HU8307892

KFKI-1983-12

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BUDAPEST

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HU ISSN 0368 5330
ISBN 963 372 043 5

ABSTRACT

A crossed beam experiment was performed to clarify the mechanism of self-focusing in a laser produced spark. The plasma was created by one beam and self-focusing was observed in the weak probe beam which crossed the plasma. Experimental results show that the cause of self-focusing is the nonuniform heating mechanism.

АННОТАЦИЯ

Исследовалась самофокусировка в лазерной плазме с помощью пересекающихся лазерных пучков. Одним из пучков создавалась плазма, а в другом слабом пучке наблюдалась самофокусировка. Результаты экспериментов показывают, что причиной самофокусировки является неравномерный нагрев.

KIVONAT

A lézer plazmában történő önfókuszálás mechanizmusának megvilágitásához kisérletet végeztünk keresztező lézer nyalábokkal. Az egyik nyaláb hozta létre a plazmát, az önfókuszálás a gyenge, vizsgáló nyalábban volt megfigyelhető. A kisérleti eredmények azt mutatják, hogy az önfókuszálódást a nemegyensulyi fütés mechanizmusa okozza.

1. Introduction

Self-focusing and filamentation of laser beams in subcritical density plasma is a major problem in laser-plasma interaction physics. The beam filamentation process may be of great consequence to the success of laser-driven fusion since the narrow light filaments which contain regions of locally higher irradiance will prevent the symmetric implosion of spherical shell targets, while resulting in increased target preheating by the energetic electrons produced [1].

Convincing evidence was given for beam filamentation by the measurement of the Thomson scattering and Fresnel reflection of an optical probe beam from filaments formed by a structured CO_2 laser beam propagating in a preformed, underdense plasma [2]. Filament formation was observed in the plasma corona of the uniformly irradiated spherical target using Schlieren imaging and shadowgraphy techniques [3]. A striking effect was observed in laser-produced spark in air, where the self-focusing results in a narrow pulse with an amplitude enlarged by an order of magnitude [4]. Investigations of the pulse distortion caused by the laser spark produced by the same laser pulse [5], and also of the temporal behaviour of light scattering in the spark [6] were carried out to reveal the origin of the high-intensity narrow light pulse.

The nonuniform, Gaussian spatial intensity distribution of the laser beam causes rarefaction of charges, i.e. lower density plasma on the optical axis because of the nonuniform heating mechanism or because of the ponderomotive force [5]. The resulting tunnel in the plasma traps the radiation thus causing self-focusing.

Another explanation for the power density increase is of geometrical optical origin [7]. The plasma is situated between the focusing lens and the focal point of the lens and, having the highest density on the optical axis the plasma as a negative lens forms a Galilean telescope with the focusing lens. Consequently the diameter of the light beam decreases, i.e. the power density temporally increases.

The above mentioned experiments suggested that the true cause of the phenomenon is self-focusing, however, in order to obtain a really convincing argument about the origin of the spike on the transmitted pulse, a crossed beam experiment was performed. In this case the probe beam was different from the beam that created the target plasma.

2. Experimental

The beam of the single mode, single frequency ruby laser was split into two beams by the beamsplitter /Fig. 1/. The intensity of the first beam could be altered by the attenuator /A/. It was focused by lens L1; however, it was so weak that it did not create a plasma. The second beam crossing the first one was intensive enough to create target plasma in air for the first beam. The crossing point could be shifted along the first beam by shifting mirror M2 and lens L2 simultaneously. Special care was needed during alignment of the system since the diameter of the focal spots was very small, approximately 10 μm.

The light of the first beam, the probe beam was detected by the fast photodiode /PD/ and a storage oscilloscope /OSC/. The photodiode was situated on the optical axis with a small aperture, much smaller than the whole width of the beam. The energy of the laser and also that of the first beam was monitored by a digital energy meter.

In order to check the relative positions of the two beams the plasma was imaged from above /not seen in Fig. 1/ thus its temporal behaviour could also be followed by means of the side scattering on the plasma fronts. The detector was a photomultiplier with a diaphragm and it could be moved shot by shot both in the x and y directions /see Fig. 1/.

The focal point of lens L2 was set at 0.23 mm beyond the crossing point, thus the probe beam interacted with the main body of the plasma cylinder.

3. Results and discussion

The first beam is attenuated only by the target plasma at low laser intensities /up to 50 kW/, independently of the position of the plasma relative to the focal point of L1. In this case a dip appears in the originally Gaussian shaped laser pulse when the plasma screens the probe beam /Fig. 2/ by scattering and absorption.

On increasing the intensity of the first beam, self-focusing can be observed at definite settings of the target plasma.

Figure 3 shows the pulse shapes of beam 1 at different intensities, when the target plasma was 0.5 mm from the focal plane in the direction of L1. The spike appears at a definite threshold intensity, which is characteristic of self-focusing. At higher laser intensities the intensity of the spike will not be relatively higher, i.e. it shows saturating behaviour.

Figure 4 shows the observed transmitted pulses of the probe beam at different target plasma settings at an intensity of 400 kW. In this figure the calculated beam radius using the measured waist data is plotted, depending on the coordinate along the beam propagation, disregarding the spherical aberration. Arrows show the location of the target plasma during the measurement. Absorption can be seen only when the target plasma is very far from the focal plane, i.e. more than 0.8 mm from it. A self-focused spike can be observed on approaching the focus from both directions, nearly symmetrical to it. It seems surprising that instead of focusing, absorption can be observed in the vicinity of the focal plane and in the focus.

These phenomena are explainable only by the thermal self-focusing effect. When the target plasma is far from the focus, the width of the plasma filament is much smaller than that of the probe beam, thus only a minor part of the beam interacts with the plasma, the interacting intensity is less than the self-focusing threshold.

The explanation for the disappearance of the self--focused spike, when the target plasma is in the focus, can only be the mechanism of self-focusing. The threshold intensity for self-focusing with the nonuniform heating /thermal/ mechanism is [8]:

$$P_{cr} = \frac{c^3}{\omega_p^2}\left(1 - \frac{\omega_p^2}{\omega^2}\right)^{1/2} \frac{2 k_e T_o m \omega^2}{e^2 N_o r^2 \nu_{ei}}$$

Here ω_p is the plasma frequency, and $e, m, c, N_0, T_0, k_e, \nu_{ei}$ and ω are the electron charge, electron mass, speed of light, electron density, electron temperature, heat conductivity of the electrons, electron-ion collision frequency and the angular frequency of the laser light, respectively. The threshold is inversely proportional to the square of the beam radius, thus it is lower when further from the focus and higher when in the focus. The beam intensity is higher than P_{cr} when moving off the focus and lower than P_{cr} when in the focus. This explains the results that self-focusing appears in a definite range on both sides of the focus, and when moving in this range towards the focus, the spike appears later.

The observation that the spike appears on both sides of the focus, i.e. not only in the convergent but also in the divergent beam, is the strongest argument that the cause of the spike is the self-focusing effect. Moreover, as the threshold intensity for ponderomotive self -focusing is independent of the beam radius, and the measured result strongly depends on it, we ascertained that the mechanism of self-focusing in a laser produced spark is of thermal origin.

We illustrate thermal self-focusing using the measured 4 μm minimal beam radius, the $1.5 \cdot 10^5$ K plasma temperature [6] and a typical density of $n=2 \cdot 10^{19}$ cm^{-3}. In this case the calculated threshold intensity for self-focusing is 1.4 MW with the target plasma in the focus, and it is only 28 kW when the target is 0.5 mm from it, where the Gaussian beam radius is 28 μm. The measured threshold value was approximately 50 kW when the target was in the converging beam and $\sim$100 kW in the diverging beam, thus the rough model gives a good approximation for its order of magnitude.

The strongest effect was observed at the above mentioned 400 kW laser intensity. In this case the axial plasma propagation was still not strongly affected, as was supported by side scattering observations. At higher intensities the interaction between the two beams becomes stronger, a plasma filament is formed also in the x direction [9], and the situation becomes much more complicated.

Summarizing the results, the experiment proved that the cause of the pulse narrowing and power density increase in a laser produced spark is self-focusing with a nonuniform heating mechanism.

The authors acknowledge the technical assistance of Gy. Csuhrán, L. Imre and Zs. Mezey and the typing skills of Miss O. Pongrácz.

Figure Captions

1. Experimental arrangement. BS: beam splitter; A: attenuator; M1 and M2: mirrors; L1 and L2: lenses; PD photodiode; OSC: oscilloscope; D: small diaphragm.
2. Pulse shapes of beam 1 on the optical axis. Pulse 1 shows the shape of beam 1 when there is no crossing plasma, pulse 2 shows the shape of beam 1 after passing through the plasma. The horizontal scale: 40 ns/div.
3. Pulse shapes of beam 1 at different beam intensities. The target plasma position is -0.5 mm.
4. Pulse shapes of beam 1 at different target plasma positions. The laser intensity is 400 kW. The solid curve shows the calculated beam radius vs. the coordinate along the beam propagation.

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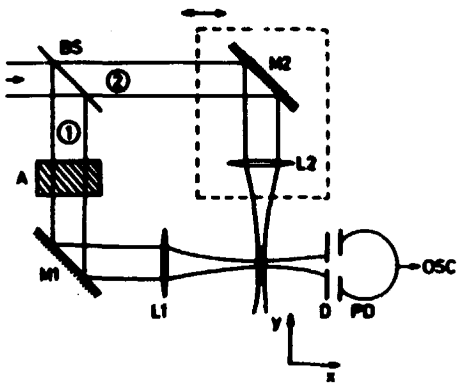

Fig.1.

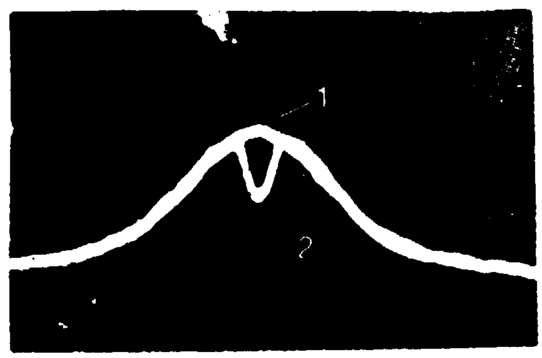

Fig.2.

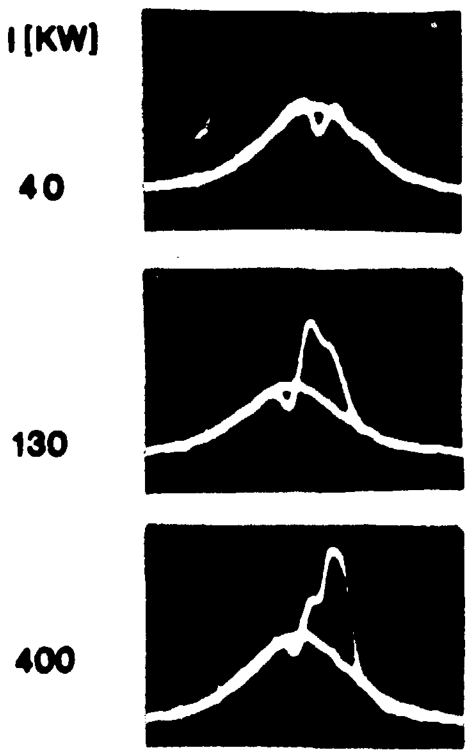

Fig.3.

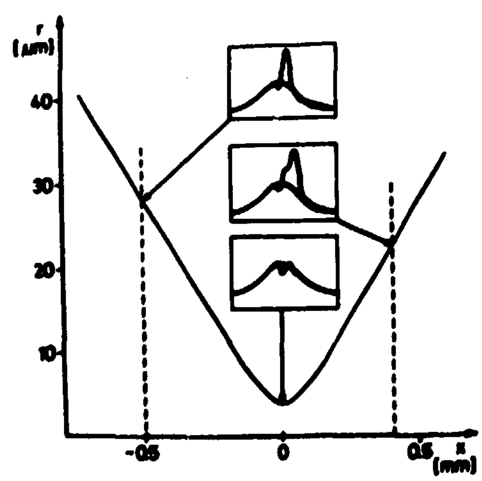

Fig.4.

Kiadja a Központi Fizikai Kutató Intézet
Felelős kiadó: Szegő Károly
Szakmai lektor: Kardon Béla
Nyelvi lektor: Harvey Shenker
Példányszám: 370 Törzsszám: 83-100
Készült a KFKI sokszorosító üzemében
Felelős vezető: Nagy Károly
Budapest, 1983. március hó