THE METROLOGY LIGHT SOURCE OF THE PHYSIKALISCH-TECHNISCHE BUNDESANSTALT IN BERLIN-ADLERSHOF

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Abstract

The Physikalisch- Technische Bundesanstalt (PTB) has gained approval for the construction of a low-energy electron storage ring in the close vicinity of BESSY II where PTB operates a laboratory for X-ray radiometry. The new 600 MeV electron storage ring, named 'Metrology Light Source' (MLS), will be dedicated to metrology and technological development in the UV and VUV spectral range and will fill the gap in the spectral range that has opened up since the shut-down of BESSY I. Moreover, the MLS can be operated with parameters optimized for special calibration tasks, which is rarely possible at a multi-user facility such as BESSY II. The MLS is designed in close co-operation with BESSY. Construction will start in the autumn of 2004 and user operation is scheduled to begin in 2008.

INTRODUCTION

PTB, the German National Metrology Institute, has been using synchrotron radiation for photon metrology in the spectral range from the UV to X-rays at the electron storage rings BESSY I and BESSY II for more than 20 years to fulfill its mission to realize and disseminate the legal radiometric units in this spectral range for Germany. Bending magnets which emit synchrotron radiation with well-defined properties are an ideal source for radiometry, especially when the storage ring can be operated as a primary source standard [1, 2, 3] which allows radiometry, limited so far by the utilization of black-body radiation to the infrared, visible and near UV spectral region, to be extended to higher photon energies up to the X-ray region [4].

At BESSY II, PTB operates a radiometry laboratory [2, 5], the PTB laboratory for UV and VUV radiometry [6], located at the BESSY I electron storage ring, was shut down at the end of the operation of BESSY I in 1999. Since then, PTB whs lacked a dedicated source for metrology in the UV/VUV spectral region. This shortcoming will soon be overcome with the beginning of operation of the MLS.

MLS DESIGN

The MLS has been designed by the BESSY GmbH [7] to meet PTB's demands for a UV/VUV source with high stability and reproducibility and to complement the spectral region covered by the BESSY II electron storage ring at the lower photon energy range.

Essential for PTB is the use of the storage ring as a primary source standard for the calibration of energy-dispersive detectors and radiation sources (source-based radiometry). For this, it is essential that relevant storage ring parameters can be measured with high accuracy. In combination with a monochromator beam line as a source of monochromatic radiation of high spectral purity, the storage ring is also used for detector-based radiometry and reflectometry. For these applications, it is essential that the electron energy and electron beam current allow adjustment as required by the current calibration task in order to achieve low relative uncertainties. The electron energy can be chosen in the range from 200 MeV to 600 MeV, i.e. the characteristic energy can be tuned in the range from 11.6 eV up to 314 eV. This allows the high energy end of the bending magnet spectrum to be adjusted in such a way, that radiation that would lead to higher diffraction orders and stray light in a monochromator is suppressed. The electron beam current can be adjusted in a range of more than 11 orders of magnitude, i.e. from a single electron (1 pA) up to 200 mA, in order to comply with the dynamic range of a device to be calibrated.

Storage Ring Layout

Fig. 1 shows the site in Berlin-Adlershof and the schematic layout of the MLS. The MLS has a circumference of 48 m and is designed as an asymmetric double-bend achromate with twofold symmetry. Each of the eight 45° bending magnets can be equipped with two front ends. The MLS has two long and two short straight sections. The long straight section can accommodate undulators of the BESSY II design which enables PTB to operate its U180 undulator [8] that had been in operation at the BESSY II electron storage ring for years in one of these sections.

Injection will be effected from a 100 MeV microtron, the energy is then ramped to the desired value. The anticipated lifetime at a maximum electron beam current of 200 mA, mainly given by residual gas scattering and Touschek scattering, is calculated to be in the range from better than 1 hour to about 10 hours for operation at 200 MeV and 600 MeV electron energy, respectively. The main parameters are listed in table 1, the horizontal and vertical beam envelope is shown in fig. 2.

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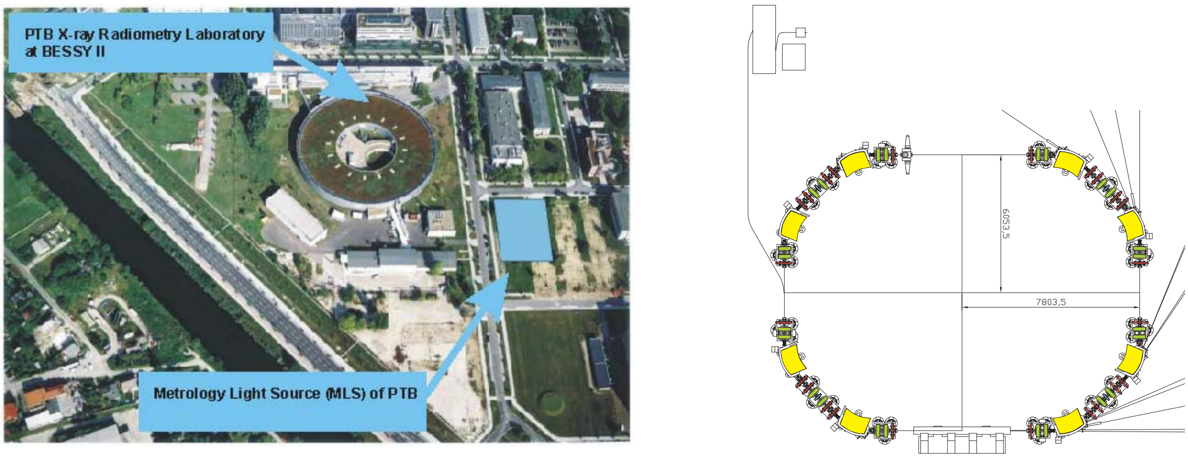

Figure 1: Location (left) and schematic design (right) of the Metrology Light Source (MLS). The MLS is part of the Willy-Wien-Laboratory of PTB constructed in Berlin-Adlershof.

Table 1: Main parameters of the storage ring

parameter	value
lattice structure	DBA
circumference	48 m
number of bending magnets quadrupole magnets sextupole magnets octupole magnets	 8 24 24 4
rf frequency harmonic number	500 MHz 80
electron energy	200 MeV to 600 MeV
electron beam current	1 pA to 200 mA
magn. induction of bending magnet	0.43 T to 1.3 T
char. photon energy	11.6 eV to 314 eV
nat. emittance (600 MeV)	100 nm rad
injection energy	100 MeV

Operation as a Primary Source Standard

The spectral photon flux of synchrotron radiation from bending magnets can be precisely calculated from Schwinger's theory [4], given that all parameters entering the equation are known. At MLS, PTB will install equipment for the measurement of these parameters with high accuracy, since the accuracy of the measurement determines the accuracy of the calculation.

The storage ring parameters taken into account in the calculation are the electron beam current, the electron energy, the magnetic induction at the radiation source point and the vertical beam size and divergence.

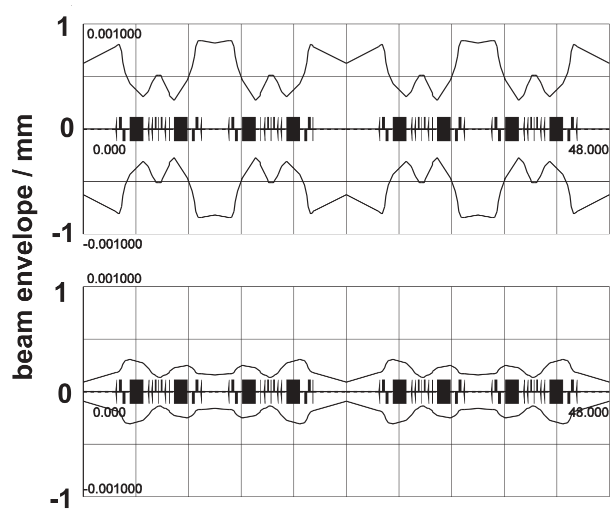

Figure 2: Horizontal (top) and vertical (bottom) beam envelope without dispersion.

The electron energy will be measured by the method of Compton back-scattering of laser photons [9]. The electron beam current, which can be altered from 1 pA up to 200 mA, will be measured by two commercial DC parametric current transformers for the range above 1 mA, single electron counting for the range below 1 nA, and with filtered photodiodes for the range in-between, as described in [1]. Additionally, the MLS will be equipped with a cryogenic current comparator (CCC) currently under development.

The bending magnet vacuum chamber is designed in such a way that a nuclear magnetic resonance probe can be brought to the radiation source point for measuring the magnetic induction. The combined vertical source size will be measured as described in [10], the geometrical quantities defining the solid angle will be determined as described in [2].

The anticipated measurement accuracy in these parameters will then allow the calculation of the spectral photon flux for photon up to 1 keV with a relative uncertainty below 0.1 %.

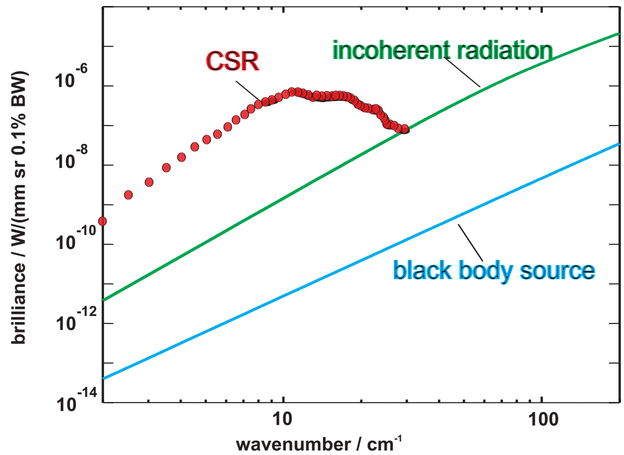

Figure 3: Expected brilliance for stable, coherent synchrotron radiation (CSR) (dots) compared with the incoherent radiation and radiation from a black body of 1200 K and 10 mm² size.

Operation for the production of coherent SR

Intense coherent synchrotron radiation (CSR) can be generated if electron bunches are compressed to 1 mm rms length at the BESSY II storage ring [11]. This option is also envisaged for the MLS by tuning the quadrupoles in an appropriate way. The required control of higher order terms of the momentum compaction factor α, with respect to momentum deviating electrons, will be performed by 3 families of sextupoles and one octupole family [7].

The emitted spectral range of the bunches compressed to 1 mm will be the same as for BESSY II. The radiated power can be estimated by applying the BESSY II results (Fig. 3). A scaling has to compare the charge per bunch limited by the bursting instability, the passing time of the bunch through the acceptance angle of the detector, and the different emission cone due to the critical energy of the dipole radiation. This yields a value of 5 % of the power per bunch in the MLS compared to the BESSY II ring. However, this only counts for the stable emission process, not for the bursting case, which depends on the maximum stored current per bunch.

The dynamic aperture of the low alpha optics tracked for 10000 turns (12 % of the damping time) shows sufficient space for ±1.75 % momentum deviating particles [7].

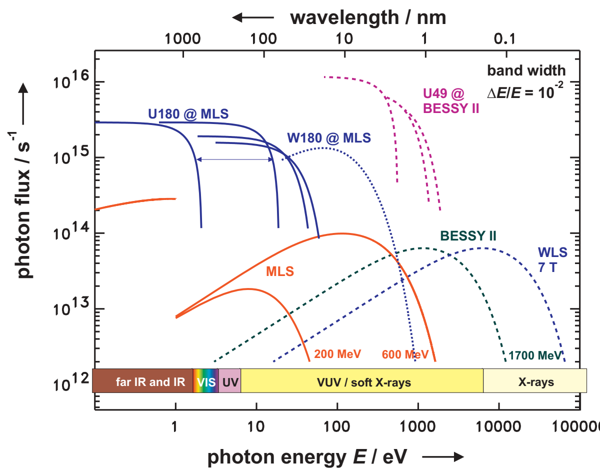

Figure 4: Spectrum of the MLS as compared to BESSY II. With the electron storage rings MLS and BESSY II (including a 7 T WLS), PTB can use synchrotron radiation in the spectral range from the THz up to the hard X-rays for photon metrology.

SUMMARY

The parameters of the MLS, especially the electron beam current and the electron energy, can be varied in a wide range in order to create measurement conditions that are taylor-made for specific calibration tasks. All storage ring parameters can be precisely measured, which enables PTB to operate the storage ring as a primary radiation source. Bending magnet radiation with characteristic energies ranging from 11.6 eV up to 314 eV will be available and so will be undulator radiation from the IR up to the EUV spectral region (Fig. 4).

The MLS complements the measurement potential available at BESSY II in the lower energy range and thus enables PTB to use synchrotron radiation from the THz up to the hard X-ray region for high accuracy photon metrology, something that is unparalleled in the world.

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