Laser and Particle Beams (2002), *20*, 161–163. Printed in the USA.

DOI: 10.1017/S0263034602202013

Influence of excited crystalline medium on interaction processes of ultrarelativistic electrons

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(Received 15 November 2001; Accepted 15 January 2002)

Abstract

New experimental results of investigations of the interactions of an intense 4.3-GeV electron beam with an aligned single crystal are given in the case when the electrons travel close to the crystalline planes (110). The growth of low energy radiation yields with the intensity of the electron beam and the peculiar properties of the produced γ-quanta at their passage through a small collimator aperture were observed. Large angular asymmetry at the scattering of low energy γ-quanta, which is evidence of high polarization of the radiation, was also detected. These unexpected phenomena may be stimulated by strong correlations of atomic excitations in crystals. The obtained results will be of use for understanding of the properties of both the excited crystalline medium and the mechanism of intense radiation under these conditions and also for practical applications of the radiation.

Keywords: Correlations; Excited atomic medium; Intense electron beam; Intense radiation; Polarization; Single crystal

1. INTRODUCTION

A substance may be excited both by an intense laser pulse and intense relativistic electron beams. The advantage of the latter is that the electrons under such conditions serve also as a diagnostic instrument for investigation of produced strong macroscopic fields in the crystal. This statement is based on earlier data (Aganyants *et al.*, 2000; Aganyants, 2001; A. Aganyants, 2001). The observed phenomenon consists of the fact that the radiation in crystal increases nonlinearly with the electron beam intensity. This intensity is a macroscopic parameter. Hence, the observed intense γ-radiation has a macroscopic nature and contains the information about the process in the excited medium. For this reason, the mentioned radiation is a principally novel kind of electron radiation. In A. Aganyants (2001), it was termed as the vacuum radiation. New experimental results given below shed some light on new properties of this radiation. The measurements were carried out using a 4.3-GeV intense internal electron beam of the Yerevan synchrotron and a diamond single crystal as the target. The produced radiation passed two collimators and sweeping magnets, entered the experimental hall and was absorbed in the Wilson's quantameter (Aganyants *et al.*, 2000) (Fig. 1).

2. EXPERIMENTAL RESULTS

1. In the first measurements, γ-radiation was detected by the missing energy of electrons. Here the synchrotron per se served as a spectrometer of missing energy. In such a case, the detection is made within a narrow low energy range and the intensity effect is strongly manifested. An increase in instantaneous beam intensity (i.e., the beam density) is achieved by inducing a faster beam dump. In this case, the main part of the beam is dumped on the diamond target at once. The electrons, the energy loss of which in the crystal is more than 1.5 MeV per revolution (synchrotron radiation losses) but no more than ~100 MeV, may be thrown out by the beam dump on the walls of the synchrotron vacuum chamber primarily near the crystal target. The produced showers will be partly detected with a scintillation counter S5 placed near the crystal. The relative monitoring of electrons interacting with the crystal was done with the quantameter. The measurement data are given in Table 1 for three orientations of the crystal when the γ-beam is collimated by a 6.7×6.7 mm^2 aperture. Contrary to A. Aganyants (2001), in the case of such an aperture, the radiation is completely absorbed in the quantameter. A sharp increase in

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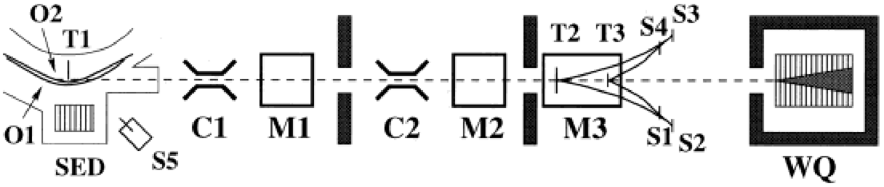

Fig. 1. The experimental setup: T1: diamond target; T2, T3: targets of pair magnetic spectrometer; C1, C2: collimators; M1, M2: sweeping magnets; SED: secondary emission detector; S1–S4: scintillation counters of pair spectrometer; S5: scintillation detector; WQ: Wilson's quantameter; O1: equilibrium orbit of electrons; O2: orbit for electron interactions with target T1.

the counting rate with electron intensity is seen in Table 1 for the crystal orientation $\psi = 0$, when electrons pass the crystal parallel to planes (110) and angle of electron incidence $\psi = 0.34$ mrad. So, the cross section of the electron radiation grows with electron beam intensity (density).

2. Similar to Item 1, analogous measurements were carried out using two different collimators with 6.7×6.7 mm^2 and 3.3×3.3 mm^2 apertures. And here the quantameter served as a γ-beam monitor. Counting rates N_d of the scintillation detector for the same quantameter data, that is, the normalized N_d/N_q rates, are given in Table 2. As is seen in Table 2, here the normalized counting rates N_d/N_q of the detector differ from one another; they depend on the collimator aperture at $\psi = 0$ and do not depend on the value of incidence angles of electrons for $\psi = 0.76$–1.1 mrad. They differ sevenfold instead of the expected fourfold or less due to the ratio of aperture areas. The unexplained twofold difference indicates that some part of the low energy radiation produced in diamond under the above conditions does not pass through the smaller aperture.

Our estimates show that all anomalous phenomena are observed when the density of the pulsed electron current of synchrotron injector exceeds the value of 3–5 μA/mm^2 when the pulse duration is 0.7 μs.

3. An interesting phenomenon was observed when on the path of γ-quanta produced under the same conditions as in Item 2, a 1.5-cm thick polystyrene target was installed. The γ-quanta scattered on the target in a forward direction at the angle of 20 mrad were detected by the scintillation counter S6 (not shown in Fig. 1) that was set at the distance of 4.5 m from this target above the collimator C1 (Fig. 1). In Table 3, the normalized counting rates $N_\perp$ and $N_\parallel$ of this detector are given for two cases when the electrons travel in diamond parallel to one of two mutually perpendicular equivalent planes (110). The measured asymmetry $A = \Sigma \cdot P = (N_\parallel - N_\perp)/(N_\parallel + N_\perp)$ of detected photons is large. This means that the polarization of γ-beam P should also be sufficiently high, as the asymmetry Σ of the cross section of processes has to always be higher than the measured asymmetry A. The origin of such a large asymmetry in the process of small angles scattering of low energy γ-quanta is unknown.

3. CONCLUSION

To understand the described phenomena (not observed so far on other accelerators), further experimental (especially of radiation spectra depending on the electron beam intensity) and theoretical studies of this effect are required. However one can consider the influence of excited medium on the processes of electron interaction in question qualitatively as follows: The first relativistic electrons of a bunch traveling through the crystal excite atoms and/or knock electrons off the atomic shells, as a result of which the electromagnetic vacuum near these atoms is excited. In case of a high intensity electron beam, the correlations of excitations in this nonequilibrium process are increased in the range of characteristic frequencies of atoms and their higher order harmonics. Therefore, the wave and coherent properties of such a medium, relativistic electrons, and related γ-quanta are manifested increasingly stronger with the intensity of the electron beam. It is not excepted that the mentioned system can turn from amplification into generation mode. High polarization and high intensity of radiation

Table 1. *The normalized counting rates N_d/N_q of the detector S5 for some orientations of crystal planes (110) at different intensities of electron beam; the diamond crystal was 100 μm thick*

Orientation of crystal plane (mrad)	Slow beam dump	Faster beam dump
$\psi = 0.97$	175 ± 7	$2 \cdot 10^3$
$\psi = 0.34$	928 ± 30	$0.52 \cdot 10^6$
$\psi = 0$	$10.1 \cdot 10^3$	$1.32 \cdot 10^6$

Table 2. *The normalized counting rates of the detector S5 for different orientations of 100-μm thick crystal for two apertures of the collimator*

Orientation of crystal plane (mrad)	Aperture 6.7×6.7 mm^2	Aperture 3.3×3.3 mm^2
$\psi = 0.76$	820 ± 28	—
$\psi = 1.1$	—	751 ± 27
$\psi = 0$	$98 \cdot 10^3$	$710 \cdot 10^3$

Table 3. *Normalized counting rates of the detector S6 of scattered low energy γ-quanta in the case of electron passage close to two mutually perpendicular planes and the asymmetry A of scattering*

$N_{\parallel}$	$N_{\perp}$	A
$152 \cdot 10^3$	$16.2 \cdot 10^3$	0.81

do not contradict this scenario. Apparently, one has to seek for possible explanations of the observed phenomenon (Items 1–3) in this direction.

It is worthwhile to note that irrespective of any explanation, the intense low energy radiation may be of use for different practical applications (Aganyants, 2001).

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