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CNA: The first accelerator-based IBA facility in Spain

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Abstract

The recently created Centro Nacional de Aceleradores (National Center for Accelerators, CNA) in Seville emerges as the first ion beam analysis facility in Spain. The laboratory is based on a 3 MV tandem accelerator model 9SDH-2 of NEC and it is primarily focused on material research and modification by means of IBA techniques: PIXE, RBS, NRA, PIGME and ERDA. The ions are delivered by two ion sources: Alphatross radio-frequency source and SNICS-II sputtering source. The ion beam handling system includes equipment for beam focusing, steering and diagnosis, a 90° analyzing magnet and a seven-port switcher magnet. A system based on magnetic steerers has been installed for high-precision beam energy scanning. In this paper the main elements of the laboratory will be described, focusing on the electronic equipment, detectors and the four beamlines planned for the moment: channeling line, microbeam line, multipurpose vacuum chamber and external microbeam. Moreover, the characteristics of the system as observed until now by means of performance tests, beam energy spread measurements and energy calibration experiments will be summarized. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

The Centro Nacional de Aceleradores (CNA) is born as a joint project between the University of Seville, the *Junta de Andalucía* (Andalusian's regional government) and the *Consejo Superior de Investigaciones Científicas* (Spanish Council for Scientific Research) for the creation of the first Spanish ion beam facility. Our Center is intended as a multidisciplinary research center, its primary aim being the material modification and analysis by making use of ion beam-based techniques: PIXE, RBS, NRA, PIGME and ERDA. The National character of our Center grants all Spanish researches, from either public or private institutions, the possibility of carrying out experiments in a wide variety of fields: Material Science, Art and Archaeometry, Medicine, Environmental Science, etc.

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In the following sections we describe this new facility, emphasizing on the characteristics of the acquisition data system, the beam lines design and the first results obtained at CNA. The 3 MV tandem accelerator, the ion sources and the beam handling system are presented in more detail in [1].

2. The building

Located in the Technological Park “Cartuja 93”, the laboratory has been built on the site occupied by the Australian pavilion during the Universal Exposition of 1992. The dimensions of the accelerator hall, 26 × 22 m^2, are conceived to house the machine and the beam lines (see Fig. 1) and also contemplate the possible future extensions of the laboratory, in particular, the installation of an AMS facility. 0.7–1 m thick reinforced concrete walls guarantee biological shielding, as it is required for the use of some ion beams, specially deuteron beams, because of neutron emission. The γ-ray and neutron radiation rate are continuously measured by two dosemeters placed on the top of the switcher magnet and this information is sent and registered at the control room. If the radiation level reaches a selected set-point, visual and audible alarms are activated inside and at the entrance of the accelerator hall. The entrance from the control room to the accelerator hall is through a labyrinth with 0.7 m thick concrete walls. Large objects can be introduced opening a 4 m high, 3.5 m wide and 0.7 m thick concrete-filled rolling door.

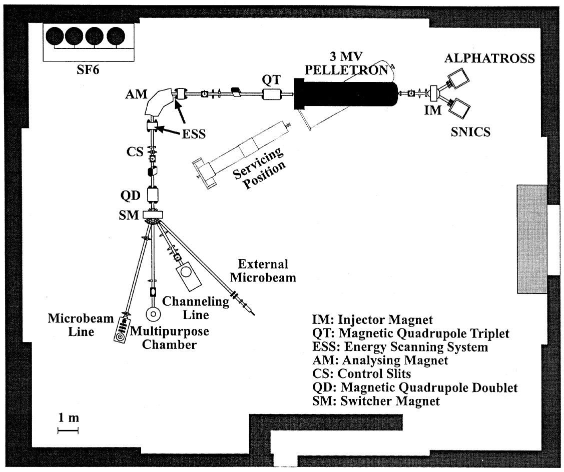

Fig. 1. Schematic layout of the acceleration system and experimental beam lines.

3. Generals

The facility has been set up around a NEC 9SDH-2 Tandem Pelletron accelerator, with a terminal potential of 3 MV. The ions can be produced by two NEC ion sources: the Alphatross, which generates ions from gases using radio frequency techniques; and the SNICS II, a cesium sputtering source that produces ions from solid samples. The sources are connected to the ±30° input ports of the injection magnetic dipole, which has a Mass-to-Energy-Product (MEP) of 15 amu-MeV. The magnet is able to bend negative ions of 70 keV and mass up to 214 amu towards the accelerator. Once the beam has been accelerated, it is analyzed using a 90° magnet with a maximum magnetic field of 13.5 kG, bending radius of 100 cm and MEP of 75 amu-MeV. The magnet is powered by a Danfysik supply model 853 (260 A, 40V, ±5 ppm stability). An energy scanning system based on the principles developed by Amsel et al. [2] has been installed around this magnet. The method combines the deflection of the beam at two well chosen points and the automatic stabilization system using the “control slits mode”. In our set-up, the beam is deflected just before and after the 90° analyzing magnet by a pair of magnetic steerers. The current through the magnetic coils is externally commanded by a Hewlett-Packard E3631A power supply, allowing a minimum current step of 0.2 mA. The energy change corresponds to 32 eV/mA for 1 MeV protons and 44 eV/mA for 2.4 MeV protons. This system allows us to scan the beam energy for resonant beam profiling in a range of ±2.5% around any central potential. The limitation for a higher scanning span seems to be due to the beam hitting the wall of the 90° magnet chamber.

At the end of the analyzed line the beam can pass directly to the 0° line or can be deflected by the switcher magnet towards one of the beam lines at ±15°, ±30° or ±45° with a corresponding MEP of 150.0, 38.1 and 17.4 amu-Mev, respectively. This magnet, driven by a Danfysik Power Supply model 858 (−2 to 140 Amps, stability of 10 ppm), generates a maximum magnetic field of ±14.3 kG at 120 A. The −2 A feature is very useful to get a precise zero field when the beam is sent to the 0° line. The magnetic fields in all the three dipoles are measured using high accuracy Hall effect probes from Group-3. Each probe is connected through a 2 m shielded cable to a 16 bit Group-3 DTM-151digital teslameter for local readout. The three units are interconnected using fibre optic cables and communicate with a Group3 DPM digital display placed at the control room, which in turn acts as a master of the complete loop. This network based on optic signals is insensitive to electromagnetic noises normally present in accelerator facilities.

All the fundamental parameters of the beam handling system (from ion sources up to switcher magnet), are controlled and monitored remotely at the console located in the control room using 0–10 V analogic signals.

4. Electronic set-up

Photon and particle detection is done using standard detectors: Si(Li) and LEGe from Canberra, including a windowless detector, an Ortec HPGe, a NaI(Tl) detector and ion-implanted Si detectors.

The whole data acquisition system is built around the Acquisition Interface Module (AIM) model 556 of Canberra. This AIM is basically a multichannel analyzer (MCA) designed with a built-in Ethernet (LAN) interface and two high-speed ADC ports. Several AIMs can be placed in the same network. The AIM serves as a link between a PC and a signal processing NIM. The Genie-2000 workstation software in conjunction with an AIM allows MCA control, spectral display and manipulation, basic spectrum analysis and reporting.

To minimize electrical noise pick-up, programmable NIM modules from Canberra (9660 Digital Signal Processor (DSP) and 9641 High Voltage Power Supply) are placed close (<2 m) to the photon detectors and all data communication between AIMs and PC (located in the control room) occurs via an Ethernet network. Signal processing takes place at the DSP module, which replaces the traditional shaping Amplifier/ADC combination in traditional analog-based systems.

Beam current and dose are measured with an Ortec 439 Digital Current Integrator in combination with a computer-controlled preset counter (Canberra 2071A). This counter starts and stops automatically the three AIMs of the network, allowing spectra acquisition using up to six detectors simultaneously.

5. Beam-line design

5.1. 0° beam line: multipurpose IBA chamber

The general purpose IBA scattering chamber is set-up in this beam line. A beam profile monitor (BPM) and a quartz piece allow the monitoring of the beam along the line so that the operator may optimize the beam transport. After the BPM, a removable beam diffuser consisting of a thin film of aluminum or gold makes possible the beam homogenization for PIXE applications. A transmission Faraday cup (TFC) containing the definition collimators (diameter 3, 1 and 0.5 mm and rectangular slits 3×0.5 mm^2 and 3×0.2 mm^2), antihalo slits and a retractable quartz is placed before the chamber entrance.

The target chamber has been designed to carry out RBS, PIXE, NRA and PIGME experiments simultaneously. Large viewing ports at different angles allow easy observation of the interior. A 400 l/s turbomolecular pump facilitates a fast pumping down while a LN_2 cold trap can also be used to improve the vacuum conditions. Two X-ray detectors can be introduced to cover the entire X-ray energy range. They are set symmetrically in a horizontal plane at 45° with respect to the beam direction. An ion-implanted Si detector is positioned at 15° in Cornell geometry. Two movable particle detectors connected to the top of the chamber can be independently placed in IBM geometry at any angle with respect to the beam direction. Various absorbers, positioned from the outside, can be inserted in front of the particle and X-ray detectors. A NaI(Tl) or HPGe γ-ray detector may be introduced through the 180° flange and placed very close to the samples to maximize the solid angle. The target holder is a rectangle of 150×112 mm^2 and can be tilted. The X and Y movements are controlled through stepping motors. This chamber is completely insulated from the accelerator, the detectors, the stepping motors and the pump, and it is, in principle, a good Faraday cup. Beam current integration can therefore be implemented by directly connecting the chamber to the integrator or by means of the TFC.

5.2. 30° beam line: channeling chamber

This line is primarily devoted to channeling analysis of crystalline samples. A parallel, well-defined beam is obtained with a telescopic system formed by two slit assemblies, each one incorporating four independent tantalum slit elements. The beam line also includes a BPM and a Faraday cup. The chamber is equipped with two particle detectors and an X-ray detector. The 50 mm diameter – electrically insulated – sample holder is mounted on a 4-axis Klinger/Microcontrole goniometer allowing X and Y positioning of the sample and X-tilt and Y-tilt angular orientation with respect to the beam. Four magnets mounted in front of the samples are used to collect secondary electrons, providing more accurate measurement of the integrated beam current. The vacuum system of the chamber comprises a 400 l/s turbomolecular pump and a LN$_2$ cold trap.

5.3. −15° beam line: microbeam chamber

The microprobe focusing system is based on an Oxford Microbeams endstation OM2000 [3], and comprises a coupled triplet of magnetic quadrupole lenses, scanning coils and an octogonal chamber. All these elements rest on two concrete blocks separated by a polystyrene foam sheet to attenuate mechanical vibrations. The quadrupoles are mounted on a support allowing precise micrometer adjustment of traverse position and tilt rotation to optimize the mechanical alignment of each lens relative to the beam path and to the other lenses. With these quadrupoles it is possible to form a spot of about one micrometer or less on the specimen. The scanning coils allow a maximum scanning area of 2.5×2.5 mm^2 for 3 MeV protons. A magnetically levitated turbomolecular pump is used to pump the target chamber.

The two sets of slits used in the microbeam system comprise four polished stainless-steel cylinders each positioned by a manual micrometer with a precision of 1 μm over a range of 5 mm. A tantalum iris is placed before the object slits to protect them against high-intensity beams. The collimator slits are used to limit the divergence of the beam entering the final lens.

The targets are mounted on a stage inserted from the top flange of the chamber through a quick release opening in the XYZ motion system. A microscope introduced through one of the ports of the target chamber allows a close examination of the front surface of the samples. The beam current is collected from the insulated sampler holder and measured with a charge digitizer (OM35e) with a sensitivity of 10^{-14} C/pulse.

A retractable Si(Li) detector is used for PIXE measurements. Ion-implanted Si detectors, an electron detector (channeltron) and an STIM detector will be installed for RBS/NRA, topographic sample imaging using secondary electrons and transmission imaging, respectively. The data acquisition system is based around the Oxford Microbeams DAQ system [3], which enables the simultaneous mapping of many elements detected by the different techniques.

5.4. 45° beam line: external beam

This line, still under development, will be mainly devoted to studies in Art and Archeometry. Due to the inhomogeneous nature usual in these kinds of objects, it is obvious that the use of external ion beam analysis combined with a good spatial resolution exhibits numerous advantages. With the idea of achieving such a good spatial resolution (≈30 μm), a series of elements have been purchased to Oxford Microbeams, including a precision quadrupole doublet lenses, a precision four jaw object slit and an exit nozzle set with micrometer adjustment. The beam line also incorporates a BPM, a four jaw collimator slit box with a Faraday cup, a 210 l/s turbo pump and two pneumatic gate valves. The experimental set-up comprehends a Si(Li) detector and an LEGe detector to cover the whole X-ray spectrum and a particle detector for RBS measurements.

The targets are mounted on a video-controlled positioning system from RLS (Ljubljana, Slovenia) which allows motorized displacement on the three axes, with ranges $X = 370$ mm, $Y = 260$ mm and $Z = 50$ mm. The resolution of the stepping motors is 12.5 μm and the maximum load of the stage is 30 kg. A laser beam and a video camera attached to a microscope make possible accurate sample positioning.

6. Performance tests and calibrations

The aim of the tests was to check the capability of the machine at low and high potentials and also specific tests were performed in view of the future most relevant experiments at the CNA. The beam current (of the most probable charge state) was measured at the +30° beam line, through a 3×3 mm^2 aperture in front of the Faraday cup installed 2 m away from the magnet. The results of the performance tests are shown in Table 1.

The absolute energy calibration of our Tandem accelerator has been determined utilizing the 991.86, 1317.14, 1364.08 and 1381.6 keV resonances of the ^{27}Al(p, γ)^{28}Si reaction and the 2409 keV resonance of the ^{24}Mg(p, p'γ)^{24}Mg reaction, respectively. Within the range of potentials studied (from about 460 to 1170 kV) the results show a linear relationship between the actual terminal voltage, V_{actual}, and the voltage read at the GVM, V_{GVM}. The relative error $(1 - V_{\mathrm{actual}}/V_{\mathrm{GVM}})$ is about 1%. The experimental beam energy spread calculated from the edge of the excitation curve for the ^{27}Al(p, γ)^{28}Si reaction at 992 keV corresponds to 1 keV (FWHM). The simultaneously measured terminal voltage ripple was around 150 V, corresponding to an energy spread of 300 eV for the proton beam. The excess width of 700 eV could arise essentially from the stripping process, which up to now has not been optimized with respect to minimum energy broadening by varying the nitrogen gas pressure, as well as from the energy spread at the injection.

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Table 1
Performance tests conditions

	SNICS-II					Alphatross			
Beam	^{1}H	^{1}H	^{28}Si	^{28}Si	^{14}N	^{4}He	^{4}He	^{4}He	^{14}N
I(μA)	7.6	2.6	15[a]	6.4	4.5	3.1	1.3	1.2	0.4
V(MV)	1.25	0.3	3.0	0.3	3.0	3.0	1.33	0.9	1.75

[a] 30 μA achieved at 2.5 MV.

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