SELF-GENERATED MAGNETIC FIELDS OF AN AIR-BREAKDOWN PLASMA PRODUCED BY TWO SEQUENTIAL LASER PULSES

V.I.Konov, P.I.Nikitin, A.M.Prokhorov

General Physics Institute of the USSR Academy of Sciences, Vavilov st.38, Moscow, USSR

Self-generated magnetic fields (SMF) in a laser plasma were studied in many Refs.[I-7] , including the case of using two laser pulses[2,7]. However, usually experiments were carried out with plasma plume on a target and at low pressures of an ambient gas $P_{ont} \sim 0.0I - I$ Tor,when a SMF amplitude has maximum. As was shown in Ref.[7], when an atmospheric air breakdown is produced by two sequential laser pulses the dependence of the SMF amplitude B upon time separation τ between pulses is resonance-like and maximum B_M values are of the same order of magnitude like those at P_{opt}.

In the present paper the spartial and temporal distribution of the SMF in a laser spark produced by double pulses in air without target is studied for the first time. The results are compared with those obtained when plasma in air was ignited on metal and dielectric targets.

Experimental setup

Each of two identical pulses of CO_2-laser had energy $E_{I,2}$= I.5 J and temporal shape shown in Fig.Ia. Laser radiation was focused by a 6-cm focal length so that the intensity in a focal spot reached the air - breakdown threshold value $\sim 10^9 W/cm^2$.

The SMF were measured by integrating the signals from two identical probes consisted of one loop ($\varnothing$ 2.5 mm) of a thin wire. Probes were located near the plasma at different points (z,r) where r is the distance from the laser-beam axis, the z axis is directed opposite to the laser beam and z=0 coincides with the focal plane of the lens. High speed photographs of plasma evolution were also recorded.

Laser spark SMF

When air-breakdown is produced by the first pulse the SMF was not recorded at the sensitivity ~ 0.0I G and the "fireball" (FB) is created in the air. Significant SMF were measured when breakdown of ionized gas in FB was occured by the second pulse with τ = 7-60 μs.

The experiments show that:

(i) Two components of asimuthal SMF are recorded near laser spark (Fig. Ib-d). The signal B_1 appears simultaneously with the second laser pulse and the components B_2 follows with the time-delay t_d depending on plasma probe distance.

(ii) The polarity and temporal shape of signals B_1 and B_2 depend upon probe location with respect to plasma fronts.

(iii) The structure of measured SMF differs at various τ because there are the singularities of ignition and evalution of optical discharge in ionized gas[7].

When $\tau \geqslant 30\,\mu s$ plasma is ignited inside FB near focal point and moves opposite to the direction of laser beam. In this case near front plasma boundary at $z > 5$ mm positive pulse B_1^+ produced by electron current flowing along z axis is recorded. Typical oscillogram of such SMF signal at the point (6.6) is shown in Fig.Ib. At the same time signal B_1 near opposite plasma boundary ($z < 0$) always has a negative polarity, which may result from transient electron flow in the direction of laser beam. In Fig.Id analogous signal recorded at point (-I.6) is shown.

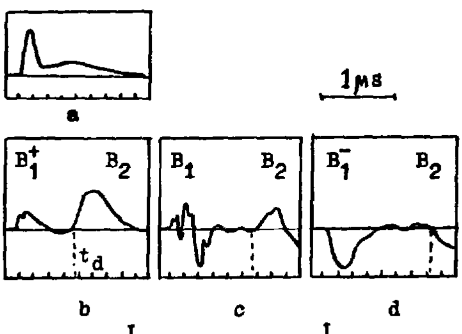

Fig.I

If the probe is approximately equidistant from plasma boundaries, then B_1 has complicated oscillatory temporal shape shown in Fig.Ic (the probe at point (3.9)).

Fig.2 shows the dependence of amplitude $B_1(z)$ at fixed r=6mm, which has 3 regions having different temporal shapes of SMF signals.

For short time separation $\tau \lesssim 10\,\mu s$ of the second laser pulse, when the discharge is ignited on the boundary of FB and propagates toward the laser beam near the front of plasma $B_1^+ < 2G$, while in the vicinity of opposite boundary $B_1^- \simeq 20$ G.

We consider the observed structure of B_1(Fig.2) is due to electric quadropole moment of laser spark, which has two potential steps $\mathcal{E}$ and $\mathcal{E}_1$ at the front and rare optical discharge boundaries, respectively [8]. The appearance of electric field of such a quadropole must produce two systems of opposite directed "fountain-like" currents in the plasma itself and in the surrounding ionized gas. They result in a SMF of different directions in front of and behind the plasma (Fig.3).

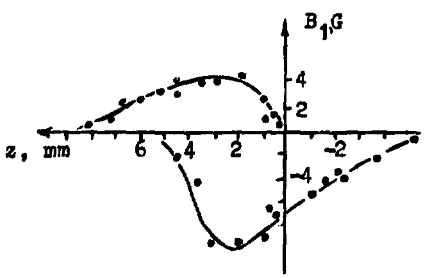

Fig.2

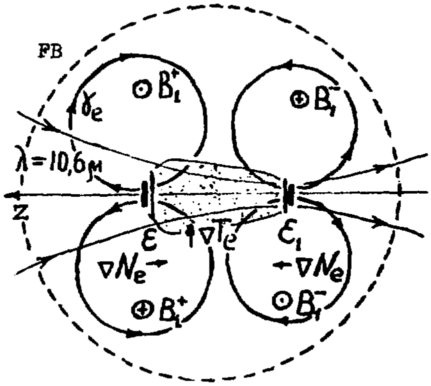

Fig.3

Detected irregular oscillatory SMF signals probably were due to turbulent motions within the FB [8] In the region where the action of $\mathcal{E}$, $\mathcal{E}_1$ is comparable turbulent fluctuations of a gas conductivity within FB can change summary current direction which cause a recording of oscillating B_1.

A time delay t_d of a second component B_2 corresponds to a moment of shock wave arrived to the probe. The appearance of B_2 is due to emf at the shock wave front detecting earlier [9] and to oscillatory current behind the front [8].

SMF of an air-breakdown plasma near a target

In the following experiments an optical discharge was ignited by the same double laser pulses at fixed $E_{1,2}$= I.5 J and τ = 30 μs, but on the targets which were placed at different distances in respect to a lens focal plane.

The experiments showed that dielectric targets don't change qualitatively a structure and amplitude of B_1 of laser spark. So, near the opposite boundary B_1^- has a negative polarity and curves $B_1(z)$ are analogous to those shown in Fig.2 but slightly deformed in accordance with change of a plasma fronts location.

An essential different structure of SMF was observed in the case of conducting grounded targets. When the rare plasma boundary contacts with a metal surface only B_1^+ is recorded with the amplitude being approximately equal to measured closely to front plasma boundary on dielectric target. If the luminous plasma was detached from the metal then the signal B_1 from the probe located near the plasma-target surface changed the polarity and amplitude B_1^- was several times larger in comparison with the initial value B_1^+.

The dependence of SMF structure of spark on target's material to our mind is due to distruction of $\mathcal{E}_1$ when plasma contacts with the grounded metal. In this case plasma is electric dipole with emf $\mathcal{E}$ only in front boundary [8].

We note in conclusion that similar effects can take place for plasma plume on a target in vacuum and the obtained results can be used for explanation of such phenomena like "spontanous polarity changing of SMF signals" [6], significant B_1 difference on dielectric and metal targets [5,6], or SMF reversal on the last stages of plasma motion [4].

References

I. V.V.Korobkin, R.V.Serov. Pis'ma v ZhETF, v.4, I03, I966.

2. G.A.Askar'yan, M.S.Rabinovich, A.D.Smirnova, V.B.Studyenov. Pis'ma v ZhETF, v.5, II6, I967.

3. J.A.Stamper et al. Phys.Rev.Lett., v.26, IOI2, I97I

4. Schwirzke F. In "Laser Interaction". (ed. by H.J.Schwarz and H.Hora Pl.Pr., New York, v.3A, 2I3, I974

5. V.V.Korobkin et al. Pis'ma v ZhETF, v.25, 53I, I977

6. S.L.Motylev, P.P.Pashinin. Kvantovaya electronika, v.5, I230, I978

7. V.I.Konov et al. Pis'ma v ZhETF, v.39, 50I, I984

8. Dement'ev D.A. et al. Kvantovaya electronika, v.8, I532, I98I

9. I.N.Goncharov et al. Pis'ma v ZhETF v.26, 55I, I977