Dynamics in submonolayer Fe-films

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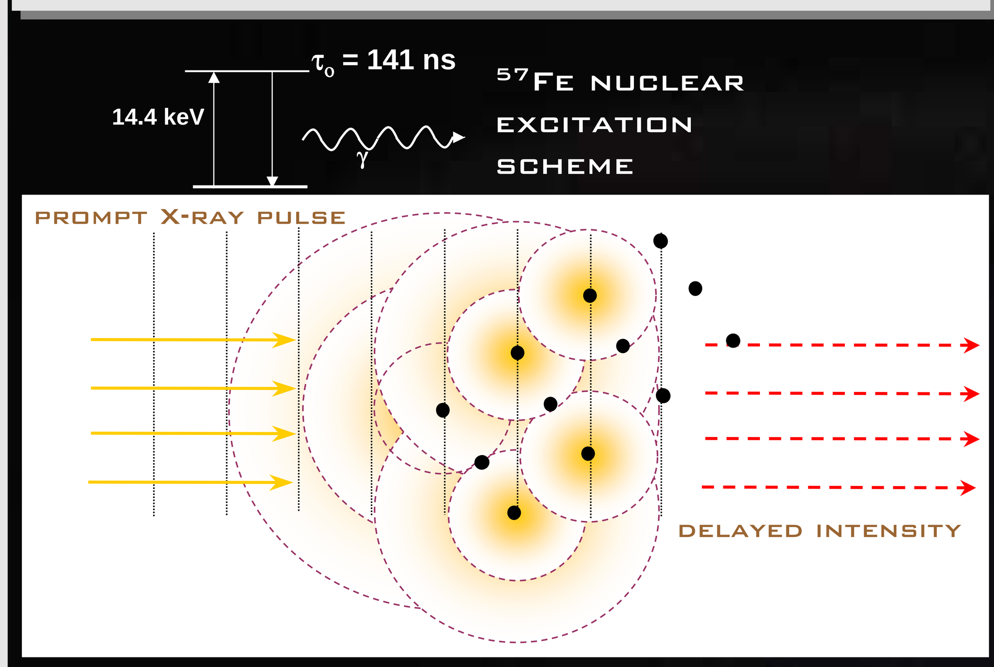
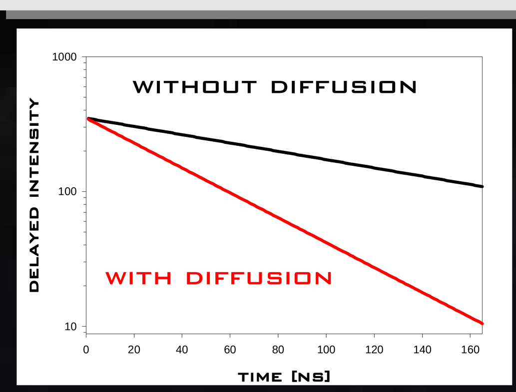
The method

Nuclear resonant scattering

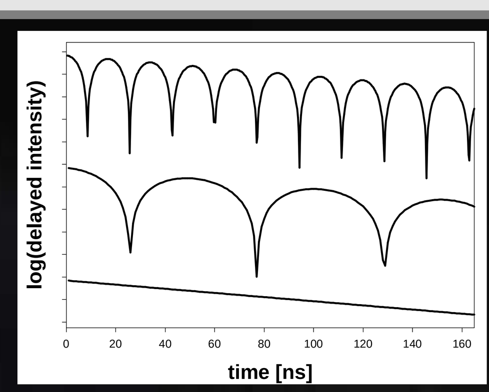


Nuclear resonant scattering of SR can be used for studying diffusion directly in the time domain. The nuclei are excited by short pulses of SR and reemit delayed radiation into 4π.

Diffusion effects



The diffusion causes an accelerated decay of the delayed intensity re-emitted by the Mössbauer atoms in the sample. From the angular dependence of the decay it is possible to determine the jump vectors and jump frequencies



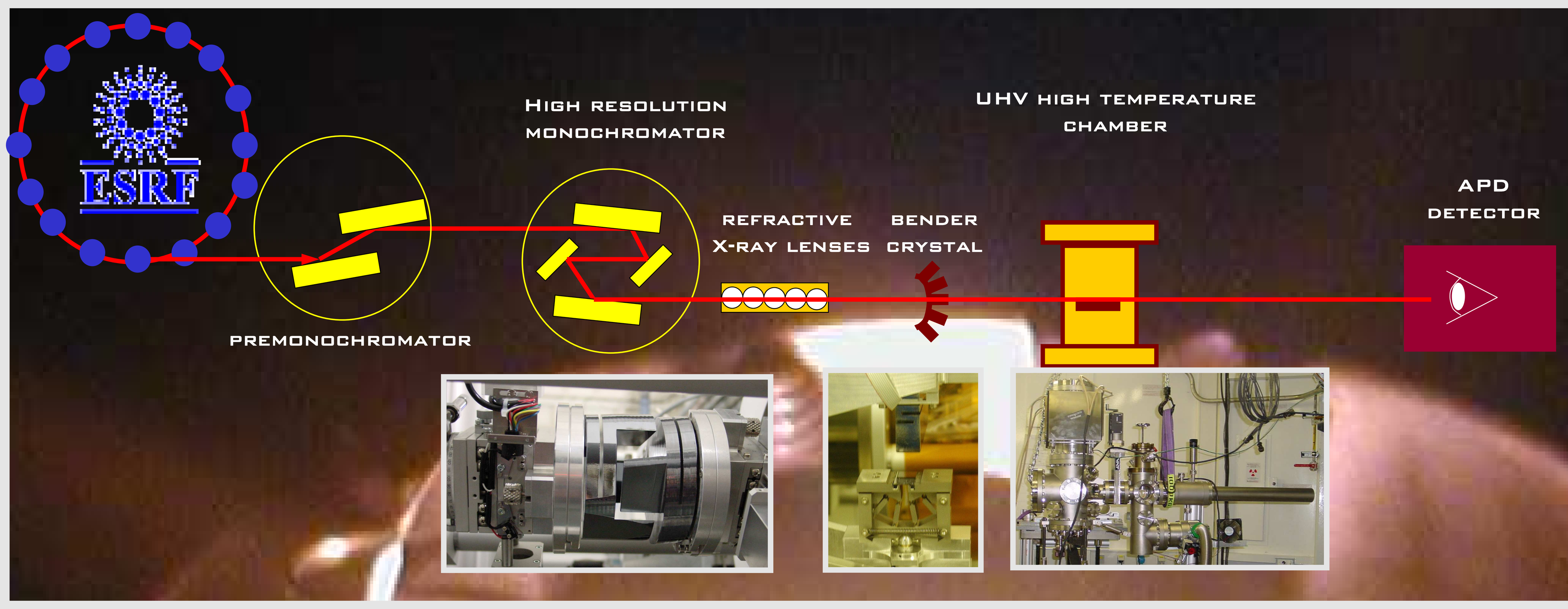
Relaxation of hyperfine interaction: Diffusing atoms lead to random fluctuation of the nearest-neighbour atomic arrangement, causing fluctuations of hyperfine interactions. The result is a simple exponential decay of the delayed intensity.

Surface sensitive investigations

The combination of nuclear resonant scattering of synchrotron radiation with the grazing incidence geometry allows a surface sensitive investigation of the following parameters:

- Hyperfine interactions: magnetisation, electric field gradient (intensity and direction)
- Dynamics and Diffusion (jump diffusion mechanism on an atomic scale - jump frequency, jump vectors)
- isotopic sensitivity

Experimental setup



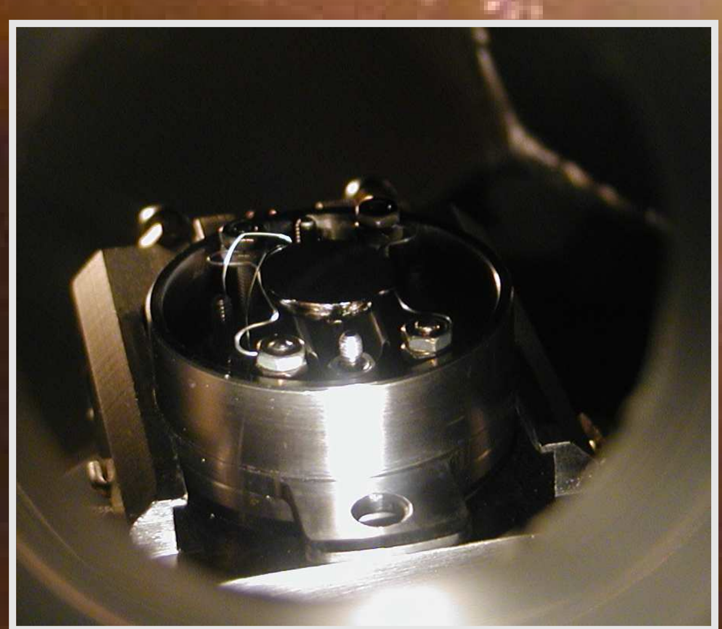
To perform time-resolved investigations a special timing mode of the synchrotron (16 bunch mode) is necessary. 16 bunches of electrons produce every 176 ns a flash of X-rays. A small part of this radiation is absorbed and after 141 ns re-emitted by the resonant nuclei in the sample. The interference of this re-emitted radiation is measured using an APD detector and ns-electronics.

For sagittal focusing (perpendicular to the scattering plane) a bender with two symmetrically cut Si (111) crystals was used. The horizontal beam width of 150 µm was achieved by refractive Be lenses. The experiment was performed in a high-temperature UHV chamber.

Dynamics investigations

Sample description

The sample was produced by MBE deposition of 0.6 ML of ^{57}Fe on a vicinal W substrate. The substrate creates (110) terraces with a width of 30 Angstroems. As proven by LEED the structure of the submonolayer is defined by the substrate and has the same orientation and lattice parameters.



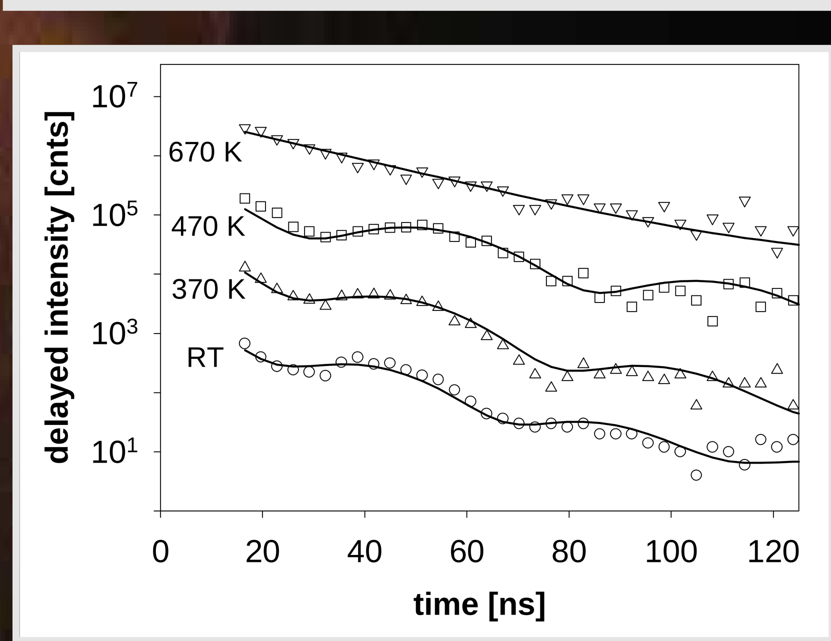
0.6 ML of ^{57}Fe on a W(110) substrate mounted on a high temperature sampleholder (-190°C - 2000°C)

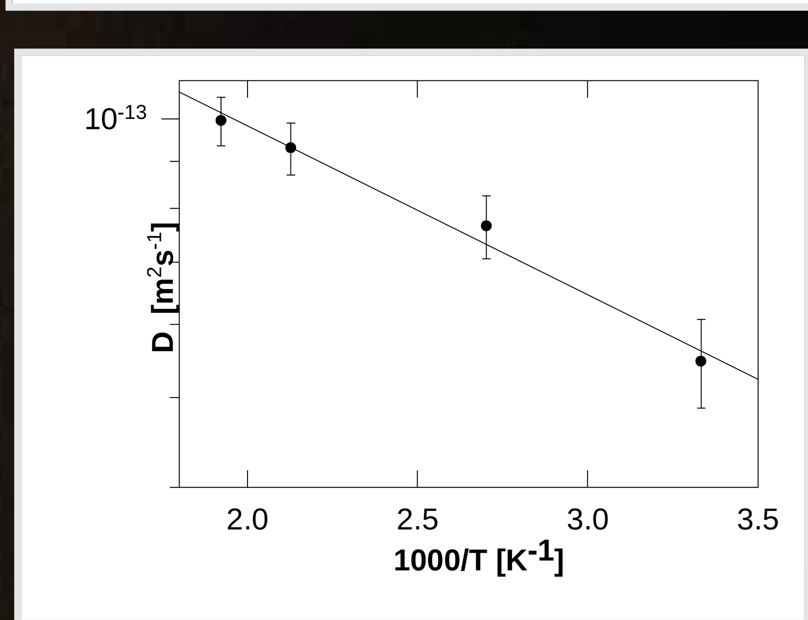
High temperature investigations

NRS spectra of a 0.6 ML iron layer on W(110) at various temperatures have been measured. They show a quantum beat as a result of the interaction of the resonant nuclei quadrupole moment of the resonant nuclei (Fe) with an electric field gradient (EFG).

In the temperature range RT - 670 K a reversible effect was observed. With increasing temperature the period of the beats increases and at 670 K the beats disappear completely.

The temperature dependence can be explained as a relaxation effect caused by diffusion of iron atoms: diffusing atoms lead to a random fluctuation of the nearest neighbour arrangement, this causes fluctuations of hyperfine interactions. The result is an exponential decay in the time domain.





Assuming a simple relaxation model of the EFG with a linear relation to the relaxation rate the diffusion coefficients shown in the picture can be estimated.

Conclusions

The investigation of structure and dynamics of a submonolayer film is possible using a synchrotron radiation source of third generation. The NRS spectra of an 0.6 iron ML on a vicinal W (110) show a beat pattern as a result of an electric field gradient tilted out of the direction perpendicular to the surface. The increase of the beat period with temperature is explained as a relaxation effect. A simple relaxation model leads to a relaxation rate, which is in the order of 10^6 s^{-1}. The diffusion coefficient, assuming a nearest neighbour jump length, is at room temperature D=5.5(6)x10^{-14} m^2s^{-1}.

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