



Circular polarisation beamline	
Current designated sector:	Facility goes to:
ID12	ID12

1.1 ID CARD

Beamline ID12 is dedicated to polarisation-dependent X-ray absorption, emission and excitation spectroscopies in the medium to hard X-ray region (from 2 to 15 keV). These are powerful tools to study fundamental properties of matter via various order parameters, e.g. spin and orbital moments, electric dipole moments or orbital anapoles. A recent development of a new technique based on X-ray detection of magnetic resonances allows one to study dynamics of those order parameters on a picosecond time scale.

1.2 SCIENTIFIC CASE

We propose to upgrade the existing ID12 beamline which is dedicated to polarisation-dependent X-ray spectroscopy in the medium to hard X-ray region (from 2 to 15 keV). This upgrade should make possible new developments of methods and instrumentation that have been initiated by the ID12 team and have already provided clear evidence of the importance of X-ray spectroscopy with polarised synchrotron radiation to study fundamental properties of matter via various order parameters, e.g., spin and orbital moments, electric dipole moment, orbital anapole etc. **X-ray magnetic linear and circular dichroism (XMLD, XMCD)** in ferro-, ferri- and paramagnetic systems (for a recent review, see Rogalev et al, 2006 and references therein), **X-ray natural circular dichroism (XNCD)** in gyrotropic single crystals (Goulon et al, 1998) as well as **non-reciprocal X-ray linear dichroism (XnrLD)** (Goulon et al, 2000) and **X-ray magneto-chiral dichroism (XM χ D)** (Goulon et al, 2002) in magnetoelectrics are now well-established techniques.

Sub-picosecond magnetism and spin dynamics are new domains of science and time-resolved XMCD on this time scale should become a state-of-the-art technique. However, at a third-generation facility, such as the ESRF, the use of the frequency domain is more favourable, while the underlying physics remain the same. It has been nicely illustrated by the development of **X-ray Detected Magnetic Resonance (XDMR)** technique (Goulon et al, 2007). This is a novel spectroscopy in which XMCD is used to probe the resonant precession of the magnetisation pumped by microwave radiation. This pump-probe technique is the only

spectroscopy that allows one to study dynamical aspects of orbital and spin magnetism separately, and therefore could be seen as the dynamic extension of XMCD. To date, XDMR experiments have been performed at frequencies up to 10 GHz, but have already confirmed the remarkable potential- of this new spectroscopy.

Increasing the pumping frequencies up to sub-THz range could transform XDMR into a unique tool to study magnetisation dynamics and would open a wide range of new applications. Paramagnetism is best studied with XMCD at low temperatures and under high magnetic fields (>5 Tesla): this implies that the XDMR spectra should preferably be measured at high frequencies (>70 GHz). Many paramagnetic systems with integer spin are EPR-silent at microwave frequencies and can only be investigated in the sub-THz frequency range. Moreover, XDMR at sub-THz frequencies would be a unique tool to study Van Vleck orbital paramagnetism, the dynamics of which remain unknown. The investigation of high-frequency modes in ferrimagnets would be another important application. Even more exciting is the possibility to detect high-frequency XDMR spectra in antiferromagnetic systems for which no *static* XMCD signal is detectable. One could even dream to extend XDMR to nuclear magnetic resonances enhanced via dynamic nuclear polarisation. In fact, XDMR is only one part of a whole research programme to study dynamical phenomena in the frequency domain with any sub-THz pump. The same approach could be extended to the investigation of a rich variety of new X-ray electro-optical or magneto-electric effects using XnrlD and XM χ D as the probes.

In a static X-ray magnetic dichroism experiment, an external field is mainly used either to align magnetic domains or to grow preferentially one type of domain with magneto-electric annealing. The required field is rather low and the largest part of the H-T phase diagram of matter remains unexplored. An XMCD and XM χ D experiment under a *static* magnetic field of up to 17 Tesla and even up to 40 Tesla within an ambitious high DC magnetic field project should open new directions in solid state physics research and should contribute to the understanding of complex physical phenomena, such as metamagnetism, exchange bias, magneto-electric and magneto-caloric effects, and many others. There is no doubt that the extension of XDMR under higher magnetic fields would be also extremely profitable.

1.3 PROJECT HISTORY

In these recent years, X-ray physics has concentrated more and more on studies of ultra-fast dynamical phenomena. Whereas X-ray Free-Electron Lasers (XFEL) should open exciting new perspectives to study ultra-fast kinetics in the time-domain at a sub-picosecond time scale, it is envisaged at the ESRF to elaborate a complementary research programme to study ultra-fast relaxation processes in the frequency domain using pump and probe experiments: high power THz radiation would be used as the pump and X-ray dichroism or scattering methods as the probe. A workshop on this topic was held at the ESRF on September 10-12, 2007.

As an important outcome of this workshop it was proposed to equip the ESRF beamline ID12 with an electron cyclotron maser (gyrotron) optimised for XDMR experiments in the sub-THz frequency range. As acknowledged by a memorandum of understanding (MoU) signed in September 2008, the ESRF and the FIR Center of Fukui University (Japan) have agreed to initiate a collaborative

effort to optimise and exploit a gyrotron dedicated to XDMR experiments at sub-THz pumping frequencies. The MoU made explicit provision for the possibility to run preliminary XDMR test experiments at the ESRF with an early-generation gyrotron source borrowed from the FIR Center FU.

The very first test experiment is scheduled in the second half of 2009.

This CDR is based on the DICHRO CDR published in the Purple Book.

1.4 BASIC TECHNICAL CONSIDERATIONS

The source of polarised X-rays are helical undulators that will be optimised to complement each other and would allow users to have full control of the polarisation state of the X-ray beam over a wide energy range (1.5 – 13 keV). To provide users with higher fluxes of polarised X-rays over the whole spectral range, we plan to use only the fundamental harmonics of undulators: therefore we are considering the installation of four HELIOS-type undulator segments mounted on a revolver-type machine and one APPLE-II type. The optical layout of the beamline is not going to be significantly different from the existing one. In order to preserve its good performance in the soft or intermediate X-ray ranges, the beamline remains as a windowless operation. As the first optical component of the beamline, we propose to keep a pair of CVD-SiC mirrors set in an antiparallel (+,-) configuration but to replace the existing four-mirror device with an improved, more efficient two-mirror system. The role of this system becomes even more important with the prospect of extending the energy range of the beamline below 2 keV. The key component of the beamline is a UHV-compatible double crystal, double cam monochromator equipped with two pairs of crystals. In a standard configuration we would still use a pair of Si(111) crystals, whilst for the experiments with circular polarisation in the intermediate energy range (1.5 – 4 keV) we envisage to use a pair of crystals with larger 2d spacings. A pair of focusing mirrors (VF-2M device) is installed downstream of the monochromator. As fluorescence detectors, beam intensity or beam position monitors, we use single- or multi-anode ion-implanted Si PNN⁺ photodiodes operated either in the photovoltaic or photoconductive modes. A multichannel array of Si drift diodes was also successfully developed by the ID12 team. Much effort has been continuously invested over the past 15 years by the beamline staff in order to carefully optimise these detectors for our specific applications. Another typical example is the ongoing development of a new class of ultrafast X-ray detectors (reaching sub-THz frequencies) using X-ray triggered transferred electron devices. This new approach looks very promising and is now covered with an ESRF patent FR08/55566 (Goulon et al, 2008).

As far as XDMR experiments at sub-THz frequencies are concerned, they are primarily envisaged in so-called longitudinal geometry, i.e. in a configuration where the sensitivity of XDMR is inherently poor (Goulon et al, 2007). In ferro- or ferrimagnetic samples, the XDMR signal becomes hardly measurable for opening angles of precession below 1°. Larger precession angles can usually be reached on increasing the pumping power in systems that exhibit narrow resonance line widths. Unfortunately, the line width increases linearly with frequency so that the detection of XDMR at sub-THz frequencies may rapidly require a pumping power in excess of 100W. This is where a high-power gyrotron source operated in the pulsed mode is a very attractive option. In paramagnets, the highest XDMR signal should be

measured under the conditions of saturated resonance. This may be possible at very low temperature if the longitudinal relaxation time becomes long enough. One should face then two conflicting requirements: a rather high pumping power to saturate the resonance while the sample heating should be minimised. Here again, the operation of a gyrotron in a pulsed mode with a rather low-duty cycle seems to be a good choice.

Actually the sensitivity of XDMR at sub-THz frequency could be greatly increased if one could make use of transverse detection geometry with full benefit of the heterodyne detection technique that was successfully exploited at low microwave frequencies (Goulon et al, 2007). A pre-requisite to extend this method up to the sub-THz frequency range would be to reduce the X-ray bunch length below 20 ps.

1.5 REFERENCES

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