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NUCLEAR RESONANCE SCATTERING OF SYNCHROTRON RADIATION – EXPERIMENTS UNDER EXTREME CONDITIONS

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Since its observation in 1985 [1], **N**uclear **R**esonance **S**cattering (NRS) of synchrotron radiation has become an excellent tool to study hyperfine interactions as well as dynamical effects in solids. It has proven to be a complementary method to Mössbauer spectroscopy. NRS combines the advantages of both local probe experiments and scattering techniques and gives valuable information on magnetic structures in solids. A series of review articles on the NRS technique can be found in [2].

Nuclear resonance scattering offers the possibility of determining local electronic, magnetic, structural or dynamic properties. NRS experiments – like all synchrotron radiation experiments – benefit from the high beam quality of 3rd generation synchrotron radiation sources, as the small beam size and divergence. This allows one to use focusing or collimating optics for tiny samples or extreme sample conditions like in high pressure and grazing incidence experiments in combination with variable temperature and strong magnetic fields. We will give an introduction to the method and will then report mainly on results from the NRS beam lines ID18 and ID22N at the ESRF.

A schematic layout of a NRS experimental setup is given in Fig. 1. We show the three main branches of nuclear resonance scattering, the **N**uclear **F**orward **S**cattering (NFS), **N**uclear **I**nelastic **S**cattering (NIS) and **S**ynchrotron **R**adiation based **P**erturbed **A**ngular **C**orrelation (SRPAC). All three experimental schemes make use of the time structure of synchrotron radiation by recording the delayed reemitted radiation, following the nuclear excitation by the synchrotron radiation pulses.

NIS is a very powerful technique for resolving the partial vibrational density of states in solids. The synchrotron radiation is tuned around the nuclear resonance with (sub)-meV resolution. The gain or loss of energy from annihilation or creation of phonons results in incoherently reemitted γ-quanta, off the pronounced elastic peak (*cf.* Fig. 1, NIS) like in Raman scattering or IR absorption. Thermodynamic properties can be derived from the density of states without the need of single crystals, which makes the method complementary to x-ray inelastic scattering.

NFS is considered as a complemetary technique to classical Mössbauer spectroscopy. In contrast to the latter it is performed in the time domain. The broad band excitation by the synchrotron radiation pulse results in coherently forward scattered radiation. The time behaviour of the decay is not a simple exponential, but exhibits pronounced modulations (see Fig. 1, NFS). The fast modulation (***quantum beats***) is due to the splitting of nuclear levels by magnetic or electric hyperfine interactions, here a magnetic hyperfine field. The polarisation of the synchrotron radiation allows one to extract the direction of the magnetization in the sample. Due to the coherent character of the scattering process one can also derive structural information, *e.g.*, from multilayer systems. Coherent multiple scattering effects (***dynamical beats***) give information about the Lamb-Mössbauer factor, *i.e.*, on the dynamical properties of solids and usually exhibit as a slow modulation, as shown in Fig. 1, as well.

The recently developed SRPAC technique (see Fig. 1, SRPAC), like NFS, bears information about magnetic and/or structural properties via hyperfine interaction. As an incoherent scattering process, SRPAC has its merits in cases where NFS fails, either due to high nuclear transition energies, where the coherent recoilfree scattering disappears, or in cases where the coherence of the NFS process is destroyed, *e.g.* by diffusion or rotational motion.

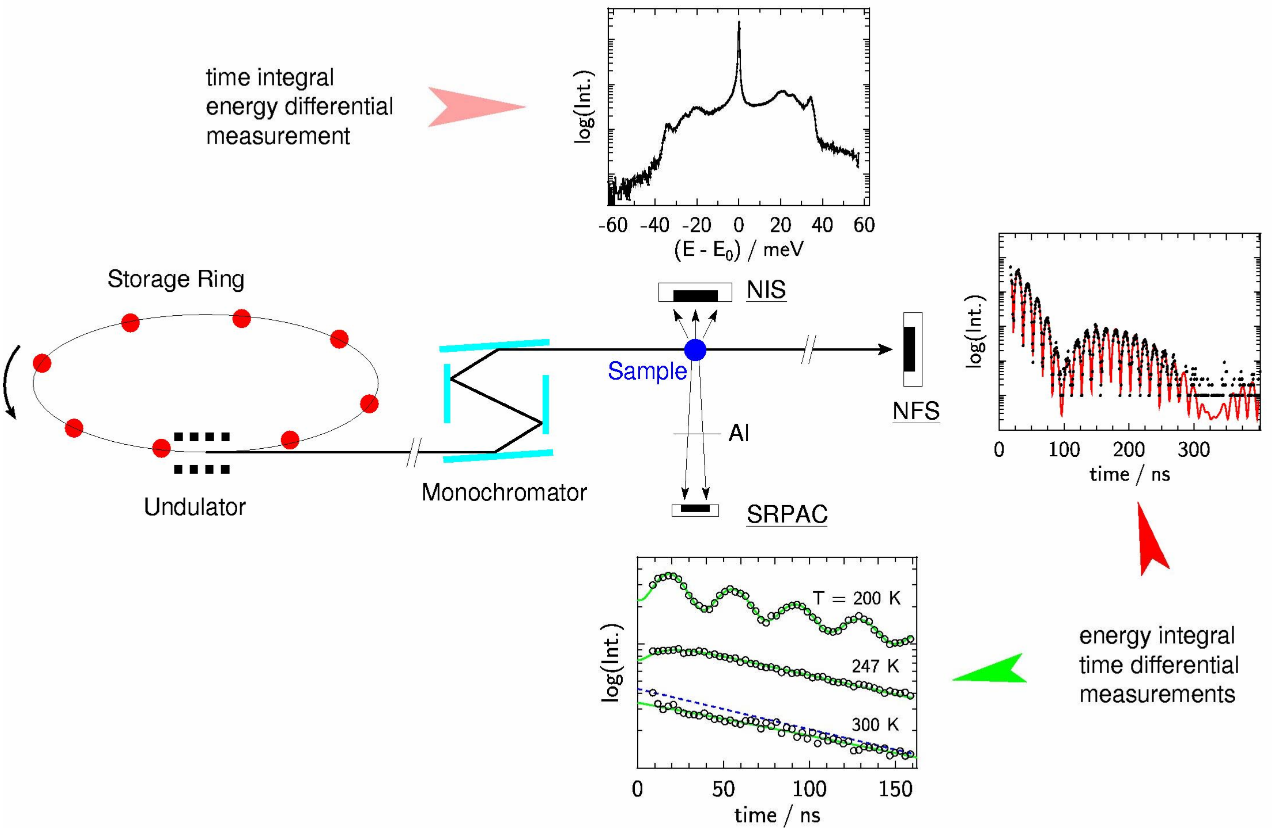

Figure 1. Schematic layout of a NRS experiment.

The nuclear resonance beamlines ID18 and ID22N at the ESRF provide the x-ray optics and the sample environment for these challenging experiments. Focusing and/or collimating compound refracting lenses enable us both to achieve highest performance of our high resolution monochromators (meV resolution in the range from 14 to 30 keV) and beam sizes down to about 100 micrometers. The beam size can be reduced further to 10 micrometers by bent Kirkpatrick-Baez multilayer mirrors. Fast avalanche photo diodes with ns time resolution serve as standard detectors for nuclear resonance scattering experiments and allow us to study, *e.g.*, magnetism or dynamics in the micro- to nanoseconds range.

References

[1] E. Gerdau *et al.*, *Phys. Rev. Lett.* **54** (1985) 835

[2] E. Gerdau, H. deWaard, eds., *Hyperfine Interact.* **123/124** (1999)