ANKA, a Synchrotron Light Source for Microstructure Fabrication and Analysis

H.O. Moser, M. Ballauff[1], V. Bechtold, H. Bertagnolli[2], J. Bialy, P. v. Blanckenhagen, C. Bocchetta[3], W. Bothe[4], C. Coluzza[5], A.N. Danilewsky[6], K. D. Eichhorn[1], B. Eigenmann[1], D. Einfeld[7], L. Friedrich, M. Haller[8], N. Holtkamp[4], V. Honecker, K. Hümmer[1], E. Huttel, J. Jacob[9], V. Kashikin[10], J. Kircher[11], H. Klewe-Nebenius, A. Knöchel[8], A. Krüssel[7], G. Kumpe, K.D. Möller[12], J. Mohr, M. Nagaenko[10], F.J. Pantenburg, M. Plesko[13], J. Schaper[7], K. Schlösser, G. Schulz[6], S. Schuppler, H. Schweickert, I. Seidel, Y. Severgin[10], I. Shukeilo[10], L. Steinbock, R. Steininger[1], M. Svandrlik[3], G. Williams[14], K. Wilson[15], J. Zegenhagen[11]

Forschungszentrum Karlsruhe, Postfach 3640, D-76021 Karlsruhe, Germany

[1]Universität Karlsruhe, Postfach 6980, D-76128 Karlsruhe, [2]Universität Stuttgart, Pfaffenwaldring 55, D-70550 Stuttgart, [3] Sincrotrone Trieste, Padriciano 99, I-34012 Trieste, [4] DESY, Notkestr. 85, D-22603 Hamburg, [5]EPFL, PHB-Ecublens, CH-1015 Lausanne, [6]Universität Freiburg, Hebelstr. 25, D-79104 Freiburg, [7]Fachhochschule Ostfriesland, Constantiaplatz 4, D-26723 Emden, [8] Universität Hamburg, Martin-Luther-King-Platz 5, D-20146 Hamburg, [9]ESRF, BP 220, F-38043 Grenoble Cedex, [10] Efremov Institute, 189631 St.-Petersburg, [11]Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1, D-70569 Stuttgart, [12]Fairleigh Dickinson University, Teaneck, New Jersey 07666, [13]J. Stefan Institute, Jamova 39, 61111 Ljubljana, [14]NSLS, Brookhaven National Laboratory, Upton, New York 11973, [15]European Molecular Biology Laboratory, Hamburg Outstation, c/o DESY, Notkestr. 85, D-22603 Hamburg

Fabrication of microstructures by X-ray deep lithography (XRDL), galvanoforming, and plastic molding (German acronym LIGA) has made its way from Forschungszentrum Karlsruhe to many labs throughout the world. The acronym ANKA stems from **Ån**gstrom and **Ka**rlsruhe to indicate the main spectral range and the location. ANKA is designed to satisfy the needs of XRDL as well as of X-ray analysis, in particular, of microstructures. Industrial demand of service in both fields will play a major role for ANKA. The main design parameters of the storage ring are an electron energy of 2.5 GeV, magnetic field of 1.5 T, and an ensuing characteristic wavelength of 0.2 nm. The lattice has fourfold symmetry with four dispersion-free straight sections, each about 4 m long. The optics is a double DBA structure with four 22.5° bending magnets per cell resulting in a compact medium-emittance design with a circumference of 97.2 m and an emittance in the range of 40 to 80 nmrad. Four 500 Mhz RF cavities are placed one in the middle of each cell. In this way, only one straight section is needed for injection leaving three for optional insertion devices. Electron current will be 200 mA in a first phase. Lifetime will exceed 17 h. Dynamic aperture is large enough to insert wigglers and wavelength shifters and to double the current when upgrading the RF system. 14 out of 32 available bending magnet radiation ports will be equipped with beamlines in the first phase.

I. INTRODUCTION

After decades of basic research with synchrotron radiation, and development of more and more powerful sources, it is time to bring synchrotron radiation based methods of microfabrication and analysis to the daily use of industry. The ANKA project planned by Forschungszentrum Karlsruhe (FZK) aims at such a transfer in the fields of microfabrication and analysis. An essential element of the philosophy behind ANKA is to commercialise the use of synchrotron radiation in these fields. Mixed beamline groups with members from universities as well as from the service staff will offer a professional full service to customers. More conventional ways of access are, of course, not precluded.

ANKA is a trade-off between low construction cost to keep down operational cost, and finally cost per service hour, and high performance to enable offering high-quality service. In a sense, ANKA is a high-performance, yet „budget-limited" synchrotron light source which could be attributed to the 2.5th generation at the cost of roughly one quarter of a 3rd generation source. A significant number of industrial partners have signed letters of intent for making use of this offer. Thanks to continued marketing their number will grow.

II. GENERAL

ANKA is embedded in the infrastructure of FZK. A 60¥60 m^2 building with additional aisles will house the accelerator and the beamlines with the endstations for microfabrication and analysis. Only this building has to be constructed. Laboratory, workshop, and office space is already available in existing near-by buildings. As far as possible, proven components or designs will be used for the accelerator and the beamlines. All together will help to keep down the construction cost for the accelerator, the beamlines with endstations, and the building.

III. SOURCE

A. Lattice

The lattice is rather compact, featuring four cells with a double Double-Bend-Achromat (DDBA) structure. There are four long dispersion-free straight sections, one for injection, three for optional insertion devices. In the center of each cell is a short dispersion-free straight section which will accommodate an RF cavity. The circumference is 97.2 m to bring down overall cost. Two optics were analysed so far, one with zero dispersion in long and short straight sections,

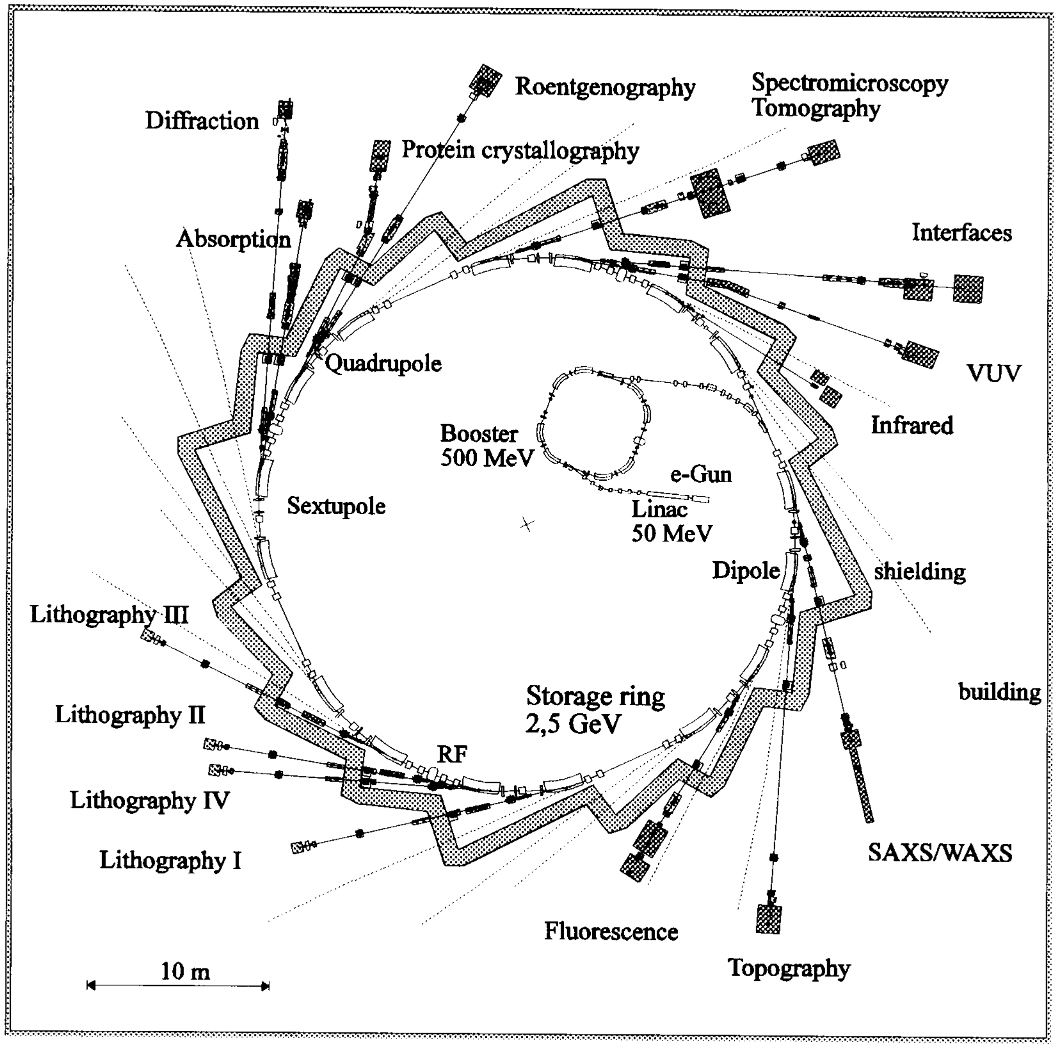

Fig. 1: Layout of the whole ANKA installation

leading to an emittance of 83 nmrad, another one allowing some dispersion in the straight sections with the benefit of reducing the emittance to roughly one half, i.e., 43 nmrad. Chromatic and harmonic sextupoles are used for correcting chromaticity and maintaining a large dynamic aperture. Chromatic sextupoles are separate, harmonic ones are integrated into quadrupoles. An overview of the whole installation is shown in figure 1. Main parameters of the ring are given in table 1. Figure 2 displays the machine functions within a cell in the zero dispersion case.

B. Components

Storage ring dipole magnets are normal conducting and have a bending angle of 22.5°. They produce a uniform field of 1.5 T across a gap 50 mm wide and about 140 mm large. Field uniformity is better than $\pm 1 \cdot 10^{-4}$ within ±35 mm horizontally. The iron yoke is laminated. End faces are parallel. A prototype is about being delivered by Efremov Institute.

Quadrupoles are derived from ELETTRA design with improved pole profiles to enlarge good field region at low power consumption. Open bore is 70 mm diameter. Maximum gradient is 22 T/m, gradient uniformity is better than ±2.3.10-4 within ±32.5 mm horizontally. They come in two lengths, 42 and 35 cm, with a power consumption of 3.6 and 3.2 kW, respectively. They have a horizontal slot 24 mm high to accommodate the vacuum chamber.

Separate sextupoles for chromatic correction are based on the DELTA design. Bore diameter is 75 mm, magnetic length 100 mm, and maximum differential gradient 800 T/m2. Harmonic sextupoles are integrated in the quadrupoles according to the DELTA design.

The vacuum chamber is made of stainless steel with an antechamber design in the dipoles and an octogonal cross section all over the electron beam duct. Synchrotron radiation is absorbed by discrete water-cooled copper blocks. Sufficient pumping capacity (2000 l/s per bend) to reach a dynamic pressure lower than 2 nTorr is provided by NEG and by Ti sublimator boosted ion pumps. Beam lifetime is mainly limited by gas scattering to about 17 h at final energy.

There are up to four RF cavities based on the ELETTRA design. Frequency is 500 MHz. Each cavity will be fed by a commercial 60 kW transmitter allowing for beam currents of

Table 1: Main parameters of ANKA

	η = 0	η π 0
Electron energy E(GeV)	2.5	
Charact. wavelength λ_c (nm)	0.2	
Circumference C(m)	97.2	
Lattice	4¥DDBA	
Tunes Q_x / Q_y	6.851/2.880	6.851/2.879
Chromaticities ξ_x / ξ_y	-15.3/-7.45	-14.9/-7.32
Natural emittance (2% coupling) ε_x / ε_y(nm·rad)	83 / 1.7	43 / 0.86
Momentum compaction α	$9.2 \cdot 10^{-3}$	0.0107
Beta functions		
Straight section β_x / β_y(m/rad)	18.8 / 6.91	17.5 / 8.53
Center of dipole β_x / β_y(m/rad)	0.65 / 9.25	0.60 / 11.12
Maximum β_x / β_y(m/rad)	19.02/20.20	17.5 / 21.0
Minimum β_x / β_y(m/rad)	0.65 / 1.27	0.60 / 1.30
Dispersion function		
Straight section η_x(m)	0.0	0.60
Center of dipole η_x(m)	0.107	0.13
Damping integral D	0.0255	0.0304
Damping times τ_x / τ_y / τ_s(ms)	2.68/2.61/1.29	2.69/2.61/1.28
Natural energy spread σ_E	$9.035 \cdot 10^{-4}$	$9.024 \cdot 10^{-4}$
Radio frequency system		
Frequency f(MHz)	500	
Number of harmonics h	162	
Energy loss per turn eU_0(keV)	642	
Overvoltage factor q	3	
Electron current I_e(mA)	200 (400 with upgrade)	
Beam lifetime τ(h)	>17	
Beam dimensions		
Straight section Σ_x / Σ_y(mm)	1.25 / 0.11	1.02 / 0.086
Center of dipole Σ_x / Σ_y(mm)	0.25 / 0.13	0.20 / 0.098

about 200 mA. Doubling the number of transmitters as a later option will upgrade the current to 400 mA.

C. Injector

Injection energy is 500 MeV. Two alternative injectors are looked at, namely a booster synchrotron with a linac preinjector and a 500 MeV linac. In this paper, the booster alternative is shown (fig. 1). Lifetime at injection energy is roughly 1.5 h. The injection process will include accumulating a current which can be accelerated by the RF system and, then, ramping it to final energy.

D. Spectra

In the first phase, radiation from bending magnets will be used. Figure 3 shows a comparison of the brightness of operational 2nd generation sources with ANKA. Options for later upgrading include a normalconducting wiggler to enhance flux and a superconducting wavelength shifter to produce harder photons.

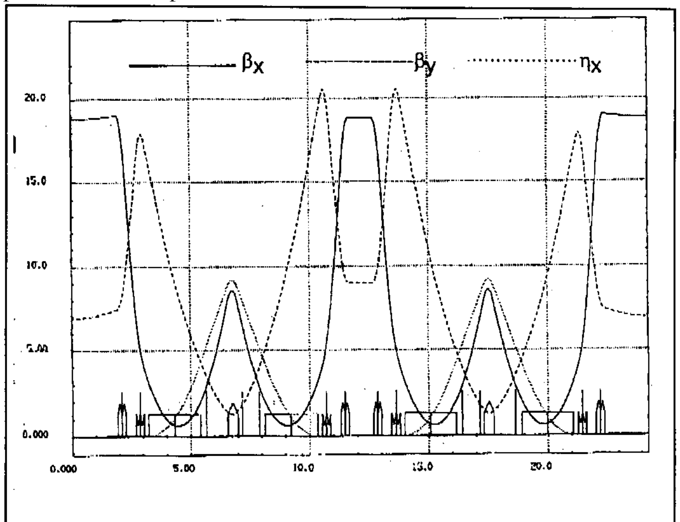

Fig. 2: Beta functions and dispersion within a quadrant.

E. Beamlines and experimental stations

14 beamlines are planned for the initial operation phase as shown in fig. 1. Four of them are for microfabrication with the LIGA process, 10 for various analytical purposes. The latter were selected according to demand expressed by industrial partners and evidenced by operational sources.

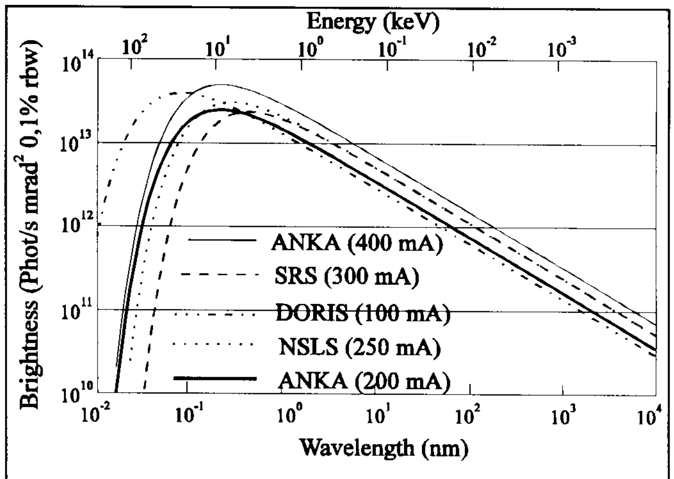

Fig. 3: Brightness of ANKA compared with other sources.

IV. CONCLUSION

Benefitting from the experience available ANKA is designed as a powerful X-ray source at moderate cost. Letters of intent signed by industry indicate that there will be a demand for full service in microfabrication and analysis.