

**ADVANCED SPECTROSCOPIES:
HIGH FLUX AND MICROFOCUS BEAMLINe**

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1. INTRODUCTION

The purpose of the beamline presented in this proposal is first and foremost to deliver the highest flux possible within a small focused beam over the 100 to 1000 eV spectral range. The flux at the sample position should be above 10^{13} photons s^{-1} within a bandwidth of 2×10^{-4} over the optimized energy range. The overall range should be 50 to 1500 eV, though answering to less stringent conditions.

In brief this will involve a medium section tunable undulator (see §3.1) and a monochromator designed to provide a resolving power of up to 5000 at full throughput (§3.2). The latter will include demagnification of the source to provide a $\sim 5 \mu\text{m} \times 100 \mu\text{m}$ spot at the exit slit. Further, a Kirkpatrick-Baez (KB) mountings with bendable mirrors will be available to focus the beam according to requirements. These fall into two categories:

- i) Instrumental constraints which dictate the need for a very well focused beam in the vertical plane. The KB mounting will provide a $\sim 1 \mu\text{m} \times 15 \mu\text{m}$ focus with no loss in flux (other than from reflections). This will provide optimum performance for high resolution resonant inelastic x-ray scattering experiments and x-ray magnetic scattering performed in the off-specular regime. A broader field of view will be provided for the photoemitted electron microscope.
- ii) Experimental constraints where the sampled area size is the essential factor (e.g., in the study of magnetic domains or dispersed objects such as contaminants or small clusters). There a $\leq 1 \mu\text{m}^2$ spot will be available at a cost in throughput (one to two orders of magnitude).

Many experiments will be dealing with magnetic samples or involving symmetry selection, thus a variable polarization undulator will be specified.

We propose to install a switching mirror to be able to work with two alternate endstations.

APPLICATIONS

The beamline will be available mainly for the following groups of experiments.

- **Resonant inelastic x-ray scattering** (RIXS) for which very high flux and small source size are crucial.
- **X-ray magnetic scattering** (XRMS) requiring very high flux especially in the diffuse scattering mode.
- **Photoemitted electron microscopy** (PEEM) which requires a high flux but only a moderately small source.

2. SCIENTIFIC CASE

2.1 Resonant inelastic x-ray scattering

2.1.1 Introduction

RIXS, also called resonant x-ray Raman scattering, just like XAS, uses a monochromatic photon beam to promote an electron from an inner shell to an unoccupied outer level. But, in opposition to XAS where it is usual to record the total electron or fluorescence yields, the experiment consists in a detailed analysis of a specific radiative decay channel. In a Raman process the energy of the scattered photon ω is less than the excitation energy Ω ; it is resonant when ω corresponds to the exact difference between two excited states. It is described by the Kramers-Heisenberg (KH) formula. Because radiative decay in the soft x-ray region is orders of magnitude smaller than non-radiative decay and because spectra are recorded within a narrow band of energies, only third generation synchrotron radiation sources provide the flux and brightness needed for these experiments. In recent years important new results have activated new theoretical studies based on the KH formulation of a second order scattering process (see for example Refs 1,2). They show that a whole new field of spectroscopy is opening up.

2.1.2 Why RIXS?

Several fields of study can be singled out to justify investing in this type of research at SOLEIL.

1. The study of x-ray absorption edges with improved resolution. Using RIXS means that the resolution of the experiment is limited not by the lifetime of the intermediate state (final state of XAS) but by the longer lifetime of the RIXS final state [3]. Caution is required in interpreting the results [4], but there is no doubt that fine detail can be revealed or highlighted by this technique (see for example Ref. 5).
2. Observation of low-lying excitations associated with the ground state (no core-hole in the final state). The information obtained is analogous to that obtained from optical spectroscopy except that the core-hole excitation makes it an element selective technique. So far relatively little work of this kind has been performed because it relies on a high resolving power to separate the inelastic signal from the elastic peak (see, for example Fig. 1 and Refs 6,7).
3. Band mapping [8]. This is especially applicable to broad band systems and where \mathbf{k} -conservation applies. Valence electron to core-hole transitions are plotted as a function of core electron-to-conduction band excitations. Excitations to a well-defined portion of the band structure require high resolution. High-resolution analysis is also needed. Technically, the consequence is that \mathbf{k} is well defined. Future developments should make it possible to perform angle resolved RIXS. The potential advantage over ARUPS is here again element selectivity, and bulk sensitivity.

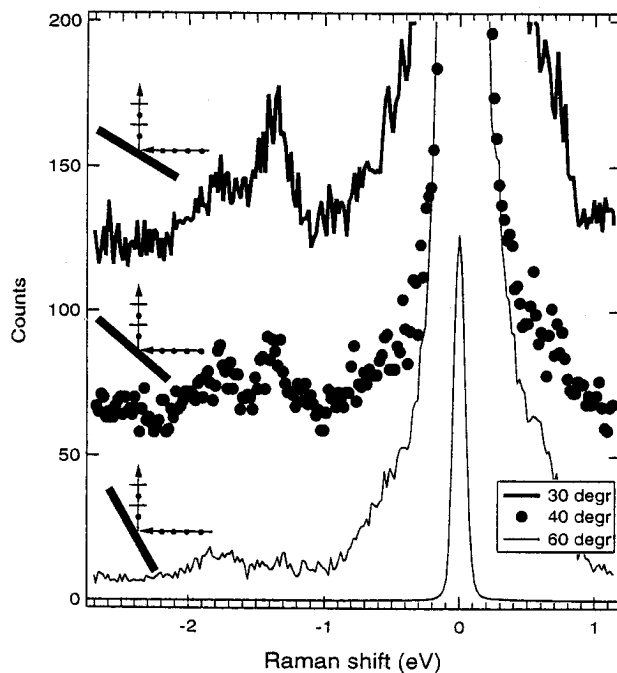


Fig. 1 Polarization dependent energy loss spectrum at the Cu $3p_{3/2}$ edge for $\text{Sr}_2\text{CuO}_2\text{Cl}_2$
 Performed at ALS on BL 7.0 [6].

4. All the above observations may be associated with the use of polarized radiation to underline symmetry effects and especially magnetic properties. The use of an all-photon technique has the obvious advantage that measurements may be performed in the presence of an applied magnetic field. So far, beamlines providing circularly polarized photons in the soft x-ray region have not been designed with RIXS in mind (in contrast to high energy inelastic scattering beamlines). This has stunted efforts to exploit the information on magnetic properties contained in the x-ray emission signal. RIXS is highly responsive to the degree of localization of the core-hole excited intermediate state, but this in itself is an important parameter in our understanding of magnetic properties. Another little explored aspect of the relation between x-ray emission and magnetism is the angular dependence of the emitted photons in relation to the direction of magnetization and incident photon polarization. Measurement of magnetic circular dichroism in the RIXS signal from a sample with in-plane magnetization perpendicular to the incident beam is an example [9]. In such experiments the x-ray absorption MCD is zero so that the analysis of the RIXS dichroism is independent of absorption effects. Another facility that will be designed into the new endstation will be magnetic pole-pieces able to concentrate a magnetic field of several T at the sample position. This will take full advantage of the insensitivity of RIXS to the presence of strong magnetic

fields. Such developments are hardly justified until the resolving power and spectral quality has been greatly improved..

5. In the presence of sufficiently bright sources, the bulk sensitivity of the RIXS technique may be fully exploited to study buried layers (such experiments are not limited by the electron mean-free path). Examples of such experiments would typically be concerned with the study of buried ultra-thin layers; for instance spin valve devices.
6. Lastly, RIXS should serve the fundamental interests of theory and computational methods applied to core-hole spectroscopies. Resonant Auger spectroscopies are proving to be powerful tool in the study of molecules [10,11]. Testing theories will certainly benefit from being able to compare both types of radiative and non-radiative experiment and from improved conditions for gas phase studies. Fig. 2 illustrates such a gas phase experiment where measurements on TiCl_4 have proved to be very challenging for theory [12]. High flux and brightness are obviously indispensable to experiments involving low density samples.

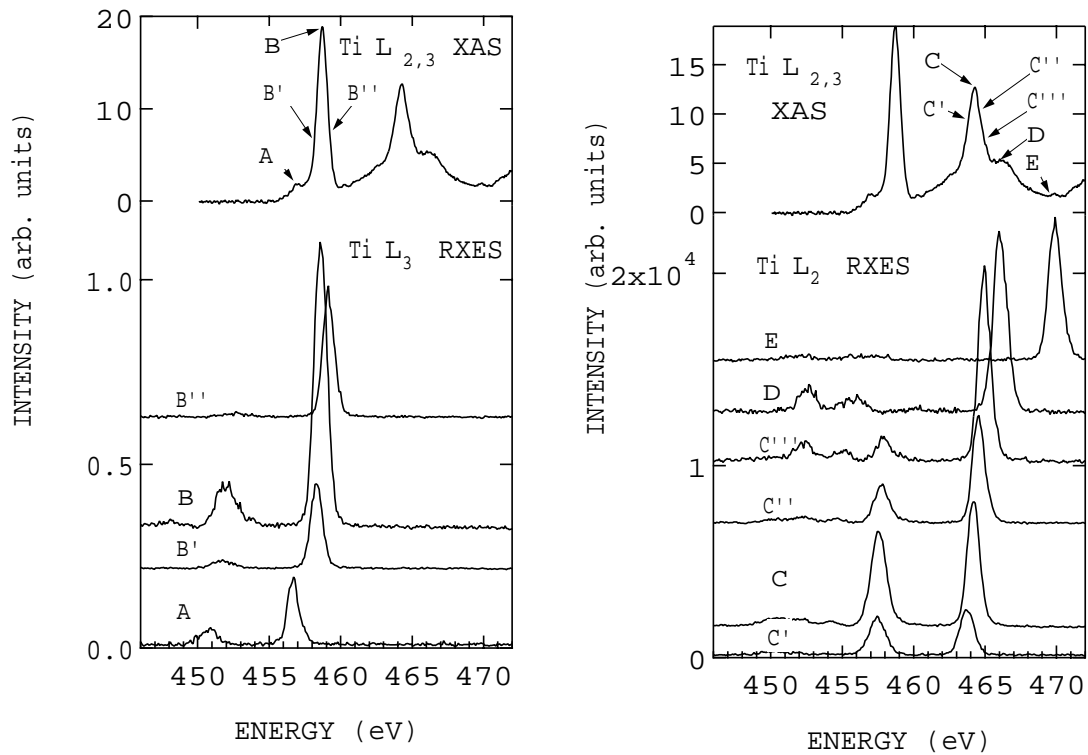


Fig. 2 RIXS taken at the Ti L-edge in gas phase TiCl_4 . Performed at ALS beamline 7.0 [12].

2.1.3 Limitations

We have already hinted at the limitations of the RIXS technique. The concern is mainly about the importance of excitonic effects which do not allow direct comparisons with one particle models or ground state properties even when the core-hole is filled in the final state [13]. Such fears are justified, but on the other hand it is reasonable to expect that the present atomic multiplet models or impurity Anderson models used to interpret spectroscopies will be backed up by first principles calculations in the near future [14]. The RIXS process involves intermediate and final states with the same number of electrons as the ground state so it should prove easier to deal with than Auger spectroscopies.

2.1.4 Instrumentation

Present status

The first generation of RIXS experiments in the soft x-ray region has relied on two types of x-ray grating spectrometer. One is capable of high resolution but requires a weighty construction analogous to standard fixed laboratory experiments [15,16]. The other, of medium resolving power and compact construction, can readily be moved from one beamline to another [17,18].

It is fair to say, that no ideal combination of beamline (in terms of flux and brightness) and spectrometer (in terms of versatility and resolution) exists to date, but plans for a better optimization of both do exist at Max II and ALS. The present situation is that the high resolution instruments (ALS, ESRF) cannot be used to the best of their performance and lack the versatility of compact instruments, especially as concerns the study of polarization effects. The medium resolution instruments have demonstrated their value because they are well adapted to a variety of low brightness beamlines delivering sufficient flux under medium resolution conditions only. In practice the resolving power of all such experiments has been in the 100 to 700 range. Improvements are now urgently needed.

New instrument

We are presently designing a slitless high resolution grating spectrometer based on the Hetterick-Underwood principle [19] within the framework of LURE "Option 1". It is designed around a plane ruled-grating with variable line-spacing and a spherical mirror. A large additional mirror to improve the collected angle in the horizontal plane will optimize efficiency and the signal-to-noise ratio. In principle, the ultimate resolving power of such a design is well over 10000. A conservative estimate suggests that for a Gaussian focus of $3 \times 100 \mu\text{m}^2$ (we assume grazing incidence at the sample), the counting rate will be increased by a factor of 5 at a resolving power of 2500 compared to instruments presently working at resolving powers ~ 300 . The signal to noise ratio will also be improved by a factor of 10. The calculated resolving power improves further as the size of the source diminishes, attaining the theoretical value of 10^4 for a $\leq 1 \mu\text{m}$

(vertical) source size. On the other hand a distinction between vertical and horizontal spot size must be made. Resolution is only weakly dependent on the horizontal spot size at the sample because our spectrometer disperses in the vertical plane. Relaxing constraints on horizontal focusing has important consequences on the total flux available at the sample because of the size and shape of the stored beam.

A high-efficiency 1024x1024 13 μ m pixel back-illuminated CCD detector will be used in a fixed position. The energy range will be selected by adjusting the grating angle using an encoded sine-bar drive. One of the special features of this design is that energy calibration is straightforward and precise.

The spectrometer will be of a compact lightweight construction. This means that it can be fully tested at various synchrotron sites before installation at SOLEIL and be manipulated with ease in angle-dependent experiments at SOLEIL.

2.1.5 Possible future developments

Non-resonant high-energy inelastic x-ray scattering experiments at ESRF have been highly successful over recent years. In such experiments the value of the incident photon energy (usually ~10-20 keV) is chosen to provide the best resolving power in back diffraction conditions for the chosen experimental set-up. Thus it is generally not possible to perform RIXS under these optimum conditions. It would be interesting to examine the needs and technical possibilities of constructing an ultra high resolution experiment capable of measuring resonant spectra with meV resolutions. It should be viewed as a separate operation drawing on the experience gained from the high flux beamline and associated x-ray spectrometer.

2.1.6 Scientific community

The significant progress made in understanding and implementing RIXS over the past few years has yet to have a significant influence on the scientific community at large. Several reasons may be invoked.

- The technique is totally dependent on synchrotron radiation.
- Under current conditions it is extremely time-consuming and in competition with other successful new techniques for the limited beamtime available at the best facilities.
- Due to its complexity and the low efficiency of the process, experiments have remained in the hands of a small number of specialized teams [in Europe: Uppsala (Nordgren), Milan and Grenoble (Braicovich), Paris (Hague)].

We believe that an analogy may be made with the two inelastic x-ray scattering (IXS) beamlines at ESRF. Though a highly specialized state-of-the-art technique IXS now attracts new groups and the installation is oversubscribed.

A “permanent” RIXS instrument with markedly improved performance and operation open to the scientific community will certainly attract physicists and chemists alike.

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2.2 X-ray magnetic scattering

2.2.1. Introduction

For more than a century, it has been known that the transmission or scattering of visible light carries information about electronic structure and magnetic order of materials (Kerr, Faraday and Voigt effects, and magnetic circular dichroism). The extension of the investigation of such phenomena to the x-ray energy range took many years. Though de Bergevin and Brunel were the first to demonstrate magnetic x-ray scattering in 1972 using a conventional x-ray source [1], it was not until the late 1980's that very large x-ray magneto-optical effects were predicted [2] and demonstrated experimentally [3-5]. This breakthrough was due to the possibility of tuning the energy of the photon beam to the onset of a core absorption edge of a magnetic element.

The first x-ray resonant magnetic scattering (XRMS) experiments were performed in the 4-10 keV energy region [4], because this matches Bragg diffraction conditions for typical lattice spacings. Next, even larger magnetic effects at core resonances located in the soft x-ray region (50-2000 eV) were observed in the 3d transition metals (TM) [5] and rare-earths (RE). This is explained by the direct involvement of the magnetic orbitals in the scattering process (3p,2p to 3d resonances in TM's and 4d,3d to 4f in RE's). Soft x-ray experiments have since been performed both in the specular reflectivity mode and the Bragg diffraction mode [6-9]. The latter experiments are performed on multilayers where the chemical modulation period matches the appropriate photon wavelength [6,8].

2.2.2 Why XRMS ?

The specific properties of soft x-ray resonant scattering that make it a major tool for investigating electronic structure and magnetism may be summarized as follows:

- Inherent sensitivity to structural properties.
- As in x-ray absorption spectroscopy, element selectivity and sensitivity to electronic properties depending on the choice of resonant photon energy.
- Sensitivity to magnetic properties and magnetic structure (magnetization depth profile, roughness, domain size, etc.)
- Large magneto-optical effects, due to direct involvement of magnetic orbitals in the electronic transitions. The high sensitivity makes it easy to investigate surface layers (down to a single atomic layer). The large field of view (only limited by photon penetration) permits the analysis of buried thin layers
- Flexibility in the choice of experimental geometries: ferromagnetic (FM) and antiferromagnetic (AF) ordering, probed by circular or linear polarization
- Imperviousness to strong or time dependent magnetic fields and to charging effects (photon-in-photon-out experiment).

Interpretation of resonant scattering results must deal with a larger number of parameters (notably structural parameters) compared to x-ray absorption spectroscopy, for instance. On the other hand, it can rely on a wider set of experimental data, since it brings into play a larger number of variables: photon energy, scattering angle, incoming and outgoing photon polarization. Supported by adequate computational models, this wealth of experimental input provides what is often a unique path to information concerning the electronic and magnetic properties of materials, in particular where the interplay between structural and magnetic properties is of interest.

It has been demonstrated, for instance, that it is possible to obtain not only average values of the magnetic moment per atom in a layer, but also a description of the magnetization profile within the layer [10]. Even element-specific ferro- and antiferro-magnetic coupling hysteresis loops may be drawn, since the magnetic field can be varied at will in a photon-only experiment. The combination of the large probing depths and of the high sensitivity is useful in the analysis of buried thin layers: magnetic moments as low as $0.1 \mu\text{B}$ could be detected and quantified for 2 \AA of Fe buried under 85 \AA of Cu [11]. Regardless of the specific interest of such a sample, this result is indicative of the capabilities of the technique.

XRMS is a relatively young tool for the investigation of the magnetic and electronic properties of materials, implying that quite often current research is oriented towards understanding the technique and proving feasibility, rather than supplying information about a given sample. The analysis of magnetic profiles is a perfect example of this situation [9,10]. Therefore, future developments of XRMS imply consolidating the technique for use in magnetic analysis on a less pioneering basis. In terms of new perspectives, two directions seem very promising, namely off-specular magnetic scattering and time-resolved analysis. The former has been the subject of investigation over the last few years, and has been used recently to address interesting problems like magnetic roughness [12] and order in closure domains [13]. The latter is more at an exploratory stage, but first results indicate that time resolved experiments would give new opportunities to investigate magnetization dynamics with all the advantages of resonant magnetic scattering of polarized soft x-rays.

2.2.3 XRMS at SOLEIL

During the two SOLEIL workshops "Lignes X-mous pour la physique et la chimie de l'état solide" and "Le Magnétisme à SOLEIL" held at LURE and Strasbourg, respectively, the need for experiments using soft x-ray specular reflectivity and off-specular scattering was highlighted. Two groups in France are strongly involved in the development of these techniques and have undertaken the construction of two experimental set-ups with two complementary concepts.

Instrument A. M. Sacchi and co-workers are now developing at LURE a new instrument for soft x-ray scattering (Option-1 funding), that is intended to be part of the experimental set up projected for SOLEIL. The instrument will meet the criteria for surface science experiments,

including *in situ* preparation and characterization in a UHV environment (10^{-10} mbar base pressure). This is a strict requirement for extending present resonant scattering studies to the domain of surface science. Though the high sensitivity of soft x-ray scattering permits the investigation of very thin surface layers [7], up to now these kind of studies have been held back by the absence of reflectometers working under UHV conditions. Our new instrument will make resonant soft x-ray scattering techniques available to the field of surface magnetism. In particular, it will be possible to analyze clean epitaxial layers prepared *in situ*, bringing together XAS, photoemission, and XRMS measurements.

In addition, we expect scattering measurements to offer new approaches. For instance, a multilayer may be used as a substrate for thin films deposition. This would allow for fine tuning of the electric field amplitude at the surface to generate standing waves,. Such an approach might be used to preferentially analyze specific parts of the overlayer, such as the interface with vacuum or with the substrate.

Instrumental development is being carried out in collaboration with the LCP-MR (Paris 6), notably Antoine Avila and Renaud Delaunay who have already contributed extensively to the design and testing of the prototype. Preliminary results are extremely encouraging, with mechanical and vacuum performances well within specifications. The fully operational instrument, IRMA (Instrument pour la Réflectivité MAgnétique), is expected to be finalized in the second half of 2002.

The research activity developed up to now has involved other groups in France and abroad, which are likely to form the first user's community for XRMS at Soleil. In France, we can cite collaborations with Martine Gautier-Soyer and Susana Gota (CEA, Saclay), and Frédéric Petroff and Vincent Cros (CNRS-Thales, Orsay). Since 1996, we have a fruitful collaboration with the group of Eric Gullikson and James Underwood at the Center for X-Ray Optics (Berkeley). Collaborations on specific subjects have been developed with other groups, including S.Nannarone and L.Pasquali (Modena, Italy), M.DeCrescenzi and P.Castrucci (Camerino, Italy), G. van der Laan (Daresbury, UK), M.Gabas (Malaga, Spain) and J.Diaz (Oviedo, Spain).

Instrument B. J.-M. Tonnerre and co-workers at the Laboratoire de Cristallographie (Grenoble) are implementing a large volume reflectometer under high vacuum (10^{-8} - 10^{-9} mbar). Basically built to perform specular reflectivity measurements, the project has been designed to allow developments that require a large volume. A project is under way to extend the possibility of probing reciprocal space parallel to the sample surface. To date, the measurement of rocking curves, in order to probe $q//$, turns out to be limited when systems exhibit small correlation distances (a few nm). Therefore it is planned to install new motions that will make it possible to perform experiments under grazing incidence conditions. The availability of such a geometrical set-up will allow us to investigate, statistically, the magnetic morphology of nano-particles. These may be either self-organized, elaborated on patterned substrates, or prepared by microlithography

techniques. It will also be possible to probe the collective behavior of an assembly of nanoparticles with respect to an external applied magnetic field or to a temperature change. The structural and magnetic complexity of these objects manifests itself in several ways and it is important to probe both the lateral and vertical dimension. The investigation of such objects is particularly difficult when they are distributed in buried layers. In that case, the use of resonant magnetic scattering is particularly appropriate. Another project, in collaboration with Urs Staub and Christoph Quitmann (SLS), concerns the development of a polarization analyzer that will be installed on the detector arm. The polarization analysis will be helpful in determining complex magnetic profiles throughout a thin layer and/or at interfaces. The experimental set-up includes a quadrupole electromagnet, designed to apply an in-plane magnetic field in any direction, which enables x-ray magneto-optics measurements to be made in transverse or longitudinal geometry and the change of geometry *in situ*. One sample holder has been designed for low temperature measurements and another, in collaboration with Michel Belakhovsky and co-workers, for high temperature measurements.

As mentioned in the introduction to XRMS, this q -space dependent technique has been used to directly probe the extension of the induced magnetism from the interface across a spacer layer (collaboration with Wolfgang Felsch, Göttingen). The investigation of depth resolved magnetization profiles across a layer by resonant magnetic reflectivity is likely to be pursued in the coming years. With researchers from Louis Néel Laboratory (Grenoble), projects are underway to apply this approach to the investigation of the exchange coupling between a rare-earth layer and a $3d$ metal layer across an antiferromagnetic layer or a non magnetic layer, as well as to the investigation of magnetic profiles inside epitaxial nanodots. Other directions are explored to use the chemical and magnetic contrast available from X-ray resonant magnetic scattering in order to determine the size and correlation lengths of magnetic objects in the nanometer scale. Nanoparticles of magnetic transition metals embedded in a insulating matrix are investigated in collaboration with A. Naudon (CNRS-Poitiers). In collaboration with Michel Belakhovsky and co-workers at the CEA Grenoble, a research activity is developed to combine XRMS and temperature effects for investigating the evolution of magnetic domains under H,T cycles.

2.2.4 High flux and Microfocus

Up to now, resonant scattering was not necessarily considered a very demanding technique in terms of photon flux. To fix the orders of magnitude, first experiments on single atomic layers were performed with a flux of 10^8 ph.s⁻¹ [7]. New directions in resonant scattering, however, are definitely more demanding, as indicated in the two examples cited above, i.e. off-specular and dynamic studies. To stick to what is already known, the analysis of specular and diffuse (magnetic) scattering over wide q ranges means spanning at least seven or eight decades in

intensity. Therefore, 10^{11} ph.s⁻¹ should be considered an absolute minimum flux for future XRMS experiments. Including dynamics in our objectives can only push this limit upward.

As far as the spot size is concerned, a large demagnification increases the beam divergence at the sample position, and is not necessarily in favor of scattering experiments. On the other hand, magnetic studies are more and more oriented towards small objects (e.g. single domains, isolated dots, etc.). As an example, dynamics studies are better performed on small samples directly prepared on micromagnets, with typical lateral size of a few tens of microns. We believe that a beamline that can deliver an intense flux in a micron size spot will open new opportunities in the field of soft x-ray resonant magnetic scattering.

2.2.5 Theoretical support

Already at this point it is important to stress the need for theoretical and computational support for this type of work. The collaboration that M. Sacchi developed with Alessandro Mirone [x-ray optics group of LURE (now at ESRF)] was until recently one of the strong points of the LURE team. A. Mirone developed the models and computer codes for data analysis and interpretation [14]. Similarly, the Grenoble group developed calculations for multilayers and thin films [10,15]. We believe that this kind of interaction between experimentalists and theorists on a day to day basis will continue to be crucial.

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2.3 X-PEEM Spectromicroscopy

2.3.1 Introduction

Recent progress in the fabrication of nanostructures requires the parallel development of new techniques to characterize these materials at the nanoscopic level. This is particularly the case for magnetic and semiconducting technologies, where the interest for submicrometric range devices has been rapidly increasing during the last decade. Moreover, many of these new materials are used for dynamic applications (magnetic recording heads, memories, sensors etc...). A advent of a technique able study them, combining good spatial (few nm) and time (sub- μ s) resolution is of primordial importance.

The high brightness of third generation synchrotron radiation sources has opened the way to surface and interface imaging with resolutions in the 10 nm range, with the perspective of further instrumental developments down to the 1 nm range [1]. Experimentally, there are two different approaches. The first uses a well focused photon beam which is scanned across the sample surface. The second employs parallel imaging techniques making use of adapted electron optics. In this proposal we opt for the second approach because parallel imaging allows time dependent measurements and promises better performance.

X-PEEM (X-ray PhotoEmission Electron Microscopy) spectromicroscopy is a derivative of classical PEEM. Tuning a photon energy just above the photothreshold, the photoelectron yield is mainly determined by the differences in the work function ϕ of the sample. The local variations of ϕ result in images of high contrast. This UV type of PEEM operation is ideally suited to study surface chemical reactions in real time [2]. Ultraviolet Photoemission Spectroscopy (UPS), X-ray Photoemission Spectroscopy (XPS) and X-ray absorption spectroscopy (XAS) at the nanoscopic level leading to element selective imaging have become available thanks to third generation synchrotron radiation facilities. Information concerning the spatial distribution of the electronic structure, chemical composition and the nature, or the local magnetization at the surface can be obtained. Dedicated beamlines with high brilliance, variable photon polarization (both circular and linear) and a broad energy range have become available recently at several facilities (notably ELETTRA, ESRF, ALS, and BESSY II). This opens a wide area of research for X-PEEM [3], and includes surface magnetism, surfaces and interfaces, surface chemistry, tribology etc..

In the following we will present a proposal for a dedicated X-PEEM endstation for SOLEIL. We will expound our scientific program illustrating it by some novel examples and applications developed over the last few years at third generation synchrotron radiation facilities. More details of the scientific program can be found in the annex.

2.3.2 Scientific program

Imaging of magnetic structures

The interest in magnetic domain imaging in the nanometer range has been rapidly increasing during the last decade. Considerable impetus has been created by the development of high-density magnetic storage devices and forthcoming spin electronics. In order to tailor the magnetic behavior of these systems to specific needs, for instance response to magnetization reversal, a detailed understanding of the structure and of the dynamics of magnetic domains is needed. In addition, the thin film nature of such devices emphasizes the surface aspect of magnetism. This situation requires magnetic domain-imaging techniques that combine surface sensitivity and high spatial resolution. For many applications, element selectivity is even more important than high lateral resolution. Magnetic storage media or building elements of spin-electronic devices are often composed of several chemical elements or intermetallic compounds, each of which distinctly contributes to the magnetic behavior. All these requirements pose a considerable challenge to conventional magnetic domain imaging techniques such as magneto-optical Kerr microscopy, Lorentz microscopy, scanning electron microscopy (SEMPA) etc...

X-PEEM magnetic microscopy is today a good candidate for an ideal surface magnetic imaging technique, as it combines the magnetic sensitivity and element selectivity with a spatial resolution below the size of the magnetic domains. One may identify three important length scales for magnetic imaging which consecutively decrease by a factor of 100. The first one is about 1 μm , set by the size of lithographically manufactured magnetic cells such as in spin valve heads or magnetic memory cells. The second one is about 10 nm, corresponding to the crystallographic grain size of typical magnetic materials. The last one is 0.1 nm, i.e. the atomic size. A spatial resolution of 22 nm using synchrotron radiation has already been achieved [4] and further improvements of this resolution may permit to access the second characteristic length scale of 10 nm.

The elemental specificity in X-PEEM magnetic microscopy arises from the characteristic binding energies of the atomic core electrons. Both XAS and XPS can be used. XAS directly exhibits the characteristic absorption edges of the elements in the sample. At the absorption thresholds of the elements the spectrum shows strong resonances arising from transitions to unfilled valence band states.

The use of polarized synchrotron radiation enables studies of the electronic and magnetic anisotropies [5], and thus allows magnetic contrast for the X-PEEM [6]. A simple description of the photon polarization by a biaxial vector for linear polarization and a vector for handed circular polarization is the physical basis for probing various anisotropies of the sample. In general, linearly polarized light can only detect anisotropy of electronic charge. In contrast, handed

circularly polarized light can measure a dipolar or vector quantity, in our case the size and direction of the electron angular momentum and spin.

a) XMCD Spectromicroscopy

For magnetic spectromicroscopy, x-ray magnetic circular dichroism (XMCD) in the total photoyield mode is exploited. Using XMCD we can determine the size, the direction and the anisotropy of the atomic magnetic moments. As an example, Fig.3 shows an image of magnetic domains in a Fe whisker recorded at the Fe $L_{2,3}$ edges [7]. The black and white regions in the image reflect the domains where the magnetic axis is aligned parallel or anti parallel to the direction of the light at fixed polarization. The grey area corresponds to domains where the magnetic axis is perpendicular to the direction of the light. To distinguish the orientation of the domains in this grey region we have simply to turn the sample in a way to align the magnetic axis parallel and antiparallel to the light.

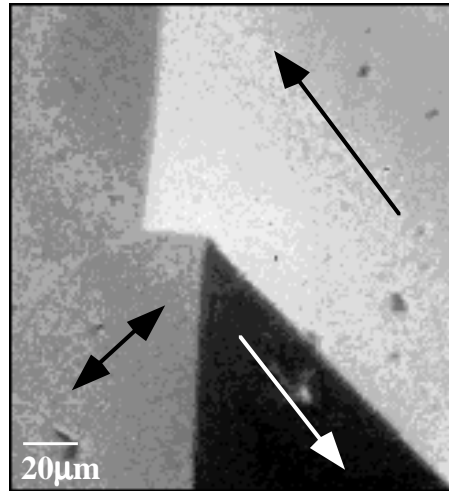


Fig. 3 Magnetic domain structure in Fe whisker recorded at the Fe $L_{2,3}$ edge with circular polarized light.

b) XMLD Spectromicroscopy:

The study of antiferromagnetic (AFM) surfaces and interfaces has posed an even more difficult challenge, since conventional techniques are mainly bulk sensitive. This limitation was overcome recently by the use of XMLD spectroscopy. In contrast to XMCD which directly measures the magnetic moment, XMLD measures the expectation value of the square of the magnetic moment. XMLD can therefore be applied for all uniaxial magnetic systems, i.e. antiferromagnets as well. Recently it was shown that XMLD spectroscopy in conjunction with X-PEEM microscopy is capable of imaging the detailed antiferromagnetic domain structure of a surface and of an interface. This has been shown on a NiO(001) thin film and on a cleaved

sample [8] as illustrated in Fig. 4. The images reveal antiferromagnetic contrast corresponding to the different in-plane projection of the antiferromagnetic axis. A (100) wall separates domains exhibiting large contrast, which are further separated by (110) and (-110) walls into domains with weaker contrast.

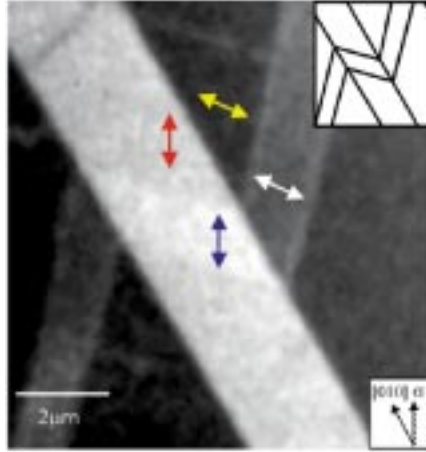


Fig. 4 XMLD antiferromagnetic image of NiO(001). The different gray scales represent the different antiferromagnetic domains as illustrated by the arrows which represent the in-plane antiferromagnetic projection of the antiferromagnetic axis.

c) Time-resolved magnetic imaging:

A new feature that we want to develop on the X-PEEM at ELETTRA and later at Soleil is temporal resolution applied to magnetic spectromicroscopy. The dynamics of the magnetization reversal in thin magnetic films has become a matter of high interest for the future of magnetic recording and non-volatile magnetic memories. Parallel to the evolution toward smaller magnetic bits and memory cells, writing and reading times approaching the ns range will be required in a few years from now. A complete understanding of the magnetization dynamics in these structures requires the ability to probe the magnetization of the individual layers as well as their mutual interaction. We have recently shown, using time-resolved XMCD, that the coupling between the magnetic layers can be very different in static and dynamic measurements [9]. We think that this is due to different processes which play a role in the magnetization reversal at low (mainly domain wall propagation) and high (mainly nucleation of reversed domains) field-sweep rates. Time-resolved X-PEEM measurements would be decisive in confirming this hypothesis. Time-resolved X-PEEM measurements are very challenging, since the secondary electrons that are

used for the image are strongly perturbed by the magnetic field necessary to switch the magnetization direction. For the time resolved XMCD measurements we have developed copper microcoils, capable of providing a relatively strong magnetic field (up to 5000 Oe) during a short time period (20-50 ns). These magnetic pulses can be synchronized with the X-ray pulses coming from the storage ring to perform dynamic measurements in a pump-probe scheme. X-PEEM images can not be acquired during the field pulses, but the relatively slow dynamics (some ns) occurring after the pulse could be measured.

Element-specific magnetic imaging exploiting both XMCD, XMLD and time resolution together with X-PEEM spectromicroscopy, its surface sensitivity and its high spatial resolution will allow us to exploit the full potential of this technique in studying several scientific problems related to surface and interface magnetism, among them:

- Exchange-coupled systems.
- Ferromagnetic/Antiferromagnetic interfaces.
- Magnetic domain structure and domain walls.
- Time-resolved magnetic imaging.
- Magnetic spectroscopy from a small area.

Surfaces and interfaces

Surfaces, interfaces and thin films have been among the most important subjects in science and technology during the last decades. Considerable understanding has been gained in this period by spectroscopic techniques especially based on synchrotron radiation experiments such as PES, XAS and surface EXAFS. Simultaneously, it has become increasingly evident that many problems can be solved only by laterally resolving methods, due to the important role played by local inhomogeneities in the physical properties of the surfaces. The insight gained by various scanning probe microscopies amply demonstrates this. Among them, STM has clearly demonstrated these last few years the importance of a good knowledge of the structure and the morphology of surfaces at atomic scale. However, despite a very high spatial resolution, what all these methods lack is chemical characterisation and/or interface sensitivity. X-PEEM spectromicroscopy has already shown that it can transfer to microscopic problems the previous macro-scale performances of surface techniques such as photoemission and absorption. This includes, for example, the identification of chemical components, and the study of their chemical state and of the related valence electronic structure. New improvements in X-PEEM instruments have recently introduced energy filters to analyse the detected photoelectrons [10,11]. This opens up new opportunities in the use of X-PEEM. Two different modes can therefore be exploited:

1. Imaging of topological, chemical and compositional inhomogeneities: In this mode, an image is formed using the photoelectrons detected by the microscope. The image represents a magnified area of the surface under study. The local variation of the intensity of the core level

reflects the elemental, compositional and topographical inhomogeneities. Suitable image treatments allow one to separate these contributions.

2. Spectroscopic measurements from small selected area at surfaces: In spectroscopic mode, X-PEEM can select a small area on the sample that can be reduced to the resolution limit (few nm) to perform “classical “ spectroscopic measurements. Therefore combining the imaging and the spectroscopic modes leads to local structural and electronic information[12]:
 - Core level photoemission: Local chemical and structural environment.
 - Valence band and resonant photoemission: electronic structure.
 - EXAFS and photoelectron diffraction: Local structure.
 - XAS, XANES: Electronic states.

Combining spectroscopic techniques with high lateral resolution will allow us to study different topics in surface and interface science as will be developed in the annex:

- Growth mode and structure of thin films and aggregates.
- Segregation, wetting and alloying.
- Band structure inhomogeneities.
- High temperature superconductors.
- Dynamical processes, like surface diffusion.

Surface chemistry

Chemical reactions, which show complex phenomena of pattern formation, have recently moved into the focus of the research interest. Among others, catalytic reactions on single crystal surfaces play a particular role not only because of their practical importance, but also due to the relative simplicity of their mechanism. Moreover, their intrinsically two-dimensional geometry makes it possible to apply various observation methods, ranging from optical and electron microscopy to scanning tunneling microscopy, and to directly study the reaction process down to the atomic resolution. The studies of the reactions fronts formed during the chemical reaction on single crystal surface have been considered as a first step in the comprehension and in the formulation of realistic models [13,14]. An impressive variety of different chemical wave patterns has been found in recent years. The experimental studies of the chemical waves have nearly all been performed with PEEM microscopy, since it can provide via the variation of the local work function, information about the chemical identity of the substrate and adsorbate species at submicrometer scale. Moreover the temporal resolution of PEEM (few ms) is always sufficient for the observed phenomena. However, the main obstacle in the formulation of realistic reaction-diffusion models for complex reactions is the limited amount of information about the lateral distribution of adsorbate species on the surface. PEEM imaging, since it is based upon work function contrast, cannot provide or very indirectly, information about the chemical identity and the concentration of the adsorbate species. The combination of X-PEEM imaging and element-specific spectroscopic techniques using synchrotron radiation, gives access to relevant

parameters such as the concentration profiles of the surface species for traveling pulse [15]. A good knowledge of these parameters leads to a better understanding of the chemical reaction mechanism and of its correlation with surface effects like alloying, the presence of contaminants and preferential oxidation close to interfaces.

Further applications

The scientific program described above represents the main scientific concerns of the persons involved in this project. However, it is clear that this program is not exhaustive to all spectromicroscopy's applications that can be developed and demanded by synchrotron users. There are a number of motivations for application of spectroscopic techniques with high spatial resolution. These include thin polymer films [16], tribology [17], small and hazardous materials [18]. In geological science [19,20] for example, XAFS has characteristics that make it very attractive for studying minerals, which have complicated chemical composition. In particular, the XAFS spectrum gives highly detailed information about the charge state and coordination of both cations and anions. Moreover, the NEXAFS spectrum is very sensitive to small distortions in the local symmetry of the absorbing atom. This kind of detail is needed in the study of geological materials, where many different mineral structures may have the same nominal stoichiometry. There is, additionally, the nearly unique opportunity to study charge state-specific magnetic properties, as reflected by XMCD and XMLD. With the high spatial resolution now available in spectromicroscopy, there are potentially many examples in which the mapping of the distribution of phases in natural materials will be aided by this technique. The method can be applied to natural samples prepared in a number of ways, including polished or cleaved surfaces, or exposed surface of small particles from soils. Such studies can also be extended to environmental specimens [21], especially those not requiring the presence of water. An example is the study of the attachment to, and modification of, mineral surfaces by microorganism (biologically produced mineral deposits, biocorrosion specimens...).

2.3.3 Experimental set-up

Within the framework of LURE "Option 1", an X-PEEM project has been developed at LURE (R. Belkhou) in collaboration with two Grenoble-based Laboratories: Lab. Louis Néel (J. Vogel) and Lab. de Cristallographie (L. Sève, M. Desantis). The aim of this project is twofold: on the one hand, to develop an experimental set-up for X-PEEM spectromicroscopy to study magnetism, surfaces and interfaces. On the other hand, a major goal of this project is to create and develop the first French community devoted to spectromicroscopy and oriented to future activity at SOLEIL. For this purpose, a collaboration with ELETTRA has been initiated, which implies the installation of a French X-PEEM microscope at the Nanospectroscopy beamline at the ELETTRA storage ring. Half of the total available beam time on the beamline (approximately

2500 h per year) will be allotted to the French X-PEEM. Beamtime will be available to users via a program committee for both the French and European communities.

Our preoccupations are not limited to the access to a third generation source, but also to develop a group with expertise in this field. For this reason, we are presently developing an active collaboration with the microscopy group at ELETTRA (M. Kiskinova, M. Marsi) who has an extensive experience in this domain. The instrument that we want to develop is based on a commercial LEEM/PEEM microscope (Elmitec GmbH.) initially designed by E. Bauer. This instrument has the advantage that it can be used in both LEEM (Structural and morphological microscopy) and X-PEEM modes. It also permits the best resolution achieved to date (8nm in PEEM mode and 22nm in X-PEEM using core level electrons [10]). However, there are a number of important developments that we want to perform on this to improve the spatial resolution:

1. XPEEM spectromicroscopy is a highly photon consuming technique, and it is not surprising that the recent improvement of the spatial resolution and the relevant scientific results coincide with the advent of high brilliance third generation synchrotron sources. Therefore, there is a special need for a high flux beamline with a wide and tuneable energy range of photons. Special attention must be paid to the size of the spot and to uniform illumination in order to maximize the photon density within the field of view of the microscope.
2. A key limitation to the performance of electron-optical X-ray microscopes is the severe chromatic and spherical aberrations of the immersion lens used. This problem constrains the X-PEEM microscope to a fairly small transmission in an attempt to offset these problems. Rempfer's group [22] has proposed a solution to this problem, by designing and testing an electron mirror, which has spherical and chromatic aberrations of similar magnitude to the objective lens, but opposite in sign. When used in combination with a properly designed objective lens, the aberration can be highly reduced. Therefore both transmission and resolution will be increased. Two major projects using correcting mirrors are presently under construction: PEEM-3 by J. Stöhr *et al.*, at ALS and the SMART project at BESSYII.
3. The incorporation of an energy filter in the X-PEEM microscope with an energy resolution of better than 150 meV for core level and valence band photoemission microscopy. The energy filter is not only necessary for imaging with primary photoelectrons but also useful for secondary electron imaging. It allows to select a narrow energy window around the maximum of the secondary electron energy distribution and, thus, to improve the spatial resolution without unacceptable loss of transmission.

All these developments will be made on the basis of the commercial 90° LEEM/PEEM with the collaboration of Pr. E. Bauer (Arizona state university), the microscopy group (M. Kiskinova and M. Marsi) and the electronic department at ELETTRA. We plan to test and operate the complete version of the X-PEEM at ELETTRA prior to its relocation at SOLEIL.

2.3.4 Scientific community:

Spectromicroscopy has never been developed in France (except for a project by F. Pollack in the 80's). Therefore, there is no specific spectromicroscopy's community involved in this experiment. However, the field of application of spectromicroscopy is very broad so that this project has attracted much attention nationally as demonstrated during workshops and meetings organized to prepare the scientific argumentations for SOLEIL. The main groups of potential users are:

- Laboratoire de Physique des Solides, Thales, Institut d'Electronique Fondamentale (Minerve and Isard Project). Orsay.
- UMP CNRS-Thompson (F. Petroff, A. Fert). Orsay.
- DRFMC/CEA (Samson, Marty, Belakhovsky), SPINTEC (Dieny, Nozieres). Grenoble.
- IPCMS Strasbourg (J.P. Kappler, F. Scheurer, B.Carriere, C. Boeglin...).
- Université de Nancy (Schuhl, Mangin, Andrieu, Dufour, Dumesnil).
- LMOV Versailles (L.Thomas).
- INSA Toulouse (J.F. Bobo, A.R.Fert).
- IRC Lyon (J.C. Bertolinni, Y. Jugnet).
- LPPM Orsay (G. Dujardin, G. Comtet, L. Hellner).
- DPM of Universite Claude Bernard Lyon (V. Dupuis, A.Perez).
- LM2N of Universite P.et M.Curie (M.Pileni)
- Universite de Rouen (J.Teillet).
- Universite de Brest (H.Le Gall).
- PALMS .Université de Rennes 1 (G. Jezequel, F. Solal).
- CRMC2 Marseille (G.Lelay, B.Aufray, P.Henri)
- Ecole Polytechnique, Palaiseau (D.Paget).
- SPCSI- CEA Saclay (P. Soukassian, N.T. Barrett).
- UMR GPS Saint-Gobain (J. Jupille).

The interpretation of PEEM images, as well as of local X-ray Photoemission and Absorption spectra asks for a strong theoretical support. For the interpretation of domain structures in nano-objects, as well as for the time-resolved magnetic PEEM measurements, micromagnetic simulations are necessary. These can be provided by J. Miltat and A. Thiaville of the Laboratoire de Physique de Solides in Orsay, who already have shown their strong interest for PEEM imaging, as well as J.-C. Toussaint from the Louis Néel Laboratory in Grenoble. For the interpretation of X-ray Absorption/Photoemission and Dichroism, good contacts exist with G. van der Laan of Daresbury Laboratory and F. de Groot of the University of Utrecht, as well as with people closely related to LURE, like Ph.Sainctavit or M.-A. Arrio of the Laboratoire de Minéralogie-Cristallographie (Paris). Modelization of growth mode processes and surface/interface structure using *ab-initio*, Montecarlo and thermodynamic calculations will be

developed by J. Creuze from LURE in collaboration with B. Legrand from the CEA-Saclay and G. Trèglia from the CRMC2 (Marseille).

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3. SCHEMATICS OF THE BEAMLIN

3.1 Source

We propose to use a medium size 7 m section to install an undulator of overall length of approximately 5.4 m (three sections of 1.8 m each). The undulator would be based on permanent magnets and its period would be between 125 and 175 mm. The exact value, as well as the evaluation of the corresponding flux and thermal load, will be defined in collaboration with the SOLEIL machine group. We expect a brilliance in excess of 10^{19} (in units of photons/s/mm²/mrad²/0.1%BW) from the source, at least over the 100-1000 eV range. The undulator should deliver a beam with **variable polarization**: linear vertical/horizontal + circular right/left (Apple II type undulator).

Assuming that the undulator gap can be scanned together with the monochromator, the peak should be narrow enough to work with the polychromatic beam of the fundamental harmonic (monochromator in zero order and filters for higher harmonics, see section 3.4). The ideal bandpass should be less than 3%. Gap tapering should be accessible in order to reach a band pass of about 10% for energy scans at fixed gap especially if undulator scanning cannot be guaranteed at all times.

3.2 Monochromator

The general scheme envisaged for the monochromator is as follows:

- no entrance slit for maximum flux
- a spherical mirror plus a varied line spacing plane grating focusing the monochromatic beam vertically onto the exit slit (zero order can be on focus)
- resolving power must attain 5000 over the entire 100-1000 eV energy range. The monochromator should be capable of covering the range 50-1500 eV, though with reduced performances
- optimization will consist in obtaining the best source/slit demagnification while satisfying the above requirements.

3.2.1 Microfocus

- Kirkpatrick-Baez (KB) with bendable mirrors (modulation of focal distance and spot size)
- demagnification of about 10:1 from the exit slit to sample position
- workable distance between last optical element and sample position of about 1 m in optimum focus conditions

3.2.2 Double end-station

The beamline should include a plane switching mirror between the exit slit and the KB mirror. This would make it possible to install a second KB (or some other refocusing device),

possibly as a future development. Thus two endstations could share the same monochromator. The advantages of such a configuration in terms of optimal use of the delivered beam have been discussed during recent SOLEIL workshops.

3.3 Optical layout

The optical layout that we propose is based on beamline 12.0 at the Advanced Light Source in Berkeley [1]. This beamline incorporates a number of novel and state-of-the-art features, of which the most significant is the monochromator using a plane, varied line spacing (VLS) grating. This design [2], first introduced at ALS in 1994 (beamline 6.3.2), is now widely used throughout the synchrotron radiation community, in particular at ALS, LURE, and Spring-8.

The design can be tailored to provide high flux at low or moderate resolution, as in the ALS 12.0 beamline, which has a resolving power $E / \Delta E$ of around 2000, or high resolution, as in the Spring-8 beamline, where $E / \Delta E$ can be in excess of 20,000.

The configuration required for the scientific programs outlined in our proposal will be similar to that of ALS Beamline 12.0, and its schematic layout is shown Fig. 5.

The monochromator is slitless: since the source is small, it acts in lieu of an entrance slit. In this way we can optimize both the beamline transmission and, for a given overall length, the demagnification. The first component that the beam encounters after leaving the source and passing through the shield wall is M1, a spherical mirror which focuses the beam horizontally onto the exit slit and also acts as a heat sink to reduce the heat load on the following optical components.

After M1, the beam strikes M2, a concave spherical mirror working at high demagnification, that forms a real image of the source at a distance of about 1-2 m. A plane grating is positioned between the M2 mirror and the focal point: thus this grating operates in a converging beam. The grooves on this grating are not equally spaced; they are ruled with a varying pitch to achieve the dual objectives of a) dispersing a focussed spectrum at the plane of the exit slit, and b) correcting the spherical aberration of the mirror M2. This is the principle of the Varied Line Spacing (VLS) grating monochromator. This design has several advantages, viz.

1. Aberrations are essentially perfectly corrected over the spectral range of the instrument ;
2. The wavelength scanning motion is very uncomplicated, amounting to a simple motion of the grating. In particular, there is no need to translate the exit slit. This simplicity leads to reliability and low cost.
3. Due to the high demagnification of M2, the numerical aperture of the beam can be better tailored to the experiment.

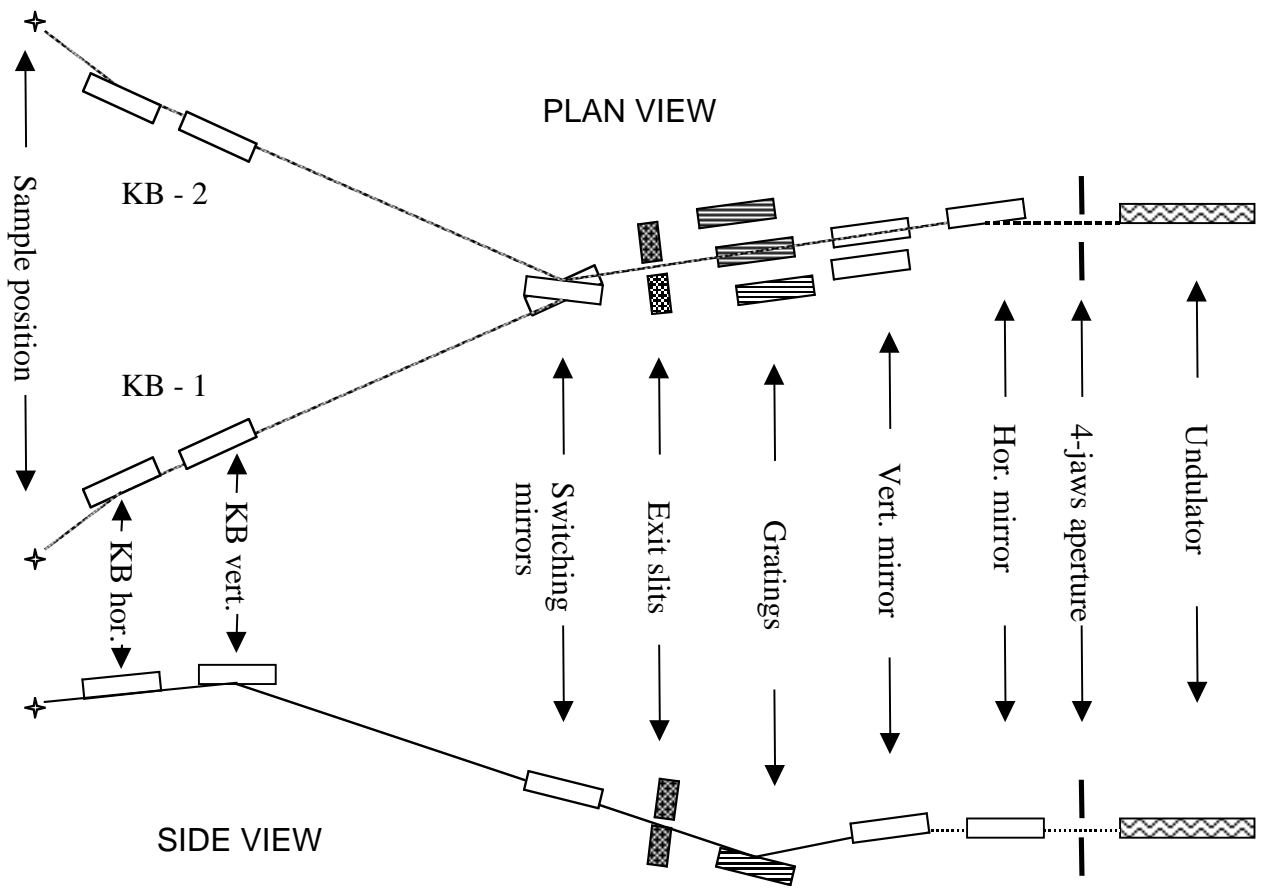


Fig.5. Schematic diagram of beamline

In addition to the vertical exit slit, necessary for monochromatization, a horizontal slit may also be installed close to the focal point in order to define, in both directions, the spot that will be imaged at the sample position.

Following the exit slit, two plane mirrors can be alternately inserted into the beam path by a translation mechanism, in order to deviate the beam horizontally into one of the two branches of the beamline.

Finally, a Kirkpatrick-Baez system of mirrors re-images the exit slit in the horizontal and vertical directions to form a small spot. The elliptical mirrors that make up the K-B assembly are flat mirrors bent into the required shape. This can be done with a high degree of precision. Fig. 5 indicates the components and sub-systems that will be required in the proposed SOLEIL undulator beamline. Details of the design will have to be refined to suit the experiments listed above.

We emphasize that the VLS design is a *fixed deviation monochromator* and, as with all such designs, the complete energy range cannot be covered with a single grating. Several gratings will be required, as on the bending magnet beamline 6.3.2 at the ALS, which uses three gratings to cover the energy range 60 to 1500 eV. The recent addition of a second grating of 1200 l/mm ruling density (at center) to beamline 12.0 has increased this beamline's energy range and its spectral resolution to $E/\Delta E \sim 12\,000$. We envisage the use of at least three gratings for the SOLEIL beamline. The usefulness of a single grating can be extended by coupling it with a second M2 mirror, with a different radius and operating at a different glancing angle. Thus with a judicious choice of three gratings and two mirrors, one can achieve six well spaced overlapping spectral bands, each with an optimum resolution. Grating changes will be implemented by well tried mechanisms, similarly for the mirror changes.

In the same way, the refocusing mirrors, used for producing an intense small beam on the sample, will rely on well-tried techniques for the production of accurately curved mirrors by bending. Such mirrors are in use around the world [3], and have achieved remarkable results in the focusing of x-ray and EUV beams to spots of small dimensions.

3.4 Harmonics rejection

The problem of higher harmonics contamination will be addressed in two different ways

In a standard use of the beamline, one can rely on the incommensurate energy positioning of higher harmonics. A slight displacement of higher harmonics with respect to integer multiples of the fundamental can be achieved by using a so-called aperiodic undulator. In this way, the higher orders of the undulator do not coincide with the higher orders of the monochromator. Therefore, the latter effectively works as an order sorter.

Applications are envisaged where the whole spectrum of the first harmonic of the undulator is needed, providing a very intense beam at the sample position with the resolving power of the

undulator bandpass (2-4%). The monochromator will be set at zero order (specular reflection into the exit slit), therefore it will not be able to filter out higher harmonics from the undulator. For this application, we propose to build an order sorter device that can be inserted in the beam path when necessary. The device combines two parts:

- a filter section, where different thin layers can be inserted in the beam in order to preferentially reduce the transmitted intensity over a given energy range, and
- a mirror section, where pre-aligned three-reflection mirror assemblies with the appropriate included angles and surface coatings can be inserted without deflecting the beam path to the experimental chamber. This combination of transmission and reflection filters has been successfully tested on the x-ray metrology beamline of the Center for X-Ray Optics at ALS (Berkeley).

3.5 Flux and microfocus

A high flux and a small spot size are the declared objectives of this project. Even in this preliminary phase, we would like to conclude with a few figures that come out of reasonable simulations.

As far as flux is concerned, we have calculated the beamline throughput over the 50-1500 eV range, assuming five reflections on mirrors (two focusing on the exit slits, one on the beam splitter, two focusing on the sample) plus one on the grating. The flux curves given Fig. 6 assume a solid acceptance angle of $0.3 \times 0.3 \text{ mrad}^2$ from a source of $20 \times 400 \text{ mm}^2$. Further we assume a brilliance of 10^{19} in standard units and a resolving power of 5000. Two estimates are given, one for six reflections on Ir coated mirrors and grating, the other for three reflections on Ni (two mirrors and the grating) and three on Ir. The latter corresponds to having different coatings on different gratings, according to their energy range (above or below 800 eV), and two coatings side by side on each of the spherical mirrors positioned before the grating. At the expense of a realignment of these two mirrors, a considerable gain in flux between 200 and 800 eV can be achieved in this configuration.

Taking into account a reasonable safety margin, 10^{13} photons/s are readily attained, complying with our goal over the 100-1000 eV energy range under the resolution conditions required. The estimate given in Fig. 6 corresponds to the best focalization without loss in flux, i.e. to a spot size of approximately $1 \times 15 \text{ }\mu\text{m}$ at the sample position, corresponding to a demagnification of about 30 in both vertical and horizontal directions. As far as the vertical direction is concerned, the spot size influences the spectroscopic performance of the instruments or the capability to perform certain experiments: the value of $1 \text{ }\mu\text{m}$ is more than sufficient. Horizontally, a spot of about $15 \text{ }\mu\text{m}$ is appropriate for performing the experiments that are presently envisaged. Microscopy applications or, more likely, studies on very small objects where very small spatial resolution is needed might require reduced lateral dimensions to about $1 \text{ }\mu\text{m}$.

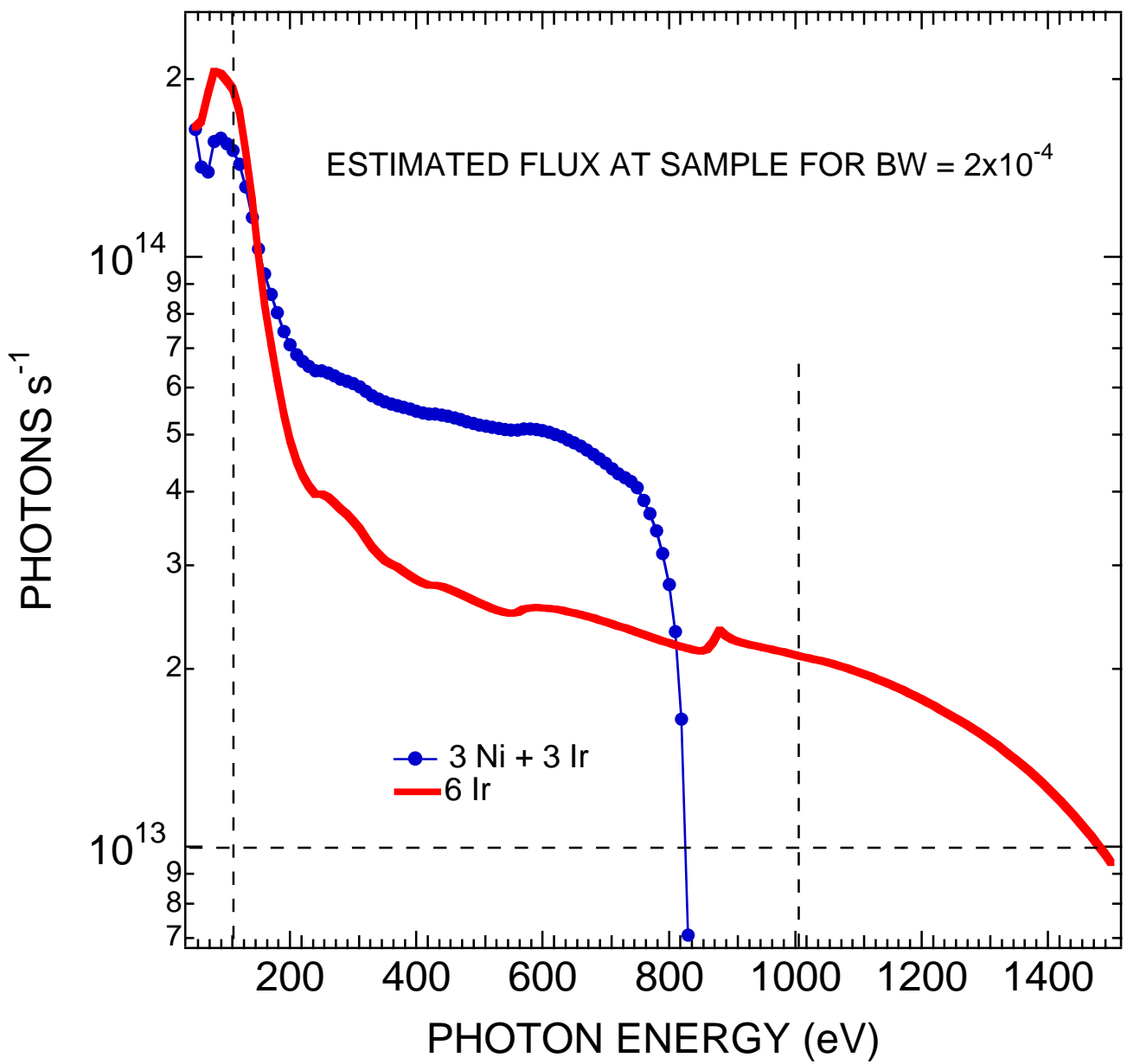


Fig. 6. Estimated flux assuming a brilliance of 10^{19} in standard units, with $R = 5000$ (i.e., $BW = 2 \times 10^{-4}$), solid angle of $0.3 \times 0.3 \text{ mrad}^2$, and grating efficiency of 30%.

This may only be achieved by masking the beam horizontally (i.e., a horizontal slit or a pinhole at the exit of the monochromator). This will be at the price of a flux loss estimated to be one to two orders of magnitude.

References

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