**OPTICAL INSTRUMENTATION**

**Filamentation Length of High-Power Sharply Focused Femtosecond Laser Radiation in Air. Effect of Light Beam Size**

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**Abstract**—The results of laboratory experiments on measurements of the length and position of the filamentation zone of femtosecond GW laser radiation at wavelengths of 800 and 400 nm propagating in air under conditions of sharp external focusing are presented. Dependencies of the length of the radiation filamentation zone on its initial radius and power are studied. Qualitatively new regularity is obtained, which consists in invariance of the observed length of the beam filamentation under variations in its diameter with the assumption of equality of the initial intensities. The feature is not typical for collimated radiation and is connected with the dominance of geometrical focusing over Kerr self-focusing of a beam during filament formation.

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**INTRODUCTION**

The propagation of femtosecond laser pulses of gigawatt power in air is accompanied by laser beam filamentation [1–3]. Outwardly, the filamentation can be observed by the appearance of thin luminous strings imaging the path of laser radiation in a medium. A physical cause of filamentation is strong spatiotemporal self-modulation of femtosecond pulses in a nonlinear self-focusing medium, which is shown by pulse compression and subsequent beam separation in a transverse section to areas with high intensity. In this case, the mean diameter of single filament in air is an order of a hundred micrometers for near IR-radiation, the peak intensity attains hundreds of terawatts per square centimeter, and the mean length varies depending on pulse power and initial beam radius.

One of the important aspects of ultrashort laser radiation filamentation in air, i.e., the effect of the initial size of a light beam on the light filament length was theoretically considered in [4]. It was established by means of numerical simulation that the principal characteristics of generated filaments (initial coordinates, length, and continuity) reveal dependence on light beam diameter under the condition of constancy of its initial power for millimeter-sized beams in the regime of single filamentation. Here the main physical cause is the role of diffraction, which increases with the beam size during self-focusing. The filament start moves away from beginning of a path; and the total filamentation length behaves nonmonotonically, first increasing with the beam size and then decreasing to almost complete cessation of filamentation for relatively wide beams ($d > 8$ mm).

In this work, we continue investigation of this problem and present the results of our complex experiments on the study of self-focusing and filamentation of femtosecond laser pulses in air under variations in the initial size and power of a laser beam. In contrast to previous investigations [4], here we consider the case of sharply focused radiation, and it has been found that this case generates a number of features in the generation process of filaments and their spatial characteristics. Specifically, according to our information, for the first time in the regime of single filamentation, we experimentally established the fact of ultraweak dependence (practically invariance) of the length of the filamentation zone of a laser beam on its radius at constant peak intensity. This result does not directly follow from the self-focusing theory of the beam and considerably differs from the features observed in the case of collimated radiation filamentation.

**EXPERIMENTAL SCHEME AND TECHNIQUE**

The experiments on self-focusing and filamentation of light were performed in the laboratory of Institute of Automation and Control Processes, Far Eastern Branch, Russian Academy of Sciences (IACP FEB RAS) in collaboration with V.E. Zuev Institute of Atmospheric Optics, Siberian Branch, Russian Academy of Sciences (IAO SB RAS) and Far Eastern Federal University (FEFU). In the experiments, we used Ti:Sapphire laser radiation with a pulse duration of 45 fs (FWHM) of gigawatt power at the fundamental
(800 nm) and second harmonic (400 nm) during focusing in air using a lens with the focal length $f = 200 \text{ mm}$. The experimental setup is schematically shown in Fig. 1.

The technique of plasma filament recording is similar to that used by the authors in [5]. In our experiments, as opposed to [5], laser beams with diameters $d_0 = 2.5, 4.5, 7,$ and $9 \text{ mm}$ were used. A beam with a diameter of 4.5 mm was formed from an initial 9-mm beam using telescope 6, where the sequence of lenses 7 and 8 was changed for beam narrowing at the same telescope base $D$ corresponding to a collimated beam at the telescope output. A beam of 2.5 mm in diameter was cut out from the initial one by diaphragm 12. The data on spatial characteristics of the filaments generated by focusing of 7-mm beams were taken from our work [5].

The beam energy and profile were measured after passing through the telescope or the aperture before focusing lens 14. A plasma filament was recorded at the same energy and power of a laser pulse for different beam diameters.

**RESUL TS AND DISCUSSION**

The major objective of our experiments was to obtain information about the possible dependence of the length and position of a filament zone of sharply focused femtosecond radiation on the initial beam size. For this purpose, the filamentation zone in the form of string or spindle-shaped area located near the geometric focus of a lens was laterally photorecorded by means of a CCD camera. This emission, as is known, is connected with plasma formation in a beam channel and is caused by fluorescence of nitrogen ionized by the intensive optical field of a pulse and, therefore, can be considered as an indicator of radiation filamentation. Images of the filamentation zone of beams of different size at two harmonics of Ti:Sapphire laser radiation recorded near the lens focus are exemplified in Fig. 2. The linear size of each picture is $60 \times 8 \text{ mm}$.

A tendency to shortening of the filamentation zone with an increase in the light beam diameter $d_0$ at its constant initial power $P_0$ is seen. This tendency is observed for the both spectral ranges of radiation.