Laser-plasma detection of the difference frequency of two light waves

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(Submitted 29 June 1984)
Pis'ma Zh. Eksp. Teor. Fiz. **40**, No. 3, 114–116 (10 August 1984)

A high-frequency component has been observed in the current flowing from a charged metal target to the plasma of an optical surface breakdown. The frequency of this current component is that at which the intensity of the light wave producing the plasma is modulated. The effect is a laser-plasma detection of the difference frequency of two light waves.

1. The application of an intense laser beam to the surface of a charged conducting target gives rise to an electric current because of the flow of charge from the target to the conducting medium which arises near the surface of the target. This conducting medium forms because of the plasma of the optical breakdown that occurs near the surface of the target and also because of photoionization of the gas around the target. The result is a change (jump) in the target potential.[1]

We have found that during a nanosecond laser pulse the current from the target is roughly proportional to the intensity of the laser beam; i.e., the current pulse from the target to the conducting medium reproduces the shape of the light pulse (Fig. 1). This property of the current is equivalent to an optical detection, i.e., to the formation of an electrical signal (a current) proportional to the envelope of optical oscillations. This optical detection makes it possible to produce current pulses near the target with a frequency equal to the frequency of an amplitude modulation of the laser beam.

The intensity of a laser beam at the target surface can be modulated at a frequency $|\nu_1 - \nu_2|$ by simultaneously applying to the target two light beams of constant intensities at the frequencies ν_1 and ν_2.

For a deep modulation of the laser beam, the spatial and temporal coherence of the light beams at ν_1 and ν_2 must be high.

These conditions can be met by using an optical arrangement with a frequency shift of a narrow-band pump source during stimulated Brillouin scattering (or "stimulated Mandel'shtam-Brillouin scattering") in a variety of active media.[2,3] In this arrangement, two different frequencies are obtained by means of the stimulated Brillouin

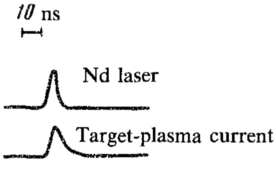

FIG. 1. The laser pulse and the current pulse from the target to the plasma.

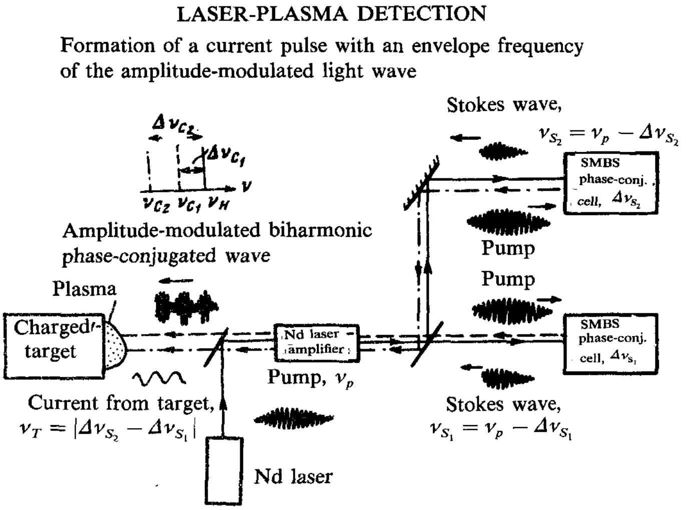

FIG. 2. Schematic diagram of the experimental apparatus.

scattering in two different media with different hypersound velocities, and a high degree of spatial coherence is achieved through the phase conjugation accompanying the stimulated Brillouin scattering. By using two different media and a single pump source, with a frequency ν_p, we can produce light fields with frequencies $\nu_1 = \nu_p(1 - (2n_1v_1/c))$ and $\nu_2 = \nu_p(1 - (2n_2v_2/c))$ and, correspondingly, modulate the intensity of laser radiation at a frequency $\nu = \nu_p/c(2n_2v_2 - 2n_1v_1)$. By combining different media and pump sources, we can produce frequencies in the range 10^8–10^{10} s^{-1} in this optical arrangement.

2. Figure 2 is a schematic diagram of the experimental apparatus. The apparatus includes a laser oscillator (Nd laser, $\lambda = 1.06$ μm), a system of laser amplifiers, "Brillouin" mirrors, and a target with a current-detection system.

The laser oscillator at the fundamental transverse TEM_{00} and at one longitudinal mode during Q switching of a brightening dye. The length of the output pulse at the level of half the maximum intensity is $\tau_p \simeq 70$ ns, and the spectral width of the output is $\Delta\nu_p \lesssim 10^{-2}$ cm^{-1}

Part of the beam from the laser oscillator is reflected from a glass plate into the system of laser amplifiers. The gain per pass of each amplifying stage is varied over the range $(1\text{–}3)\times 10^{-2}$. The amplified beam is split by a half-silvered mirror into two beams of equal intensities and focused by lenses into cells $L_1 = L_2 = 70$ cm long filled with compressed SF_6 and Kr. The SF_6 pressure is 21 atm, and the Kr pressure 33 atm. The back-scattered beams resulting from the stimulated Mandel'stam-Brillouin scattering are brought into coincidence at the half-silvered mirror and amplified in the system of laser amplifiers. The energy of the light at the output from the amplifier cascade reaches $E \simeq 1$ J.

Figure 3, a and b, shows oscilloscope traces of the pulses of the Stokes components during the stimulated Mandel'stam-Brillouin scattering in SF_6 and Kr. At the

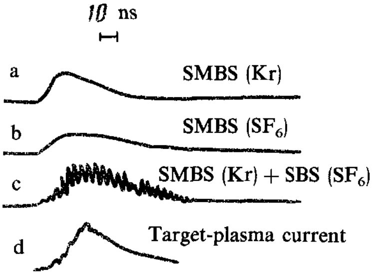

FIG. 3. Oscilloscope traces of the pulses of the Stokes components and of the current.

specified pump energies, we achieved phase conjugation during stimulated Mandel'stam-Brillouin scattering in each of the cells in this optical arrangement. The phase conjugation provided spatial coherence of the light beams at the different frequencies.

Figure 3c is a trace of the intensity of the beam at the output from the amplifier cascade during simultaneous generation of Stokes components in the two cells. The period of the intensity oscillation is 5 ns, which corresponds to the beat period of the two Stokes components in the stimulated Brillouin scattering of the beam from the Nd laser ($\lambda = 1.06\ \mu m$) in the SF_6 ($v = 113$ m/s) and the Kr ($v = 224$ m/s). The intensity modulation is not a 100% modulation because of the different intensities of the Stokes components, which are consequences of the different values of the reflection coefficients for the stimulated Brillouin scattering in the SF_6 and the Kr. The pump beam was focused onto the charged target by a lens with a focal length $F = 0.5$ m.

The target in these experiments was a brass plate 18 mm in diameter. The shape of the current pulse in the plasma-target system was measured with an S7-10B oscilloscope, which was connected to the target through an isolation capacitor with $C = 1000$ pF.

3. Figure 3d is a trace of the current pulse in the system of the target and the conducting medium during the application of an intensity-modulated laser pulse to the target (Fig. 3c). The target in this experiment was separated from the lens by a distance $L = 33$ cm, which corresponds to a focus size $d = 2$ mm and to an energy density $P = 20\ J/cm^2$ at the target surface. The target potential was $U = 15$ kV.

We see from this figure that the current pulse is amplitude-modulated at a frequency corresponding to the frequency of the intensity modulation of the laser beam, $\nu \sim 200$ MHz. In other words, a high-frequency component arises in the current flowing from the target. The maximum amplitude reached by the high-frequency current component in our experiments was ~ 3 mA.

In summary, we have observed a high-frequency modulation of the current from a charged target at the frequency of the intensity modulation of the light wave which produces the plasma (this effect is a laser-plasma detection of the difference frequency of two light waves.

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Translated by Dave Parsons
Edited by S. J. Amoretty