PRODUCTION OF 'GIANT' PULSES OF SCATTERED RADIATION FROM PUMP WAVE SPOT RUNING OVER THE ELECTRON BEAM*

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Abstract

To generate ultrashort electromagnetic pulses it is suggested to scan a spot formed by pump wave along an electron beam. When pump spot velocity is equal to the group velocity of scattered radiation the short 'giant' pulse of scattered radiation with amplitude increasing proportional to interaction distance will be produced. The running spot of pump wave can be realized after reflection of frequency chirped laser beam from echelette grating.

INTRODUCTION

In [1] the generation of millimetre wave superradiance (SR) pulses have been observed in the process of stimulated backscattering of relatively long pump wave pulse by extended electron bunch with the length restricted by cooperative length (the distance of the scattered wave propagation during the time of instability growth up). Under such conditions the scattered radiation represented a single pulse with peak power strongly exceeding the level of spontaneous emission.

In this paper we study the alternative method of generation superradiance type pulses in the process of stimulated scattering when the relatively short spot illuminated by pump wave runs over the quasi-continuous electron beam. Obviously scattering and beam modulation take place only in area illuminated by pump wave. In the case when the pump spot moves with group velocity of scattered radiation the pulse of scattered radiation propagating along electron beam will be amplified continually by fresh (unmodulated) electrons due to difference between signal wave group velocity c and electron translational velocity $v_{||}$. As a result the peak amplitude of scattered pulse increases proportionally to shifting distance. The running spot of pump wave can be realized after passing (reflection) of frequency chirped laser pulse from frequency depended refraction system like prism or echelette grating (see Fig. 1). It should be noted that the shifting direction and velocity of the pump wave spot are not correlated with the phase and group velocities of this wave. For our purpose to obtain the large frequency conversion the direction of spot shifting should be approximately opposite to the group velocity vector.

In the case of scattering of laser radiation by a moderately relativistic electron beam with energy ~1-3 MeV above process can be used to produce intense SR pulses either at UV band (up frequency conversion), at terahertz band (down frequency conversion) or bands depending on direction of scattered wave propagation with respect to electron beam. Correspondingly at the first case illuminated spot should run together with scattered wave in the direction of electron motion while in the second case this spot together with scattered wave should run at opposite direction.

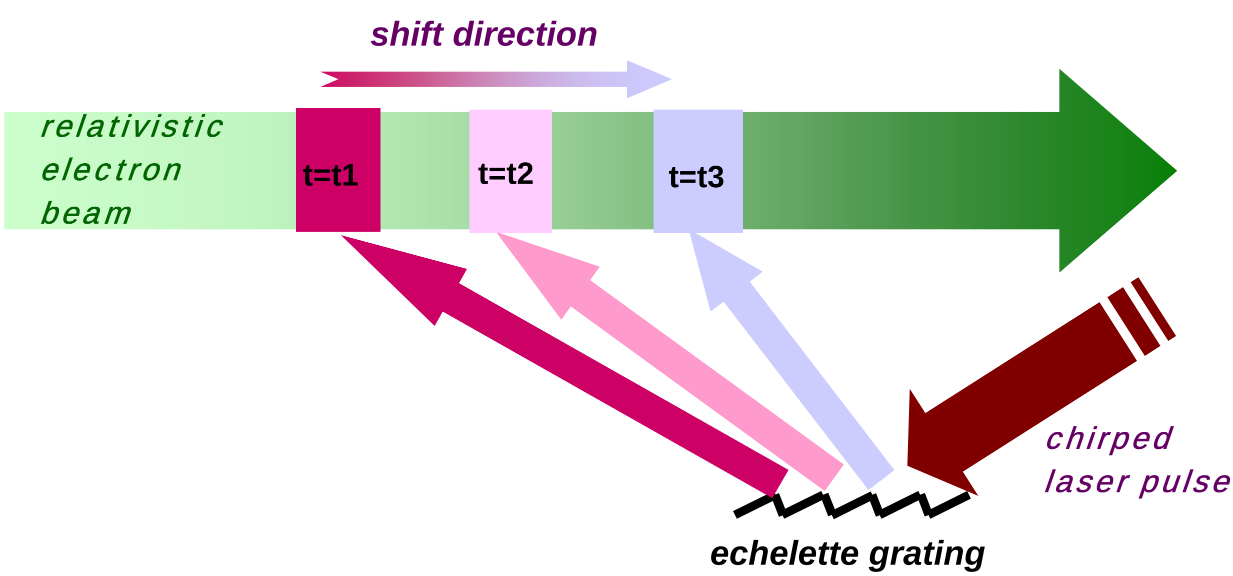

Figure 1: Echelette scheme of scanning of pump field spot using frequency chirped laser pulse.

*Work supported by … Russian Fund for Fundamental Researches, grant 05-02-17553
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MODEL AND BASIC EQUATIONS

Let us consider the process of stimulated scattering in situation when the spot illuminated by a pump wave runs along electron beam with velocity u in the direction of electron motion. In this case due to the Doppler effect the frequency of scattered radiation ω_s essentially exceeds the frequency of pump wave ω_i. Neglecting pump wave exhaustion the generation of pulses of scattered radiation in the above process can be described by the system of equations including the nonstationary equation for scattering signal amplitude and the averaged electron motion equations [2]:

$$\begin{aligned} &\left(\frac{\partial}{\partial z}+\frac{1}{c}\frac{\partial}{\partial t}\right)a_s = i\chi(t-z/u)k_c a_i I\,\frac{1}{\pi}\int_0^{2\pi} e^{-i\theta}d\theta_0 \\ &\left(\frac{\partial}{\partial z}+\frac{1}{v_{\|}}\frac{\partial}{\partial t}\right)^2\theta = \mu k_c^2\chi(t-z/u)\,Im\{a_s a_i^* e^{i\theta}\} \end{aligned} \quad . \quad (1)$$

Here $a_{i,s}=eA_{i,s}/m_0\gamma_0 c^2$ is the dimensionless amplitude of scattered and pump waves, $\theta=\omega_c t-k_c z$ is the electron phase respect to the combination wave, $\omega_c=\omega_s-\omega_i$, $k_c=\omega_c/c-\omega_i/c$, $\mu=\gamma_0^{-2}\beta_{\|}^{-3}$, I is the dimensionless parameter which is proportional to the beam current. Function $\chi(t-z/u)$ describes the profile of the spot illuminated by pump filed. Introducing the new independent variables

$$Z=C\frac{\omega_c}{c}z, \quad \tau=C\frac{\omega_c c(t-z/v_{\|})}{1/c-1/v_{\|}} \qquad (2)$$

and assuming that the velocity of pump spot is equal to the group velocity of scattered signal (u=c) Eqs. (2) can be presented in the form

$$\begin{aligned} &\frac{\partial a}{\partial Z}+\frac{\partial a}{\partial \tau} = -\frac{i}{\pi}\chi(\tau-Z)\int_0^{2\pi} e^{-i\theta}d\theta_0 \\ &\frac{\partial^2\theta}{\partial Z^2} = \chi(\tau-Z)\,Im\{a e^{-i\theta}\} \end{aligned} \quad , \qquad (4)$$

where $a=\mu a_s a_i^* C^{-2}$, $C=\left(\omega_p^2|a_i|^2\right)^{1/3}$ is the gain (Pierce) parameter. Under assumption that the development of instability starts from the small perturbation of electron beam density the initial and boundary conditions can be

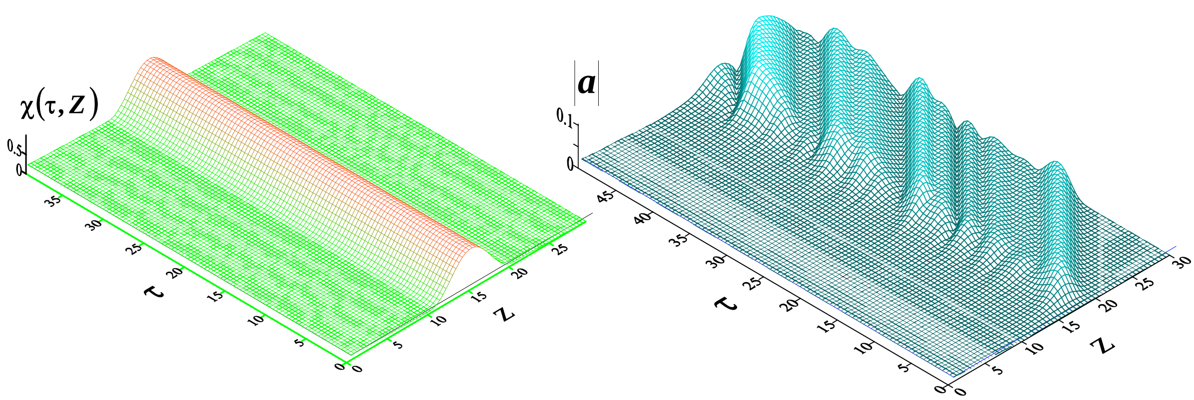

Figure 2: Production of the SASE signal in the case of standing pump field spot.

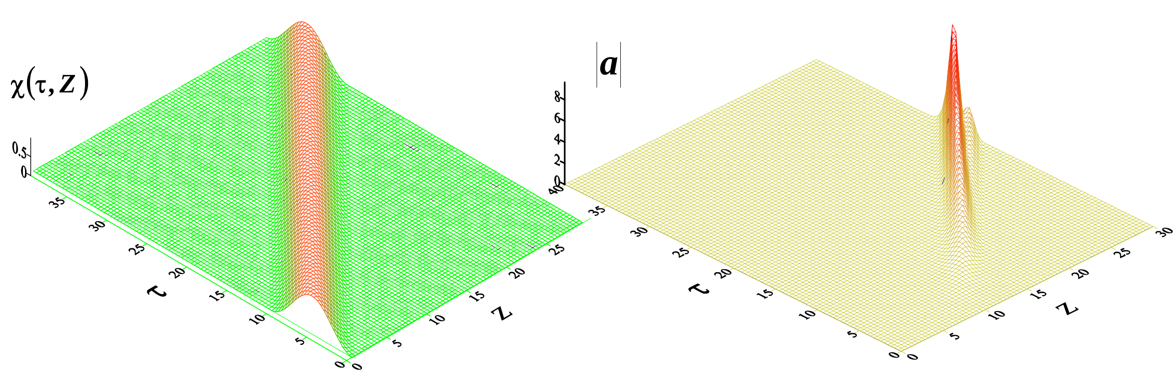

Figure 3: Production of ‘giant’ single pulse in the case of moving pump field spot.

written in the form

$$\theta\big|_{Z=0} = \theta_0 + r\cos(\theta_0 + \varphi(\tau)),\quad \theta_0 \in [0,2\pi],\ r << 1$$
$$\frac{\partial\theta}{\partial Z}\bigg|_{Z=0} = 0,\ a\big|_{Z=0} = 0 \qquad (5)$$

where $\varphi(\tau)$ is the random function.

SIMULATION RESULTS

Let's consider at first the traditional situation with the unmovable $u = 0$ bell-shaped pump spot: (see Fig. 2a). In this case, due to the slippage, radiation escapes from pump spot. As a result the well-known multi-spikes regime of SASE [3,4] is realized (Fig. 2b) when different parts of beam radiate practically independently.

The totally different situation takes place when the pump spot moves along the electron beam together with scattered signal: $u = c$ (Fig. 3a). But because electron velocity $v_{||}$ is slightly less than c. the interaction (scattering) spot slips along beam and the pulse of scattered radiation formed at initially stage of interaction propagates through the unmodulated electrons being effectively amplified (see Fig. 3b). As a result the scattered radiation represents the single short pulse with amplitude essentially exceeding the amplitude of spikes in the SASE regime (compare with Fig. 2b). In the ideal situation the amplitude of above 'giant' pulse growths proportionally to the interaction distance L (see Fig. 4).

It is important to note that due to short lifetime of individual electrons in the interaction spot above process is less sensitive to the spread of beam parameters in comparison with traditional steady state regime (see Fig. 5).

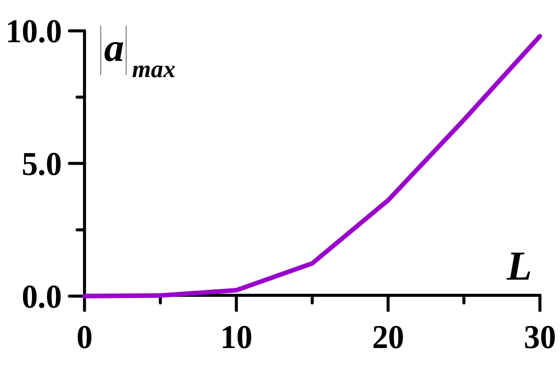

Figure 4: Dependence of pulse peak amplitude on the shifting distance.

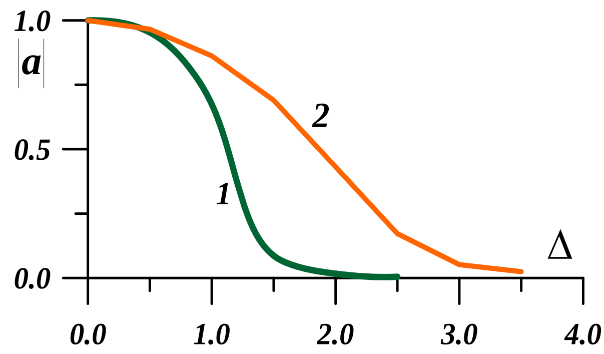

Figure 5: Dependence of radiation peak amplitude on electron velocity spread Δ for steady state regime (1) and 'giant' pulse regime (2).

CONCLUSION

In conclusion lets make preliminary estimations of possible experiments on backscattering of 10 μ CO_2 laser radiation by high current () relativistic electron beam. For electron energy 3 MeV scattered wavelength ~200 nm will belong to UV bands. For laser pump pulse with duration 1 ns the shift of pump spot will be about 30 cm. For power density of pump wave ~150 GW/cm^2 and current density 30 kA/cm^2 the gain parameter is $C \approx 6.3 \cdot 10^{-5}$. As a result for initial perturbation $r = 0.001$ the maximal power density of scattered radiation can achieved ~1 GW/cm.

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