Short Wavelength
Imaging & Spectroscopy Sources
(SWISS)

SWISS 2012

Summer School on

Short-Wavelength
Imaging & Spectroscopy Sources

UNIVERSITÄT BERN xub Short-wavelength Plasma-Radiation Laboratory

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FNSNF FONDS NATIONAL SUISSE SCHWEIZERISCHER NATIONALFONDS FONDO NAZIONALE SVIZZERO SWISS NATIONAL SCIENCE FOUNDATION

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University of Bern, 'Exwi' Building, Room B6
Sidlerstrasse 5, CH-3012 Bern, Switzerland
10-11 September 2012

Rafael Abela, *SwissFEL:* Synchrotrons & X-ray FEL
Philipp Aebi, *Uni Fribourg:* Deep UV Photoemission
Christian David, *P. Scherrer Institut:* Fresnel Zone Plates
Thomas Feurer, *Uni Bern:* Fourier Optics
Manuel Guizar-Sicairos, *P. Scherrer Institut:* X-ray wavefronts
Larissa Juschkin, *RWTH Aachen:* Plasma EUV Imaging
Ursula Keller, *ETH Zurich:* Ultrafast XUV Pulses
Annie Klisnick, *CNRS Université Paris-Sud:* Laser XUV Sources
Peter Lienemann, *ZHAW:* X-ray Elemental Analysis
Alan Michette, *King's College:* X-ray Microscopy in the Lab
Zulfikar Najmudin, *Imperial College:* Table-top Synchrotron
John Rodenburg, *University of Sheffield:* Lensless Imaging
Gian Lorusso, *IMEC*: OPC & EUV effects in Lithography
Sergiy Yulin, *Fraunhofer IOF:* Multilayer XUV Optics

Website: www.kas.unibe.ch/swiss
Contact: Prof. Dr. Davide. Bleiner, University of Bern (bleiner@iap.unibe.ch)

The summer school on "short-wavelength imaging & spectroscopy" (SWISS) is organized by the Short-wavelength Plasma Radiation Lab at the Institute of Applied Physics of the university of Bern. The school is promoted by the Mittelbau Verein of the University of Bern (MVUB), the national competence center for research "MUST" (Molecular Ultrafast Science & Technology), the "Limat" (Light & Matter) research program, and the Swiss National Science Foundation (SNSF).

The school's international distinguished lecturers will offer a two-day introduction in light sources, optics, imaging, spectroscopy, and applications in short-wavelength nano-diagnostics. Live experiments developed within MUST and Limat will be demonstrated. Day 1 (kick-off) is Monday 10 September 2012. The ***no-fee* registration** includes accommodation for a limited number of places. Registration is thus accomplished on a *"first come, first served"* principle.

Participants with a poster summarizing their research achievements or future research projects are also waived the registration fee as well as students. Only title (but no abstract) submission is required for poster presentation. The registration remains open until all places are filled. No admission is possible without registration via website portal or after all the available places are booked.

Three sessions on each day are foresees: (i) sources, (ii) optics & methods, (iii) applications. The 45-minute lectures focus on specific topics and have a tutorial character. The posters will remain up for the whole duration of the school. Get-togethers are organized on Day 1 early morning, with a visit at a Bern's attraction, and on Day 1 evening (grill dinner). The school is concluded on Day 2 at 17.30. Register today for free, and do not miss the opportunity to network with your peers. Information on the summer school & registration at: ***www.kas.unibe.ch/swiss***

Prof. Dr. Davide Bleiner
Institute for Applied Physics
University of Bern

Detailed lecture contents by speaker:

Accelerator short-wavelength sources

Rafael Abela, Paul Scherrer Institute, 5232 Villigen PSI, Switzerland.

Abstract

The Paul Scherrer Institute is running a third generation synchrotron source (SLS) and is planning the construction of a X-Ray Free Electron Laser (SwissFEL) facility, which will produce 20 fsec pulses of coherent x-rays in the wavelength range 0.1 to 7 nm, with extremely high peak brightness. These characteristics will provide opportunities for new experiments in chemistry, solid state physics, biochemistry and materials science. The lecture will present the most important achievements of synchrotron-based research and also focus on novel applications with free-electron laser facilities, the description of the fundamental aspects of the facilities, as well as the challenges to be tackled.

Lecture contents:

- **Synchrotron**
  - **Principles**
  - **Advanced instruments**
  - **Capabilities & Applications**

- **Short-wavelength Free-electron laser**
  - **Principles**
  - **Advantages & Challenges**
  - **World-wide facilities**
  - **The SwissFEL**

A synchrotron light-source based on a compact plasma accelerator

Zulfikar Najmudin, Blackett Lab., Imperial College London, zn1@ic.ac.uk

Abstract

This lecture discusses the generation and application of intense x-ray sources based on the synchrotron radiation produced by electrons in a laser wakefield accelerator. We discuss the principle of electron acceleration using lasers in a plasma, and its advantages over standard acceleration techniques. We then discuss the production of synchrotron acceleration by accelerating charges and how it can be applied to the situation of a laser wakefield. We discuss the imaging properties of this radiation source, and finally discuss the scaling of the radiation generation with present and future state-of-the-art laser systems.

Lecture contents:

- **Laser wakefields**
  - **Advances in high power laser systems**
  - **Production of a laser wakefield**
  - **Electron injection**
  - **Energy gain in a laser wakefield, and present status.**

- **Radiation Generation with laser wakefields**
  - **Radiation generation by charged particles**
  - **The synchrotron limit**
  - **Betatron radiation in particle accelerators**
  - **Synchrotron radiation from laser wakefields, with present status**
  - **Imaging properties of laser driven betatron source**
  - **Future prospects.**

Ultrafast XUV pulses

Ursula Keller, ETH Zurich, Physics Department, keller@phys.ethz.ch

Abstract

This lecture gives an introduction to femtosecond and attosecond pulse generation in the XUV regime using high harmonic generation (HHG). We first discuss the generation of the intense infrared (IR) laser pulse that is required to generate HHG. We will explain important concepts such as passive modelocking based on Kerr lens modelocking (KLM) and/or semiconductor saturable absorber mirror (SESAM), chirped pulse amplification (CPA), pulse compression using hollow core fibers and filaments, carrier-envelope offset phase, and SPIDER technique. We then continue with the basic concepts in HHG and attosecond pulse generation with the semi-classical three step model, the electron trajectories, the atto- and harmonic chirp. We will conclude with an outlook into attosecond spectroscopy.

Lecture contents:

- **Intense few-cycle pulse generation in the near infrared**
  - **Passive modelocking (KLM and SESAM)**
  - **Ti:sapphire amplifier system, chirped pulse amplification (CPA)**
  - **Pulse compression into the two optical cycle regime**
  - **Carrier envelope offset phase: detection and stabilization**
  - **SPIDER**

- **High harmonic generation (HHG) and attosecond pulse generation**
  - **Three step model for HHG**
  - **Attosecond pulse generation**
  - **Electron trajectories, quantum path interference**
  - **Attosecond pulse characterization: RABBITT**
  - **Attochirp and harmonic chirp**
  - **Outlook attosecond measurement techniques**

Plasma-based XUV lasers

Annie Klisnick, CNRS Université Paris-Sud, annie.klisnick@u-psud.fr

Abstract

This lecture is an introduction to the generation of plasma-based XUV lasers and their use as a source for scientific applications. We first discuss the main conditions required to create population inversions and amplify XUV radiation. We give an overview of the main properties of the different types of XUV lasers beams that are currently operational worldwide, while comparing them to other ultrashort, high-brightness sources existing in the same spectral range. We discuss recent demonstrations of applications of plasma-based XUV lasers to high-resolution imaging and interaction with matter at high intensity. Finally we conclude with current prospects for extending these sources to shorter wavelength and higher output intensity.

Lecture contents:

- **Generation of plasma-based XUV lasers**
  - **Population inversions and laser transitions**
  - **Active medium: hot and dense plasma**
  - **Properties of XUV laser beams, present status**
  - **Comparison to other ultrashort XUV sources**
- **Development of applications: recent achievements**
  - **Diagnostic of dense plasma**
  - **High resolution imaging of nanostructures**
  - **Interaction with matter at high intensity**
- **Ongoing and future developments**
  - **Towards X-ray lasers in the keV range**
  - **High intensity in the femtosecond range**

Fresnel zone plates

Christian David, Laboratory for Micro- and Nanotechnology, Paul Scherrer Institut, CH 5232 Villigen-PSI, Switzerland, christian.david@psi.ch

Abstract
Many scientific applications using soft and hard x-rays require high resolution x-ray optics. This lecture gives an overview of the different kinds of x-ray optics (reflective, refractive and diffractive), and then focuses on the specific properties of diffractive x-ray lenses, i.e. Fresnel zone plates. The essential figures of merit such as diffraction efficiency and spatial resolution are discussed. Moreover, the most relevant nanofabrication techniques for the manufacture diffractive x-ray lenses are described, and examples of applications are given.

Lecture contents:

- **Introduction to x-ray optics**
  - **X-ray mirrors**
  - **Refractive x-ray lenses**
  - **Fresnel zone plates**
  - **Basic x-ray microscope set-ups**

- **Fresnel zone plates**
  - **Resolution limit**
  - **Diffraction efficiency**
  - **Resolution - transverse coherence length**
  - **Fabrication techniques**
  - **Examples for applications**

Fringes, speckle analysis & phase retrieval

Manuel Guizar-Sicairos, Paul Scherrer Institut, WLGA-227 5232 Villigen PSI, Switzerland, manuel.guizar-sicairos@psi.ch

Abstract
Over a few decades several techniques have emerged to overcome limitations given by lens numerical aperture and aberrations. Manufacturing of efficient X-ray optics with high numerical aperture remains difficult, thus such lensless imaging methods based on coherent illumination, have found an important application at these wavelengths. We will review the basic principles and reconstruction algorithms of X-ray holography, coherent diffractive imaging of isolated specimens, and scanning X-ray diffraction microscopy. Techniques that completely circumvent the use of X-ray optics and rely on computational phasing of measured intensity patterns for imaging. Recent results of the above mentioned techniques, applications for X-ray wavefront measurement and their extension to 3D imaging will also be discussed.

Lecture contents:

- **X-ray lensless imaging**
  - **Fourier transform holography**
  - **Coherent diffractive imaging of isolated samples**
  - **Extension to 3D imaging**

- **Scanning X-ray diffraction microscopy (SXDM)**
  - **Basic principle and reconstruction algorithms**
  - **Application for X-ray wavefront characterization**
  - **Phase tomography**

Fourier optics

Thomas Feurer, University of Bern, Institute for Applied Physics, Sidlerstrasse 5, CH-3012, Bern, Switzerland. thomas.feurer@phys.ethz.ch

Abstract

This lecture gives an introduction to Fourier Optics. I first discuss the general concept of transfer functions in Fourier optics, specifically in the paraxial approximation, and derive the transfer functions for several important optical elements from first principles. Based on the transfer functions for individual elements I show how transfer functions for more complex optical setups can be derived. Within this formalism I will discuss several examples with an emphasis on imaging, specifically on lens-less imaging applications.

Lecture contents:

- **Transfer functions**
  - **The concept of transfer functions**
  - **Transfer function for free space propagation**
  - **Transfer function for lenses and curved mirrors**
  - **Transfer function for phase masks and holograms**
  - **Transfer function for dispersive elements, i.e. prisms and gratings**

- **Complex optical systems**
  - **Simple imaging setups**
  - **Setups involving dispersive elements**
  - **Traveling wave excitation**
  - **Lens-less imaging**

Multilayer reflective optics

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Abstract

The good prospects of EUV and soft X-rays to be applied to next generation lithography systems (λ = 13.5 nm), microscopy in the “water window“ (λ = 2.3 - 4.4 nm), study of high-order harmonic generation (10 - 30 nm), astronomy and spectroscopy (λ = 5 - 80 nm), plasma diagnostics and EUV/X-ray laser research have led to considerable progress in the optics development for this spectral range. At the Fraunhofer IOF Jena multilayer optics development cover the full spectral range from 1.0 nm to vacuum ultraviolet around 200 nm. The paper summarizes recent progress and the present knowledge in preparation and characterization of high-reflective multilayer optics for the VUV and soft X-ray range with regard to different narrowband and broadband designs, minimization of structure imperfections, enhanced thermal and radiation stability.

Lecture contents:

- **Basics of EUV coatings**
  - **Reflectivity of a single boundary**
  - **Reflectivity of a multilayer stack**

- **Design of multilayer structures**
  - **High reflective mirrors**
  - **Broadband and narrowband mirrors**

- **Multilayer fabrication**
  - **Sputtering vs. evaporation**

- **Multilayer imperfections**
  - **Interface-engineering**

- **Stability of multilayer structures**
  - **Thermal stability**
  - **Radiation stability**

Diffractive Imaging & Ptychography

John Rodenburg, University of Sheffield, Dept. of Electronic and Electrical Engineering, Sir Frederick Mappin Building, Mappin Street, Sheffield, UK, J.M.Rodenburg@shef.ac.uk

Abstract
Ptychography, a form of lensless or lens-assisted diffractive imaging, was originally proposed as a thought experiment for solving the crystalline X-ray phase problem by Hoppe in the late 1960s. It can take diverse forms. We first examine it in terms of the extremes of sampling in real and reciprocal space. When sampling is dense in both planes, the method is sometimes called scanning diffraction microscopy (see the presentation by Guizar-Sicairos). When real space sampling is as dense as one illumination position for every reconstructed pixel, then Wigner distribution deconvolution can allow direct removal of partial coherence effects (a key issue in diffractive imaging). To date, ptychography has been formulated assuming the projection approximation is valid for any one 2D ptychographic image. In fact, when a substantial range of incident beam angles are in the illuminating beam (as is the case in soft X-ray STXM), the 2D approximation quickly breaks down, although in principle the same data should allow for depth-of-field discrimination. Structured illumination can also be used to obtain super-resolution reconstructions.

Lecture contents:

- **A brief history of ptychography, starting with Hoppe's gedankanexperiment**

- **Sampling in ptychography**
  - **The crystalline case: very sparse (two pixels) in real space**
  - **The scanning sector detector case: very sparse (three pixels) in reciprocal space**
  - **Wigner distribution deconvolution (WDD): dense sampling in both real and reciprocal space**
  - **Direct deconvolution of partial coherence via WDD**

- **3D diffractive imaging**
  - **Ptychography with structured illumination**
  - **3D CDI methods and ptychography – a comparison**
  - **Bragg reflection ptychography**

- **Super-resolution**

Applications in the X-Ray Spectro-microscopy

Alan Michette, King's College London, Department of Physics, Strand, London WC2R 2LS, UK, alan.michette@kcl.ac.uk

Abstract
X-ray spectroscopy is a powerful tool for diagnosing the emission characteristics of x-ray sources. It may also be used in characterizing the elemental and chemical states present in compound materials, including the spatial distribution of these states - spectromicroscopy. This presentation will describe the appropriate spectroscopic techniques along with examples of their uses – the characterization of laser-plasma sources and the study of chemical state distributions in medium density fibreboard. The possibility of using laboratory-scale sources for spectromicroscopy, as opposed to synchrotrons, will be discussed, taking into account the signal to noise ratios that are required to provide the necessary precision.

Lecture contents:

- **Spectroscopy**
  - **Emission Spectroscopy**
  - **Absorption Spectroscopy**

- **X-Ray Spectromicroscopy**
  - **Elemental and Chemical State Analysis**
  - **X-Ray Microscopy of MDF Samples**
  - **Absorption Spectroscopy with Laser-Plasma Sources?**

Plasma Extreme-UV Imaging

Larissa Juschkin, RWTH Aachen, Steinbachstrasse 15, 52074 Aachen, Germany, juschkin@ilt.fraunhofer.de

Abstract

The lecture addresses microscopy with plasma based laboratory extreme ultraviolet (EUV) sources. As an example, a Schwarzschild objective-based EUV microscope is presented to be used, e.g., in future inspection of EUV mask blanks in EUV lithography. The system can be operated in bright and dark field mode using a table-top discharge-produced plasma source. For defect inspection purpose the dark field mode is preferred, with increased contrast and sensitivity of the system to small structures. The characteristics of the used Schwarzschild objective as imaging component such as large object field and moderate magnification become advantageous for high process speeds. As necessary it can be zoomed in with the help of a second magnification step using an adapted zone plate lens. Possible defect-detection limits with large field of view and moderate magnification are discussed in terms of required irradiation dose and system performance.

Lecture contents:

- **Microscopy**
  - **Etendue considerations**
  - **Laboratory sources**
  - **Dark field microscopy**
  - **Sensitivity vs. throughput**

- **Application examples**
  - **Defect inspection of EUV masks and mask blanks**
  - **Water window microscopy with laboratory sources**
  - **Observation of growth processes of nano-structures**

Optical proximity corrections and extreme UV-specific effects in EUV lithography

Gian Francesco Lorusso, IMEC, Litho Department, Kapeldreef 75, BE-3001 Heverlee, Belgium. lorusso@imec.be

Abstract

In this lecture we discuss the requirements for optical proximity correction (OPC) in Extreme Ultraviolet Lithography (EUVL). As EUVL enters the pre-production phase, the need to qualify the Electronic Design Automation (EDA) infrastructure is pressing. In fact, it is clear that EUV will require OPC, having its introduction shifted to more advanced technology nodes. The introduction of off-axis illumination will enlarge the optical proximity effects, and EUV-specific effects such as flare and shadowing have to be fully integrated in the correction flow and tested. We have performed a model calibration exercise on a pre-production EUVL scanner. A model calibration mask has been designed, manufactured and characterized. The mask has different flare levels, as well as model calibration structures through CDs and pitch. The flare modulation through the mask is obtained by varying tiling densities. The generation of full-chip flare maps has been qualified against experimental results. The model was set up and calibrated on an intermediate flare level, and validated in the full flare range. Wafer data have been collected and were used as input for model calibration and validation. Two-dimensional structures through CD and pitch were used for model calibration and verification. We discuss in detail the EUV model, and analyze its various components, with particular emphasis to EUV-specific phenomena such as flare and shadowing.

Lecture contents:

- **Extreme Ultraviolet Lithography**
  - **Status**
  - **EUV-specific effects**
    - **Shadowing**
    - **Flare**

- **Optical Proximity Corrections**
  - **Model calibration**
  - **Model verification**
  - **Correction implementation**

Photoemission with short-wavelength sources

Philipp Aebi, University of Fribourg, Physics Department, philipp.aebi@unifr.ch; Claude Monney, Paul Scherrer Institute, Swiss Light Source, claude.monney@psi.ch

Abstract

This lecture gives an introduction to photoemission with short-wavelength sources. We first introduce the basics of photoemission on crystalline solids and extend its description to angle-resolved photoemission spectroscopy (ARPES). We explain what essential information on the band structure of solids can be retrieved with ARPES and how it can be theoretically modeled by the spectral function under reasonable approximations. We then discuss the source requirements for doing photoemission and enumerate the different possibilities available nowadays (UV lamps, lasers, synchrotron light …). We then continue by extending the lecture to the timely topic of time-resolved ARPES.
In a second part, we give examples of recent experiments using laser setups for static and time-resolved ARPES on high temperature superconductors and charge density wave systems.

Lecture contents:

- **Photoemission spectroscopy**
  - **The band structure of crystalline solids and the principle of photoemission**
  - **Angle-resolved photoemission spectroscopy (ARPES)**
  - **What does ARPES measure? The spectral function**
  - **Source requirements and possibilities**
  - **Pulsed sources in ARPES: time-resolved spectroscopy**

- **Applications in solid-state physics**
  - **Static laser ARPES experiments: high-temperature superconductors (HTSC)**
  - **Time-resolved ARPES experiments: charge density wave materials and HTSC**

Elemental Analysis with X-ray Fluorescence Spectrometry

Peter Lienemann, Institute of Chemistry and Biological Chemistry, Zurich University of Applied Sciences, Einsiedlerstrasse 31, CH-8820 Wädenswil, peter.lienemann@zhaw.ch

Abstract

X-rays are ideal for the characterization of solid samples, and they provide thanks the X-ray methods (XRF, XRD, XAS, and XRR) complementary analytical informations. The X-ray fluorescence is one of the four instrumental basic methods of the elemental analysis, besides atomic absorption, atomic emission, and mass spectrometry. Main advantages are the fact that non-vacuum operation is possible and the sample does not have to be conductive. The various analytical requirements are embed in the architecture of a XRF spectrometer. For the excitation there are available, on one hand for bulk-analysis, the X-ray radition from tubes and radio-nuclides, and on theother hand for the micro-analysis, accelerated electrons, protons, and Synchrotrons. The resolution of fluorescence lines is accomplished with wavelength- or energy-dispersive detection (WD-XRF or ED-XRF). The lecture will cover all these aspects and demonstrate the utility of the method by means of practical examples.

Lecture contents:

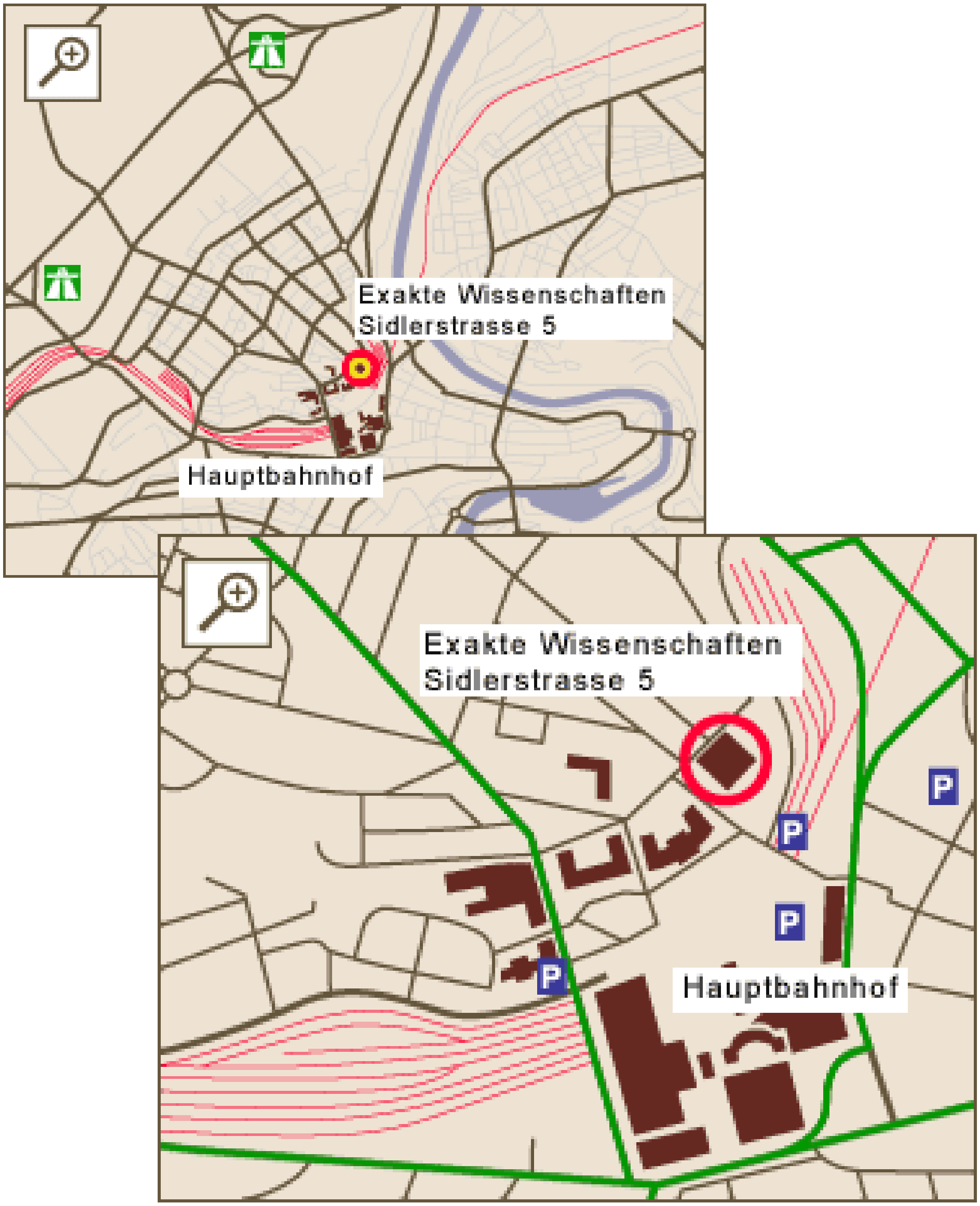
- **X-ray Spectrometry: Capabilities for solid-sample analysis**
  - **Elemental composition (XRF)**
  - **Elemental Neighbors (XAS)**
  - **Crystal structure (XRD)**
  - **Thin film thickness (XRR)**

- **Physical principles**
  - **Atomic Physics**
  - **Scattering**
  - **Lines**
  - **Bragg law, Moseley Law**

- **Instrumentation**
  - **Architecture of a XRF spectrometer**
  - **X-ray Tubes**
  - **Crystal Analyzer & Resolution**
  - **Calibration strategies**
  - **Detectors**
  - **Wavelength versus Energy Dispersive Detection**
  - **REM-EDX**
  - **Mobile Systems**
  - **Micro-XRF**
  - **Synchrotron-based Analysis**

- **Practical Examples**

Venue of the school: University of Bern, “ExWi” Building



Detailed information on http://www.iap.unibe.ch/content.php/map/

Promoters of the school:

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