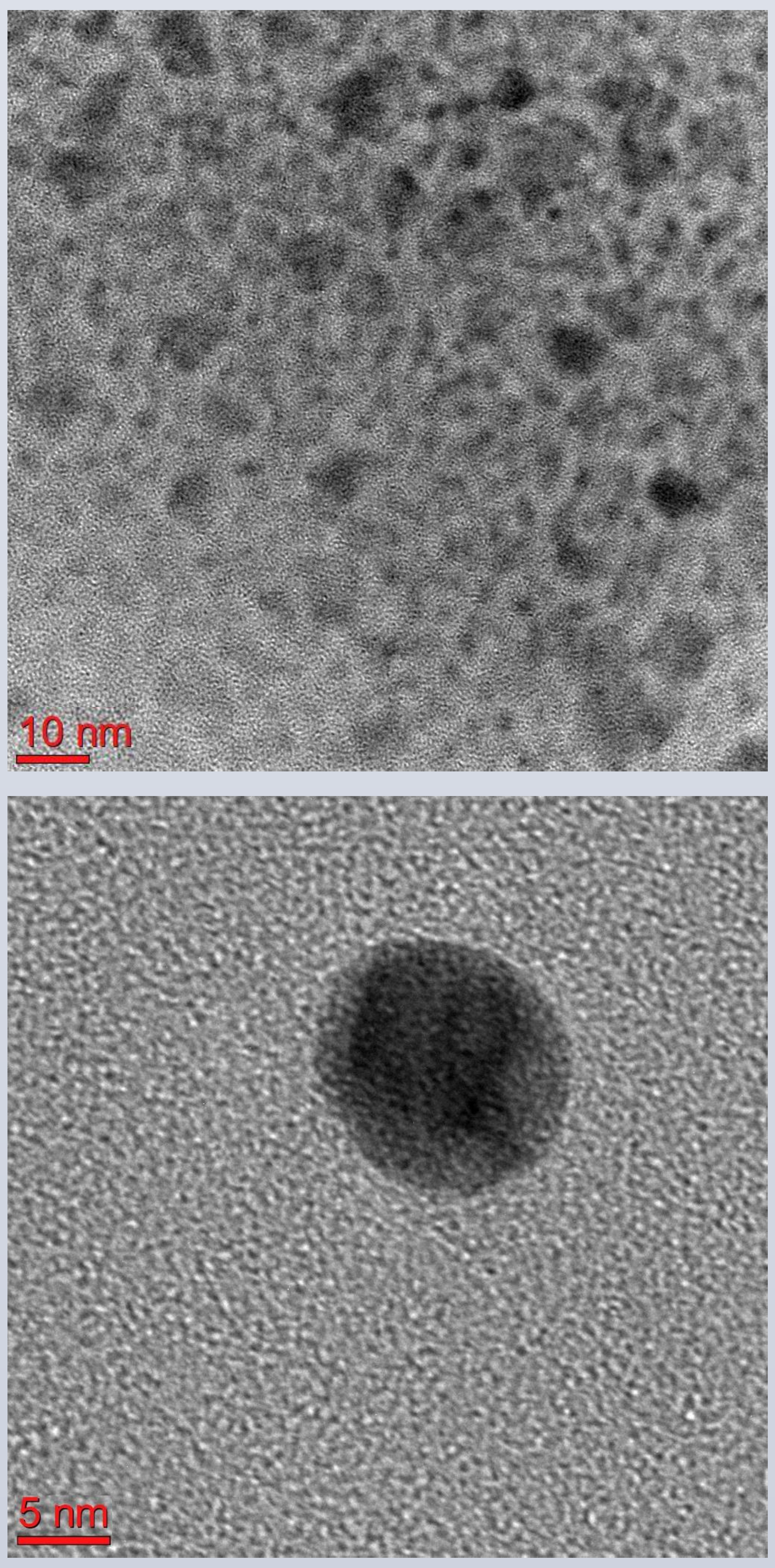
Matrix + CdC_8 C NPs
sizes of NPs ≈ 8-12 nm



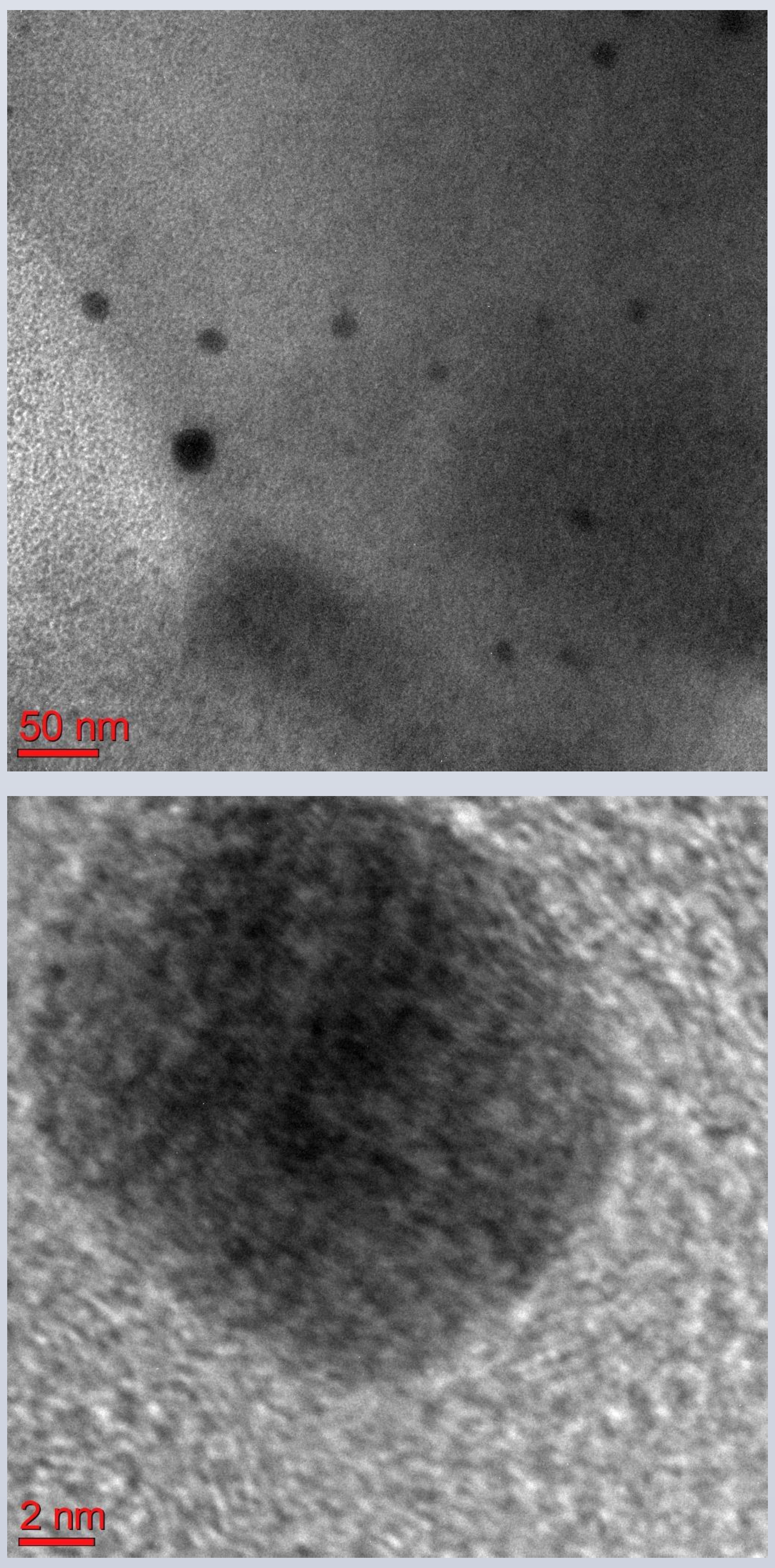
Matrix + CdC_8 Au NPs
sizes of NPs ≈ 20-25 nm

Structural properties

For a study of the sizes of C and Au NPs, we dissolved the nanocomposite CdC_8 + 2wt% C + 4mol% Au NPs in Hexane - C_6H_{14}, then dropped 1 µl of the obtained substance onto the top of the carbon film supported copper grid and let it dry. For imaging, we used the transmission electron microscope FEI Titan Tecnai G2 F20 which is equipped with a Gatan Tridiem 863P post column image filter (GIF) and a high angle energy dispersive X-ray (EDX) detector.



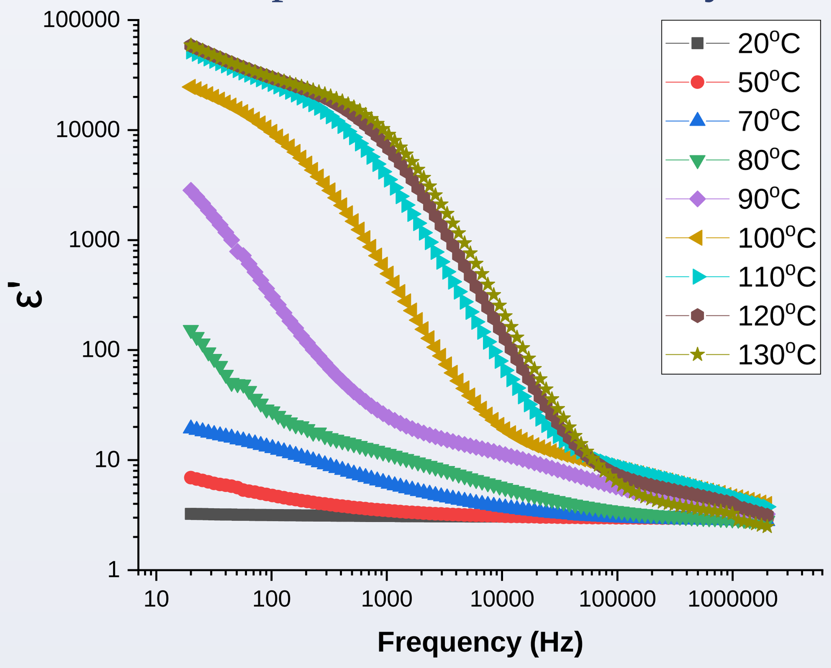
TEM images of CdC_8 C NPs
sizes of NPs ≈ 8-12 nm



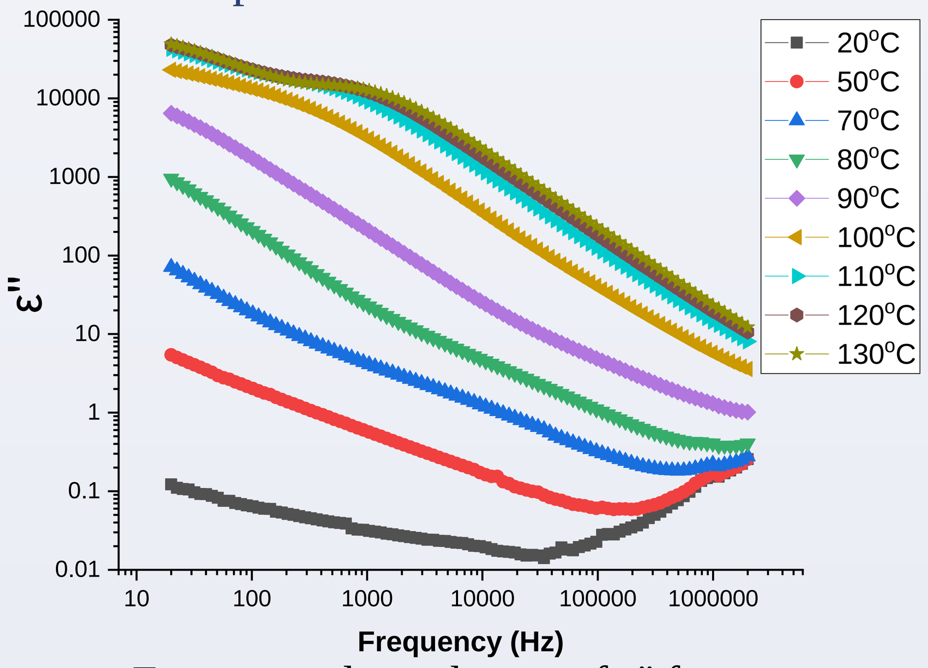
TEM images of CdC_8 Au NPs
sizes of NPs ≈ 8-12 nm

Dielectric properties

Frequency dependences of ε' and ε'' for the matrix CdC_8 from 20°C to 130°C. A significant dispersion of these values in dependence from 20 Hz to 2 MHz is observed at high temperatures. For the obtained results, it is 90°C and higher. Therefore, it was for these temperatures that the analysis of dielectric spectra was carried out.



Frequency dependences of ε' for a pure matrix CdC_8 on temperature and from 20 Hz to 2 MHz.



Frequency dependences of ε'' for a pure matrix CdC_8 on temperature and from 20 Hz to 2 MHz.

Cole-Cole plots were built and analyzed. The relaxation times, the thickness of the near-electrode layer in which the relaxation process occurs, and the value of α are determined and are shown in the tables below.

Pure matrix CdC_8

T, C	τ, c	l_W, нм	α
90	0,022	3,75	0,06
100	0,0030	2,52	0,12
110	0,00061	2,75	0,06
120	0,00039	2,43	0,06
130	0,00030	2,75	0,06

CdC_8 + 2wt% C

T, C	τ, c	l_W, нм	α
90	0,018	2,63	0,03
100	0,0020	3,50	0,03
110	0,00077	2,93	0,03
120	0,00030	1,62	0,06
130	0,00026	1,50	0,06

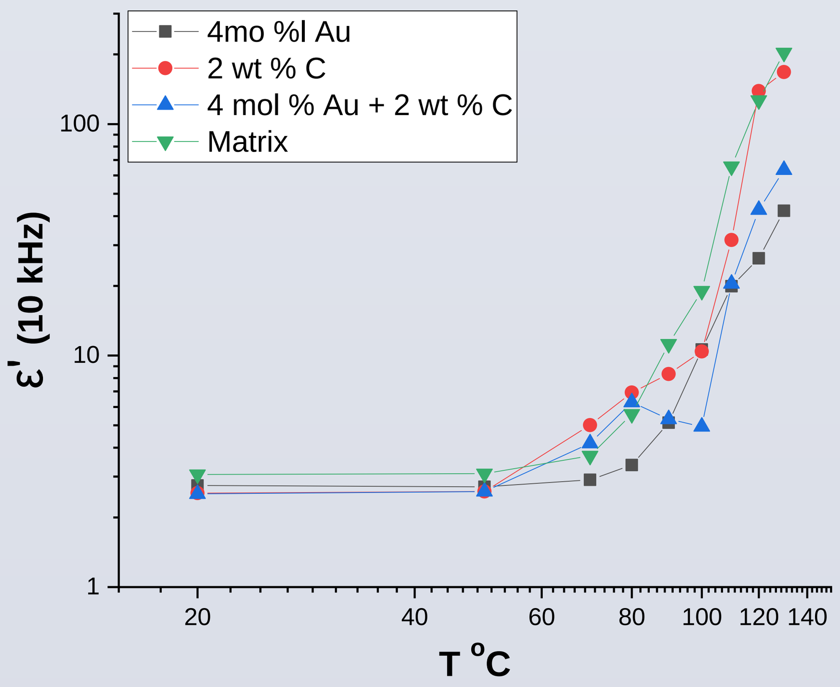
CdC_8 + 4mol% Au

T, C	τ, c	l_W, нм	α
90	0,039	8,3	0,03
100	0,028	3,4	0,06
110	0,019	3,05	0,06
120	0,010	3,04	0,06
130	0,0058	3,36	0,06

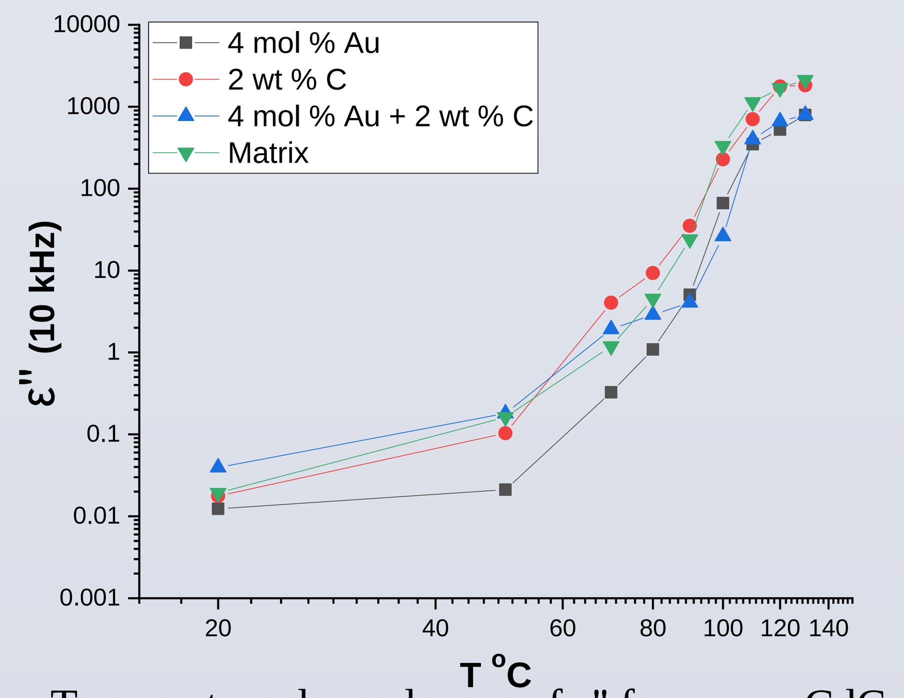
CdC_8 + 2wt% C + 4mol% Au

t, C	τ, c	l_W, нм	α
90	0,03	5,24	0,22
100	0,023	3,20	0,06
110	0,00044	4,77	0,06
120	0,00049	3,05	0,06
130	0,00052	2,4	0,06

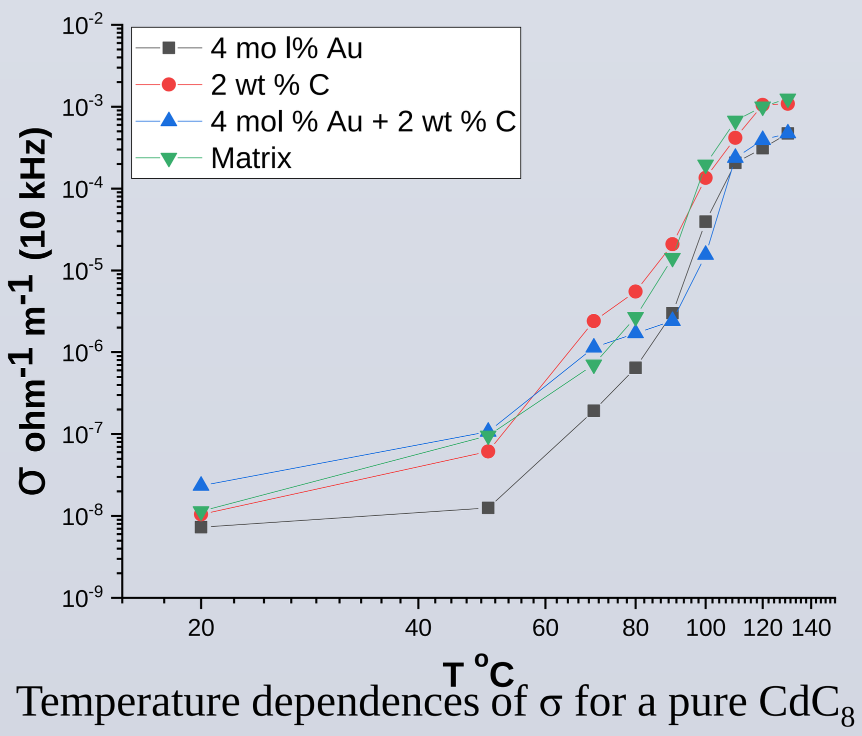
We compared ε', ε'', σ and tgδ for a pure CdC_8 matrix and with a matrix with synthesized nanoparticles (2wt% C), (4mol% Au) and (2wt% C + 4mol% Au) at a frequency of 10 kHz, where was no frequency dispersion.



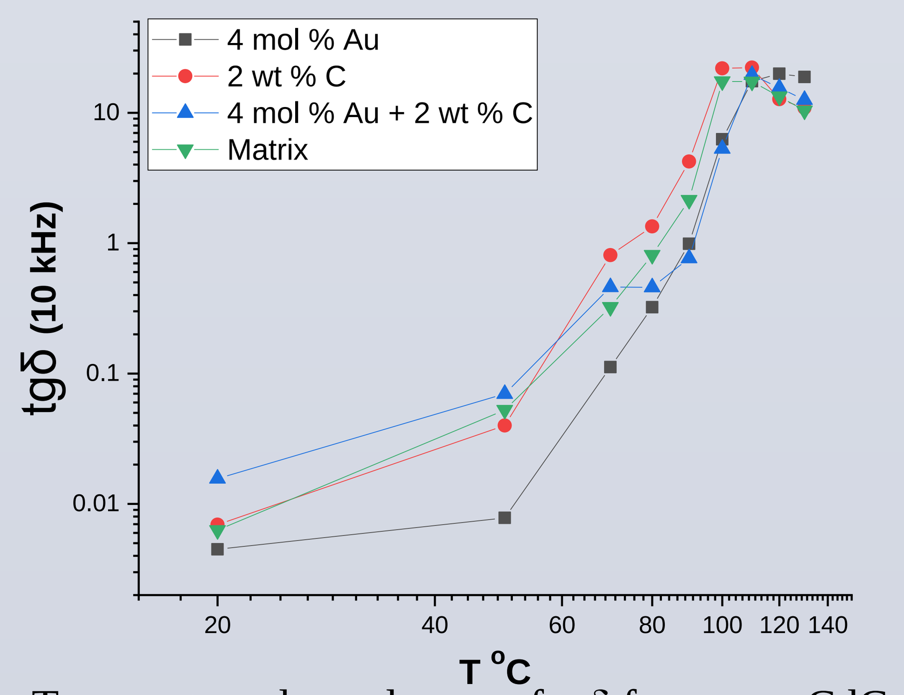
Temperature dependences of ε' for a pure CdC_8 matrix and a matrix with (2wt% C), (4mol% Au) and (2wt% C + 4mol% Au) at 10 kHz



Temperature dependences of ε'' for a pure CdC_8 matrix and a matrix with (2wt% C), (4mol% Au) and (2wt% C + 4mol% Au) at 10 kHz



Temperature dependences of σ for a pure CdC_8 matrix and a matrix with (2wt% C), (4mol% Au) and (2wt% C + 4mol% Au) at 10 kHz



Temperature dependences of tgδ for a pure CdC_8 matrix and a matrix with (2wt% C), (4mol% Au) and (2wt% C + 4mol% Au) at 10 kHz

Conclusions

Ionic liquid crystals based on metal-alkanoates are a promising class of glass-forming materials suitable for fabrication nanocomposites with various types of NPs. The size distribution and the average size of synthesized various types of NPs in CdC_8 were determined by TEM. The dielectric properties of ε', ε'', σ and tgδ were studied. The relaxation times, the thickness of the near-electrode layer in which the relaxation process occurs, and the value of α are determined. Metal-alkanoates with synthesized NPs have very interesting dielectric properties and are promising for use in electro-optical devices.