CHARACTERIZATION OF MLS THZ RADIATION AT A DEDICATED BEAMLINE

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Abstract

The Physikalisch-Technische Bundesanstalt (PTB), the German national metrology institute, is operating the low-energy electron storage ring Metrology Light Source (MLS) in Berlin-Adlershof in close cooperation with the Helmholtz-Zentrum Berlin (HZB). The MLS is designed and prepared for a low-α machine optics mode based on a sextupole and octupole correction scheme, for the production of coherent synchrotron radiation in the FIR and THz region. Here we present first results from the commissioning of a dedicated THz beamline.

INTRODUCTION

In recent years, the strength of electron storage rings as unique sources of IR radiation has become apparent and is increasingly being exploited around the world [1, 2]. A rapidly growing number of IR beamlines at several storage rings has been realized or is planned taking advantage of this unique IR light sources. Synchrotron radiation sources have major advantages in the IR range compared to conventional thermal sources: (1) higher photon flux in the far-IR, (2) higher brilliance, (3) pulsed radiation in the ps range, (4) polarized radiation, and at a few storage rings [3, 4] (5) intense coherent synchrotron radiation (CSR) in the lower energy part of the far-IR (sub-THz to THz) with gain up to 6 to 9 orders of magnitude compared to conventional synchrotron radiation emission. The new dedicated low-energy storage ring MLS serves PTB as a radiation source for the THz, IR, visible to the soft X-ray range with special flexibility in its operation parameters [5]. The electron energy of the MLS can be tuned to any value from 105 MeV up to 630 MeV and the electron beam current can be adjusted in the range from one stored electron (1 pA) up to 200 mA. The MLS can be operated with parameters optimized for special calibration tasks, which, at a multi-user facility such as BESSY II, is only rarely possible. Additionally, the MLS is the first electron storage ring worldwide designed and prepared for low-α operation mode based on the octupole correction scheme, for the production of CSR in the far-IR and THz region. This option strengthens the MLS as a strong THz radiation source [4, 5]. CSR from storage rings could bridge the gap between microwaves and black body radiation since it offers powerful broadband radiation in the frequency range below 1.5 THz and allows imaging at the diffraction limit, ellipsometry and time-resolved spectroscopy including pump-probe experiments [6, 7].

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THE MLS THZ BEAMLINE

At the MLS three beamlines dedicated to the use of IR and THz synchrotron radiation are operational: (1) The undulator IR beamline provides edge radiation from NIR to FIR and with the long period undulator U180 installed, high flux in the MIR spectral range (up to 20 µm for an electron energy of 200 MeV), (2) a dedicated THz beamline optimized for the FIR/THz spectral range, and (3) the MLS-IR beamline optimized for the MIR to FIR [8]. At the adjusted IR beamline we were able to make first measurements in the THz spectral range [9].

All IR beamlines consist of an arrangement of mirrors which allows - in combination with a special port of the dipole chamber – the transport of the beam to the experiment. After all mirror reflections the σ-polarization of the electrical wave vector of the radiation is horizontally oriented. The propagation of sub-terahertz electromagnetic waves from the source point to the experiment through a typical IR beamline is strongly affected by diffraction. This is why we decided to build a dedicated THz beamline with large extraction optics and a larger window (Fig. 1).

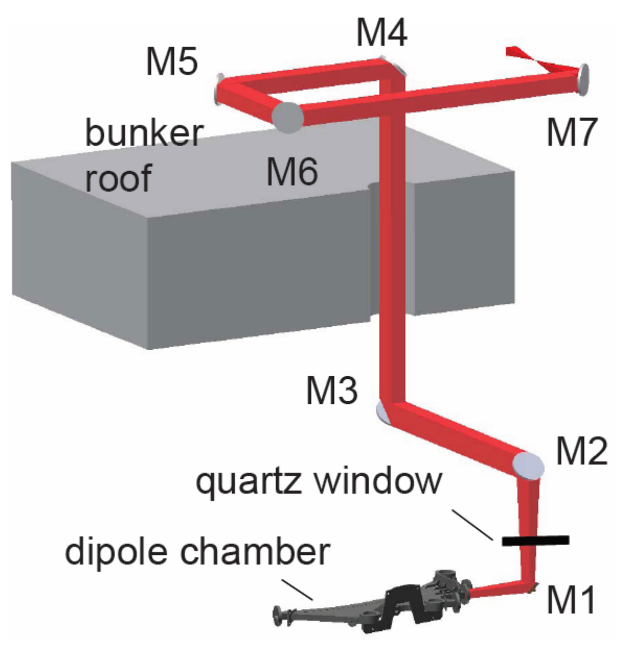

Figure 1: Layout of the MLS THz beamline. For details see text.

The cylindrical extraction mirror M1 allows - in combination with a special port of the dipole chamber - a horizontal and vertical collecting angle of 64 mrad (h) × 43 mrad (v). M1 is placed at a distance of 1550 mm from the source, the first position possible outside the vacuum chamber of the dipole magnet. M1 and M2 collimate the THz radiation horizontally and vertically, respectively. Both mirrors are cylindrical and deflect the beam by 90° upwards (M1) and towards (M2) the storage ring. A quartz window with a diameter of 130 mm after the first mirror M1 separates the UHV of the storage ring from the rest of the beamline. The following optical elements M3 to M6 are planar mirrors and transport the beam to the toroidal mirror M7. M7 focusses the beam and sends it to the experiment. Radiation safety requires this complex optical path. The nominal diameter of the beamline tube is 250 mm throughout the THz beamline.

COMMISSIONING RESULTS

Low-α Mode at the MLS

Under normal operation of the MLS at 630 MeV, high ring currents, and bunches of about 5 mm length (1 σ bunch length) the measured far IR power is temporally smooth and varies linearly with beam current, as expected for incoherent synchrotron radiation. When the bunch length is shortened, bursts of radiation are emitted (see Fig. 2a and Fig. 2b. The time structure is rather complex and varies with operating conditions.

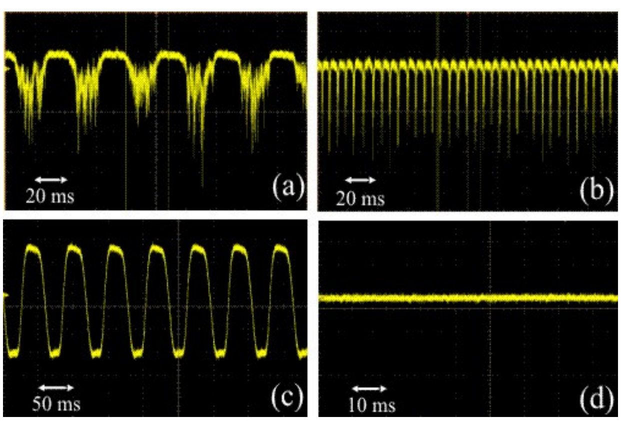

Figure 2: Oscilloscope traces of bursting and stable THz signals at MLS for 630 MeV electron energy, low-α optics, and a cavity voltage of 200 kV measured with an InSb-detector: Bursting at 50 mA ring current: The chopped THz signal amplitude (a) and the unchopped THz signal amplitude (b) show bursting instabilities. Stable THz radiation at 19 mA ring current: The chopped THz signal amplitude (c) and the unchopped THz signal amplitude (d) are constant and show no bursting instabilities.

At MLS the bunch length can be adjusted by varying different parameters like α-value, ring current, and cavity voltage. For a fixed rf-voltage the bunch length is proportional to $\alpha^{1/2}$, where α is the momentum compaction factor. By lowering α, the bunches become shorter. The MLS has a unique possibility, to control the higher orders of α and to achieve bunch length reductions by more than a factor 10 in the sub-mm range. The higher orders of α are controlled by suitably placed sextupoles and octupoles [10].

Three low-α operation optic modes for different ring energies, 350 MeV, 450 MeV and 630 MeV are operational [10]. Additionally, at the MLS we have the opportunity to produce short bunches in normal operation at lower ring energies but the bursting power is about two orders of magnitude lower than for low-α operation at high energies [9]. Stable CSR can also be obtained. Figure 2 shows the results for the low-α mode at 630 MeV and a ring current of 19 mA. Figure 2c shows the chopped detector signal in the THz spectral region. The signal amplitude is only dependent on the rf-voltage. Without chopping, the signal amplitude is smooth and shows no signs of bursting instabilities (see Fig. 2d). So the THz radiation is stable within the time resolution of a liquid-helium-cooled InSb hot electron bolometer of few micro-seconds.

Optical Beam Path and Focus

First measurements with calibrated filter radiometers and an IR-camera in the visible and near infrared spectral range reveal the very good adjustment of the optical path of the THz beamline. All the flux expected from theoretical calculations is measured at the experiment. The shape and size of the focus is also as good as expected. Figure 3 shows the focus of the THz radiation (all radiation with a wavelength longer than 500 µm) in the low-α mode at the THz beamline. Its FWHM size is approximately 4 mm in diameter and is located at the same position as the focus of the visible and near infrared light.

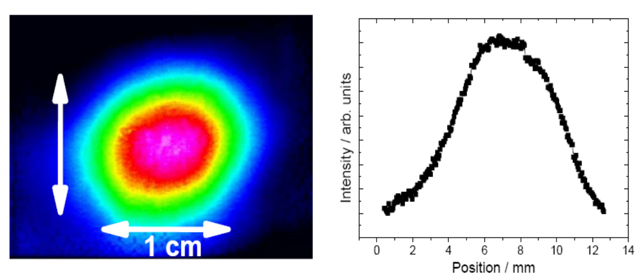

Figure 3: Left: Focus of the THz beamline after mirror M7 (see Fig. 1). Right: Beam profile of the focussed THz radiation.

Spectrum

Figure 4 shows a typical FTIR spectrum in the low-α mode at the MLS. It was taken with a state of the art rapid scan FTIR spectrometer extended for THz applications by a special silicon beamsplitter. The spectral resolution was set to 0.25 cm^{-1}. The THz spectrum covers the range from 1 cm^{-1} to 20 cm^{-1}. The power gain compared to the normal operation mode is in the range of 5 to 6 orders of magnitude. The modulation in the spectrum is caused by the silicon beam splitter.

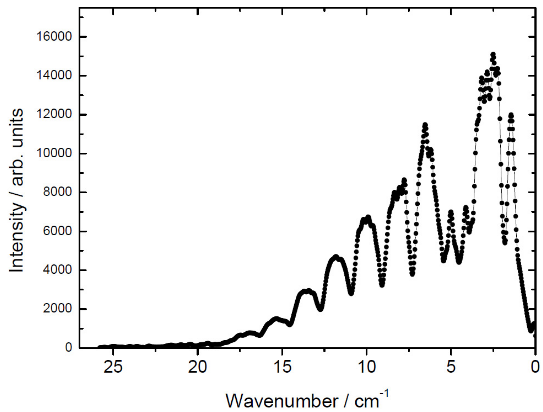

Figure 4: Typical FTIR spectrum at the MLS THz beamline in the low-α mode for 630 MeV. The spectrum is taken in the bursting mode.

For long wavelength the spectrum is expected to be limited by shielding effects of the vacuum chamber. The "cut off" wavelength can be approximated by

$$\lambda_{\text{cut off}} \approx \sqrt{\frac{6h^3}{\pi\rho}} \quad (1)$$

where h is the full vertical aperture of the dipole chamber and ρ the bending magnet radius of the electron orbit in the dipole magnet [7]. Due to this condition the long wavelength part of the radiation is suppressed. For the MLS the "cut off" wavelength can be calculated with Eq. 1 to a value of around 7 mm. From Fig. 4 one can clearly derive a peak with reasonable intensity at about 1.4 cm^{-1} which corresponds to the wavelength of 7 mm and fits very well with the calculation.

Up to now the short wavelength part of the CSR spectrum is limited to about 20 cm^{-1}. There are several effects which could suppress the high frequency part, such as intra beam scattering or ion trapping [10, 11]. In case of emitted CSR bursts the bunches expand in phase space and suppresses further bursts within the damping time. This mixture of effects could possibly suppress the THz signals.

Power

We measured the absolute averaged THz power in the focus of the IR and THz beamline using a Thomas Keating power meter [12]. These measurements were done with a set of filters blocking the visible, NIR and MIR radiation. At the IR beamline the measured power is depending on the chosen α in the range of a few hundred micro-watts. At the THz beamline with larger optical elements and different transmission windows compared to the IR beamline more than two orders of magnitude more power was measured in the THz range (see Fig. 5). The highest average THz power of about 60 mW gives with the machine parameters of the MLS a peak power of about 35 W.

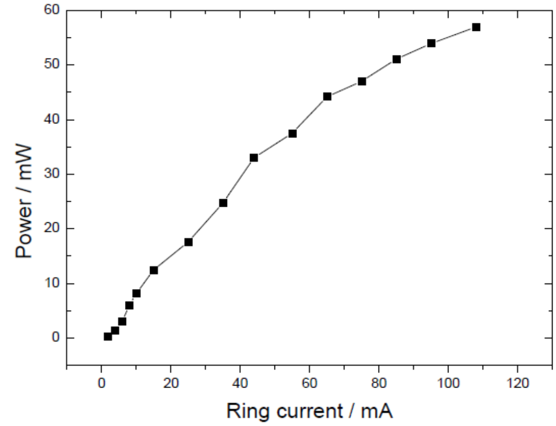

Figure 5: Averaged THz power measured in the focus of the THz beamline. Data were taken in low-α operation at an electron energy of 630 MeV.

SUMMARY

The MLS as one of the few low-energy storage rings worldwide is expected to be an ideal IR synchrotron radiation source. A special mode of operation allows the production of CSR and thus the production of THz/FIR radiation with enhanced intensity making the MLS an promising radiation source for THz metrology. A dedicated beamline provides this radiation at the experiments. PTB will continue to optimize the MLS as an IR and THz radiation source in a systematic and quantitative way based on well characterized optical components and calibrated detectors [13, 14]. Radiometry, spectroscopy and microspectroscopy will be performed after setting up dedicated experimental stations and typical instrumentation (FTIR spectrometers, microscopes, bolometers) at the beamlines.

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