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ALBA. Synchrotron light source
ALBA. Font de llum de sincrotró

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Abstract: ALBA is a third generation synchrotron light source located in Cerdanyola del Vallès. This user-oriented large facility is based on an accelerator system with three main components: linear accelerator, booster and storage ring. Different types of magnetic devices within the storage ring produce photons with energies ranging from UV up to hard X-ray. The first phase, with seven beamlines, became operational in May 2012. Different synchrotron radiation techniques are available including diffraction, spectroscopies and imaging. The project, present status and future perspectives are briefly described.

Keywords: Synchrotron, large facilities, analysis, structure.

***Resum:** ALBA és una font de llum de sincrotró de tercera generació que es troba a Cerdanyola del Vallès. Aquesta gran instal·lació orientada a l'usuari es basa en un sistema d'acceleradors amb tres components principals: l'accelerador lineal, el* booster *i l'anell d'emmagatzematge. Els diferents tipus de dispositius magnètics dins de l'anell d'emmagatzematge produeixen fotons amb energies que van des de l'ultraviolat fins als raigs X. La primera fase de set línies de llum va entrar en funcionament el maig de 2012. Estan disponibles diferents tècniques de radiació sincrotró, incloses la difracció, l'espectroscòpia i la imatge. Tot seguit es descriu breument el projecte, l'estat actual i les perspectives futures.*

***Paraules clau:** Sincrotró, grans instal·lacions, anàlisi, estructura.*

Introduction

Synchrotron light emitted by accelerated electrons, first detected in 1946 in the General Electric synchrotron, was used parasitically for decades in high energy physics (HEP) synchrotrons until 1968, when the first dedicated synchrotron, Tantalus, was built [1]. Since then, the number of light sources and their users have markedly increased and their utilisation across different disciplines opens new horizons.

The evolution of the characteristics of synchrotron light sources is usually divided into generations: *i*) the first generation comprises HEP rings; *ii*) the second generation is formed by dedicated rings; *iii*) the third generation includes more advanced rings with straight sections for insertion devices; *iv*) the third-plus generation comprises rings with magnetic lattices optimised to achieve very low emittances; and *v*) the fourth generation is formed by linear free electron lasers (FEL), which have the highest brilliance.

Synchrotron light emitted in accelerators is remarkable, just as is shown by the properties of the emitted photons, which feature: *i*) a highly brilliant source, due to the small cross section of the electron beam; *ii*) a high degree of collimation of radiation; *iii*) a broad and continuous spectral range from infrared up to hard X-rays; *iv*) a (partly) coherent nature; *v*) a high degree of polarisation which can be tuned by variable magnetic fields; and *vi*) a pulsed time structure defined by the frequency and length of electron bunches.

ALBA history and description

The ALBA project was approved in 2003, with funding provided on a 50-50 basis by the Spanish and Catalan governments. Built on a green field site, its construction began in 2006. The building and services were ready in 2008, when the accelerator installation started. The whole accelerator system was commissioned by 2010. The seven first beamlines (BLs) were installed in the meantime and commissioned in 2011/2012. The first official users were hosted in Spring 2012 and by February 2013 all Phase I BLs were operational.

The photon beam characteristics depend strongly on the electron beam energy and emittance, and on the magnetic fields of dipoles and insertion devices in the storage ring. The choice of these parameters defines the boundaries of the

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source and of the required infrastructures and therefore also the cost range. Several third generation light sources are based on a 3 GeV electron beam: the infrastructure dimensions are well suited to the country's laboratories and the applications range from structural biology to material science (see below). The development of undulator technology with small gaps and short periods allows high photon energy to be reached in these medium size synchrotrons.

The photon beam brilliance (ideally as high as possible) depends closely on the electron beam emittance, which is a measure of the electron transverse beam dimension and divergence. Once the energy is defined, the emittance (ideally as low as possible) depends strongly on the total length of the storage ring circumference: the larger the number of dipoles, or the lower their magnetic field, the lower the emittance of the electron beam. ALBA's main parameters are shown in table 1. Among its sister light sources, ALBA is the one with the most compact design, optimised to reach a low emittance even with a ring circumference smaller than that of other similar facilities.

Table 1. ALBA synchrotron light source main parameters, as May 2013

Parameters	Units
Electron beam energy	3 GeV
Storage ring circumference	269 m
Natural horizontal emittance	4.4 nm rad
Nominal beam current	250 mA
Number of operating beamlines	7
Number of total possible beamlines	30
Number of 8 m straight sections available	3
Number of 4 m straight sections available	6

ALBA is located at the Parc de l'Alba, a 340-hectare science and technology park where other research and technology institutions are also found or will be in the future. The main building of the ALBA Synchrotron is a snail-shaped structure with a diameter of over 140 metres (see figure 1). It contains the main elements of this scientific facility: the accelerators and the beamlines. An office annex and two secondary structures contain auxiliary technical facilities.

The ALBA electron beam is produced in a 90 kV DC thermionic gun, followed by a bunching system designed to reduce the energy spread and the electron losses. The gun produces pulses of few nC at a repetition rate of a few Hz. A linear accelerator (LINAC) made up by two travelling wave constant gradient accelerating sections increases the beam energy up to 100 MeV. The LINAC works both in single-bunch and multi-bunch mode. The 100 MeV beam is injected into the booster, which accelerates the beam up to the final 3 GeV energy. The booster and the storage ring share the same tunnel, surrounded by a 1 m thick concrete wall. The choice of a booster length similar to that of the storage ring has the advantage of providing an electron beam with a low emittance. The electron beam is bunched, with a maximum 448 bunches, as defined by the harmonic number (the ratio between total orbit length and radiofrequency wavelength). The beam temporal structure can be tuned from single bunch configuration, to all bunches filled, or bunches train, according to the user's needs. The lattice is optimised for high photon flux density. The accelerator and beam line control system is based on the Tango open source and the Sardana graphical interface developed at ALBA and subsequently adopted by several new generation synchrotron light sources.

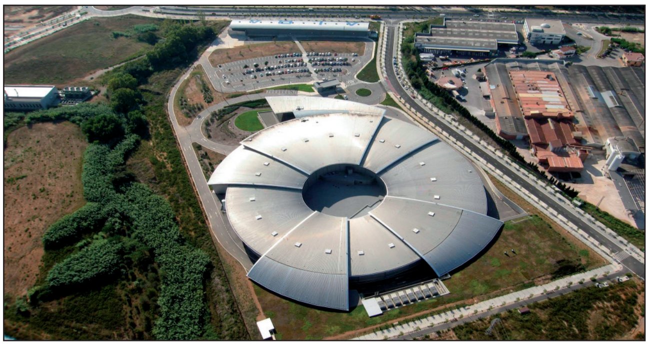

Figure 1. The ALBA building, containing accelerators, beamlines and offices.

The storage ring contains 16 dipoles, 8 short straight sections and 12 medium and 4 long ones. Some of these sections are used for housing the RF cavities (6 in all, installed in pairs) and the injection kickers. The storage ring vacuum chamber has 34 windows for light extraction. Nine of them are in use at present (2 for accelerator diagnostics and 7 for the phase I beamlines).

ALBA beamlines

Table 2 summarises the main characteristics of the first seven ALBA beamlines. These BLs may be classified according to

Table 2. Main characteristics of ALBA beamlines, as May 2013

Beamline	Section	Experimental techniques	Scientific applications
MSPD #2 end-stations	Chemistry	– High resolution powder diffraction – High pressure diffraction	Structure of materials Time resolved diffraction Mineralogical phase analysis
MISTRAL	Life science	– Soft X-ray full field transmission X-ray microscope	Cryogenic tomography of biological samples. Spatially resolved spectroscopy
NCD	Life science	– Small and wide angle X-ray scattering/diffraction – Scattering of proteins in solution	Structure and phase transformations of biological fibers, polymers, solutions. Time resolved X-ray studies
XALOC	Life science	– X-ray diffraction of macromolecular crystals	Macromolecular crystallography (emphasis on large unit cells)
CLÆSS	Chemistry	– EXAFS, Quick-EXAFS – XANES – XES, IXRS	Material science, chemistry, time resolved studies, cultural heritage
CIRCE # 2	Physics	– Photoemission microscopy – Near atmospheric pressure photoemission	Nanoscience and magnetic domain imaging (PEEM). Surface chemistry (NAPP)
BOREAS # 2	Physics	– X-ray magnetic dichroism – Resonant magnetic diffraction	Surface magnetism and magnetic structures

their main fields of scientific application: *i*) those mainly devoted to life sciences (including soft condensed matter); *ii*) those devoted to the physics of hard condensed matter and especially magnetic structures, electronic structures and nanoscience; and *iii*) those devoted to chemistry including state-of-the-art analytical tools.

In the first beamline group (life sciences) we find MISTRAL, NCD and XALOC.

MISTRAL [2] (transmission soft X-ray microscopy, TXM) is an X-ray full-field transmission microscope that can provide cryo-tomographies of biological material with very high spatial resolution (up to 30 nm in 2D and 60 nm in 3D). It is optimised in the water window, i.e., in the spectral range between the absorption edge of carbon and oxygen. It can provide biological material maps with an excellent penetration depth and no need to cut the sample, in contrast to transmission electronic microscopy. The possibility of a complete rotation of the sample in few minutes allows precise tomographic reconstructions. Samples are kept under cryogenic conditions during experiments. The beamline has a grating monochromator which allows spectroscopic imaging of high interest for material characterisation. There are only three instruments of this type in operation worldwide. Photon energy range of the beamline optics: 270-2,600 eV; photon energy range of the microscope: 270-1,000 eV. The field of view can be changed from 10 μm to 16 μm.

The **NCD** [3] (non crystalline diffraction) beamline is devoted to small-angle X-ray scattering (SAXS) and wide-angle X-ray scattering (WAXS) and both measurements can be simultaneously carried out. There are two different two-dimensional detectors (for SAXS and WAXS) to study materials with approximately periodic spatial structures. Examples are biological applications (fibre tissues and solutions) and polymers. The detectors' quick acquisition rate (in the millisecond range) allows the study of dynamic processes in a very short time scale. The optics allow variable beam spot size at the sample: minimum 70 (horizontal) × 30 (vertical) μm^2. Photon energy range: 6,500-13,000 eV.

The **XALOC** [4] beamline is devoted to macromolecular crystallography (MX). It allows the performance of MAD (multiwavelength anomalous diffraction) for structure determination. The diffractometer and the optics of the beamline allow the adaptation of the size and divergence of the beamline to the crystal within a specific range. The experimental end-station is equipped with a robot for samples whose 6-axis changer arm may also be used to filter a large number of samples of crystallisation plates. It has a state-of-the-art PILATUS detector of 6 megapixels. Variable beam spot size at the sample: minimum 50 (H) × 6 (V) μm^2. Photon energy range: 5,000-22,000 eV.

The second beamline set (physics) includes CIRCE and BOREAS.

CIRCE [5, 6] is a photoemission spectroscopy and microscopy beamline with a helical undulator providing variable-polarisation soft X-rays. It has two advanced experimental end-stations for the characterisation of surfaces, thin films and nanostructures. The first end-station is a photo-emission electron microscope (PEEM), also equipped with an electron gun for low-energy electron microscopy (LEEM) and an electron energy analyser. This instrument permits a variety of chemical, morphological and magnetic imaging techniques fully adapted to the field of nanotechnology. The second end-station is for near ambient pressure photoemission (NAPP). The main novelty of this instrument is that photoelectron spectroscopy can be performed on samples under pressures of up to 20 mbar. There are only a few instruments of this kind worldwide and they are starting to make major contributions in some fields like catalytic processes, environmental sciences and surface sciences, where gas/solid or gas/liquid interactions play an important role. Both experimental stations have facilities for on-site sample preparation (metal evaporators, gas exposure, heating, cooling, etc.). The beam spot size at the PEEM sample position is variable, with a minimum of 30 (H) × 4 (V) μm^2; at the NAPP sample position it is 100 (H) × 20 (V) μm^2. The photon energy range is 100-2,000 eV.

BOREAS [7] is a beamline with a helical undulator to produce variable-polarisation soft X-rays. The first experimental end-station is devoted to X-ray magnetic circular dichroism (XMCD) and X-ray magnetic linear dichroism (XMLD) techniques, allowing the study of advanced magnetic materials under magnetic fields of up to 6 T along the axis and up to 2 T in the horizontal/vertical plane perpendicular to the beam. The second experimental end-station, which is currently under commissioning, will be devoted to soft X-ray magnetic scattering (SXRS). This instrument is based on an ultra-high vacuum reflectometer including a newly-developed revolving magnet (based on high-temperature superconducting coils of copper compounds) for the research of magnetic anisotropies on magnetic surfaces, thin films, nanostructures and bulk single crystals. The beam spot size at the sample is variable, minimum 100 (H) × 20 (V) μm^2. The photon energy range is 80-4,000 eV.

The third beamline set (chemistry) includes MSPD and CLAESS.

The **MSPD** [8, 9] beamline is devoted to material science and powder diffraction (MSPD). The first end-station, equipped with a large heavy duty 3-circle diffractometer and two detectors, allows the efficient collection of high-resolution data by means of 13 analyser crystals and the high-speed collection of data for the study of chemical kinetics, phase transitions, etc., by means of a micro strip detector system (MythenII). The second end-station is devoted to experiments on diffraction under high pressure with diamond anvil cells and a CCD detector, allowing users to analyse the crystalline structure of matter under extreme pressure values (up to ~50 GPa). For high-resolution powder diffraction, the beam spot size at the sample is variable, with a minimum 100 (H) × 100 (V) μm^2; the high-pressure end-station provides a minimum spot size of 10 (H) × 10 (V) μm^2. Photon energy range: 8,000-50,000 eV.

CLAESS [10] is an advanced hard X-ray absorption beamline equipped with a fast monochromator which allows the recording of EXAFS (extended X-ray absorption fine structure) spectra in about 2 minutes. In the future, it will be operating at about 100 ms in the intermediate energy range (7-9 keV). It will have an original X-ray spectrometer of in-house design which will allow the performance of high energy resolution fluorescence spectral analysis and inelastic X-ray scattering experiments (IXRS). The beamline has two chemical reactors and an automated system for the management of gases in XANES/EXAFS (X-ray absorption near edge structure) measurements during chemical reactions under conditions close to those relevant to industrial catalysis. Beam spot size at the sample: 300 (H) × 150 (V) μm^2. Photon energy range: 5,000-45,000 eV.

ALBA operation

ALBA has two modes of access: public and proprietary. Public use is freely granted after evaluation of proposals by an international panel which assigns them a ranking per beamline based on scientific excellence. Conversely, industrial/proprietary access is evaluated in terms of safety and technical feasibility alone and the applicable fee is quoted. For public use, two calls for proposals have already been issued: one in 2011 and the other in the autumn of 2012. Some 200 proposals, about 20% of which were from international applicants, were submitted in each of these calls. As from 2014, two calls for proposals will be issued each year and the third call is to be issued in September 2013 [11] for the period March-July 2014. Up to now, the ALBA beamlines have had an average overbooking of slightly over 50%.

Experiment classification is always difficult but about half of the proposals come from the life science area and especially macromolecular crystallography. About one third of the proposals are focused on material science and the remaining 15% relates to other areas, mainly including chemistry.

Outlook in the future

Our primary mission is to provide users with excellent infrastructure and human and technical support to carry out their experiments. ALBA's personnel are firmly committed to this goal. Additionally, the years to come will be devoted to exploiting the infrastructure's potential for hosting new beamlines. Infrared spectro-imaging, angular resolved photoemission and micro- and nano-focusing are among the proposed new beamlines. The user community will be participating in the discussion on the final list of new beamlines. The financial resources needed for the construction of new beamlines have not yet been secured and ALBA's management is investigating every possibility.

As a by-product, the building of the ALBA infrastructure and its technological instruments has led to the creation of various laboratories, which were used in the construction and installation phases and which are now excellent tools for new developments and cooperation with other facilities. These facilities include the optics and metrology laboratory, based on in-house design, which has become a reference in the synchrotron light community and which has cooperation programmes under way or about to begin with several laboratories. Other laboratories, like the one devoted to magnetic measurements, have also been implemented.

Conclusions

Phase I of the ALBA Synchrotron Light Source project has been successfully completed, involving the construction and commissioning of its infrastructure, its accelerator and its first seven beamlines. This facility went into operation in compliance with the highest international standards for hosting public and industrial users.

ALBA, the largest ever scientific infrastructure built in Spain, is an example of the qualitative step forward that our country's science and technology system has taken in the last decade. Moreover, it has shown the international scientific community that we can successfully build and routinely operate a complex large facility, something that was not obvious a decade ago.

Additionally, ALBA is a unique facility in terms of the background of its scientific and technical personnel. No other scientific facility in Spain brings together over: *i*) twenty accelerator physicists; *ii*) twenty mechanical engineers; *iii*) thirty electronic, computing and control engineers, and *iv*) forty scientists specialised in synchrotron radiation applications. Our staff are our main asset and this richness of backgrounds will allow us to tackle the challenging technical and scientific projects ahead of us.

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