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STUDY OF THE PROCESS CRYOCAPTURE OF CARBON DIOXIDE MOLECULES BY SOLID WATER FILMS

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Abstract

To date, more than 140 different molecules have been identified in the interstellar medium. Dust particles were also discovered and some of these molecules were frozen at temperatures (10–20K) with the formation of molecular ice. Understanding the adsorption and desorption processes of these formed ices is critical to understanding the processes that lead to the formation of stars and planets. Highly sensitive surface sensing techniques, including temperature-programmed desorption and reflectance adsorption infrared spectroscopy, are increasingly used to study interactions between condensed objects. This kind of experimental data provides an understanding of the processes occurring in ice of astrophysical significant molecules from several surfaces of model cosmic surfaces.

The purpose of the research was to obtain experimental data on the processes of adsorption and thermal variation in thin films of cryocondensate of astrophysical significant molecules of substances. Research is aimed at understanding the mechanisms of adsorption and desorption on amorphous porous samples under conditions like those in outer space. Using the method of vacuum condensation of substances on cryogenic surfaces, experimental results of the structural transformation of films, their optical characteristics were obtained, and methodological recommendations for identification were developed. [1]

The fundamental knowledge obtained during the experiments has practical significance in the technologies and processes occurring on the low-temperature surfaces of cryogenic equipment of spacecraft. Thus, this article is devoted to the experimental study of the processes of adsorption and desorption of astrophysical significant molecules of substances formed on low-temperature surfaces of cryogenic vacuum equipment. Study of relaxation processes and thermally stimulated structural-phase transformations in samples condensed at low temperatures. The objects of research are cryocondensate of gases such as nitrogen, carbon monoxide, alcohol, water, and other substances whose condensation forms amorphous structures at low temperatures. The research results are aimed at establishing the relationship between condensation conditions (substrate temperature and gas phase pressure) and the properties of the resulting cryofilms, such as growth rate, optical characteristics and thermal adsorption.

Experimental setup

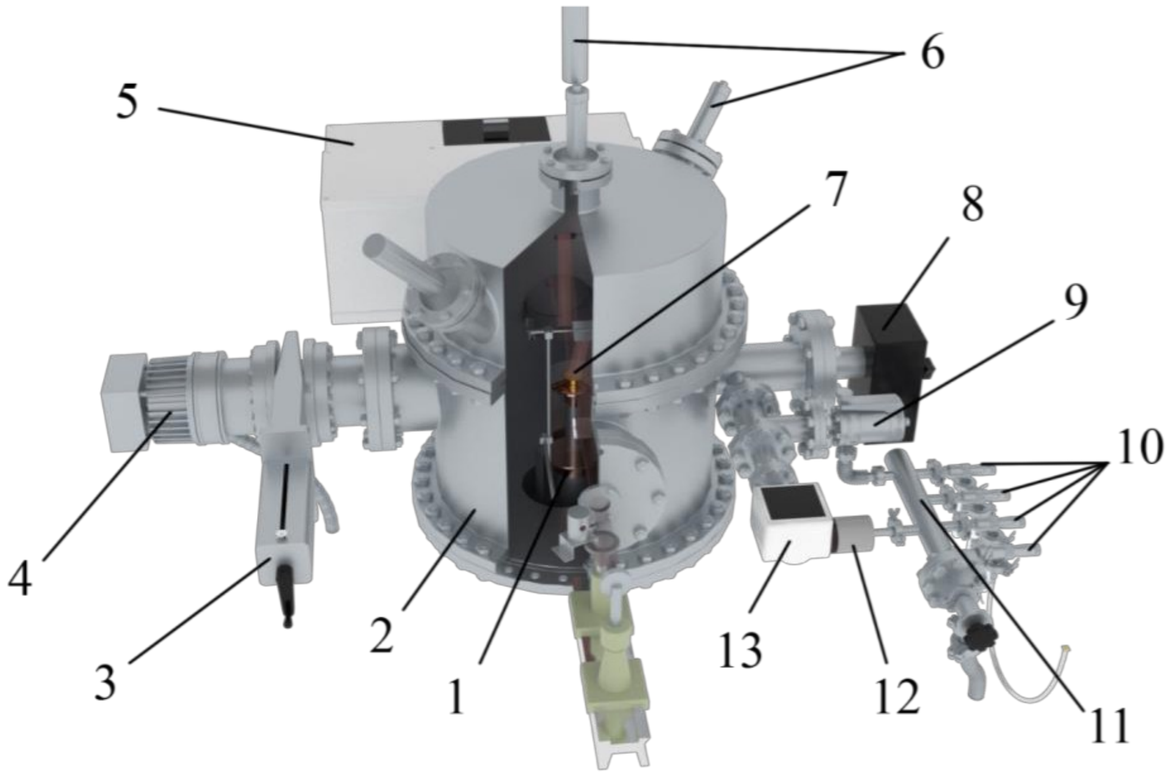

Figure 1. A three-dimensional model of the experimental setup

1 – refrigerator; 2 – vacuum chamber; 3 – sliding vane pump; 4 – turbomolecular pump; 5 – FTIR; 6 – double beam laser interferometer; 7 – substrate; 8 – mass spectrometer; 9 – high-precision leak valve; 10 – needle leak valve; 11 - sample preparation system; 12 – baratron; 13 – pressure sensor

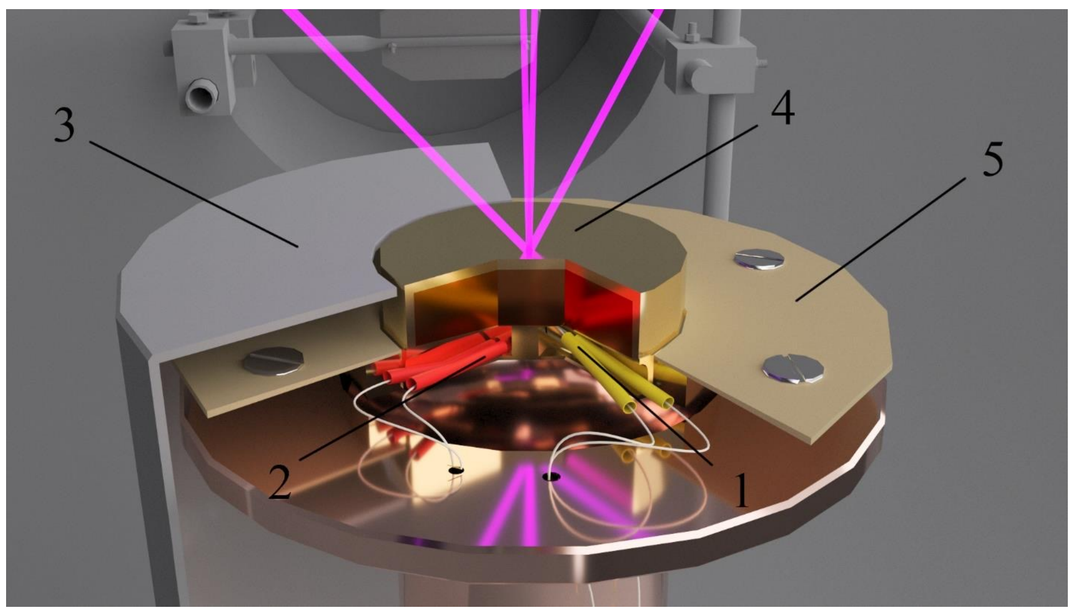

Figure 2. A three-dimensional model of a part of the setup near which the substrate is located

1 – heating element; 2 – thermal sensor; 3- protective cover; 4 – gold-coated substrate; 5 – pressure ring

Experimental results

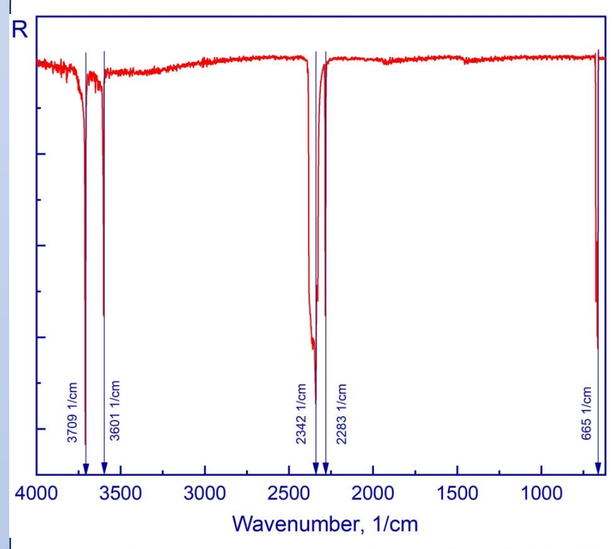

Figure 3. A spectrum of a solid CO2 film deposited at 15 K in the mid-IR range

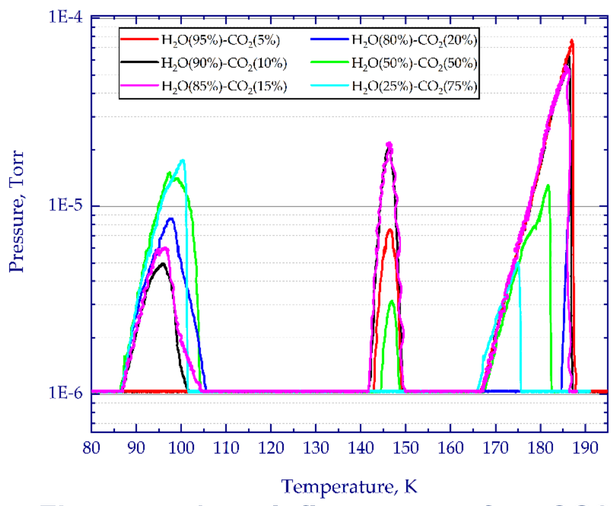

Figure 4. Influence of CO2 concentration on the quantitative composition of the possible clathrate structures in the film

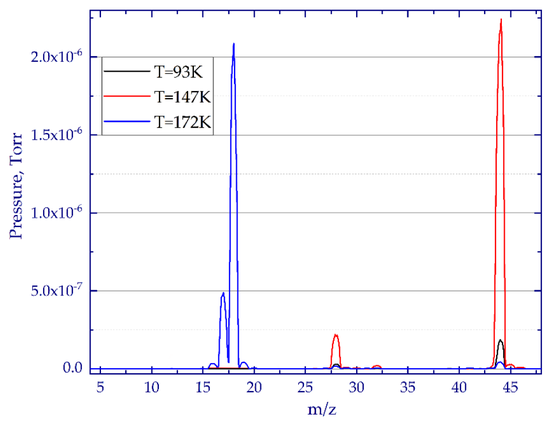

Figure 5. Mass spectra of the condensation mixture of water and CO2

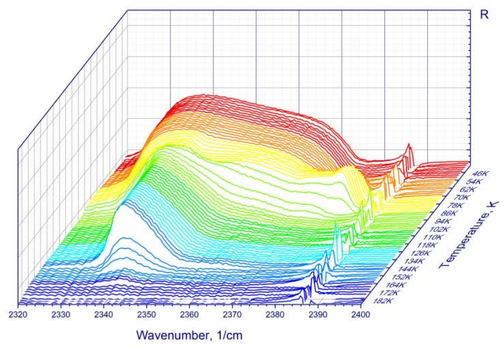

Figure 6. Temperature evolution of the v3 vibrational mode of CO2

Conclusion

The formation of the clathrate hydrate structures of CO2 molecules mixed with the H2O molecules, obtained using PVD, was investigated in this research. Two methods of analysis were used to achieve greater accuracy: mass spectroscopy and FTIR spectroscopy.

The data obtained suggest the presence of CO2 hydrates in the mixtures under study. Moreover, drawing an analogy with other works, the formation of sI-type hydrates is hypothesised. This is indicated by the IR spectra. Detection of a temperature that is not typical for the sublimation of CO2 may also indicate the formation of clathrate structures holding carbon dioxide in the spherically organised water structures. The increase in refractive indices when water concentration approaches 25% compared with the other concentrations also indicates the growth of the structures less dense than the amorphous carbon dioxide condensates or amorphous water ice. This interesting pattern is evident in other clathrate-forming mixtures, which arouses interest in the detailed calculation of this phenomenon for such structures.

Of course, the rate and characteristics of the formation and decomposition of carbon dioxide hydrates require extensive additional research. Currently, there is not enough data on the physical characteristics of their structure and the influence of the formation parameters on these characteristics. That is why it is important to carry out more experiments related to condensation and different methods of obtaining carbon dioxide clathrates. In addition, the identified spectra are useful for the detection of CO2 hydrates and clathrates on celestial objects.

Reference

[1] Golikov, O., Yerezhep, D., Akylbayeva, A. et al. Cryovacuum setup for optical studies of astrophysical ice. - 2023- Sci Rep 13, 21155 https://doi.org/10.1038/s41598-023-48541-3