ИЗВЕСТИЯ ВЫСШИХ УЧЕБНЫХ ЗАВЕДЕНИЙ
Т. 56, № 10/3 ФИЗИКА 2013

UDC 621.378.33, 535.621.33

D.V. APEXIMOV, O.A. BUKIN**, E.E. BYKOVA*, Yu.E. GEINTS*, S.S. GOLIK**, A.M. KABANOV**, O.I. KUCHINSKAYA***, G.G.**MATVIENKO, A.A. ZEMLYANOV***

FILAMENTATION LENGTH OF HIGH-POWER SHARPLY FOCUSED FEMTOSECOND LASER RADIATION IN AIR

The results of the laboratory experiments on measurements of length and position of filamentation zone of femtosecond laser GW radiation at the wavelengths of 800 and 400 nm with millimeter-sized aperture propagating in air under the conditions of sharp external focusing are presented. The dependences of 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 zone with respect to variation of its diameter with the assumption of equality of the initial intensities. The regularity is not characterized for collimated radiation and connected with geometrical focusing dominance over Kerr self-focusing of the beam during filament formation.

Keywords: *femtosecond laser, filamentation, fluorescence, plasma channels.*

The propagation of femtosecond laser GW radiation in air is accompanied by the phenomenon of the light beam filamentation. Visually filamentation manifests itself in the form of a thin luminous filaments plasma channels generated by optical filaments in the propagation medium. Spatio-temporal localization of energy in these pulses filamentation in gases and transparent dielectrics is accompanied by the generation of plasma channels, conical emission, the formation of supercontinuum radiation, as well as strengthening of the nonlinear optical interaction of laser radiation with the medium. The unique properties of filamentation give entirely new possibilities for the use of femtosecond laser technologies in various fields of activities [1, 2]. In the problems of atmospheric optics interesting opportunity of wiring lightning strikes on a given path through the creation of extended ionized channels – filaments, significantly expands the opportunity to probe the atmospheric parameters of the so-called white light lidar. In addition, the studies of the filamentation tightly focused laser beams from the point of view of establishing the influence of the geometrical focus and Kerr self-focusing on the spatial characteristics of the filaments are of special interest [3, 4].

The experiments on the filamentation of light were performed in the laboratory of the Institute of Automation of Controlling Systems of Dalnevostochny Federal University RAS in collaboration with the Institute of Atmospheric Optics RAS. In the experiments the radiation of Ti: Sapphire-laser with a pulse duration of 45 fs of GW power in the primary (800 nm) and the second harmonic (400 nm) focused by means of lens having a focal length f = 200 mm in the air was used. The structure of the experimental stand schematically is shown in Fig. 1.

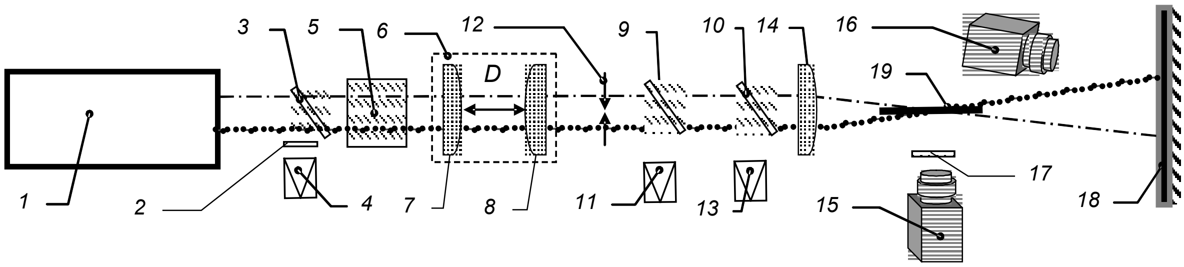

Fig. 1. Schematic of the experiment: *1* – a laser system (Spitfire Pro40F, Spectra Physics); *2* – Attenuator; *3*, *9*, *10* – revolving plate; *4* – autocorrelator (PSCOUT PL-SP-LF, Spectra Physics); *5* – harmonics transformer (β-BaB2O4); *6* – a telescope with a lens = 500 mm (*7*) and (*8*) C–250 mm; *11* – the energy meter (Spectra Physics 407A); *12* – aperture = 2,5 mm; *13* – meter beam profile (Newport LBP-HR); *14* – focusing lens f = 200 mm; *15* – CCD-camera («videoskan-285/P-USB»); *16* – camera (Sony DSC-F828); *17* – linear polarizer (LPVIS100, THORLABS); *18* – screen, *19* – filamentation region.

The registration of plasma filaments was carried out at the same values of the energy and power of the laser pulse for different beam diameters. The main objective of the experiments was to obtain experimental data on the possible dependence of the length and position of the zone of the filament tightly focused femtosecond pulses on an initial size of the beam. To achieve this goal side photographic of filamentation zone was carried out using of CCD-camera. This zone presents a luminous thread-or spindle-shaped area located near the geometric focus of the lens. This emission is associated with the plasma formation in the channel and is due to fluorescence of nitrogen ionized by intense optical field pulse, and thus can be considered as an indicator of radiation filamentation. The very intensity of fluorescence is proportional to the number of free electrons formed during the laser pulse in the channel of the beam in the ionization of the gas molecules. Sample image of zone filamentation beams of various sizes on two harmonics of Ti: Sapphire-laser, recorded near the focus of the lens is shown in Fig. 2.

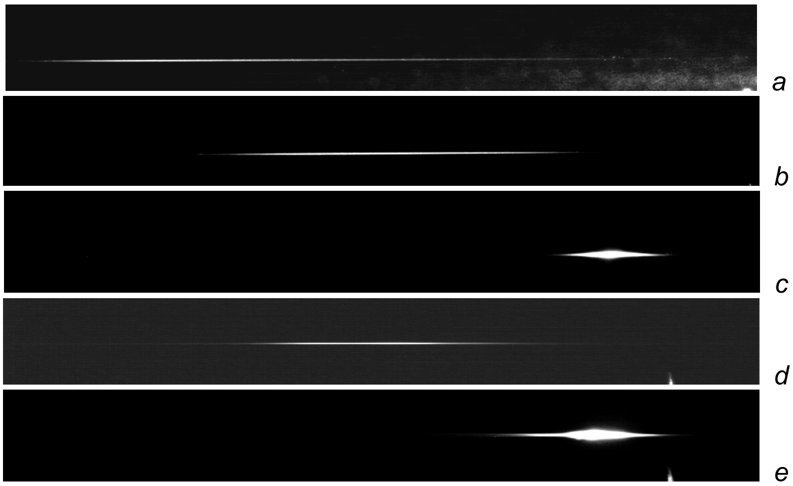

Fig. 2. Images of the filamentation of radiation with λ_0 = 800 nm and P_0 = 30 GW (*a*, *b*, *c*); 400 nm and P_0 = 8 GW (*d*, *e*), obtained at the CCD-matrix. The initial diameter of the laser beam was: d_0 = = 2,5 (*a*) 4,5 (*b*, *d*) and 9 mm (*b*, *d*). Frame in the lower right corner on the last two frames shows the position of the geometrical focus.

The figure shows a tendency to shortening of filamentation with increasing the diameter of the light beam at a constant of its initial capacity. This trend is observed for both spectral bands of radiation. In addition, increasing the size of the beam increases the transverse dimension (width) and brightness of illumination, and it shifts to the geometric focus of the lens.

The results of experimental measurements of the length of the filamentation of the radiation power is shown in (Fig. 3), from which it follows that the length of the filamentation increases monotonically with increasing intensity of the laser pulse, reaching a value of about 5 cm for the narrowest of the beam used in the experiments (diameter source beam of 9 mm). Angle dependence decreases with increasing size of the light beam and a wide beam (d_0 = 9 mm) filament length parameter slightly varies with laser power. Small and almost constant size recorded plasma region (~ 1–1,5 cm) at a sufficiently high power pulse on both harmonics may indicate a change of regime of propagation and realization of optical breakdown in the focal beam waist.

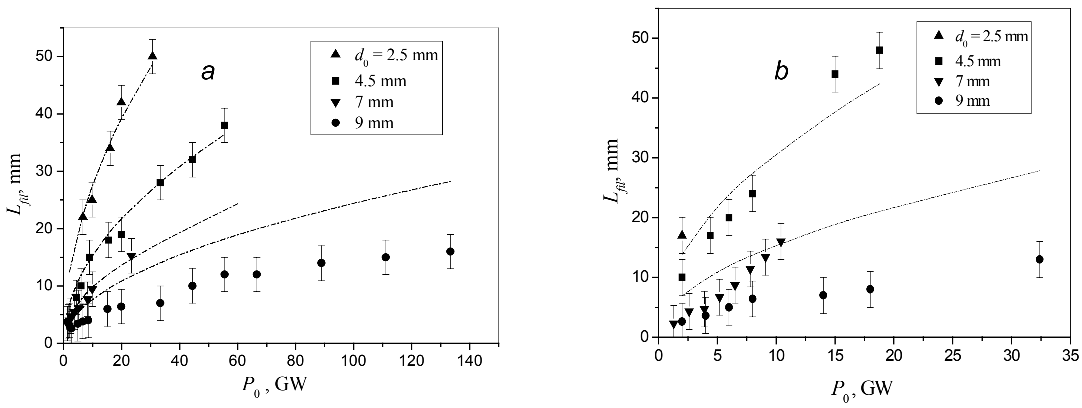

Fig. 3. Dependence of the length of the filamentation on the peak radiation power for λ_0 = 800 nm (*a*) and 400 nm (*b*); bar – approximation.

The dependence of the length of the filamentation on the laser pulse intensity for different sizes of beams is shown in Fig. 4 and differs from dependence on the power. Practically For all diameters experimental values of the filament length «pulled together» in a curve that is well described by a linear dependence of the length of the optical breakdown near the geometric focus, without taking into account the nonlinear self-focusing of the beam.

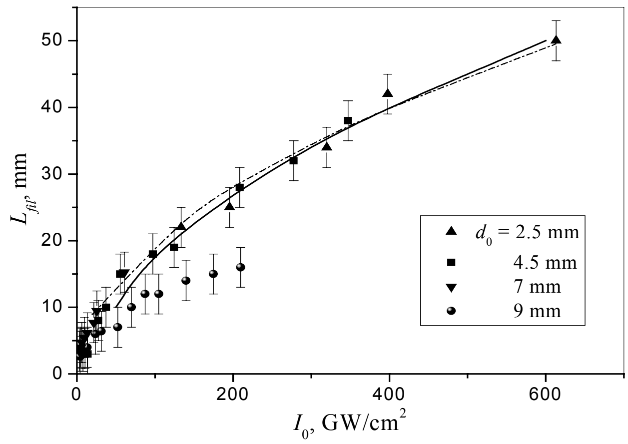

Fig. 4. The dependence of the length of filamentation at different peak pulse intensity λ = 800 nm); bar - approximation, solid line - numerical calculation [4].

The same trend is observed for the dependence of the distance on the focusing lens up to the beginning of the filament length of the so-called «self-focusing». This is presented in Fig. 5.

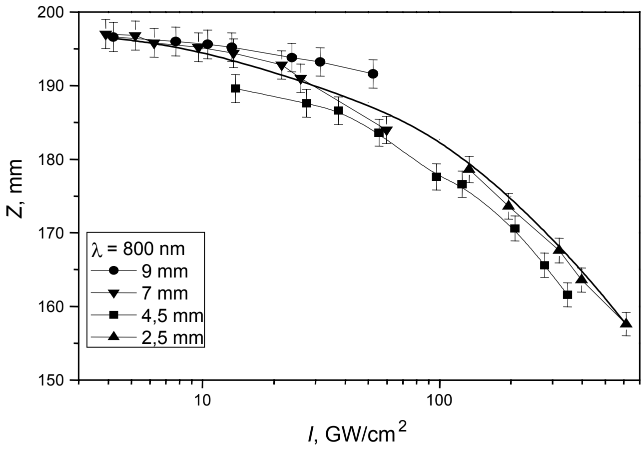

Fig. 5. Dependencies of start position filamentation (positions nonlinear focus) on the intensity of the laser pulse with a wavelength of 800 nm, for beams with different diameters.

The figure shows that for all beam diameters the measured distance to the start of the plasma column is well described by the curve calculated by the formula derived from the laws of geometrical optics, without taking into account focusing in a medium with cubic nonlinearity $Z = f(1 - (I_0/I_{th})^{1/2})$ (1), where Z – the distance from the lens to the beginning of the filament, I_0 – initial pulse intensity, I_{th} – the threshold intensity of multiphoton ionization of air (the best agreement with the experimental data obtained by $I_{th} = 1{,}33 \cdot 10^{13}$ W/cm^2). It should be noted that in the experiments of broadening the spectrum of the radiation is associated with the phase modulation of the light wave [6], as well as substantial asymmetry of observed plasma channel relative to the geometric focal point (Fig. 2) indicates that, in these experiments filamentation of the laser beam is observed.

In summary, the results of the laboratory experiments on measurements of a length and the position of filamentation zone of femtosecond laser GW radiation with millimeter-sized diameter aperture propagating in air under the conditions of sharp external focusing suggest the detection of at least two wavelengths qualitatively new and not previously mentioned in the literature of the laws, namely the invariance of the observed length of the glow (filamentation) in relation to the diameter of the beam under the condition of the same peak intensity. The specified pattern does not result from the theory of stationary self-focusing of a collimated or weakly focused radiation and is explained by mainly the linear nature of the transverse compression of the light beam to the nonlinear focus.

REFERENCES

1. Гейнц Ю.Э., Землянов А.А., Кабанов А.М., Матвиенко Г.Г. Нелинейная фемтосекундная оптика атмосферы / под общ. ред. д.ф.-м.н., профессора А.А. Землянова. – Томск: Изд-во Института оптики атмосферы СО РАН, 2010. – 212 с.
2. Кандидов В.П., Шлёнов С.А., Косарева О.Г. // Квант. электроника. – 2009. – Т. 39. – № 3. – С. 205–228.
3. Гейнц Ю.Э., Землянов А.А. // Оптика атмосферы и океана. – 2013. – Т. 26. – № 1. – С. 11–17.
4. Апексимов Д.В., Букин О.А., Быкова Е.Е. и др. // Оптика атмосферы и океана. – 2013. – Т. 26. – № 3. – С. 247–252.
5. Букин О.А., Быкова Е.Е., Гейнц Ю.Э. и др. // Оптика атмосферы и океана. – 2011. – Т. 24. – № 5. – С. 351–358.
6. Апексимов Д.В., Букин О.А., Быкова Е.Е. и др. // Прикладная физика. – 2012. – № 6. – С. 14–22.

*Institute of Atmospheric Optics them. VE Zuev SB RAS
**Institute of Automation and Control Processes, Far Eastern Branch of Russian Academy of Sciences
***National Research Tomsk State University
E-mail: OlesyaTSU14@mail.ru

Article submitted July 15, 2013.

Апексимов Дмитрий Владимирович, к.ф.-м.н., ст. науч. сотр.;
Букин Олег Алексеевич, д.ф.-м.н., зав. лабораторией;
Быкова Елена Евгеньевна, науч. сотр.;
Гейнц Юрий Эльмарович, д.ф.-м.н., гл. науч. сотр.;
Голик Сергей Сергеевич, к.ф.-м.н., зав. лабораторией;
Землянов Александр Анатольевич, д.ф.-м.н., зав. лабораторией;
Кабанов Андрей Михайлович, д.ф.-м.н., ведущ. науч. сотр.;
Кучинская Олеся Ивановна, магистрантка;
Матвиенко Геннадий Григорьевич, д.ф.-м.н., директор.