# BACKWARD X-RAY TRANSITION RADIATION FROM MULTILAYERED TARGET FOR SUBMICRON BEAM DIAGNOSTICS *

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*Abstract*

In this work we develop the idea of diagnostics of short relativistic electron bunches with use of backward X-ray TR (transition radiation). As was shown by A.P. Potylitsyn et al, backward transition radiation from the single surface is too weak, and the enhanced mechanism is desired. So, in this paper we explore the spectral and angular characteristics of resonant backward X-ray TR from point of view of submicron beam diagnostics for the ultrarelativistic charged particles bunches. We show, that the multilayered structure may be rather effective target, and also show that the effects of interference of radiation fields from the layers lead to strong dependence on properties of the layers and the oblique incidence angle.

## INTRODUCTION

Backward transition radiation (TR) is a TR arising in the direction of mirror reflection relative to the charged particles trajectory. Therefore for oblique incidence it can be emitted under big angles which is useful from point of view of measuring of the radiation.

In spite of the fact that backward TR in X-ray frequency domain is much weaker than forward TR [1], it has recently been proposed by A.P. Potylitsyn and others [2, 3] as an instrument for submicron electron beam diagnostics.

So far X-ray TR has not been explored theoretically for backward geometry. In this work we deal with the idea to use the multilayered target in order to enhance the resulting radiation, i.e. to use resonant backward X-ray TR (the idea suggested by Prof. A.P. Potylitsyn). We show that the expressions obtained coincide in special case of forward resonant X-ray TR with the results by L. Durand [4] and X. Artru [5]. We explore the spectral and angular characteristics of resonant backward X-ray TR form point of view of submicron beam diagnostics for the ultrarelativistic charged particles bunches. The role of absorption in the target material is analyzed.

## TR FROM A SINGLE SLAB

We will consider the oblique incidence of the charge on the target (multilayered, generally speaking – see Fig. 1). In this part we will consider backward UV and X-ray TR from a single slab. The field of TR can be obtained with the method suggested by Loyal Durand [4] and developed in our recent works [1,6,7].

The charged particle field $\mathbf{E}^0(\mathbf{r},\omega)$ polarizes the substance and creates the polarization current density

$$\mathbf{j}(\mathbf{r},\omega)=\frac{\omega}{4\pi i}\left(\varepsilon(\omega)-1\right)\mathbf{E}^0(\mathbf{r},\omega) \qquad (1)$$

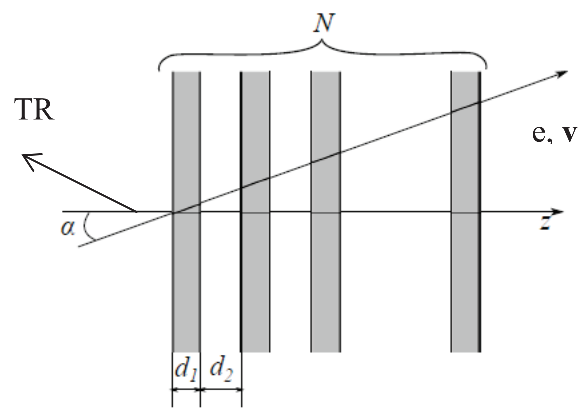


Figure 1. Charged particle generates backward UV and X-ray TR at oblique incidence on a stack of layers.

For UV and X-ray frequencies domain

$$\omega \gg \omega_p,\ \ \varepsilon(\omega)=1-\omega_p^2/\omega^2+i\varepsilon'', \qquad (2)$$

the radiation field can be obtained in form [1]

$$\mathbf{E}^R(\mathbf{r},\omega)=\frac{e\beta_z}{2\pi c}\frac{e^{ikr}}{r}\frac{(\varepsilon-1)\mathbf{n}\times\mathbf{n}\times\mathbf{h}}{\left(1-\beta_y\sin\theta\cos\phi\right)^2-\beta_z^2\cos^2\theta}\times$$
$$\times\frac{\exp\left(i\frac{\omega}{c}\frac{d_1}{\beta_z}\left(1-\beta_y\sin\theta\cos\phi+\beta_z\sqrt{\varepsilon-\sin^2\theta}\right)\right)-1}{1-\beta_y\sin\theta\cos\phi+\beta_z\sqrt{\varepsilon-\sin^2\theta}} \qquad (3)$$

where $\mathbf{k}=\frac{\omega}{c}\mathbf{n}$, $\mathbf{n}=\{\sin\theta_m\sin\phi,\sin\theta_m\cos\phi,-\cos\theta_m\}$,
$\mathbf{h}=\{\beta_z\sin\theta\sin\phi,\beta_z\sin\theta\cos\phi-\beta_y\beta_z,1-\beta_z^2-\beta_y\sin\theta\cos\phi\}$
$\sin\theta_m=\frac{1}{\sqrt{\varepsilon}}\sin\theta$; $\theta$ and $\varphi$ are the angles of observation. After that the spectral-angular characteristics of radiation are calculated as

$$\left.\frac{d^2W}{d\omega d\Omega}\right|_{(B)}=cr^2\left|\mathbf{E}^R(\mathbf{r},\omega)\right|^2 \qquad (4)$$

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The dependences of radiation on the oblique incidence angle $\alpha$ , target properties that are described by dielectric function $\varepsilon(\omega)$ and target thickness are shown at the Figures 2-4.

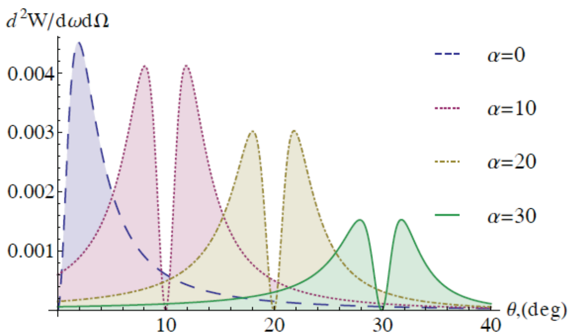



Figure 2. Angular distribution of radiation for lithium at $\gamma=30$, $\phi=\pi$, $d=1nm$, $\hbar\omega=100eV$ for different incidence angles.

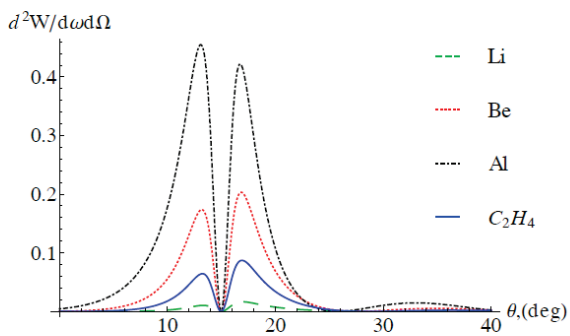



Figure 3. Angular distribution of backward TR for different target materials. Parameters: $\gamma=30$, $\phi=\pi$, $\alpha=15^0$, $d=50nm$, $\hbar\omega=100eV$.

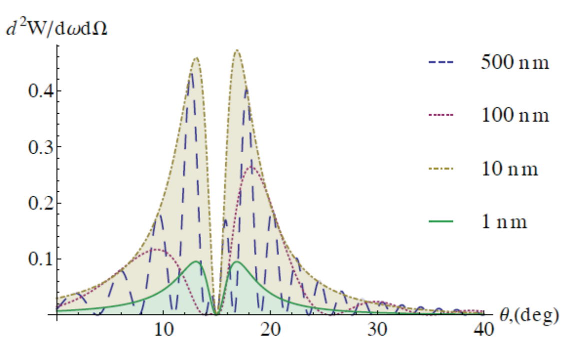
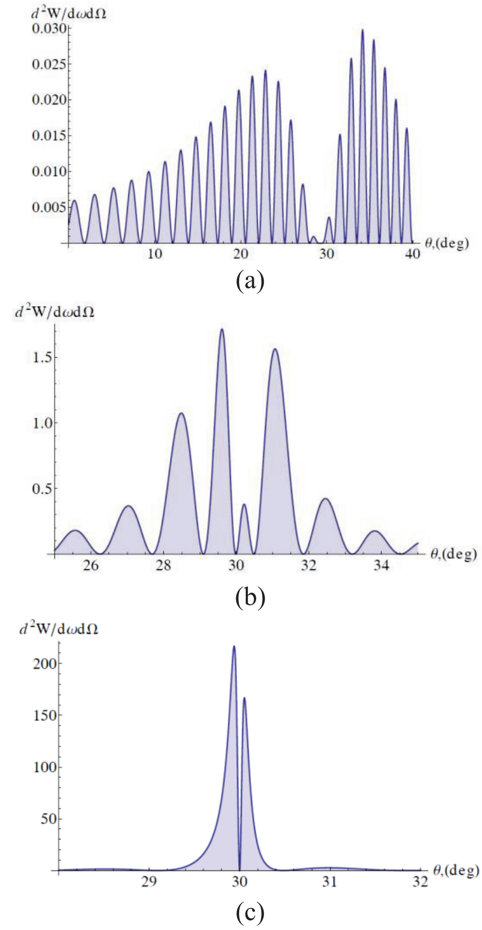



Figure 4. Angular distribution for different thicknesses of the target made from aluminum. Parameters: $\gamma=30$, $\phi=\pi$, $\alpha=15^0$, $d=50nm$, $\hbar\omega=100eV$.

The strong oscillations in dependence on these parameters take place when the argument of oscillating exponent in Eq. (3) is large.

The next three Figures 5. a,b,c demonstrates that the oscillations disappear when the Lorentz-factor that is directly proportional to the particles energy increases. At the energy big enough (Fig. 5c) the radiation distribution has the usual for TR form.




Figures 5. a,b,c. TR from aluminum target for different Lorentz-factors (a) $\gamma=10$, (b) $\gamma=100$ and (c) $\gamma=1000$; the other parameters are $\phi=\pi$, $\alpha=30^0$, $d=500nm$, $\hbar\omega=100eV$.

It should be noticed also that the TR characteristics depend on the absorbing properties of the target, which is shown at Fig. 6.

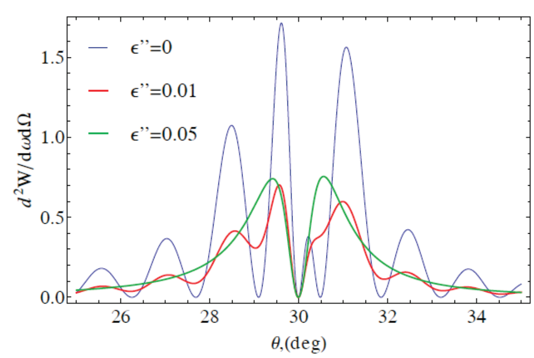



Figure 6. Angular distribution of TR from aluminum target for different values of imaginary parts of dielectric function $\varepsilon''$. The other parameters are $\gamma=100$, $\phi=\pi$, $\alpha=30^0$, $d=500nm$, $\hbar\omega=100eV$.

## TR FROM A STACK OF LAYERS

Let us consider the case of stack of $N_i$ layers with different properties $\varepsilon_i$ and thicknesses $d_i$, $i=1,2$ (see Fig. 1; $N=N_1+N_2$ ). When going through the i-th layer, the radiation acquires the phase

$$\phi_i = \frac{\omega d_i}{c\beta\cos\alpha}\times \times\left(1+\beta\sin\alpha\sin\theta\cos\phi+\beta\cos\alpha\sqrt{\varepsilon_i-\sin^2\theta}\right). \quad (5)$$

Then the total field of radiation is described by the sum

$$\mathbf{E}^R_{total} = \mathbf{E}_1\frac{1-\exp\left[iN_1(\phi_1+\phi_2)\right]}{1-\left[i(\phi_1+\phi_2)\right]}+ +\mathbf{E}_2\exp\left[i\phi_1\right]\frac{1-\exp\left[iN_2(\phi_1+\phi_2)\right]}{1-\left[i(\phi_1+\phi_2)\right]} \quad (6)$$

The field $\mathbf{E}_1$ here coincides with the one from Eq. (3). The field $\mathbf{E}_2$ is obtained this way and thus has the form

$$\mathbf{E}_2(\mathbf{r},\omega)=\frac{e\beta_z}{2\pi c}\frac{e^{ikr}}{r}\frac{(\varepsilon_2-1)\mathbf{n}(\varepsilon_2)\times\mathbf{n}(\varepsilon_2)\times\mathbf{h}}{(1-\beta_y\sin\theta\cos\phi)^2-\beta_z^2\cos^2\theta}\times \times\frac{\exp\left(i\frac{\omega}{c}\frac{d_1}{\beta_z}\left(1-\beta_y\sin\theta\cos\phi+\beta_z\sqrt{\varepsilon_2-\sin^2\theta}\right)\right)-1}{1-\beta_y\sin\theta\cos\phi+\beta_z\sqrt{\varepsilon_2-\sin^2\theta}}\times \times\left(\exp\left(i\frac{\omega}{c}\frac{d_2}{\beta_z}\left(1-\beta_y\sin\theta\cos\phi+\beta_z\sqrt{\varepsilon_2-\sin^2\theta}\right)\right)-1\right) \quad (7)$$

The Eq. (6) with Eqs. (3) and (7) in case $\alpha=0,\ N_1=N_2$ turns into results of papers [4, 5].

As it was shown by Victoria Sofronova [8], for TR of a bunch and uniform distribution the intensity has the form

$$\left.\frac{d^2W}{d\omega d\Omega}\right|_{(B)} = cr^2\left|\mathbf{E}^{\mathbf{R}}(\mathbf{r},\omega)\right|^2\times \times\left\{N+N(N-1)\left|\frac{4\sin(\omega l/2c\beta)}{c\beta/2l\omega}\frac{J_1(b\rho/2)}{b\rho/2}\right|^2\right\} \quad (8)$$

where

$$\rho=\frac{\omega}{c}\left[\frac{\sin^2\theta\left(\sin^2\varphi\cos^2\alpha+\cos^2\varphi\right)}{\cos^2\alpha}+ +\frac{\sin^2\alpha-2\beta\sin\theta\cos\varphi\sin\alpha}{\beta^2\cos^2\alpha}\right]^{1/2} \quad (9)$$

The coherent part of TR in relativistic case represents very sharp distribution. The analysis of it should be carried out separately; here we will give the plots describing incoherent part of radiation, corresponding to the first term in Eq. (8). The example of distribution is given in Fig. 7.

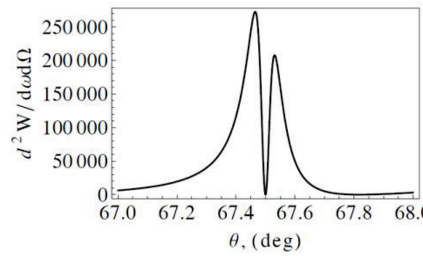



Figure 7. TR from a stack of layers: $N=10$, $\alpha=67.5^0$, $\phi=\pi$, $\hbar\omega=190\,eV$, $d_1=6.6nm$, $d_2=4.4nm$, $\gamma=1739.5$.

## CONCLUSION

In conclusion we would like to stress once more, that our estimations confirm that multilayered structure may be rather effective target in EUV and soft X-ray domain of radiation spectrum. It means that using multilayered structures might be very good way to enhance the EUV TR and use it for submicron relativistic beams diagnostics. On the other hand, we have demonstrated that the effects of interference of radiation fields from the layers lead to strong dependence on properties of the layers and on the oblique incidence angle, which strongly influence on the characteristics of radiation to be observed.

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