First commissioning results in the IR/THz range at the electron storage ring Metrology Light Source

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Abstract—**The Physikalisch-Technische Bundesanstalt (PTB) has set up a low-energy electron storage ring in Berlin-Adlershof in close cooperation with the BESSY GmbH. The Metrology Light Source (MLS) is the first machine designed and prepared for a special machine optics mode (low-α operation mode) based on an octupole correction scheme, for the production of short bunches and coherent synchrotron radiation (CSR) in the FIR/THz spectral range. In our contribution we present first commissioning results which clearly indicate that the MLS in combination with dedicated beamlines offers intense, stable, and well focussed THz radiation.**

I. Introduction

Synchrotron radiation sources have major advantages in the IR range compared to conventional thermal sources, higher photon flux in the far-IR, higher brilliance, pulsed radiation in the ps range (the light is emitted from electron bunches which allows fast time-resolved measurements), and polarized radiation. Additionally, electron storage rings can deliver intense coherent synchrotron radiation (CSR) in the lower energy part of the far-IR (sub-THz to THz) with gains up to 6 to 9 orders of magnitude higher than conventional, incoherent synchrotron radiation emission [1, 2, 3].

The MLS has been designed and is operated by the BESSY GmbH to meet PTB's demands for a permanently accessible radiation source mainly for radiometry and metrology with high stability and reproducibility. The electron energy of the MLS can be tuned to any value from 100 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 [4, 5, 6]. 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 establishes the MLS as a strong THz radiation source [4, 5, 7, 8].

II. IR and THz beamlines at the MLS

At the MLS three beamlines dedicated to the use of IR and THz synchrotron radiation are under construction respectively 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), (2) a THz beamline optimized for the FIR/THz spectral range, and (3) the MLS-IR beamline optimized for the MIR to FIR [8]. All results presented here were taken at the MLS-IR beamline.

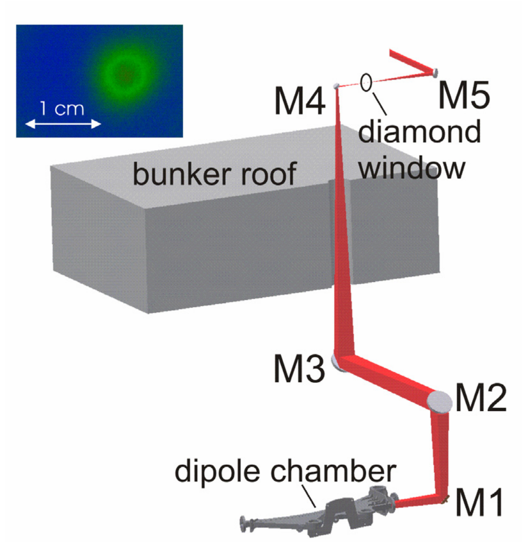

Fig. 1. Optical design of the MLS-IR beamline. The inset shows the focus of the CSR taken with an infrared camera in the THz spectral range in the low α mode.

The beamline consists 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.

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 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. With this adjusted beamline we were able to make first measurements in the THz spectral range. The inset of Fig. 1 shows the focus of the THz radiation (all radiation with a wavelength longer than 500 µm) in the low α mode. Its FWHM size is approximately 3 mm in diameter and is located at the same position as the focus of the visible and near infrared light.

III. Coherent synchrotron radiation at MLS

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 [1, 2]. Intense CSR can be generated if electron bunches become shorter than the emitted wavelength [3]. Then all the electrons in a bunch emit synchrotron radiation in phase. The CSR intensity is proportional to the square of the number of electrons per bunch in contrast to the linear dependence of the usual incoherent radiation. Since the number of electrons per

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bunch is typically very large (≥ 10^8), the potential intensity gain for a CSR source is huge. During the past few years, at BESSY II a new technique to generate stable, coherent THz radiation from the electron storage ring has been developed [9, 10]. The option to produce CSR is also envisaged for the MLS. Additionally, at the MLS we have the opportunity to produce short bunches in normal operation at lower ring energies and ring currents [7].

Under normal operation of the MLS at 630 MeV and high ring currents, and bunches of about 5 mm 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. The time structure is rather complex and varies with operating conditions. Typically, bursts occur with varying amplitude and at time intervals ranging from 1 ms to 10 ms. The growth rate and time decay of these bursts is faster than the resolution of our used detectors. We measured the time-averaged bursting power with a LHe-cooled Si bolometer in combination with a lock-in amplifier and a set of THz filters. Fig. 2 shows the detector signal as a function of ring current. One can clearly see that the ratio between signal and ring current is not linear as is expected for incoherent synchrotron radiation. So the result provides a strong hint for the existence of CSR.

The MLS has a unique capability, to control the higher orders of α and to achieve bunch length reductions by a factor 10 in the sub-mm range. The higher orders of α are controlled by suitably placed sextupoles and octupoles. By careful tuning of the optics, stable CSR is generated at the MLS.

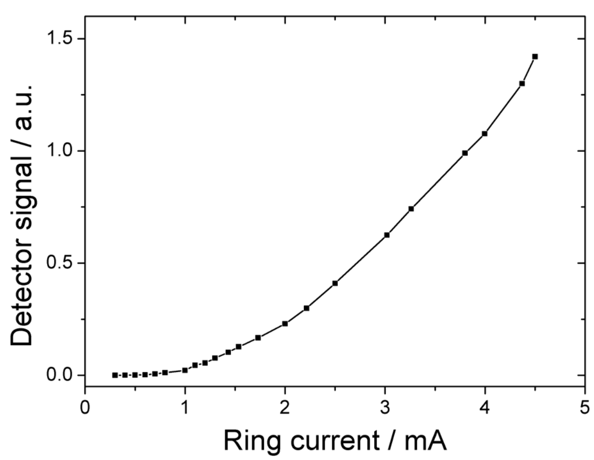

Fig. 2. Detector signal of the emitted radiation in the THz spectral range as a function of stored ring current. The measurements were done in the low α mode at 630 MeV with a LHe cooled Si bolometer.

A first proof of stable CSR has been obtained. Fig 3. shows the results for the low α mode at 630 MeV and a ring current of 19 mA. Fig. 3a 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. 3b). So the THz radiation is stable within the time resolution of a liquid-helium-cooled InSb hot electron bolometer of few micro-seconds. Furthermore, with the dedicated low α optics the MLS has the potential to produce reliable and stable 0.3 ps rms long electron bunches ideally suited for time resolved measurements [3].

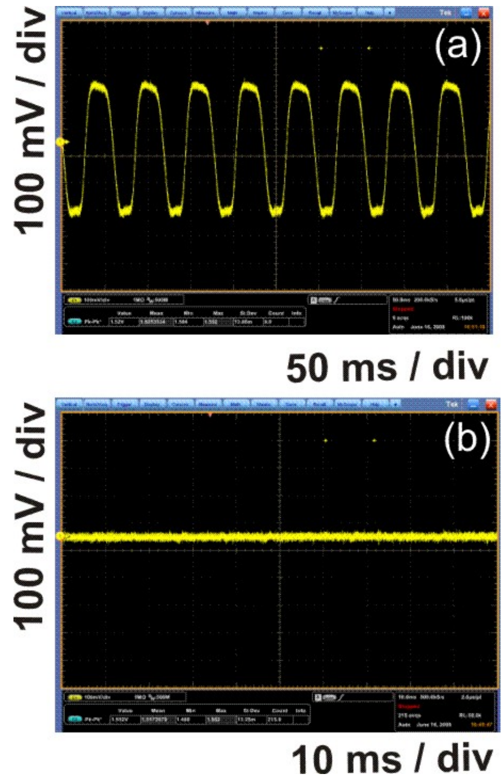

Fig. 3. Oscilloscope traces of stable THz signals at MLS for 630 MeV electron energy, low α optics, 19 mA ring current, and a cavity voltage of 200 kV measured with an InSb-detector: (a) The chopped THz signal amplitude. (b) The unchopped THz signal amplitude is constant and shows no bursting instabilities.

IV. Summary

In summary, the MLS project is well under way. The MLS-IR beamline is well adjusted and ready for measurements in the infrared and THz spectral range. At the MLS we have the opportunity to produce short bunches in normal operation at lower ring energies and ring currents [7]. Furthermore, a special mode of operation will allow the production of bursting and stable CSR and thus the production of THz/FIR radiation with enhanced intensity.

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