THz STUDIES AT A DEDICATED BEAMLINE AT THE MLS

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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 special machine optics mode (low-α operation mode) based on a sextupole and octupole correction scheme, for the production of coherent synchrotron radiation in the THz region. At the MLS a bending magnet beamline dedicated to the use of THz synchrotron radiation is in operation. Low-alpha operation optic modes for different ring energies, are available. We compare the THz power and THz spectra taken in different low-α modes and discuss the results.

THZ BEAMLINE AT THE MLS

The Metrology Light Source (MLS) is the first electron storage ring worldwide designed and prepared for production of THz radiation by applying a special machine optical mode (low-α operation mode) [1, 2]. In this mode high power coherent synchrotron radiation (CSR) in the THz spectral range can be produced. At the MLS, a bending magnet beamline dedicated to the use of THz synchrotron radiation is operational. The THz beamline is optimized for the FIR/THz spectral range from 100 µm to 7 mm [3-5]. The IR and THz experimental stations at the MLS for the near, mid and far IR wavelength region are accessible to the PTB as well as to an interested scientific community for a broad field of applications. Dedicated low-α beam time for users is only offered by three storage rings world-wide, namely ANKA, BESSY II and the MLS. Up to now, ANKA and BESSY II provide the users with only 12 days of low-alpha beam time per year. The ring current for low-alpha operation is typically an order of magnitude lower than for normal operation which limits the use for the users in the UV and X-ray spectral range at multi-user facilities. The MLS, as a small machine with its high flexibility in changing the storage ring parameters, is now running one day per week (on average) in the low-α mode.

The experimental stations are equipped with an optimal instrumentation for microspectroscopy measurements: a Fourier-transform spectrometer and an IR microscope for life and material science investigations. A state-of-the-art rapid scan FTIR spectrometer Vertex-80v (by Bruker Optics) extended for THz applications and a maximum resolution of 0.06 cm^{-1} is now operational. The infrared microscope HYPERION 3000 (Bruker Optics) completes the experimental setup (see Figure 1).

Figure 1: Picture of the experimental set-up at the MLS THz beamline.

Typical IR beamlines at electron storage rings 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 oriented horizontally. 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. 2). Table 1 shows the dimensions of the optical elements in the THz beamline.

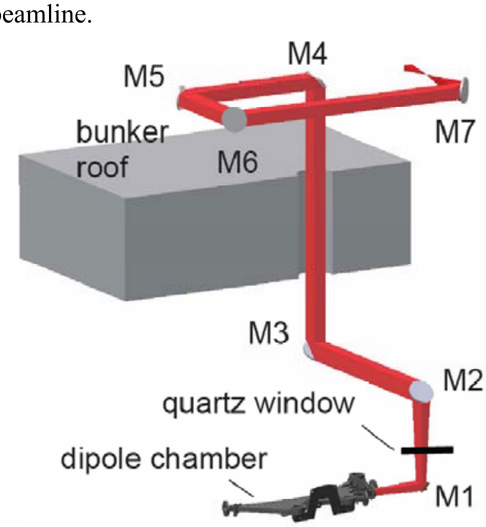

Figure 2: Layout of the MLS THz beamline.

After mirror M7 the beam is transported to two different experimental stations: Station 1 is equipped with an FTIR spectrometer for spectroscopy and station 2 is used for the tests of THz detectors [6].

Table 1: Optical Elements of the MLS THz Beamline

Opical element (mirror)	Distance to source point (mm)	Type	Dimensions d = diameter (mm)
M1	1550	cylindrical	110 × 110
Window	2072	z-cut quartz	d = 89
M2	2450	cylindrical	d = 240
M3	4450	planar	d = 240
M4	7050	planar	d = 240
M5	8450	planar	d = 240
M6	9450	panar	d = 240
M7	11850	planar	d = 240

LOW-ALPHA MODES

Under normal operation of the MLS at 630 MeV, high ring currents, and bunches of about 7 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 The time structure is rather complex and varies with operating conditions. 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 [1]. Two low-α operation optic modes for different ring energies, 450 MeV and 630 MeV were prepared [1].

Optical Beam Path and Focus

Figure 3 shows the focus of the THz radiation (all radiation with a wavelength longer than 100 µm) in the low-α mode at 630 MeV at the THz beamline. Its FWHM size is approximately 1.7 mm in diameter and lies directly on the focus of the visible and near infrared light.

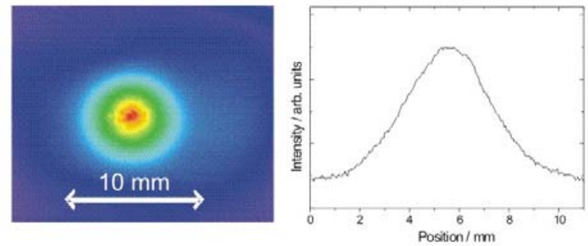

Figure 3: Left: Focus of the THz beamline. Right: Beam profile of the focussed THz radiation.

THz Spectrum in the Low-Alpha Mode

Figure 4 shows a typical FTIR spectrum in the low-alpha mode at the MLS. The wavelength range, where the coherent radiation has more intensity compared to the incoherent THz spectrum, is 5 cm^{-1} to about 50 cm^{-1}. The long wavelength cut-off is determined by the 50 µm Mylar beamsplitter. Together with earlier measurements we can estimate a CSR spectrum ranging from 1.4 cm^{-1} to below 50 cm^{-1}. This corresponds to a frequency range from 0.05 THz to 1.5 THz The power gain compared to the normal operation mode is in the range of 4 orders of magnitude.

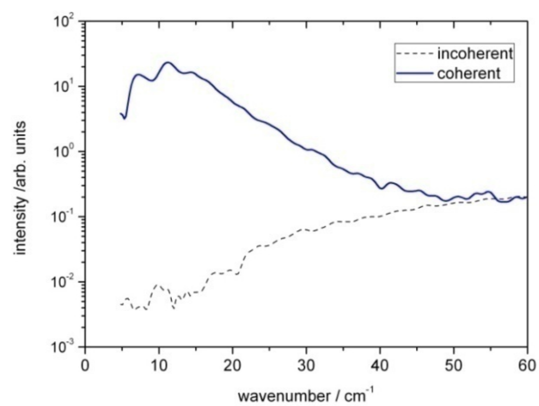

Figure 4: Typical FTIR spectrum at the MLS THz beamline in the low-α mode for 630 MeV and 70 mA ring current (blue line). Also shown is the incoherent synchrotron radiation (black dots).

THz Power

We measured the absolute averaged THz power for the low-α modes at 450 MeV and 630 MeV in the focus of the THz beamline using a Thomas Keating power meter. At the IR beamline the measured power is depending on the chosen α in the range of a few hundred micro-watts. Figure 5 shows that the THz power for both low-α modes is nearly identical. The highest average THz power of about 60 mW gives with the machine parameters of the MLS a peak power of about 35 W.

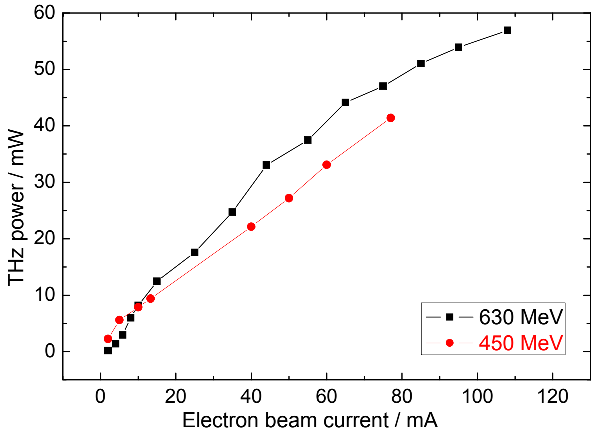

Figure 5: Comparison of the averaged THz power measured in the focus of the THz beamline for the low-α modes at 630 MeV (squares) and 450 MeV (circles).

THz Spectra for 450 MeV and 630 MeV in Low-α Mode

Figure 6 compares low-alpha spectra for 450 MeV and 630 MeV for two different electron beam currents. For both low-alpha modes the behavior is as expected: the waist and the intensity of the spectra growth with increasing electron beam current. The shape of the spectra for the different electron beam energies is comparable.

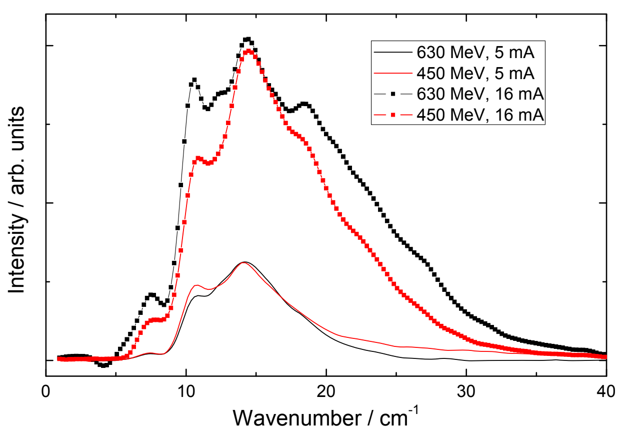

Figure 6: FTIR spectra for the two low-α modes at 450 MeV and 630 MeV for two different electron beam currents.

From theory it is predicted that the THz radiation at the MLS is independent on the electron energy. At the MLS we find that at 105 MeV the CSR is strongly suppressed and at 250 MeV we derived a more intricate picture [7], where we see an unexpected suppression of CSR signals at short bunches and high rf-voltage. So, at the MLS the low-α optics for lower electron energies is still under investigation

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 a promising radiation source for THz metrology. The low-α mode is prepared for two different ring energies. For 450 MeV and 630 MeV THz power and spectral behavior are nearly identical and ready for user operation

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