# USE OF LASER SYSTEMS TO STUDY VARIATIONS IN THE DISPERSE COMPOSITION OF HETEROGENEOUS PLASMA FLOWS

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*We present some results of the experimental investigation of the disperse phase of a chemically active plasma. In this study we managed to acquire data on aerosol microstructure as a function of height in the flames from burning different pyrotechnic compositions.*

The disperse composition of a condensed phase (CPh) produces an essential effect on the optical radiation transfer, distribution of charges over the plasma volume, on the charge mobility, as well as on the chemical processes in a chemically active plasma. In this connection, it is important to know, when developing laser pump sources that use optical radiation yielding from chemical reactions in a combustion plasma of burning pyrotechnic compounds (PTC), the disperse composition of the condensed phase. When using the energy of aluminum and magnesium oxidizing, most suitable for diagnostics are optical methods since they provide for a contactless analysis without sampling to be performed in real time. The methods of diagnostics that are based on sampling have a significant error because of high temperature and chemical conversions that may occur within the plasma volume.

To make the diagnostics of the CPh disperse composition in the plasma of burning PTC we have arranged an experimental set-up that includes a plasma generator (PG), an optical system for collecting and transmitting scattered radiation, sources of sounding radiation, a data acquisition system for measuring and storing the data on the intensity of radiation scattered at different angles. The plasma generator is assembled from two coaxial cylinders mounted on a horizontal support that may be moved vertically. The inner cylinder of the PG served as a support for a PTC sample, while the outer one for forming a directed plasma flow.

The optical system for collecting the scattered radiation was made from a group of optical waveguides mounted on holders that were tough mounted on the working table. In front of each waveguide we placed a diaphragm of 0.5 mm in diameter and a microlens with the $f/D$ ratio of 2:1. Besides, we could insert there a band, gray, or an interference filter (at low light intensity). In this optical arrangement we can measure the values of scattering phase function, at the scattering angles within the ranges from 0.5 to 2.5, 5 to 175, and 177.5 to 180 degrees. Besides, we measure the optical density of plasma at the emission lines of argon-ion, He–Ne, and neodymium lasers. The small-angle scattering light flux from the volume under study is collected with a lens of 1 m focal length that focuses it onto a linear array of optical waveguides. To measure full scattering phase function we use an array of optical waveguides whose input ends are placed along an arc of a circle with the radius of 250 mm. The radiation scattered by the volume backwards is separated from the incident radiation with a dividing plate and then it is focused with a lens of 150 mm focal length onto a linear array of optical waveguides. To measure the transmission spectra we direct laser beams to the volume studied so that they intersect at small angles in it. Then, after passing 3 to 4 meters, each beam is focused by a corresponding lens of 50 mm focal length onto a 1-mm-diameter diaphragm behind which there is installed an optical waveguide.

The input ends of all the waveguide arrays are mounted in one plane. The output ends of the optical waveguides are coupled with FD–10G photodiodes. Electrical signals from the photodiodes are proportional to the intensity of corresponding light fluxes. These signals are finally stored in a RAM. The data acquisition system provides for simultaneously memorizing 16 input signals, during $15 \pm 2.5$ ns interval, which are then digitized in a succession at a rate of 4 kHz.

The whole set of data acquisition and storage units are packed in a metal housing that protects this equipment against the electromagnetic interference. The accuracy of measuring the light fluxes has been assessed from calibration experiments with isotropically emitting sources placed in the volume to be studied. Thus estimated measurement accuracy was found to be better than 3.5% in all measurement channels. The account for other irregular influences like, for instance, random fluctuations of the flame position and light noise occurring in the waveguides at high intensity of radiation gave the total experimental error to be on the order of 15 to 20%.

In the experiments we have studied the PTC samples that contained magnesium (up to 30%), aluminum (up to 20%), and admixtures of nitrates of alkali and alkali-earth metals. The samples had a cylinder shape of 20 mm diameter and 70 mm height.

The data recording starts at the moment of PTC inflammation, that is when a plasma flow develops. The rate of data recording has been set depending on the intensity of burning and synchronously with the shots of an ILTI–406 Nd:YAG laser. When storing 64

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readouts the RAM stops the recording process. After that, the data stored in the memory may be looked through on the screen of an oscilloscope either in the frame by frame mode or in the regime of motion picture. The frames selected as informative may then be printed out and/or plotted.

Using this experimental set-up we have managed to measure the small-angle scattering phase function, full scattering phase function, the backscattering phase function, as well as absorption spectra of plasma in different cross-sections along the flame axis. The absorption spectra recorded have the view described by both ascending and descending, with increasing wavelength, curves in the spectral region studied. The optical density of the aerosol flow observed reached the values up to 3, depending on composition of a PTC sample studied. Among a wide variety of the scattering phase function shapes that were observed in the experiments we would separate out three most typical ones. Those are a dumbbell-shaped scattering phase function with the large axis along the beam and showing the minimum in scattering at 110 to 140 degrees angles, a pear-shaped one showing enhanced scattering into the backward hemisphere, and, finally, a camomile-shaped scattering phase function comprising many peaks and valleys with up to tenfold intensity jumps on the angular intervals as narrow as 10 to 20 degrees. These typical scattering phase function shapes that correspond to different compositions of the PTC samples studied are depicted in Fig. 1. As it follows from the experiments burning of each sample of one and the same composition exhibits certain individual features, what is confirmed by the time behavior of the flame optical density. So, the parameters measured experimentally for a series of samples of one and the same composition will fluctuate about some average value. In the experiments we have noticed a correlation between the flame optical density and its brightness. The velocity of the combustion products outflow was 5 to 15 m/s in the free burning mode and showed a dependence on the amount of gaseous products and modal size of the condensed phase.

When processing the experimental data we have used a “SpektrB software package developed in the IAO SB RAS and a “RestSizeB program developed in TPU. These computer codes use some regularizing algorithms. Since we have no any *a priori* information on the complex refractive index of plasma we were forced to optimize our computations relative this parameter. In our simulations we have varied the real part of the refractive index from 1.5 to 2, while the imaginary one from 0.01 to 0.5. By solving certain test tasks we have established that “SpektrB package is able to reconstruct the position of modes in a bimodal size spectrum and to estimate the ratio between the mode amplitudes.

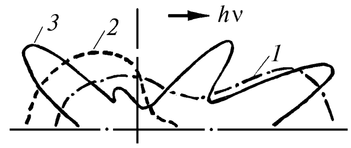


*FIG. 1. Typical scattering phase functions: dumbbell-shaped (curve 1); pear-shaped (curve 2); and camomile-shaped scattering phase function (curve 3).*

Figure 2 presents typical behavior of the modal radii along the flame axis. It is important that about 60 to 70% experimental points are being grouped about the mean curve. Dashed curves in this figure show the range within which lie all values of the size in the corresponding cross section. The ratio of the range widths at the flame origin and at its far end, as well as the behavior of the modal radii and the range widths themselves depend on the PTC sample composition. For the compositions tested in this experiments the modal radii varied from 0.1 to 0.8 and from 5 to 20 microns, respectively.

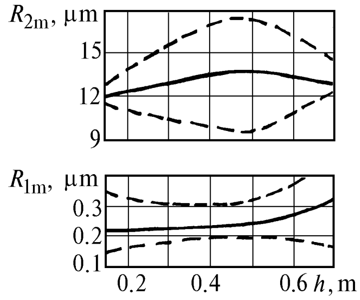


*FIG. 2. Modal radii of aerosol particles as functions of height along the flame axis.*

In the middle part of the flame, where the chemical reactions are most intense, the range of size observed widens by 4 to 10 times as compared to the initial one. The variation in the size distribution width, that is a decrease or increase in the distance between the modes with increasing height above the PTC sample surface well correlate with the PTC composition.