On the possibility of obtaining relativistic velocities of the metal-dielectric front as a result of evaporation of a film by high-intensity light

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The possibility of achieving relativistic (and even faster than light) velocities of the evaporation front of a metal film due to transverse action of high-intensity light is indicated. Preliminary experiments on obtaining the high velocities are described. Metal-front velocities higher than 4×10^9 cm/sec were obtained. The possibility of using such moving fronts for Doppler conversion of frequencies and faster-than-light emission and acceleration of particles is indicated.

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The radiant evaporation of a metallized film is now widely used for Q switching,[1,2] for shortening pulse fronts,[2] for creating microwave pulse windows,[3] etc. The possibility of achieving relativistic (and even faster than light) velocities of the evaporation front of a film as a result of transverse action of high-intensity light is pointed out in this paper. Also described here are preliminary experiments to achieve the high velocities, and the possibility of using such fronts for Doppler conversion of frequencies and for faster-than-light emission and acceleration of particles is indicated.

1. Let us assume that a high-power light flash, normally incident, acts on a thin, metallic film (for example, a plated metal layer with a thickness of a hundred angstroms on a polymer film). For a given flux density $I(z,t)$ (z is the coordinate along the film) we obtain the time t of film evaporation from the condition

$$\int_{t_0}^{t} a\, I(z,t')\, dt \approx \Lambda\rho_0 h ,$$

where α is the absorption coefficient, Λ is the specific heat necessary for evaporation, ρ_0 is the density, h is the thickness of the film, and t_0 is the moment of the onset of evaporation. From this we obtain $z_f(t)$—the coordinate of the front of the metal-dielectric transition. For example, if I does not depend on the time after start-up, then $t \approx \Lambda\rho h/\alpha_{\rm eff} I(z) \approx B/I(z)$ and given that $I = I_0 - (\partial I_0/\partial z)z$ we obtain $\dot z_f \approx (1/I'_z)(B/t)$. If $I = I_0[z_0/(z+z_0)]^k$, we obtain

$$z = z_0\left\{(I_0/B)^{1/k}\, t^{1/k} - 1\right\}$$

and

$$\dot z = \frac{1}{k}\, z_0\, (I_0/B)^{1/k}\, t^{1/k-1} .$$

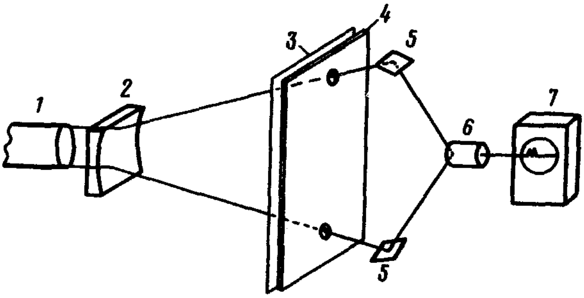

FIG. 1. Laser set-up: 1—laser, 2—negative cylindrical lens, 3—metallized Lawsan film, 4—shield with two holes, 5—mirrors, 6—photodetector, 7—oscilloscope.

For example, at $k = 1$, $\dot{z}_f = \text{const}$; at $k = \frac{1}{2}$, $\ddot{z}_f = \text{const}$, etc. The wavefront always moves in the direction of intensity decrease.

A second possible method of realizing fast front motion is to evaporate the film by the action of an obliquely incident light flash. In the case of small variation in intensity and in the film thickness, the delay determines the motion of the front $\dot{z}_f = c'/\sin\theta$, where θ is the incidence angle of the light front ($\dot{z}_f < c'$).

It is possible to produce a motion of the front by moving or scanning the high-power beam over the film surface.

In the examined cases any velocities of motion of the front, even those faster than light, can be realized, with the exact velocity delay depending on the specified accuracy of the thickness and properties of the film and on the light intensity.

Let us point out that the metal–dielectric transition time is much less than the heating time, since the transition occurs suddenly after vigorous evaporation temperatures have been reached (a type of explosive breakup of the metastable, superheated state).

Let us also point out that the usual velocities of the evaporation front of a metal along a laser beam generally lie within the interval 10^4–10^5 cm/sec ($\sim\rho_{\text{cr}} V_{\text{escape}}/\rho_0$, where ρ_{cr} is the critical vapor density, ρ_0 is the initial density of the metal, and V_{escape} is the escape velocity of the vapors), i.e., the transverse velocities of the front are much higher than these velocities.

2. An experiment was set up to demonstrate the attainment of high film evaporation front velocities. The experiment is shown schematically in Fig. 1. The beam of the laser (1) was broadened with a cylindrical lens (2) having a focal length $F = 5$ cm. At a distance of 3.5 m the normal beam gave a band of light 3.5 m long and 5 cm wide. The width of the band can be reduced to 1–2 mm by prefocusing with a conventional lens having $F = 3$ m or with cylindrical lenses placed near the film (3) on which the beam acted.

The laser produced a lasing wave[4] that propagated along the end of the rod in the direction of the chord of the cylindrical lens surface. The wave was initiated by a local

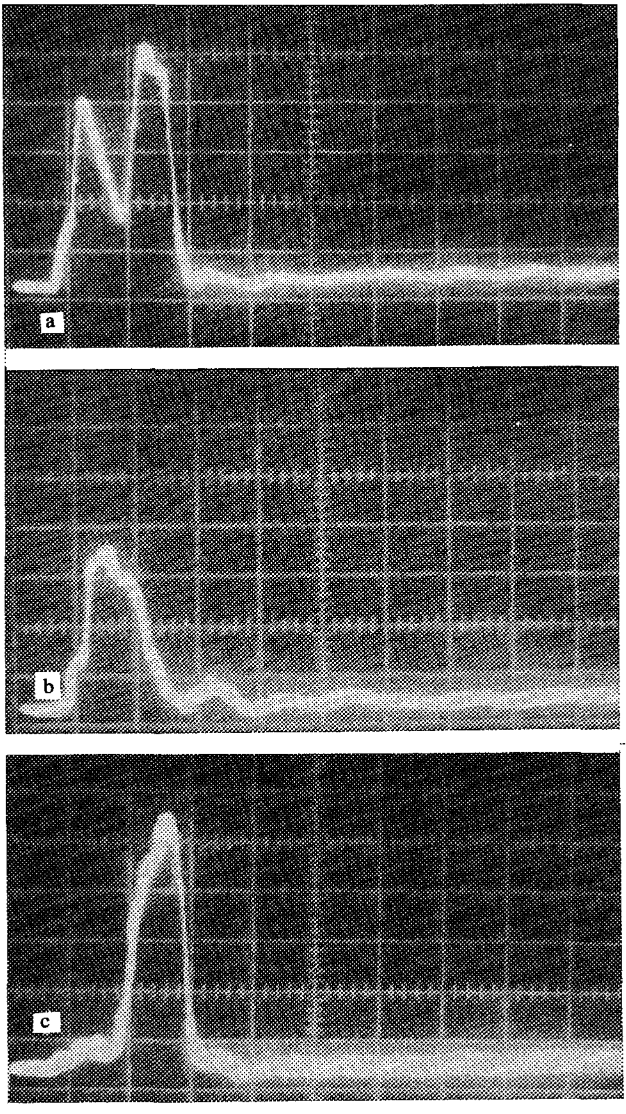

FIG. 2. Oscillograms of pulses from photodetector: a—both holes in shiled are open; b—first hole is blocked; c—second is blocked. 100 nsec/div sweep.

clearing of the film in the laser cavity by means of a spark gap—the microbreakdown caused a local burn-out of the metal film covering the cavity. From this point the lasing wave traveled from the edge along the end of the active element due to broadening of the beam that eroded the film in the cavity at the rate of 3×10^7 cm/sec. The lens (2) transformed this velocity, increasing it a hundred fold. After scanning the film

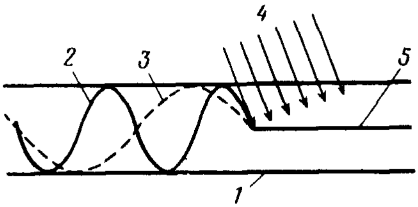

FIG. 3. Scheme for obtaining Doppler frequency shift as a result of reflection from disappearing metallic film: 1—waveguide, 2—incident wave, 3—reflected wave with changed frequency, 4—laser radiation that evaporates the film, 5—metallic film that blocks the waveguide.

(3), the beam burned through it, since its power density was high. During the burning the beam entered the holes in the plate (4) and was directed by the mirrors (5) onto the FEK-04 photodetector (6). Figure 2 shows oscillograms of the flashes. The velocity of the evaporation front was determined from the delay of one flash relative to the other. Even for the base distance of 3.5 m to the film this velocity exceeded 4×10^9 cm/sec, which demonstrated that very high metal–dielectric front velocities can be achieved.

A 2 to 3-mm-wide strip was burned away on the film. With a beam path length of 3.5 m and a laser flash energy of ~ 100 J, we can see that the energy density necessary for evaporating the film is of the order of fractions of a J/cm^2, in agreement with Refs. 1–3 and with studies made by us on the use of stretched films such as disappearing mirrors for pulsed reflection and shortening the duration of high-power light flashes and as vanishing mirrors of optical cavities that emit a high-power flash and terminate subsequent lasing.

3. The rapidly moving fronts of a metallic surface can be used to observe Doppler shifts and broadenings of the frequencies of light and radio waves, such as in the case depicted in Fig. 3. Let us assume that the metal film (5), located in the waveguide (1), blocks the propagation of the wave (2) along it. Thus, the disappearance of the film due to the action of the laser beam (4) causes a Doppler change in the frequency $\omega' = (1-\beta')/(1+\beta')\,\omega_0$ $(\beta' = u/C')$ of the reflected wave (3).

Strong reflection from the film can be ensured not only by selecting the film orientation along the electric field of the wave, but also by placing the film at certain points of the waveguide, which causes it to be blocked.

It is also possible to observe Cerenkov effects due to polarization or currents in the film at faster-than-light evaporation front velocities.

The high velocities of the edge fields in the film, because of its polarization as a result of connection to an electric potential or plasma heating, can also be used to accelerate particles.

The examined effect of high-velocity metal evaporation front attracts considerable interest not only because of the possibility of observing relativistic effects, but also because of the high transfer coefficients of properties at the front, which cause much stronger reflections and perturbations of fields than other possible nonlinear objects (moving and focus in nonlinear media[5]).

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