SPATIAL AND SPECTRAL STRUCTURE OF A PLASMA PLUME INDUCED BY THE MULTIPULSE LASER EVAPORATION OF THE MATERIAL

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UDC 553.1

The results of experimental investigations of the spatial and spectral structures of a plasma plume formed under the influence of nanosecond laser pulses with energies from 10 to 20 mJ on the material are presented. It is shown that most advantageous for the emissive analysis is the multipulse influence with a periodicity of 10÷12 μs on a sample. In this case, the informative component of the plume is most isolated in space from the noise component, and the useful signal becomes stronger due to the accumulation of a periodically incoming identical information. With regard for both the indicated factors, we have succeeded to increase the signal-to-noise ratio in real measurements approximately by an order.

One of the most promising directions in the modern spectroscopy is the laser-induced emissive analysis of materials, which combines the rapidity of spectral measurements with the slightly destructive character of a local light influence on the material. The principal reason impeding a broad application of this method in practice is the difficulty of quantitative analysis of low-alloyed components. The problem arose first of all because of the presence of a noise component in the registered spectra that is the luminescence of gases on the front of a blast wave that is created by the explosive process of optical disruption of the atmosphere close to the sample surface. Because of this, the signal-to-noise ratio really achievable by this method turns out to be substantially decreased.

Among the methods that were proposed by different authors to overcome the indicated difficulty, the most constructive are regarded the surrounding of the sample with artificially rarefied atmosphere [1], the additional excitation of the plasma of an evaporated material by an additional electric discharge [2], or the application of registration systems with high temporal resolution [3]. However, all of them are based on a substantial technical complication of measuring-recording system, which inevitably results in an overall rise in the price of a device.

A substantially more economical solution was proposed in [4], where it was shown that a substantial improvement of the "signal-to-noise" ratio can be obtained passing on to the multipulse mode of influence on the material. In this case, the best results are obtained with the sequence period of nanosecond pulses equal to 10÷12 μs. The last is to be explained by particularities of the dynamics of formation of the plasma plume, where the plasma density for the indicated time reaches its upper value [5], and also by the optimal influence of each pulse on absorption conditions for the subsequent one [6, 7].

The present work is a logic continuation of the indicated researches. Its objective is a more detailed investigation of the correlation between spatial and spectral structures of the evaporated material plume.

We used the same experimental setup that was described in [4] with the only difference, which was a passive Q-modulator in the form of the BND-dye introduced in the polymeric matrix. During the action of one pumping pulse, it ensures the generation from one to 20 light pulses with energy of 10 or 20 mJ with a duration from 10 to 15 ns and with a sequence period from 10 to 30 μs at the pumping energy variation from the threshold value to that higher by a factor of 5. Measurements related to a variation in the number of radiation pulses were performed at the same exposure dose of the material. In this case, with a change of the number of pulses within one generation train, the

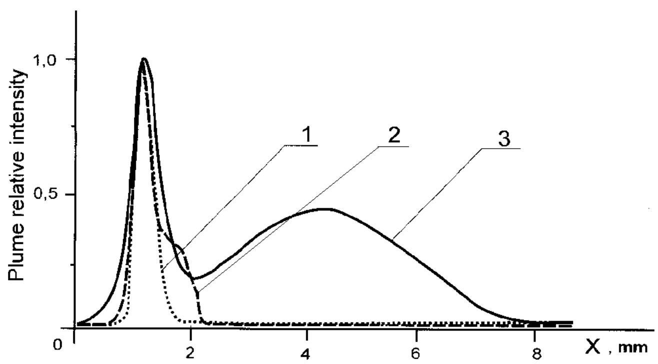

Fig.1. Spatial distribution of the plume intensity in the area of a line of Cu (448 nm) depending on the sequence period of laser pulses T: *1* — monopulse, *2* — $T = 30$ μs (two pulses), *3* — $T = 10 \div 12\,\mu$s (multipulse operation)

equalization of the cumulative exposure dose was achieved by means of a corresponding change of the number of trains themselves.

For the study of spectral characteristics, we used a spectrograph DFS-452 with a photovoltaic device on the basis of a linear CCD-array (1024 pixels sized 12 × 500 μm). The spectral band of observation was chosen by a perpendicular position of this array to the entrance slit of the spectrograph. To study the spatial structure of the plume, the CCD-array was oriented parallel to this slit. In this case, the adjustment on a separate spectral line or a necessary part of the spectrum was achieved by means of a small translating shift of the array along the focal surface of the spectrograph. All measurements were performed under normal atmospheric conditions.

Let us note that, by the parallel variant of orientation of the CCD-receiver, plume, and slit of the spectrograph, the precision of measurements was decreased because of an artificial exaggeration of the role of the noise component of radiation by the array. Actually, the spectral line under the study is registered in this case by a relatively small area of every pixel sized about 12 × 50 μm (where 50 μm is the entrance slit width of the spectrograph). At the same time, the background signal with a continuous spectrum overlaps surely the whole aperture of this pixel (12 × 500 μm). The obvious nonequivalence in the use of the surface of the light-sensitive element for the registration of a useful component and a noise one is equivalent to the application of different receivers for this purpose that differ one from another by sensitivity.

Measurements have confirmed the earlier noticed fact of a preferential localization of radiation with a bright-line spectrum containing the useful information in the upper part of a plume and the noise luminescence with a continuous spectrum in the lower part. The spatial distribution of the plume intensity for different variants of laser influence on the material is demonstrated by Fig.1, where the varied parameter is the time between of laser pulses. The axis of the plume corresponds here to the horizontal axis X, the distance along which characterizes the remoteness of the luminescence area from the sample surface.

As we can see, the biggest intensity of the noise component of plasma corresponds to the monopulse influence on the material, when the spatial distribution of this component practically coincides with the general plasma configuration. The situation changes qualitatively already by the two-pulse mode of influence, when we observe the distinct spatial isolation of the noise luminescence with a continuous spectrum from the radiation with a bright-line spectrum carrying the useful information. In this case, in the upper part of the plume, a large zone (from one third to a half of the total height) free of noise illumination and suitable for an effective reading of the useful information is released.

As explained in [4], such an abrupt weakening of the influence of the noise component is conditioned by a considerable decrease of the atmospheric pressure in the plume formation area. The fact is that the appearance of the plume is preceded practically always by the optic disruption of air near the sample surface. As a result, the local density of the atmosphere drops approximately by two orders (the effect of "burning out" of air [8]). In this case, the recovery of the initial density needs the time of about 100 μs. Thus, the influence of the first and subsequent pulses on the sample occurs in our case under an essentially decreased air pressure responsible for the background radiation.

The indicated evolution of the plasma luminescence is also confirmed by measurements of the degree of overlapping its useful component and the noise one along the torch axis (Fig.2). As a useful spectrum component, the copper line with a center at a wave length of 448 nm was chosen, and the registration of the noise component was performed by tuning the receiver beyond this line. For this method of observation, the plume part remote from the sample with transition to the two-pulse mode turns out to be cleared of noise illumination. At the same time, as seen from two last shots in Fig.2, the subsequent increase of the number of pulses does not almost influence the plume structure.

The transition to the multipulse variant of influence on the sample is justified for another reason. In this case, one more important factor intervenes: the amplitude of the useful signal begins to increase owing to the multiple

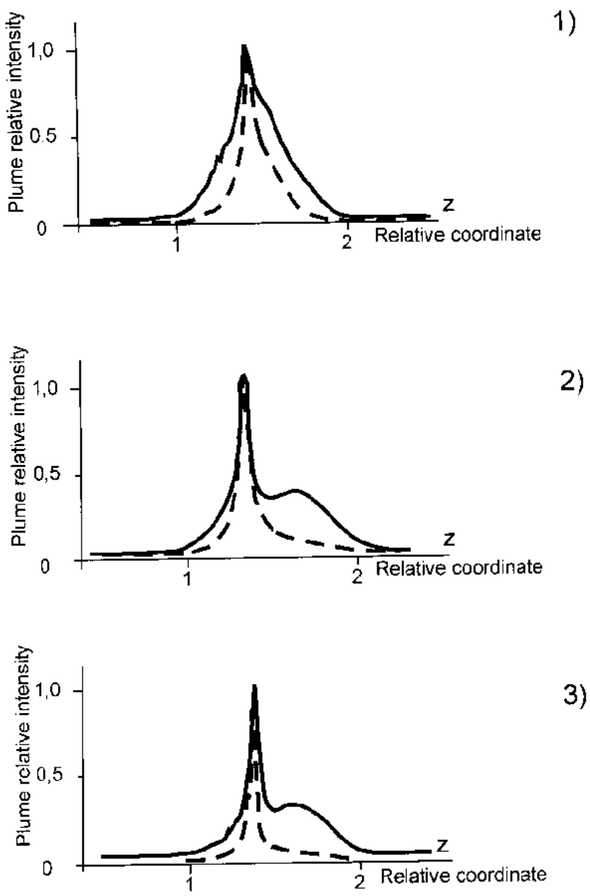

Fig.2. Distribution of the intensities of a separate line of Cu (448 nm) and the noise radiation (dotted line) along the plume axis depending on the same sequence period of laser pulses T as in Fig. 1

repetition of the measurement process and the subsequent accumulation of the same periodically incoming information by the recording system. The given circumstance allows one not only to improve the signal-to-noise ratio approximately by an order, but also opens qualitatively new possibilities for the detection of weak spectral lines.

Thus, the advantage of the multipulse method of influence on the material is reached by a combined action of two favorable factors: a general decrease of the noise radiation component and an increase of the amplitude of the useful signal owing to the repetition of the measurement process. Under these conditions, the plume peak is most advantageous for the analysis. Its natural remoteness from the sample surface essentially simplifies the registration of a useful signal and makes the protection of used optic elements from the influence of evaporated components to be easier.

Let us notice that, under equal conditions of the laser-induced evaporation of the material, the plume generated on the use of an iron sample, significantly exceeds, by its size, the plume from a copper sample. This result is a consequence of different thermal conductivities of the indicated materials, i.e. of different velocities of thermal relaxation of the incoming luminous energy initiating the blasting evaporation of the irradiated area. The dependence of the plume size on the type of a used material is one more real factor which must be considered in the design of a laser spectrometer, in particular in the development of a system of automated recording of light signals.

The authors express their deep gratitude to V.I. Bezrodny for providing with high-quality Q-modulators.

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Received 19.08.03

ПРОСТОРОВА І СПЕКТРАЛЬНА СТРУКТУРА ПЛАЗМОВОГО ФАКЕЛА ПРИ БАГАТОІМПУЛЬСНОМУ ЛАЗЕРНОМУ ВИПАРОВУВАННІ МАТЕРІАЛУ

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Р е з ю м е

Наведено результати експериментального дослідження просторової і спектральної структури плазмового факела, що утворюється при дії на матеріал наносекундних лазерних імпульсів потужністю від 10 до 20 мДж. Показано, що найсприятливішим для емісійного аналізу є багатоімпульсний режим впливу з періодичністю 10÷12 мкс. У цьому випадку інформативна складова факела є найбільш відокремленою в просторі від шумового компонента, а корисний сигнал підсилюється завдяки нагромадженню однотипної інформації, яка надходить періодично. З використанням обох зазначених факторів співвідношення сигнал/шум у реальних вимірюваннях вдалося підвищити приблизно на порядок.