1.0 Introduction

Since the beginning of this century the interaction between the light and matter (diffraction, diffusion, photoemission, etc.) has led to the development of sophisticated techniques from the characterization c atoms and molecules in all types of environments.

Synchrotron light is an accelerator based light source that covers the complete electromagnetic spectru from infrared to hard x-rays, produced when high energy electron pass between the poles of magnets that are designed to “bend” them into circular orbit around an evacuated synchrotron ring the magnetic field causes them to accelerate (change direction) and emit electromagnetic radiation in a direction tangential to their path. It is also thought to arise when high energy electron spiral around a magnetic field lines in interstellar space, and it may be responsible from strong radio emissions from such celest sources as the crab nebula.

Synchrotron light was first observed in 1947 and considered to be unfortunate and annoying side effec of accelerators that were developed for high-energy physics experiments In the 1960's and early 70's pioneering use was made of the light in a parasitic mode -so called first generation.

In the mid-1970's its unique properties and value were beginning to be appreciated and facilities totall dedicated to synchrotron light, such as the National Synchrotron Light Source (NSLS) were constructe These early dedicated facilities, in which most synchrotron light is produced at bending magnets, are called second generation sources. They were developed using a special “Chasman –Green” lattice of dipole, quadrupole, and sextupole magnets that produced a brightness increase of two orders of magnitude. The NSLS at Brookhaven National Laboratory (BNL) is an example of a second- generati facility. In the last decade new ways of enhancing the yield, and particularly brightness of synchrotron light were developed.

The next improvement came with the demonstration of “insertion devices”. They consist of linear arra of dipole magnets alternating in orientation and having a variable “gap” between the poles through which the electrons or positrons travel. These “insertion devices” are placed in straight sections of the storage ring which make wiggles (long period) or undulations (short period) in the charged particle trajectory which reinforces the light emitted by the accelerated electrons, much as multiple passes through a medium with a population inversion is the basis for the special properties of lasers

A wiggler generates a quasi continuum, with a flux higher than a bending magnet roughly in proportio to the number of wiggles. In an undulator the self-reinforcing aspect of the interaction of the electron beam with the magnetic structure leads to an N2 gain in brightness, a highly collimated, partially coherent point source, and a very highly structured energy spectrum. It is the concentration of all of th emission into the narrow undulator lines that creates the many orders of magnitude higher brightness o undulators. Currently, second-generation rings produce a maximum brightness of 10^4 photons/s/0.1%bw/mm^2/mrad^2. (Brightness is a combination of flux, source size, and beam divergence Its given in units of number of photons per second in a certain energy band width, divided by source area and by the solid angle of the radiation cone). The peak energy can be tuned by changing the gap between the magnet poles - a technological challenge given the forces and precision required, but one which is fully solved.

Recently, third-generation storage rings have been designed specifically to take advantage of insertion devices primarily undulators. Synchrotron light facilities which emphasize insertion devices, and have high brightness electron beam (small, highly collimated) are the third generation sources. They have a brightness of 10^8-10^{20}photons/s/0.1%bw/mm^2/mrad^2. Third generation light sources for synchrotron radiation are mainly defined by a low emittance, offering SR at the diffraction limit at least in the vertical plane. It is these sources that are creating tremendous excitement in many areas of science today.

Because the energy distribution of photons in synchrotron radiation follows a black-body curve which has a characteristic “critical” energy, storage ring are designed to take advantage of specific segments the electromagnetic spectrum. Soft X-ray rings typically run at relativistic electron energies of 0.8 to 2 giga-electron volts (GeV). “Soft” X-ray rings, such as the Advanced Light Source (ALS) at Berkeley and the Vacuum Ultraviolet (VUV) ring at the National Synchrotron Light Source (NSLS), are used primarily for photoelectron spectroscopy studies, photochemistry, imaging at absorption edges of light elements, and magnetic and standard circular dichroism. Hard X-rays are produced by electrons or positrons accelerated to higher energies, from 2.6 to 8 Gev. At these facilities, diffraction and extende X-ray absorption fine structure (EXAFS) spectroscopy are the primary technique used. Topograpy, tomograpy, and medical imaging are the other important techniques that make use of hard X-rays.

2.0 Instrumentation

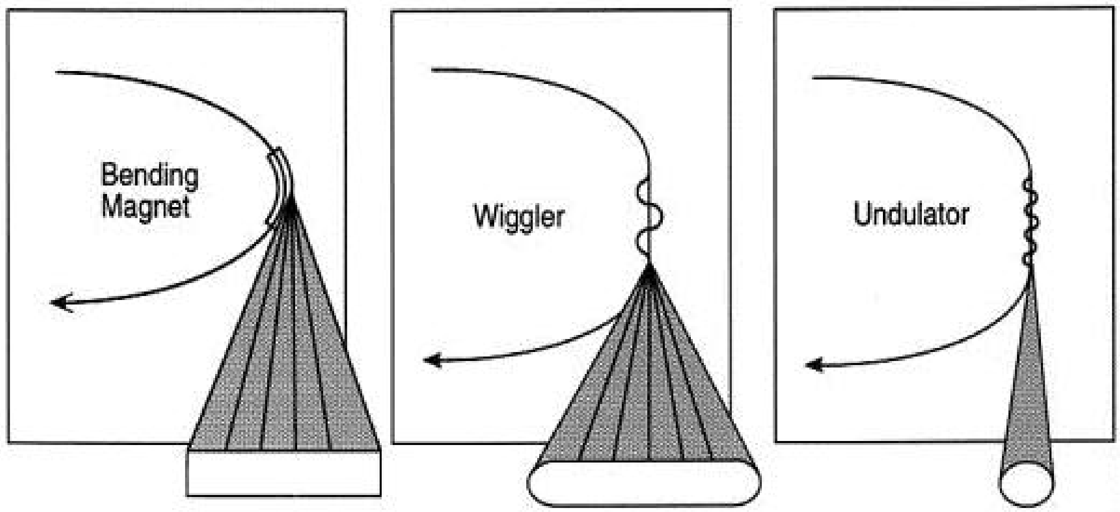

Fig. 1 Schematic of the three approaches used for synchrotron light generation. Bending magnet light is available at all sources. Wigglers or undulators, which are periodic magnet structures installed in straight sections, provide much enhanced flux and brightness. (Figure courtesy of ALS, LBNL)

The Storage Ring

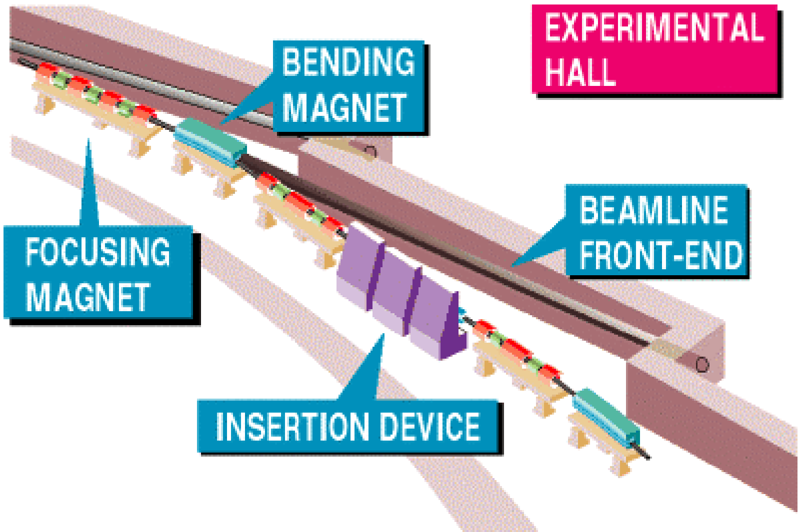

Fig 2: The storage ring, which is the source of X-ray where the needle thin electron beam is travelling with nearly the speed of light in ultra high vacuum.

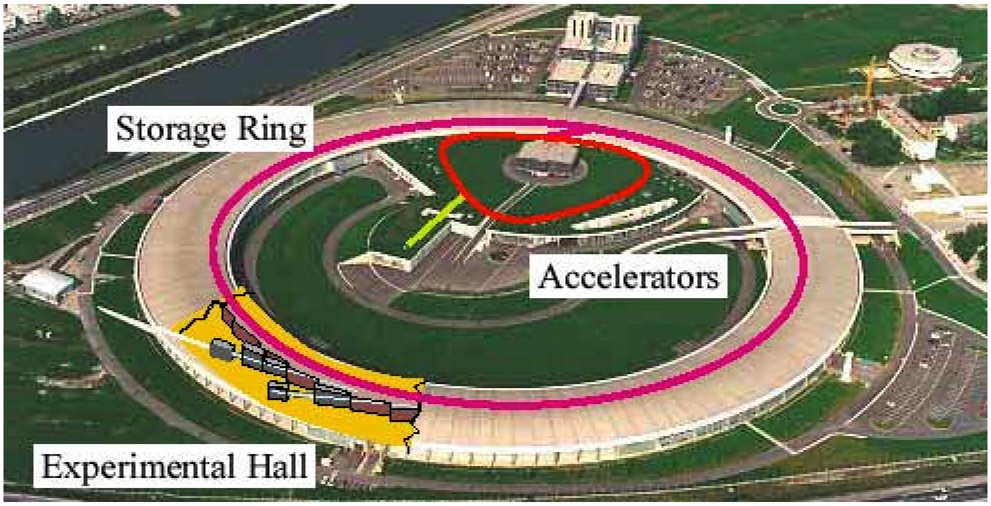

Fig. 3. This is the “machine” producing X-rays at the European Synchrotron Radiation Facility (ESRF)

Radiation emitted by an electric charge travelling in a magnetic field, due to transverse acceleration. T total energy loss is given by

$$\mathrm{d}W/\mathrm{d}t = (2c/3)e^2\beta^4[E/(m_0c^2)]^4(1/r^2)\ ,$$

with

$$\begin{aligned} m_0 &= \text{rest mass of particle} \\ E &= \text{energy of particle} \\ r &= \text{bending radius.} \end{aligned}$$

Due to the factor $[E/(m_0c^2)]^4 = \gamma^4$ {PRIVATE}, synchrotron radiation is mainly observed with low-mass particles, e.g. as a major energy loss in electron ring accelerators.

The mean energy loss of electrons in a circular orbit due to synchrotron radiation is (per revolution)

$$W_\tau = t_\tau(\mathrm{d}W/\mathrm{d}t) = (4\pi/3)e^2\beta^3\gamma^4/r = CE^4/r$$

with

$$\begin{aligned} &t_\tau = \text{revolution time} = 2\pi r/(c\beta)\ , \\ &C = 8.85\times10^{-5} \quad [\mathrm{GeV}^{-3}/\mathrm{m}]\ . \end{aligned}$$

In a machine with bending and straight sections, the energy loss per revolution is independent of the straight sections. In LEP, with a bending radius *r* = 3100 m and bending sections over {PRIVATE}L_b = 19500m, the radiated energy per revolution and particle at collision energy $\sqrt{s}$ {PRIVATE}= 92 GeV i {PRIVATE}W_r=180 MeV, the energy per second and particle ({PRIVATE}{PRIVATE}t_r = 89 μs) is {PRIVATE}d*W*/d*t* = 2000GeV/s.

In electron colliders, synchrotron radiation limits the bending power that can be installed and imposes lower limit on the ring radius; the effect has, on the other hand, been used to determine and monitor beam parameters in accelerators.

Photons radiated as synchrotron radiation have a broad energy spectrum at low energies; above a *critic energy* $\in$**= 3hcγ^3/2r** the falloff is exponential. **{PRIVATE}**$\in_c$ is also the median of the power distribution, viz. an equal amount of energy is radiated below and above $\in_c$ {PRIVATE}. Radiated photons are concentrated in a forward cone with opening angle (FWHM)

$$\Theta \approx \frac{2}{\gamma}\sqrt{\frac{\epsilon_c}{\epsilon}}$$

3.0 Properties of synchrotron radiation

Because of the unique characteristics of the emitted light, its use has become essential in numerous research sectors, both fundamental and applied. Synchrotron radiation has properties that make it a valuable tool for X-ray studies of atomic arrangements in molecules and in crystals. These include natural collimation, that is, the waves in the beam are nearly parallel: they do not fan out as waves fror X-ray tubes do, and so require no focusing; extremely high intensity; broad spectral band width in a smooth, featureless continuum; high polarization, fully tunable and small beam size about 1 sq mm.

Synchrotron light is virtually unique in its ability to tune photon energy with continuous coverage ovei ranges and with the excellent intensity, a small but intense X-ray beam allows time-resolved studies oi extremely small samples even for poorly interacting compounds. This leads to many different types of applications in spectroscopy- mapping the quantized energy levels of a gas, liquid or solid target and using these results to learn about the electronic and geometric structure of the sample. Much of the spectroscopy with synchrotron light deals with inner-shell or core levels for which energies above 50 are required.

4.0 Application of synchrotron radiation to surface science

Synchrotron radiation photoemission spectroscopy is one of the most important tools for establishing relationships between structural and electronic properties at surfaces. Thus, core-level shifts (CLS) are related to charge transfer electronic screening, geometrical structure and other basic properties of the electronic structure. The ascription of the XPS components to atomic features is of great importance because it can be used to follow processes on surfaces such as surface dynamics and chemisorption.

The high flux and resolving power of the new third generation synchrotron radiation sources allow for a clear identification very close Therefore, it is possible to use the CLS components to gather information about the first stages of the growth and the evolution of different systems**.** High-resolution synchrotron radiation photoemission has been used to investigate the formation of the Cu(110)+c(2_2)-Si surface alloy. The complex spectra of the Si 2p core-level are analyzed as multiple component spectra for different Si coverages and annealing temperatures of the surface alloy. The results show that c(2_2) islands are formed from the very beginning of the growth and that Si has a high diffusion length on Cu. The thermal stability of the surface alloy has been studied by measuring real-time photoemission spectra at different temperatures.
The surface alloy is stable up to 180°C. Above this temperature disruption of the surface alloy and clustering of the Si atoms can be observed.

Fig 4. Si 2p core level photoemission spectra obtained for varous Si coverage on Cu (110). Points represent experimental data and lines the result of the fit. Dotted curves at the bottom of every spectrum represent the four different components used for the decomposition of the peaks. The Cu (110)+(2x2)-Si surface alloy is obtained for a coverage of 0.5ML. The upper spectrum is for an approximate coverage of 6ML.

Due to the fact that synchrotron radiation is highly tunable it is used in surface EXAFS and NEXAFS spectroscopies for determining the local atomic structure and electronic properties around the X-ray absorbing atoms. The two examples below illustrates this:

(a) Surface structures of submonolayer alkanethiol $CH_3(CH_2)_{n-1}SH$ (n= 6, 12) adsorbed on Cu (111) were investigated using SK-edge EXAFS, NEXAFS, and CK-edge NEXAFS spectroscopies to elucidate the detailed adsorption structures and their chain dependence. The local information around the S atoms was obtained from S K-edge NEXAFS and the surface EXAFS (i.e the distanc of the S-C and S-Cu bonds, adsorption site of the S atom, the polar angle of the S-C bond γ and th electronic properties around the S-atom) and information of the whole molecule was obtained fro C K-edge NEXAFS.

Fig. 5 shows C K-edge NEXAFS spectra from 0.3 ML C_6 and C_{12} thiols adsorbed on Cu (100), at normal and grazing incidences along with those of randomly oriented multilayers. In the NEXAFS spectra from submonolayer thiols depend strongly on polarization. Peak A is the most intense at norma incidence and almost disappears at grazing incidence, implying that the C-H bond is parallel to the surface. Peak B_1 is assigned to the transition moment being parallel to the alkyl chain. Peak B_2 in contrast, is enhanced at grazing incidence, indicating that the molecular chain of the alkanethiol is nea perpendicular to the surface.

(b) Ultrathin Mn films grown at room temperature 0n Cu (100) was studied with extended X-ray absorption fine structure (EXAFS) assisted by low energy electron diffraction (LEED). The experimen was carried out on the beamline 4.2 at the synchrotron radiation source, Daresbury Laboratory that ca operate in a photon energy range between 640 and 10,000 eV. To work in the photon energy range necessary to the study of X-ray absorption spectra at the Mn K-edge (binding energy = 6539 eV) the monochromator was equipped with a pair of Si (311) crystals and Pt-Cr stripes in the plane mirror wer selected (synchrotron radiation covers a broad spectrum hence must be monochromated). The EXAFS obtained for different values of the film thickness is shown in Fig 6 below.

5.0 Advantages of Synchrotron radiation

Synchrotron radiation is orders of magnitude brighter than X-rays produced by a laboratory source and this brightness has opened up new fields of research and allowed investigation of previously unmeasurable samples. More photons produce higher signals, which make it possible to measure a sample more rapidly or examine smaller, thinner, and lower density samples. Three basic approaches can be used: diffraction, which yields cystallographic structural information; spectroscopy, which can be used to probe electronic structure and bonding; imaging or microscopy, which can be used to measure the spatial variation of a chosen characteristic across a sample.
Since electrons or positrons circulating around the evacuated storage ring in “bunches” the emitted photons have a pulsed time structure, and thus pump-probe experiments can be performed on a time nanoseconds.

As opposed to other laboratory sources (X- ray tubes, discharge lamps, lasers) which emit at well defined wavelengths, synchrotron radiation is “white”: covers continuously the entire spectrum. The free choice of the working wavelength has permitted, on one hand, to cover spectral regions which had previously been virtually unexplored because of the lack of appropriate sources (far ultraviolet and soft X-ray regions), and on the other hand to selectively probe nearly all the electronic energy levels of all the atoms.

6.0 Limitations of Synchrotron radiation

The use of synchrotron radiation, particularly in the range of several keV, requires the design of shielded, remote controlled experiments. The accelerator is a source of dangerous radiation, therefore heavier protection is required at this level in order to work in conditions of complete safety under the regulatory authorities.
Depending on the kind of experiment in question sometimes the light has to be monochromated.
It’s very expensive.

7.0 Conclusion

Due to its unique properties synchrotron radiation is an extremely powerful means of investigating matter and has become an indispensable tool for probing the structure and properties of all types of materials.

8.0 References:

1. J.L. Jordan-Sweet, Synchrotron X-ray scattering techniques for microelectronics-related materials studies, *Journal of Research & Development* Vol. 44, No. 4(2000)
2. Adam P. Hitchcock, Applications of synchrotron light to physics and chemistry, *Physics in Canad* 55 (1999) 191-198
3. S.D'Addato, P. Finetti, An extended X-ray absorption fine structure study of Mn ultrathin films grown on Cu(100) *Surface Science* 471 (2001) 203±208
4. C. Rojas , F.J. Palomares, M.F. Lo´ pez , A. Goldoni , G. Paolucci, J.A. Marti´n-Gago, Formation and stability of the Cu(110)+c(2_2)-Si surface alloy studied by high resolution XPS *Surface Science* 454–456 (2000) 778–782
5. A. Imanishi, K. Isawa, F. Matsui, T. Tsuduki, T. Yokoyama, H. Kondoh, Y.Kitajima, T. Ohta; Structural studies of adsorbed alkanethiols on Cu(111) by use of S and C K-edge X-ray absorption fine structures. *Surface Science* 407 (1998) 282–292
6. Y. Kamiya; A new high-brilliance light souce of the university of Tokyo. *Journal of electron spectroscopy and related phenomena,* Vol. 92 (1-3)(1998) pp. 301-309.
7. J.Nordgen; Instrumentation for soft X-ray emission spectroscopy, *Journal of electron spectroscopy and related phenomena,* Vol. 110-111 (1-3)(2000) pp. 1-13.
8. M.E. Couprie, D. Nutarelli and M. Billardon; Implementing storage rings free electron lasers for users on synchrotron radiation facilities: from Super-ACO to SOLEIL*, Nuclear Instruments and Methods in Physics Research B*, Vol. 144(1-4) (1998) pp.66-74