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SCHOTTKY DIODE DETECTORS FOR MONITORING COHERENT THZ SYNCHROTRON RADIATION PULSES*

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Abstract

Examination of the wideband zero-bias Schottky diode detector as an instrument for monitoring synchrotron radiation delivers the intrinsic diode response time to terahertz synchrotron radiation of less than 6 ps along with the three orders of magnitude dynamic range and a noise equivalent power of 10 pW Hz$^{-1/2}$. This allows one to control simultaneously the spectrum and the stability of the amplitude and duration of single-bunch pulses of the coherent THz synchrotron radiation.

INTRODUCTION

Coherent synchrotron radiation (CSR) in the terahertz (THz) frequency range from electron storage rings is a powerful tool for user application and diagnostics of the electron-beam. The emission spectrum and pulse duration of the THz CSR depends sensitive on the shape and size of the electron bunch from which the radiation is emitted [1]. On the other hand, extremely high brilliance promotes CSR to a powerful source for spectroscopy in the terahertz frequency range [2]. The ultimate spectral resolution of this technique depends on the stability of the source radiation. Among available direct THz detectors only superconducting micro-bolometers [3, 4] and Schottky diodes [5] are capable to resolve CSR pulses from adjacent electron bunches. Here we present recent photoresponse measurements of CSR with a quasioptical zero-bias Schottky diode detector which was produced at ACST GmbH.

SCHOTTKY DIODE DETECTORS

The zero-bias Schottky diodes with different monolithically-integrated broad band planar antennas are fabricated using thin-film process [6]. Diodes were mounted on the rear side of a 6-mm (radius) lens from silicon with large room-temperature resistivity and packaged into the standard detector modules. Modules contain either low-noise amplifiers for moderate signal modulations (DC to 2 MHz) or a microwave (0.1 to 6 GHz) amplifiers. Alternatively, the diode can be directly connected to the outer connector of the module by means of the ultra-wideband transmission line. The detector modules with different amplifiers are shown in Figure 1. Typical spectral sensitivity of the zero-bias Schottky diode detector (SDD) without an amplifier is shown in Figure 2. The spectrum was obtained with the Fourier transform spectroscopy (FTS) and normalized to the spectral sensitivity of a Golay Cell detector which was measured with the same FTS instrument.

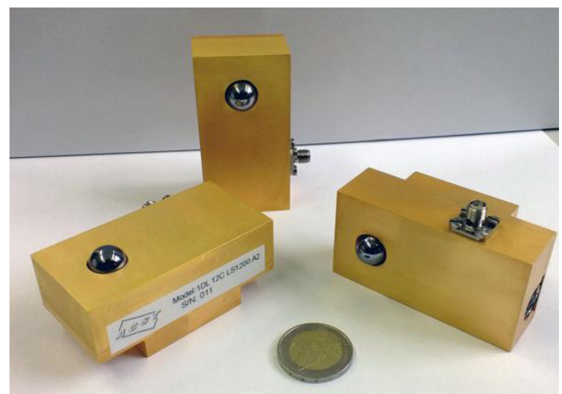

Figure 1: A photograph with commercially-available standard Schottky diode detector modules incorporating the detector and different amplifiers.

CSR RESULTS

The Physikalisch-Technische Bundesanstalt (PTB), the German national metrology institute is operating the low-energy electron storage ring Metrology Light Source

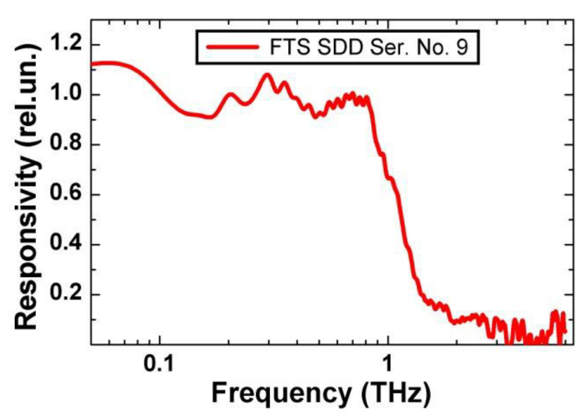

Figure 2: FTS spectral sensitivity of the typical ´Schottky diode without an amplifier. It was normalized to the spectral sensitivity of a Golay Cell detector.

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(MLS) in Berlin-Adlershof in close cooperation with the Helmholtz-Zentrum Berlin (HZB). The MLS is designed and prepared for a special machine optics mode (low-α operation mode) [1] for the production of coherent synchrotron radiation in the THz region. Measurements described below were performed at a bending-magnet beam line optimized for THz synchrotron radiation [7].

Below the bursting threshold [1], the CSR pulse energy is relatively low that results in voltage amplitudes of the response transients at the diode well below 100

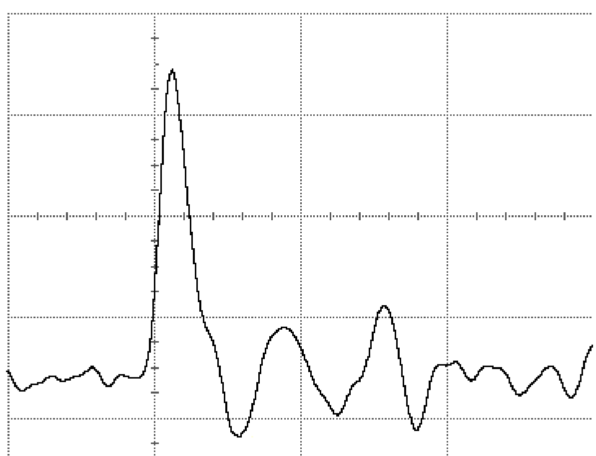

Figure 3: Real-time response of the Schottky diode detector to the CSR pulse of a single electron bunch. Horizontal span is 400 ps. The symmetric part of the response transient has the full width at half maximum less than 20 ps.

microvolts. Futher amplification is necessary to visualize or record these transients. Consequently, the recorded response of a Schottky diode detector to CSR pulses strongly depends on the readout electronics. Although an increase in the bandwidth of the readout improves the time resolution in the record, it also increases electronic noise that sets the smallest detectable energy of the CSR pulse. At larger ring currents, above the bursting

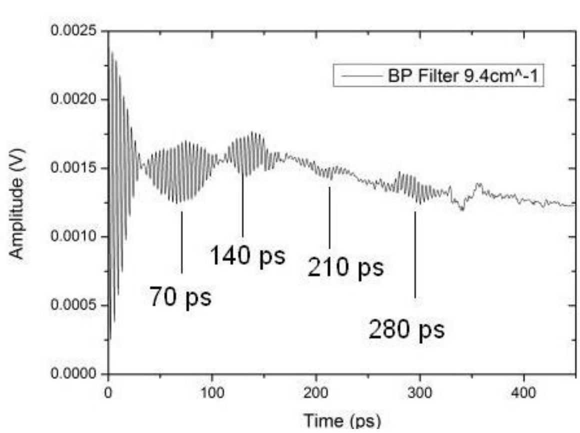

Figure 4: Interferogram of the CSR after a band-pass filter which was measured by a combination of the Schottky diode detector and Martin-Puplett interferometer.

threshold, the CSR pulse energy becomes sufficiently large to allow for recording the detector response without preliminary amplification. However, jitter in the arrival time of electron bunches [8] reduces the overall time resolution.

Figure 3 shows the response of the detector without amplifiers to THz CSR pulse from a single electron bunch. For these settings of the storage ring the full width at half maximum (FWHM) of the synchrotron emission in the visible range was 10 ps. The FWHM of the symmetric

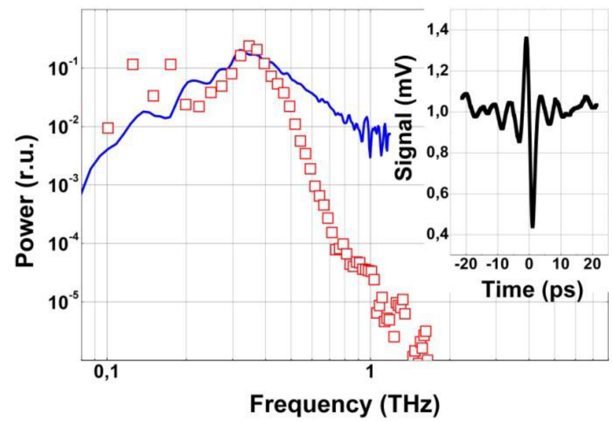

Figure 5: CSR spectrum measured with the standard FTS instrument and a slow broad-band bolometer (solid line) and the spectrum obtained as the Fourier transformation (symbols) of the interferogram. Inset displays the interferogram which was measured with the Schottky diode detector and the Martin-Puplett interferometer.

part of the detector response was less than 20 ps. This corresponds to the readout bandwidth of 18 GHz which was set by the coaxial cable connecting SDD with the real-time oscilloscope. We therefore expect the intrinsic response time of the detector to be less than 6 ps. Figure 4 shows the interferogram which was obtained with the same SDD and a Martin-Puplett interferometer (MPI). For these measurements the optics of the beam line was changed and the CSR was pre-filtered with a 9.4 cm^{-1} band-pass filter in order to have the time stamp. The interferogram clearly reproduces three satellites in the real-time transient with the same time-marker and hence supports the suggestion that they are caused by the reflections in the diode coupling optics.

We further compare the CSR spectrum measured with a slow bolometer and the standard FTS instrument with the spectrum measured with SDD. Both spectra are shown in Fig. 5. They were measured at the same settings of the storage ring. For the measurements with SDD we used MPI and averaged the response over many bunches. The spectrum was obtained as the numerical Fourier transformation of the recorded interferogram (see the inset in Fig. 5). The odd-symmetry of the interferogram is the consequence of the circular polarization of the planar antenna, which couples radiation to the Schottky diode. The spectrum represents a convolution of the true CSR

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spectrum and the spectral sensitivity of the detector. They practically coincide at low frequencies while above 0.8 THz the spectral density obtained with SDD decreases faster than the FTS spectral density. This correlates with the decrease in the spectral sensitivity of SDDs above 1 THz as it is seen in Fig. 1. The decrease in the spectral sensitivity of SDDs at high frequencies is most likely connected with the intrinsic capacitance of the diodes. We do not expect any noticeable variations in the radiation coupling efficiency via the planar antenna and the lens at frequencies less than a few terahertz.

In conclusion, we have demonstrated applicability of the zero-bias Schottky diode detectors for monitoring coherent synchrotron radiation. SDD is capable of controlling simultaneously the bunch-to-bunch stability of CSR and its average spectral density. Schottky diode detectors exhibit a broad-band spectral response with a strong roll-off above 0.8 THz. The intrinsic response time is expected to be less than 6 ps along with the intrinsic jitter of less than 2 ps. Non-saturated responsivity of the detector, which relates the amplitude of the voltage transient to the total CSR pulse energy in the detector quasioptical mode, was approximately 1.5 mV/fJ. The dynamic range of the detector spans almost three orders of magnitude from 3 fJ to 1 pJ.

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