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The Synchrotron Radiation Facility at Frascati

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In this paper we give a brief description of the Synchrotron Radiation Facility at Frascati. Particular emphasis is given in describing the most significant instrument developments during the last few years.

I. INTRODUCTION

The Adone storage ring in Frascati came into operation in 1969. It was one of the first rings designed for high-energy colliding-beam experiments. At the end of the high-energy physics experiments, the Adone storage ring was partially dedicated to synchrotron radiation for about one-third of the running time. Table I summarizes some of the storage ring parameters. Since 1979 the radiation from a bending magnet is utilized in a first laboratory called Programma per l'Utilizzazione della Luce di Sincrotrone (PULS). In 1980 a conventional 1.8-T five-pole wiggler was installed on the storage ring, and a new laboratory, Progetto Wiggler Adone (PWA), was built to use such wiggler as a synchrotron radiation source.

Presently, there are eight beam lines in operation (six on a bending magnet and two on the wiggler) covering the energy range from 2 eV to 33 keV. There are currently some 60 proposals in operation, covering the fields of solid-state physics, biology, material science, etc., involving some 170 scientists.

II. THE PULS LABORATORY

Ten milliradiant of a bending magnet radiation are delivered to five different beam lines which are briefly described in the following.

The *x-ray beam line* accepts the radiation emitted by 1 mrad of orbit in the spectral range between 1.8 and 12 keV A 75-μm beryllium window separates the UHV beam line from the monochromator and the experimental stations. The monochromator allows the use of either Si(111) or Si(220) channel-cut crystals or of an independent InSb double crystals $(n, -n)$ mounting which extends the available range down to the Si K edge. The experimental apparatus includes a sample chamber for measurements of x-ray absorption and fluorescence in solids, liquids, or gases. The sample can be cooled down to about 15 K. The data acquisition and control system is based on VME and data analysis programs are made available from the facility. Recently a dispersive EXAFS apparatus has been installed and tested to perform absorption measurements on relatively small samples (the spot size ~0.5 mm) and in much shorter times than those required in the standard technique (fractions of a second compared to tens of minutes).[1]

The *soft x-ray beam line* is equipped with a Grasshopper monochromator mounting either a 600- or 1200-lines/mm grating and covering the range from 50 to 900 eV. A cylindrically bent plane mirror focuses 2.5 mrad of orbit onto the exit slit and a second cylindrical mirror bent to a toroid refocuses the monocromatized beam onto the sample.[2] The experimental UHV chamber is equipped to

TABLE I. Source (Adone storage ring) parameters.

Energy of the electron beam		$E = 1.5$ GeV
Maximum beam current		$I_{max} = 80$ mA
Number of electron bunches		$N_b = 1$–3–18
Magnetic radius		$R = 5$ m
Critical energy (bending magnet)		$E_c(B) = 1.5$ keV
Critical energy (wiggler)		$E_c(W) = 2.7$ keV
Pulse repetition		$\tau = 350$–117–19 ns
Pulse width		$2\sigma_t = 1.2$–0.3 ns
Radio frequency		$R_f = 51.8$ MHz
Spectral flux at a critical energy from a bending magnet		$N = 2\times10^{12}$ photons/s mrad 0.1% bandpass
Spectral flux at a critical energy from a wiggler ($I = 100$ mA)		$N = 1.4\times10^{13}$ photons/s mrad 0.1% bandpass
Vertical emittance		$\epsilon_v = 10^{-8}$ mrad
Horizontal emittance		$\epsilon_h = 2.6\times10^{-7}$ mrad
Electron-beam size (4% coupling)	Bending magnet	Straight section
	$\sigma_x = 0.8$ mm	$\sigma_x = 1.76$ mm
	$\sigma_z = 0.4$ mm	$\sigma_z = 0.16$ mm
Electron beam divergence		
Horizontal	$\sigma_{x'} = 260\,\mu$rad	$\sigma_{x'} = 150\,\mu$rad
Vertical	$\sigma_{z'} = 31\,\mu$rad	$\sigma_{z'} = 17\,\mu$rad

prepare "*in situ*"clean semiconductor, metal, and metal-oxide surfaces as well as semiconductor-semiconductor, metal-semiconductor, and metal-metal interfaces, etc. Samples can be studied by angular-integrated photoemission and by absorption spectroscopy.

The *photoemission spectroscopy beam line*, which collects 2 mrad of the orbit has now been upgraded. In fact, a new 1-m TGM monochromator has been studied and purchased by Jobin-Yvon to substitute the previous 30-cm TGM; the new monochromator will give access to the energy range from 10 to 150 eV with a resolving power ranging from 200 to 500. The experimental chamber is devoted to angular integrated photoemission experiments.

Two milliradiants are used by the *Hilger and Watts beam line* on which a 1-m normal incidence monochromator is installed. This monochromator uses three gratings to cover the energy range between 4 to 40 eV with a resolving power better than 1000. A newly installed grating holder allows one to change the prealigned gratings without breaking vacuum. Two different experimental apparatus are available to the users; a reflectometer to measure reflected, transmitted and diffused light and a chamber to measure luminescence.

PLASTIQUE is the new beam line dedicated to time-resolved measurements on biological material.[3] During 1989 this beam line has come into operation and external users have been accepted from 1990. The wavelength range is 200 to 800 nm, in order to excite biological molecules with fluorescence bands in the UV range; this is the only beam line in the world in the 200–280-nm range for phase fluorometry. Lifetimes in the order of nanoseconds can be measured with a precision of 1 ps with a multifrequency phase fluorometer.

A new experimental area has been recently created to access to the radiation from a different bending magnet; the new beam line "canale ad alto flusso" (CALF) is under construction. It collects about 30-mrad horizontal divergence of light emitted from Adone. The photon energy range is between 10 and 400 eV with an expected resolving power of 5×10^{-4}. The optical configuration consists of three bent plane mirrors shaped to form ellipses; the monochromator is a TGM. The beam line will be devoted to angular-resolved and integrated photoemission as well as to photoabsorption measurements in the VUV range.

III. THE PWA LABORATORY

Three beam lines, BX1, BX2-S, and BX2-L, are collecting the wiggler radiation. Line BX1 collects 1 mrad of the radiation emerging along the wiggler axis. It is equipped with a channel cut Si(111) or Si(220) crystal and covers the energy range between 3 to 30 keV. Four experimental stations are serially connected to the monochromator and allow the users to perform different experiments. An x-ray absorption station used to perform EXAFS and XANES studies is x-ray fluorescence apparatus is used for trace element analysis, an x-ray diffractometer as well as a small-angle scattering apparatus are used for crystallography studies on proteins and polymers. BX2-S and BX2-L are split by 1.5° grazing angle mirror from a common line forming an angle of 1.7° with the wiggler axis; the straight section, called BX1S, collects 1 mrad while the 2 mrad of deflected beam is used to feed BX1L.

BX2S has similar geometrical and spectral characteristics of BX1, and a similar monochromator is used to deliver a monochromatic beam in the range between 3 and 30 keV in three experimental stations connected in serial mode, where users can perform experiments on: fluorescence and absorption spectroscopy in the x-ray region with sample temperature control; angle- and time-resolved spectroscopy; and standing waves spectroscopy.

The BX2S beam line is essentially devoted to x-ray lithography. The beam line gives access to photons with energy ranging from 1.5 to 3 keV with a maximum uniformity of the intensity on the resist, it allows one to expose an area of about $10\times 10\ cm^2$ with fast exposing cycles.

To obtain the complete exposure of the wafer without moving it, a vertical scanning of the beam is necessary. This is done by a flat mirror vertically deflecting and oscillating for $\pm 0.15°$ around the grazing angle of 1.5°. A 25-μm-thick Be window is placed in front of the exposure chamber in order to reject the soft part of the spectrum. In cascade with the exposure chamber a MAX-1 mask-wafer aligner has been in operation since 1988.

In series to the lithography apparatus a new x-ray microscopy apparatus is being installed. The instrument will consist of: a double reflection monochromator which uses two W/Si multilayers with $d = 25$-Å spacing to allow operation between 400 and 500 eV with good transmission and a resolving power of about 70; a Fresnel zone plate to focus the x-rays onto the sample; a system for the submicrometric scanning of the sample; and a high efficiency detector.

Finally, the BX1 beam line has been recently used for mammography studies. In fact, several mammographs have been done on surgically removed human breast specimen containing cancer nodules due to the presence of infiltrating duct carcinoma. The breast specimens were imaged using both synchrotron radiation and a conventional mammography unit combined with a 3M screen film. In images obtained using synchrotron light it is possible to observe details and structures not detectable in the conventional one. In addition, a preliminary dosimetric comparison shows that the doses delivered with the two radiographic techniques should be comparable. In conclusion, the results obtained show that synchrotron radiation can be used to carry out mammographic images of higher contrast and better resolved than those obtainable by conventional means.[4]

[1] F. D'Acapito, F. Boscherini, C. Marcelli, and S. Mobilio, these proceedings.

[2] P. Chiaradia, M. Fanfoni, S. Priori, P. De Padova, P. Nataletti, I. Davoli, and S. Modesti, Vuoto XVI, 83 (1986).

[3] G. De Stasio, N. Zema, A. Savoia, T. Parasassi, N. Rosato, and F. Antonangeli, Rev. Sci. Instrum. (in press); G. De Stasio, these proceedings.

[4] E. Burattini, M. Gambaccini, P. L. Indovina, M. Marziani, and O. P. Rimondi, these proceedings.