Measurement of Long-lived Isotopes using Stroboscopic Detection of Synchrotron Radiation

Nuclear resonant elastic scattering of synchrotron radiation provides information on the hyperfine interactions between nuclei and their surroundings [1]. Traditionally, this information is deduced from the time response of the radiation to the nuclear excitation. In these experiments it is imperative that the time between two successive bunches is larger than the decay time of the nuclear ensemble. We present here an alternative to this method, called stroboscopic detection, in which the constraint on the bunch mode is significantly relieved, and which has the potential for providing complementary information.

Stroboscopic detection is performed in the heterodyne setup, meaning that two samples are put in the beamline: the sample under investigation and a single-line reference sample with known characteristics. The reference sample is given a variable velocity and thus its resonance energy is shifted by the Doppler-shift. The spectra are then taken as a function of the velocity of this reference sample. In nuclear resonant scattering experiments, it is crucial that the data corresponding to non-scattered photons is not incorporated in the spectrum because the number of non-scattered photons is several orders of magnitude larger than the number of nuclear resonantly scattered photons. This is related to the linewidth of the nuclear excited level, which is several orders of magnitude smaller than the bandwidth of the synchrotron radiation, even after the best high resolution monochromator. Because the nuclear resonantly scattered photons are delayed due to the lifetime of the nuclear excited level, they can be separated from the non-scattered photons by time-gating. Typically in stroboscopic detection, the fundamental frequency of this time-gating is equal to or is a multiple of the bunch frequency [2]. The intensity, integrated within the periodic set of time-windows as a function of the Doppler velocity is called the stroboscopic spectrum. This spectrum consists of several stroboscopic order components, each resembling a conventional Mössbauer spectrum.

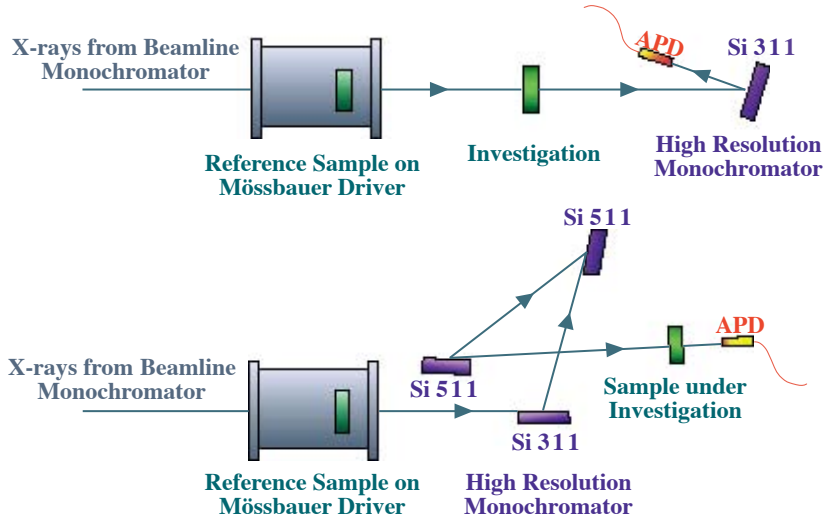

Fig. 1. Experimental setup for both experiments.

A specific property of stroboscopic detection is that the bunch mode is decorrelated from the lifetime of the nuclear isomer. The repetition frequency of the bunches is only restricted by the time response of the detector. Therefore, it is possible to study systems with a lifetime that is much longer than the bunch period, even longer than the circulation period of the electrons in the storage ring. To illustrate that resonances of long-lived isotopes can be detected using stroboscopic

detection, we performed two measurements at beamline **BL09XU** on ^{181}Ta. The lifetime of the isomeric state in a single ^{181}Ta nucleus is 8.7 μs. We used two ^{181}Ta metal foils with respective thicknesses of 3.8 μm and 2.8 μm. The decay time of the total nuclear ensemble was about 15 times shorter than the lifetime of the isomeric state in a single nucleus [3].

We performed two experiments, both in a velocity range of about 2 mm/s. The bunch mode in the first experiment was the 203-bunch mode, which has a bunch separation of 24 ns. The second experiment was performed in the 1/12 filling +10 single bunches mode. A picture of the experimental setup of both experiments can be found in Fig. 1. The delayed count rate in the first experiment was 6 counts per minute and in the second experiment this was 18 counts per minute. These low count rates are caused by the narrow linewidth of the nuclear excited level, which is linked to the large lifetime. The higher delayed count rate for the second experiment can be linked to a better efficiency of the avalanche photodiode detector [4] and a better high-resolution monochromator.

Figure 2 shows the experimental spectra. Because we are only interested in the resonance of the zeroth stroboscopic order, the shape of the time-windows is not crucial. In order to optimize from point of view of statistics, they are taken as broad as possible. For the first experiment (Fig. 2(a)), the first stroboscopic order spectrum component is out of the velocity range, and hence, only the zeroth order stroboscopic resonance can be observed. In the second spectrum, several stroboscopic resonances are generated within the velocity range. These constitute the negative sidebands in the spectrum (Fig. 2(b)).

In conclusion, with these two experiments we demonstrated the potential of stroboscopic detection to contribute to the research on long-lived isotopes. Thereby, the strength of stroboscopic detection is that there is no inherent restrictions on the lifetime of the nuclear levels to be investigated.

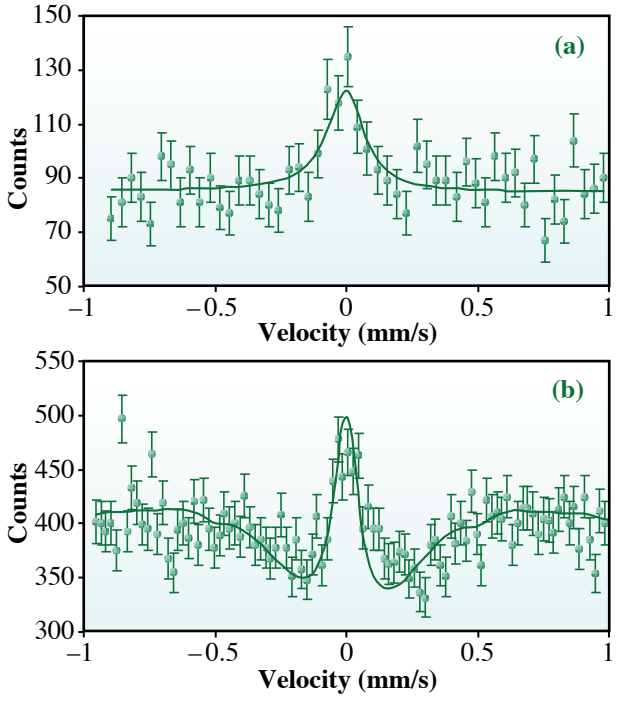

*Fig. 2. Stroboscopic spectra of two ^{181}Ta metal-foils with a bunch-mode of **(a)** 203 single bunches and **(b)** 1/12 filling + 10 single bunches.*

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References

[1] E. Gerdau and H. de Waard, Hyperfine Interact. **123-125** (2000) and references therein.
[2] R. Callens, R. Coussement, C. L'abbe, S. Nasu, K. Vyvey, T. Yamada, Y. Yoda, and J. Odeurs, Phys. Rev. B **65** (2002) 160404(R); R. Callens, R. Coussement, T. Kawakami, J. Ladriere, S. Nasu, T. Ono, I. Serdons, K. Vyvey, T. Yamada, Y. Yoda and J. Odeurs, Phys. Rev. B **67** (2003) 104423.
[3] A.I. Chumakov *et al.*, Phys. Rev. Lett. **75** (1995) 549.
[4] A.Q.R. Baron, Hyperfine Interactions **125** (2000) 29.