STUDIES OF POLARISATION OF COHERENT THz EDGE RADIATION AT THE ANKA STORAGE RING *

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Abstract

In synchrotron radiation sources coherent radiation is emitted when the bunch length is comparable to or shorter than the wavelength of the emitted radiation. At the ANKA storage ring this radiation is observed as so-called edge radiation (emitted in the fringe field of a bending magnet). This radiation exhibits a radial polarisation pattern. The observed pattern, however, is influenced by the radiation transport in the beam line. A detector system based on a superconducting NbN ultra-fast bolometer with an intrinsic response time of about 100 ps as well as conventional Si bolometers were used to study the beam polarisaion. This paper reports the observations made during measurements.

INTRODUCTION

Coherent synchrotron radiation (CSR) is emitted from electron storage rings for wavelengths equal to or larger than the length of the electron bunches (see for example [1–3]). The high-intensity CSR typically covers the frequency range up to about 1.5 THz. In the emission of coherent radiation, the amplitudes of the electromagnetic fields add up linearly, resulting in a quadratic enhancement of the radiation's intensity. The total power radiated by a bunch consisting of N particles can be expressed as

$$P_{\text{total}} = NP_{\text{incoherent}}\,(1 + N\, f_\lambda)$$

where f_λ is a form factor describing the effect of the longitudinal charge distribution in the bunch. For a Gaussian charge distribution with RMS length σ_s the form factor is given by $f_\lambda = \exp\left(-(2\pi\sigma_s/\lambda)^2\right)$. This shows that the radiated intensity for a given wavelength will increase with decreasing bunch length.

At the ANKA synchrotron radiation facility the emitted radiation is generated in the fringe field of the bending bending magnets, as so-called edge radiation. Edge radiation has the advantage of being more collimated than regular dipole radiation, thus allowing longer wavelengths to pass than would otherwise be possible. In contrast to main field dipole radiation, the spatial emission characteristics shows an annular pattern very similar to that of coherent transition radiation. Figure 1 shows a calculation of the spatial intensity distribution of synchrotron edge radiation at a frequency of 3 THz at the source point using the SRW code. The polarisation of the emitted radiation is radial.

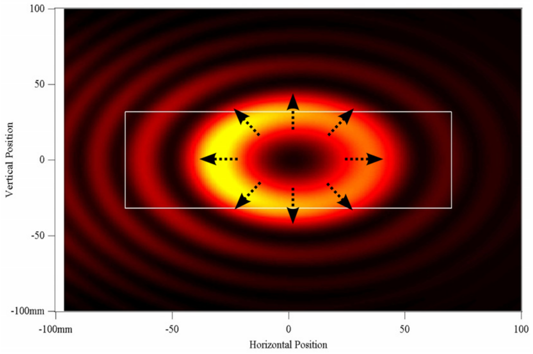

Figure 1: Calculated spatial intensity distribution of synchrotron edge radiation at a frequency of 3 THz at the source point. The typical annular characteristic is clearly visible. The direction of polarisation is indicated by the overlaid arrows.

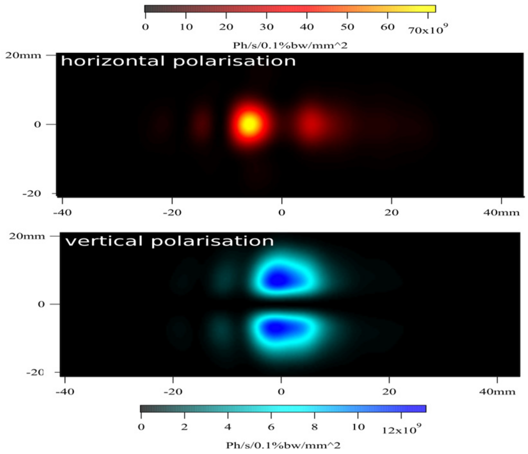

Figure 2: Calculated spatial intensity distribution at the final focus point in the ANKA-IR1 beamline. The upper image shows the horizontal, the lower image the vertical polarisation of the incident THz radiation. The vertical fraction is significantly reduced in intensity so that the overall polarisation can be considered as dominantly linear.

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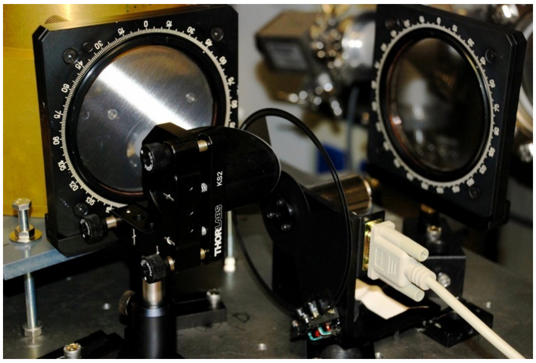

Figure 3: Photograph of the measurement setup in the ANKA-IR1 beamline showing the configuration with a Silicon bolometer, chopper and polariser plus analyser.

Due to the transport of the radiation from source point to detector, the influence of mirrors and apertures along the beamline have to be taken into account. Figure 2 shows the calculated change to the spatial distribution at the focus point. The first mirror (indicated in Figure 1) cuts away a fraction of the initial distribution. The resulting intensity at the focus is shown in Figure 2 in its horizontal (upper part) and vertical (lower part) components. The right hand side horizontal component is about a factor 2-3 less intense than the left hand side. The intensity reduction with respect to the dominant horizontal component is even more pronounced so that the overall polarisation can be considered as dominantly linear.

THE HOT ELECTRON BOLOMETER

A detector system based on a superconducting NbN ultra-fast bolometer [4] with an intrinsic response time of ≈100 ps was used. The system was jointly developed by the University of Karlsruhe (Institute of Micro- and Nanoelectronic Systems) and the German Aerospace Center (Berlin). The NbN bolometer is embedded into a planar log-spiral antenna which is integrated with an elliptical silicon lens. The detector covers the spectral range from 10 to 150 cm^{-1} mainly determined by the antenna [5]. The response to a few picoseconds long radiation pulse had the full width at half maximum of 165 ps that was defined by readout electronics. A system noise equivalent power of $6 \times 10^{-9}\,\mathrm{W\,Hz}^{1/2}$ was optically measured for cw radiation at 0.8 THz.

MEASUREMENTS

For the polarisation studies the ANKA storage ring was operated in the so-called low-α_c mode for operation with short bunches at a beam energy of 1.3 GeV. In order to cover a larger intensity range a multi-bunch filling pattern was chosen. The measurements of polarisation presented in this paper were performed at the diagnostics port of the ANKA-IR1 beamline [6]. The THz radiation was deflected onto the detector using an off axis paraboloid mirror so that the beam waist of the radiation is matched to the antenna pattern of the detector. The wire grid polariser was placed between mirror and detector system. For a determination of the background a second grid polariser was placed between diagnostics window and mirror to select a polarisation direction. The residual background intensity was found to be very small. Figure 3 show a photograph of the setup. To understand the influence of the detector system on the observed polarisation behavior a detector system based on a Silicon (Si) bolometer was used in addition to the above mentioned HEB system. In this case the detection is very slow (time scale 100 μs) and a chopper and lock-in amplifier were used for the data acquisition. The HEB signal was simply recorded with a high bandwidth (6 GHz) oscilloscope. To increase the measurement accuracy averages over 100 consecutive revolutions were taken.

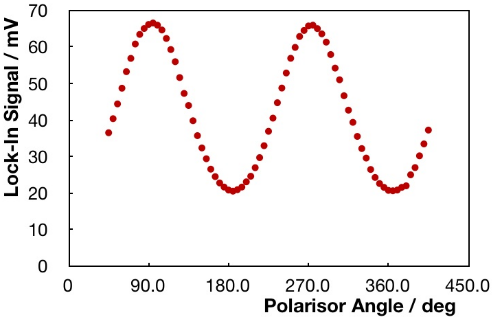

Figure 4: Polarisation measured with a Silicon bolometer. A polarisor setting of 90 deg corresponds to a polarisation in the orbit plane as indicated in Figure 2. The polarisation characteristics is mainly linear with components of other polarisation directions with less then half the amplitude of the main polarisation direction. With setup of Figure 3 a background of about 5 mV was determined.

Figure 4 shows the polarisation behaviour measured with

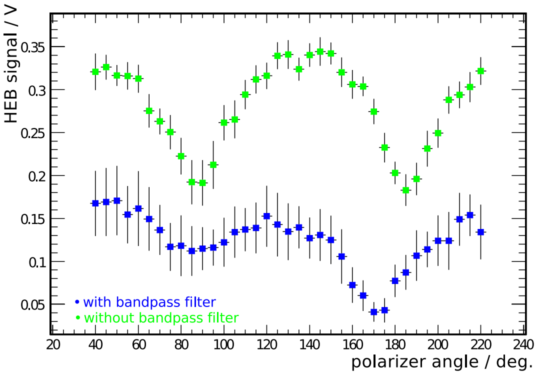

Figure 5: Polarisation measured with a detector system based on a hot electron bolometer. The green points represent a measurement without the blue points with the bandpass filter. The fact that the first minimum seems less expressed for the dataset with filter could indicate a frequency dependent polarisation of the detector system.

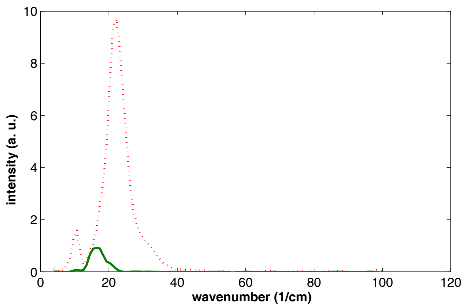

Figure 6: FTIR spectrum of emitted coherent synchrotron edge radiation at the ANKA-IR1 beamline without (dashed curve) and with a custom made bandpass filter [7] (solid curve).

the Si bolometer. The polarisation characteristics is mainly linear with components of other polarisation directions with less then half the amplitude of the main polarisation direction. With the setup of Figure 3 a background of about 5 mV was determined. The measurements with the HEB system are displayed in Figure 5. In contrast to the Si bolometer datasets these measurements show a quadrupole-like behaviour with a minimum of the signal both around 90 and 180 degrees. Datasets with and without a bandpass filter to reduce the spectral bandwidth are shown. The filter characteristics can be seen in Figure 6 where the effect of the filter on a FTIR spectrum of the emitted coherent synchrotron edge radiation at the ANKA-IR1 beamline is shown.

DISCUSSION

Both measurements with Si and HEB detector systems clearly indicate the existence of more than one direction of polarisation in the incident THz beam. The Si detector is not polarised whereas the HEB has an elliptical polarisation that might be frequency dependent. The fact that the bandpass visibly softens the first minimum and therefore makes the behaviour more similar to the Si datasets underlines the likelihood of a frequency dependence within the HEB detector system. To understand the observations, a simple three component model of the THz beam polarisation composed of two regions with vertical polarisation of opposite sign and one with horizontal polarisation after the SRW calculations shown in Figure 2 was used. Assuming that the regions don't overlap on the Si detector the (incoherent sum) signal intensity can be written as

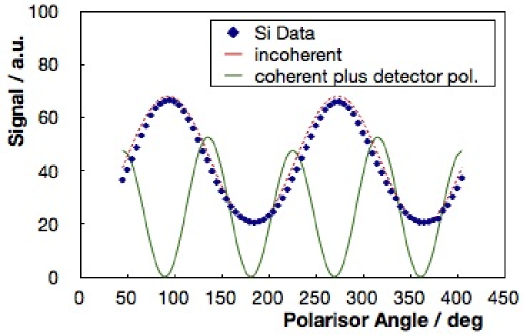

Figure 7: Simple three-component model of polarisation in comparison with the Si bolometer measurements according to Eq.(1) (dashed line) and Eq.(2) (solid line). The second case shows a behaviour similar to the observed one displayed in Figure 5.

$$I = A\sin^2\phi + B\cos^2\phi = (A-B)\sin^2\phi + B \quad (1)$$

where A and B are the total intensities of the horizontal and vertical components, respectively, and ϕ is the polariser angle. This is shown as the dashed curve in Figure 7. Assuming for simplification that the HEB is sensitive to only one polarization direction and in addition that the partial beams overlap and thus interfere when focussed on the detector, one expects an intensity modulation of the form

$$I = ((\tilde{A}\sin\phi + \tilde{B}\cos\phi)\cos(\phi-\alpha))^2 \quad (2)$$

which at least qualitatively can explain the observed behaviour. Here α stands for the angle of the detector's polarisation preference with respect to the vertical axis.

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