Artificial microburst dielectrics produced in laser–sol interactions

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The possibility of producing artificial dielectrics for electromagnetic radiation through the formation of microbursts at particles in laser-bombarded sol clouds is studied. The changes in the dielectric function and the possible reflection coefficients for electromagnetic waves at slabs of such dielectrics are calculated. Calculations are also carried out for refraction and focusing. Some possible applications are pointed out.

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The formation of microscopic laser bursts at inhomogeneities in a gas and in vacuum in laser beams[1–3] can cause not only a scattering of the electromagnetic radiation[2] but also changes in the effective dielectric function; i.e., there can be changes in the refraction and focusing of electromagnetic waves. In this letter we are reporting a study of the production and properties of microburst dielectrics.

1. Let us assume (Fig. 1) that a laser beam with an intensity $I > I_{\text{th}}$ is incident on a cloud of particles (a sol, a hydrosol, etc.), where I_{th} is the threshold for the formation of a microburst at each particle. The plasma cloud which forms has a polarizability

$$\alpha \cong \frac{\omega_r^2}{\omega_r^2 - \omega^2 + i\nu\omega}\, a^3 \sim a^3 \qquad \text{for } \omega_r > \nu \text{ and } \omega_r > \omega,$$

where ω_r is the resonant plasma frequency of the cloud ($\omega_r \sim \omega_p/\sqrt{3}$) for a quasispherical cloud, and a is the size of the plasma cloud, which may be many times the original dimensions of the particle, a_0. For extended plasma clouds of radius a and length l, and for radio waves polarized in the direction transverse to the axis of the clouds (this is the usual case in which the radio waves are incident from the side of the laser beam, since microbursts are frequently stretched out in the direction opposite the laser

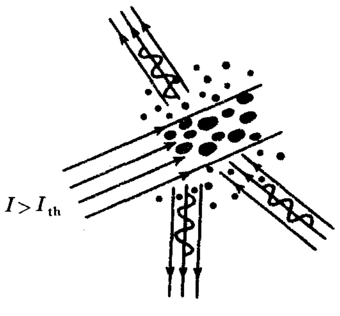

FIG. 1. Reflection and refraction of radio waves by a microburst dielectric.

beam), the polarizability is

$$\alpha \cong \frac{1}{2}\,\frac{\omega_r^2\, l a^2}{\omega_r^2 - \omega^2 + i\nu\omega} \cong \frac{1}{2} a^2 l \qquad \text{for} \quad \omega_r > \nu$$

or $\omega_r \gg \omega$, where $\omega_r \cong \omega_p/\sqrt{2}$. For dense clouds which are stretched out along the electric field of the radio wave, the polarizability increases sharply, $\alpha \sim l^3/2\ \ln(l/a)$ for $l \gg a$. The dielectric function, $\epsilon = 1 + 4\pi\alpha N$, may change considerably from its initial value $\epsilon = 1 + 4\pi\alpha_0 N$ by an amount $\Delta\epsilon \cong 4\pi\Delta\alpha N$, where α depends on the intensity I, the pulse length t, and the absorption of the light. This circumstance can be exploited to change the spatial distribution of the dielectric function by adjusting the laser intensity distribution.

2. An experiment was carried out to determine the conditions for the formation of, and the manifestation of, an artificial microburst dielectric.

A single-pulse neodymium laser (pulse length of 30 ns) produced a beam with an intensity $I \gtrsim 10^8$ W/cm^2, which was applied to a sol cloud (powdered B_4C with particle sizes $a_0 \cong 10\ \mu$m, microscopic water droplets, etc.) The particle concentration, $N \cong 10^3$ cm^{-1}, and the intensity I were chosen such that the microbursts did not overlap, forming a finely dispersed plasma structure (Fig. 2a) with emitting clouds $10^2\ \mu$m in size. The dimensions of the bursts were determined in order of magnitude by means of the laser-supported detonation wave: $l \sim v_D t \sim (I/\rho_0)^{1/3} t \sim 0.1$–3 mm. Under these conditions we obtained $\Delta\epsilon \cong 10^{-2}$–0.3, i.e., large changes in the dielectric function.

During laser bombardment of particles in 2 vacuum, the dimensions of the plasma clouds that fly out are $a \cong \mathrm{v}t$, where the high velocity is $\mathrm{v} \cong kT_0(Z+1)/2m_i$, T_0 is the initial heating temperature, Z is the charge of the plasma ions, and m_i is their mass; we thus find $\epsilon = 1 + 4\pi(\mathrm{v}t)^3 N$ and $\dot\epsilon \sim t^2$.

We might note that a microburst dielectric consisting of a multitude of plasma

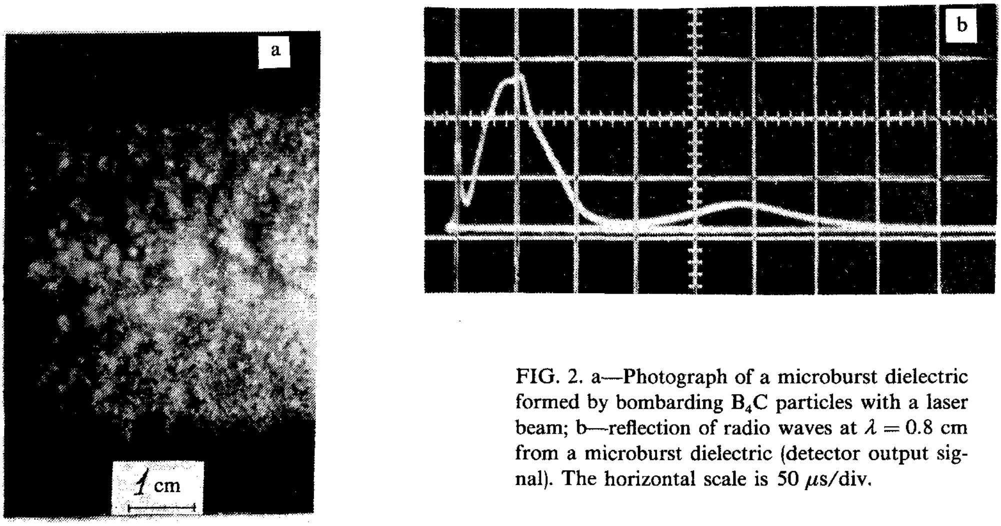

FIG. 2. a—Photograph of a microburst dielectric formed by bombarding B_4C particles with a laser beam; b—reflection of radio waves at $\lambda = 0.8$ cm from a microburst dielectric (detector output signal). The horizontal scale is 50 μs/div.

clouds at a high plasma density has an average value $\epsilon > 1$, in contrast with a uniform distribution of such a plasma, in which case we would have $\epsilon < 0$.

We studied the interaction of radio waves with a slab of an artificial dielectric of this type. The waves at $\lambda \cong 0.8$ cm from a GZ-30 oscillator were incident on a sol slab of this sort; during the laser bombardment, we studied the reflection of the radio waves and the arc-over. Figure 2b shows an oscilloscope trace of a reflection signal, which shows a high reflection capability. The maximum reflection was detected at the specular angle, showing that a slab of an artificial microburst dielectric is formed (the homogeneity condition $N\lambda\!\!\!^{-3} \gg 1$ was satisfied).

The change in the refractive index $\Delta n \cong \Delta\epsilon/2$ (with $\epsilon - 1 < 1$), can be found from estimates of the reflection coefficient:

$$R \cong \left(\frac{n-1}{n+1}\right)^2 \sim \frac{1}{4}(\Delta n)^2 \sim \frac{1}{16}(\Delta\epsilon)^2 \sim 0,1.$$

We find $\Delta\epsilon \sim 1$, i.e., rather large changes in the refractive index.

3. A slab of artificial dielectric with a distribution $n(r) \cong n(0) - Ar^2$

$$n \cong 1 + 2\pi\alpha(r)N \cong n(0) + 2\pi\{\alpha(r) - \alpha(0)\}N(r),$$

which is formed at a sol cloud of thickness L will cause a focusing to an angle $\theta \cong (\partial n/\partial r)L \cong 2ArL$; i.e., it focuses the wave at a distance $F \sim r/\theta \sim \frac{1}{2}AL$. The focusing properties of the lens can be changed by changing the distribution of the laser beam, $I(r)$ [in the case $\alpha \cong a^3 \sim IT\pi a^2 \sim q_1\pi a^2$, for example, a change in the energy density $q(r)$ leads to a pronounced change $\alpha(r) \sim q^3(r)$ for $a \gg a_0$ and $\alpha \sim q$ for $a_{\mathrm{abs}} \sim a_0$]. The absorption lengths for the laser beam, $L \sim (1/\pi)a^2N$, can be made quite large by shortening the laser pulses (if the main stage in the expansion of the plasma clouds occurs after the end of the laser pulse).

Artificial dielectrics can be used[4,5] to improve long-range reception, to transport radiant energy from space stations, in laboratory apparatus and experiments concerned with the production and use of media with parameters that are artificially varied over time, for both radio waves and light waves.

4. These artificial dielectrics have several properties of physical and practical interest.

They can also be used to study electrodynamic systems whose dielectric function varies rapidly over time, $\epsilon(t) = 1 + 4\pi\alpha(t)N$. In such a system,[6] one should observe pronounced changes in the wave amplitude and frequency (especially in the case of a resonator) during the motion of an ϵ-formation front and a modulation of the transmission and reflection (especially upon a change in the number of waves in the slab). In such systems it may be possible to observe emission from a charge at rest or in uniform motion and also from constant electric fields upon a change in the value of ϵ of part of the medium.

There may also be a change in the imaginary part of $\epsilon(t)$, in particular, as a result of a change over time in the electron collision rates and density. Some new types of absorption associated with the work performed by the field on particles with a variable polarizability may appear.[7] For example, a calculation of the work performed by the field on a system of conducting spheres of variable radius,

$$\dot{A} = \frac{E_\circ^2}{4\pi} N\dot{V}_1 = \frac{\partial I_{\text{radio}}}{\partial z},$$

gives $L_a = c/N\dot{V}_1 = 3c = \dot{\epsilon}$ as the depth for this absorption. This depth can become appreciable at high values of $\dot{V}_1$, the velocity at which the volume of each particle of the artificial dielectric is expanding rapidly.

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