Terahertz Radiation at ANKA, the New Synchrotron Light Source in Karlsruhe

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Abstract. ANKA is a new synchrotron light source at the Karlsruhe Research Center in southwest Germany. The acronym stands for Ångström Source Karlsruhe. The ANKA-IR beamline provides a high brilliance infrared beam through the near, mid and far-infrared range. The far-infrared range is of particular interest, since at frequencies lower than around 200 cm^{-1} (6 THz) synchrotron light begins to outperform conventional thermal sources in terms of total intensity as well as brilliance. The extraction of the entire flux is a challenge in the THz range, since the natural vertical divergence of synchrotron radiation increases with wavelength and the opening angle for collection is limited by design constraints. At ANKA-IR, this problem is solved by the collection of radiation emitted from a bending magnet edge source, which has a much smaller vertical divergence than conventional synchrotron radiation emitted from the constant magnetic field region within the dipole magnet. Edge radiation at ANKA permits the extraction of the entire infrared flux down to around 100 cm^{-1} (3 THz) while with conventional synchrotron radiation this would only be the case for frequencies down to 2500 cm^{-1} . ANKA-IR provides usable intensity down to 4 cm^{-1} (120 GHz).

Key words: edge radiation, far infrared, synchrotron radiation, terahertz radiation

1. Introduction

A synchrotron light source is a particle accelerator dedicated to the production of synchrotron radiation, providing a high brilliance beam of photons covering an extremely broad spectral range. Synchrotron radiation is emitted when electrons moving at relativistic speeds interact with a magnetic field, and covers a spectral range extending from the hard X-ray to the terahertz range. Beamlines are set up at intervals around the electron beam storage ring, each dedicated to a particular experimental method such as X-ray diffraction, UV fluorescence, IR spectroscopy, etc. At each beamline, the required spectral range is extracted and brought via appropriate optics to the experimental endstations.

Figure 1. Plan of the ANKA synchrotron light source facility.

2. The ANKA Facility

ANKA (Figure 1) is a new synchrotron light source at the Forschungszentrum Karlsruhe (Karlsruhe Research Center), a government research facility in the south-west of Germany. The acronym stands for Ångström Source Karlsruhe. A plan of the facility is shown in Figure 1. The electron storage ring is 110.4 m in circumference and was designed to store a 2.5 GeV electron beam at a nominal current of 400 mA [1, 2]. The machine has been in operation since September 2000 and is now running routinely at full energy and 200 mA current.

3. The ANKA-IR Beamline

The infrared beamline at ANKA was opened last year as Germany's first synchrotron infrared beamline [3], closely followed by the new infrared beamline

Figure 2. Front and side elevations of the ANKA-IR beamline optics. a, dipole entrance edge (source); b, dipole vacuum chamber; c, dipole chamber 0° port; d, intensity absorber; e, gate valve; f, first mirror chamber; g, intensity absorber; h, video camera; i, diamond window; j, second mirror chamber; k, window valve, M1, M4, M5, M'5, flat mirrors; M2, M3, toroidal mirrors.

at BESSY in Berlin [4]. ANKA-IR produced its first visible photons in March 2000. The first infrared spectra were measured in July 2000. The first publishable research data were obtained in December 2001, in a study of superconducting materials using ellipsometry in the 100 to 700 cm^{-1} ($3\text{--}21\text{ THz}$) spectral range [5].

The layout of the beamline optics is shown in Figure 2. Synchrotron radiation in the infrared spectral range is separated from the shorter wavelength ranges at the water-cooled beryllium mirror M1. M1 reflects the IR component of the incident light beam upwards. The infrared beam is then focused by the first toroidal mirror M2 in the vicinity of a diamond window (Figure 2, i) in the 2:1 image of the source. The diamond window separates the rest of the beamline from the ultra high vacuum conditions necessary for the storage ring operation. The second toroidal mirror M3 equivalent to M2 refocuses the IR beam downwards, and after a last reflection by a further flat mirror M4 through the radiation shielding wall into the experimental

Figure 3. Plan of the ANKA-IR beamline and end stations.

hutch, a 1:1 image of the source is produced in the experimental hutch. The beam can be diverted to either of two Bruker IFS-66v FTIR spectrophotometers, both equipped with the necessary beam splitters and detectors for spectroscopy in the near, mid and far infrared ranges (Figure 3). An additional exit port is available for experiments that do not require the FTIR spectrophotometers. The synchrotron radiation that reaches the experimental hutch covers the wavelength range from 500 nm to 2.5 mm ($20\,000$ to 4 cm^{-1} , 600 THz to 120 GHz). The equipment provided limits the useable range below about 625 nm ($10\,000\text{ cm}^{-1}$).

4. Edge Radiation

Extraction of THz radiation from a synchrotron light source poses a particular challenge, because the natural vertical divergence of synchrotron radiation increases with the wavelength of the radiation, according to the relation

$$\theta_{\text{nat}}(\text{radians}) = 1.66188 \left(\frac{\lambda}{\rho} \right)^{\frac{1}{3}}$$

where λ is the wavelength of the radiation and ρ is the radiation of curvature of the bending magnet [6]. Using ANKA's radius of curvature of 5.559 m , this expression

yields a divergence of less than 1 mrad in the X-ray range, but increasing to 30–135 mrad (1.7–7.8 °) across the THz range. At the same time, the maximum possible acceptance angle for beam extraction is limited by design constraints with respect to the bending magnets. At ANKA, the vertical acceptance angle is 14 mrad. This would lead to considerable loss of flux in the THz and mid-infrared ranges, with the emission angle only falling below the acceptance angle at frequencies higher than 2500 cm⁻¹.

The solution to this problem employed at ANKA is to use edge radiation as the source, i.e. synchrotron radiation emitted as the electron beam enters the magnetic field of a dipole. Radiation from this source has considerably lower vertical divergence than conventional synchrotron radiation [e.g. 7–9], which is emitted as the electron beam follows a curved path through a homogeneous magnetic field. Using edge radiation, the 14 mrad acceptance angle is only exceeded by the emission divergence at frequencies below 100 cm⁻¹, and an adequate flux intensity is maintained all the way down to 4 cm⁻¹. To our knowledge, ANKA and the SRC in Madison, Wisconsin, are the only synchrotron facilities in the world to provide an infrared edge radiation beamline for the use of the general scientific community.

5. Conclusions

ANKA-IR is now available to the scientific community as a source of high brilliance THz radiation, and welcomes applications for beam time from academic and commercial users. A call for proposals was recently announced with a deadline of 31 December 2002. Proposals will be subjected to peer review and will receive beam time from March 2003. Application forms and instructions for applicants are available on the web at <http://www.fzk.de/anka/>.

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