New Positron Annihilation Setups for Active Materials

Background

Positron annihilation spectroscopy (PAS) is a well established technique for studying defects in materials. Various nano-structures in materials can be effectively examined by means of PA techniques because of their high affinity to trap positrons. After injection of the positron in a material it diffuses and is drawn by defects where it can be trapped and thereafter annihilates. Further, if the material contains more than one type of defect of additional elements, the positron preferably interact with one type of atoms: selective trapping. The improvement of the theoretical understanding of positron trapping and the refinement of the micro-electronic components allow the technique to give reliable qualitative and quantitative information on defects in materials. PAS techniques have been shown to provide valuable fundamental understanding of the microscopic processes that contribute to irradiation embrittlement of nuclear materials [1, 2].

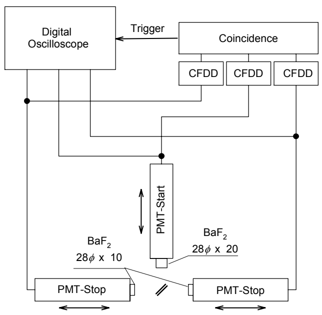
Objectives

At SCK•CEN, a big effort is devoted to the parametric study of neutron radiation damage in nuclear reactor components (PWR, BWR, ADS, Fusion, ...) as function of many parameters such as chemical composition, irradiation temperature, neutron flux and dose. New PA spectrometers measuring radioactive materials have been recently added to the microstructural techniques available at RMO.

Principal results

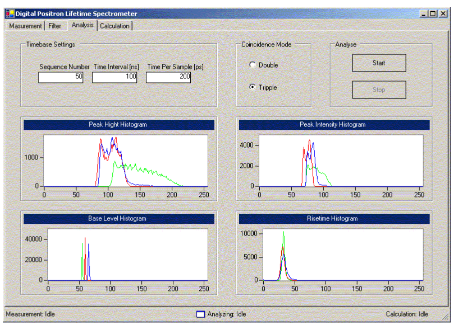
Positron lifetime spectrometer

The positron lifetime spectrometer (PLT) has been recently installed at LHMA in compliance with ALARA rules [3]. The PLT setup consists of a digital oscilloscope (LeCroy WaveRunner 6100A, 1GHz, 4-Channel, 5 GS/s, 4 Mpts), three movable scintillation detectors based on single crystal BaF_2 scintillators and Hamamatsu H3378-51 photomultipliers (PM) (optimal selected for transit time spread, typical 0,37 ns, HV = 3000 V). Time differences are measured between the arrivals of a 1274 keV start gamma (birth of postron) from ^{22}Na and two positron-electron annihilation gammas (stop-γ-rays) of 511 keV. The digitalisation of the PM signals in the oscilloscope allows a clear definition of the coincidence events and also a reduction of the background signals. The time resolution of 170 ps full-width at half-maximum (FWHM) is achieved for the positron lifetime measurements of radioactive specimens. The measurement of irradiated steels was possible thanks to the mobility of the detectors that allow the decrease of their dead time even in the presence of high activity sources.

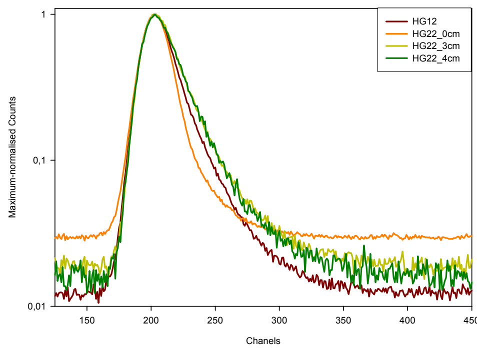


Schematic overview of the PLT spectrometer

Picture of the PLT spectrometer installed at LHMA



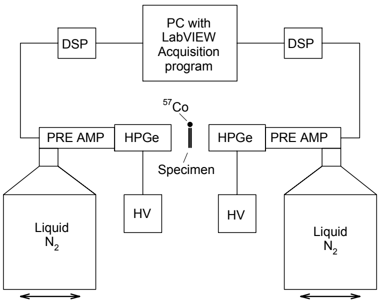
User interface of the PLT spectrometer



PLT spectra of same active material measured with detectors at different distance

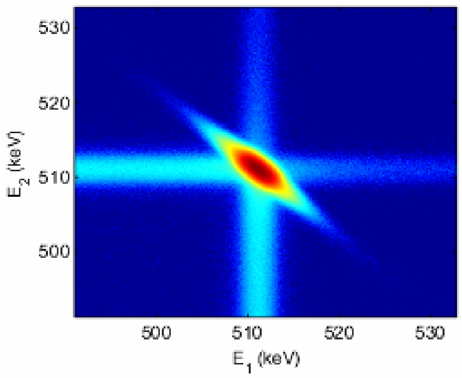
Coincident Doppler broadening spectrometer

The Coincident Doppler broadening spectrometer (CDB) setup consists of two movable high purity Ge detectors (coaxial HPGe type GC3018) with high energy resolution (FWHM = 0.8 keV at 122 keV and FWHM = 1.8 keV at 1332 keV) with build-in preamplifier (model 2101P), a digital signal processor (DSP Canberra Model 2060) for each detector and personal computer (PC) with LabView acquisition board card and acquisition program. Both the electronics (two detectors and coincidence) as well as the hardware (biological shielding, mobility of detectors) have been optimized to measure highly active specimen with moderate detector dead time (< 20%) and very low background.

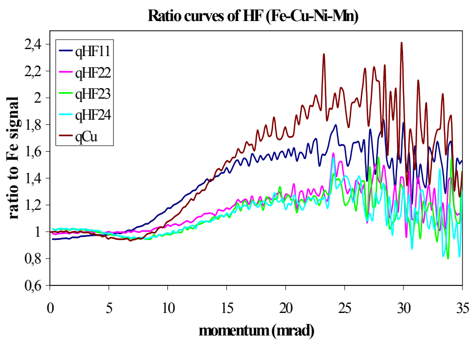


Schematic overview of the CDB spectrometer

Picture of CDB spectrometer installed at LHMA



A 2D spectrum obtained from a highly active specimen



CDB ratio curves of irradiated Cu-rich material

Future work

In the current lifetime spectrometer an external coincidence unit is used to reduce the amount of events to be digitized. It is possible to eliminate these steps by real-time processing of the incoming events. Therefore an additional processing with high speed computers is planned.
For high activity sources the detector distance is enlarged but the detection efficiency decreases while the measurement time increases dramatically. To reduce this effect extra detectors are planned to be added in parallel to the main stop detector.

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Main reference

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[3] K. Verheyen, M. Jardin and A. Almazouzi SCK•CEN-BLG-982 & M. Jardin, K. Verheyen, A. Almazouzi SCK•CEN-BLG-983 (2005)