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ScienceDirect

Nuclear Instruments and Methods in Physics Research A 580 (2007) 190–193

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Fast infrared detectors for beam diagnostics with synchrotron radiation

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Available online 13 May 2007

Abstract

Beam diagnostic is a fundamental constituent of any particle accelerators either dedicated to high-energy physics or to synchrotron radiation experiments. All storage rings emit radiations. Actually they are high brilliant sources of radiation: the synchrotron radiation emission covers from the infrared range to the X-ray domain with a pulsed structure depending on the temporal characteristics of the stored beam. The time structure of the emitted radiation is extremely useful as a tool to perform time-resolved experiments. However, this radiation can be also used for beam diagnostic to determine the beam stability and to measure the dimensions of the e^- or e^+ beam. Because of the temporal structure of the synchrotron radiation to perform diagnostic, we need very fast detectors. Indeed, the detectors required for the diagnostics of the stored particle bunches at third generation synchrotron radiation sources and FEL need response times in the sub-ns and even ps range. To resolve the bunch length and detect bunch instabilities, X-ray and visible photon detectors may be used achieving response times of a few picoseconds. Recently, photon uncooled infrared devices optimized for the mid-IR range realized with HgCdTe semiconductors allowed to obtain sub-nanosecond response times. These devices can be used for fast detection of intense IRSR sources and for beam diagnostic. We present here preliminary experimental data of the pulsed synchrotron radiation emission of DAΦNE, the electron positron collider of the LNF laboratory of the INFN, performed with new uncooled IR detectors with a time resolution of a few hundreds of picoseconds.

PACS: 85.60.Gz; 07.77.Ka; 07.85.Qe

Keywords: Beam diagnostic; Synchrotron radiation; Bunch length; Fast photon detectors; Infrared detectors

1. Introduction

Beam diagnostics with synchrotron radiation is a powerful and well-established tool used in electron and positron storage rings. Synchrotron radiation beam diagnostics are usually used for imaging and allow measuring the beam cross-section as well as the longitudinal structure, i.e. the bunch length. This latter application needs extremely fast photon detectors with a resolution time ranging from sub-nanosecond to a few picoseconds. The knowledge of the bunch length is important in an electron storage ring to investigate its beam dynamics. The most common methods used to monitor the bunch length employ streak cameras, a technique that returns an image of the temporal structure of the beam with a resolution time of about 1 ps or below, or small button electrodes [1].

Alternative methods measure the time domain or the frequency by a Fourier transform of the electrical signal at

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0168-9002/$ - see front matter
doi:10.1016/j.nima.2007.05.081

the output of fast photon detectors. The principal advantage of the photon beam diagnostic is that it is a direct and non-destructive method. In addition, it is significantly cheaper than a streak camera based system. However, previous experiences in beam diagnostics at storage rings highlighted the importance to employ different methods and compare the measurements of the bunch lengths [2].

Different fast photon detectors have been already used in electron and positron storage rings covering the range from infrared to X-ray wavelengths. The most used are: avalanche photodiodes, InGaAs Schottky photodiodes, PIN Si photodiodes, diamond detectors, photon counting detectors, etc. [2–8]. The bandwidth of these fast photon detectors is limited to about 25 GHz or higher cut-off frequencies allowing detection of light pulses with a FWHM of tens or few hundreds of picoseconds. Recently new technological capabilities have allowed the development of fast infrared detectors working at room temperature and optimized to detect NIR and mid-IR wavelengths.

Infrared photon detectors are sensitive to a large wavelength range: from approximately 1 μm to about 200 μm, a region that is typically divided in three main energy domains: NIR (1–5 μm), mid-IR (5–20 μm), far-IR (20–200 μm). Fast photon detectors are photo-electromagnetic, photo-conductive or photo-voltaic uncooled IR devices optimized for the mid-IR range [9]. They are built using HgCdTe semiconductor crystals and allow obtaining sub-nanosecond response times. These uncooled detectors may efficiently work with brilliant and fast sources as quantum cascade lasers, free electron lasers or synchrotron light sources [10].

Preliminary experimental data of the pulsed synchrotron radiation emission with uncooled IR detectors has been performed at DAΦNE, the collider of the LNF laboratory of the INFN, achieving a resolution time of about few hundreds of picoseconds. In this paper, we will describe the experimental setup, present the experimental results and give a brief description of potential beam diagnostic applications based on this detector technology.

2. Experimental setup description

DAΦNE is an e^+/e^- collider, with center of mass energy at 1.02 GeV, designed to operate at high current levels (>2 A) and up to 120 bunches [11]. DAΦNE could work with different bunch structures, presently, it operates by filling 105 consecutive electron buckets out of the available 120, with a gap of 15 bunches to avoid ion trapping in the electron beam. In this bunch configuration, the minimum bunch distance is 2.7 ns and the maximum single-bunch current is ~20 mA. Bunches (supposed to be identical) are characterized by a quasi-Gaussian shape with a duration in the range of 100–300 ps FWHM. To observe the light, we need a port and at DAΦNE an IR photon beam is extracted from a bending magnet located in the external arc section of the electron ring. Indeed, since 2001 an infrared SR beamline is operational at DAΦNE: Synchrotron Infrared Beamline At DAΦNE (SINBAD). This beamline is dedicated to Infrared Interferometry and Microscopy and collects the radiation emitted by one of the DAΦNE bending magnets at wavelengths from about 10 to 10,000 cm^{-1} (1–1000 μm). [12].

Measurements with different single-element uncooled photon detectors have been performed at DAΦNE to detect the pulsed structure of the IR emission at the end of the SINBAD beamline [13]. The infrared detectors have been placed at the focus of the last toroidal mirror at the entrance of the interferometer. The experimental setup used to monitor the DAΦNE SR emission is briefly summarized below.

A 1 mm^2 single-element uncooled photoconductive detector has been placed at the focus of the last toroidal mirror of the SINBAD beamline, after a diamond window separating the high vacuum inside the beamline from the interferometer station working at lower vacuum pressure or at atmospheric pressure. The SINBAD optical system demagnifies the source image by a factor 2.3 at the final focus and its size is about $1.5 \times 2.0\,mm^2$ at mid-IR wavelengths. The IR device is a high-speed photoconductive detector, manufactured on a tertiary HgCdTe semiconductor substrate, operating at room temperature and optimized at 10.6 μm. This device is front-side illuminated and the absorption of the radiation at any wavelength occurs in the narrow energy gap absorbing layer. All IR detectors used in the experiments have been produced by VIGO System Ltd.

The detector was biased by a current of about 20 mA through a bias tee (model MiniCircuits ZFBT-4R2G) using a 500 Ω resistor connected in series to its DC input. The bandwidth of the bias tee was 10–4200 MHz. The output amplified by two-linear voltage amplifiers configuration was characterized by an input impedance of 50 Ω, a bandwidth of 0.05 MHz–1 GHz, a voltage gain of about 20 dB and a Noise-Figure (NF) of 3.5 dB. The signals have been analyzed by an oscilloscope model Tektronix TDS 820 with a bandwidth of 6 GHz and a rise time of 58.3 ps. In order to suppress the high-frequency background noise detected using single-shield RG58 cables detector, amplifiers and scope were connected by double-shielded RG223 cables.

3. Experimental results

Fig. 1 shows the filling pattern constituted by 105 electron bunches separated by 2.7 ns and the gap between the last and first bunch detected with the IR photodetector with the setup described above. The total current was 664 mA.

Fig. 2 shows the signal of a single bunch measured by the PC detector. The bunch current in this measurement was about 2 mA. The FWHM of a single pulse has been estimated to be about 600 ps. The estimated rise time is