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The miniaturised Mössbauer spectrometer MIMOS IIA: Increased sensitivity and new capability for elemental analysis

M. Blumers [a], B. Bernhardt [b,*], P. Lechner [c], G. Klingelhöfer [a], C. d'Uston [g], H. Soltau [c], L. Strüder [d,f], R. Eckhardt [c,d], J. Brückner [e], H. Henkel [b], J.G. Lopez [a], J. Maul [a]

[a] University of Mainz, Institute for Anorganical and Analytical Chemistry, Mainz, Germany
[b] von Hoerner & Sulger GmbH Schwetzingen, Germany
[c] PN Sensor GmbH München, Germany
[d] Max-Planck-Institut Halbleiterlabor, München, Germany
[e] Max-Planck-Institut Chemie, Mainz, Germany
[f] Max-Planck-Institut für extraterrestrische Physik, Garching, Germany
[g] Centre d'Etude Spatiale des Rayonnements, Toulouse, France

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ABSTRACT

The Miniaturised Mössbauer Spectrometers MIMOS II on board the two Mars Exploration Rovers (MER) have now been collecting valuable scientific data for more than five years. Mössbauer Spectrometers are part of two future missions: Phobos Grunt (Russian Space Agency) and a joint ESA—NASA Rover in 2018. The new advanced MIMOS IIA instrument described in this paper uses Silicon Drift Detectors (SDD) allowing also X-ray fluorescence chemical analysis (XRF) simultaneously to Mössbauer acquisitions. This paper highlights the features and technological improvements of the new spectrometer MIMOS IIA.

1. Introduction

The *MI* niaturised *MO* essbauer *S* pectrometer MIMOS II (Fig. 1) is a contact instrument to be placed on rock or soil samples not requiring any sample preparation. MIMOS II instruments are on board the two NASA MER rovers on the surface of planet Mars since January 2004 still fully operating after more than 5 years [1–4]. An advanced Mössbauer instrument MIMOS IIA has now been developed for ESA's ExoMars rover mission to be launched in 2018. Major improvements like simultaneous acquisition of Mössbauer (MB) and XRF spectra and results from a breadboard setup are presented in this paper.

2. Customized silicon drift detector

All MIMOS instruments operate in backscattering geometry. A ^{57}Co source irradiates a sample area in ≈ 10 mm distance from the detector surface. MIMOS II is using four square shaped PIN diodes with a sensitive area of 1 cm^2 each. The advanced version MIMOS IIA will be equipped with a ring of Silicon Drift Detectors developed by PN Sensor GmbH and produced at the MPI semiconductor laboratory. Fig. 2 shows one of the four quarters of the new SDD ring with integrated FET. The main goal of the new detector system design was to combine high energy resolution at high counting rates and large detector area while making maximum use of the area close the collimator of the ^{57}Co Mössbauer source. Fig. 3 shows a spectrum of a ^{55}Fe source taken with our customized SDD. The energy resolution at 5.9 keV is 131 eV FWHM at $-40\,^{\circ}$C. The total sensitive area of the SDD ring is 360 mm^2 and the active Silicon thickness is 450 μm. The SDD ring is divided into four individual chips each with two SDD cells of 45 mm^2 sensitive area. The chips are processed in 20 photolithography steps and eight ion implantation steps [5].

3. Preamplifiers and control electronics

MIMOS IIA preamplifiers and control electronics are developed and built at von Hoerner & Sulger GmbH, Schwetzingen, Germany, in close cooperation with University of Mainz. Readout of the SDD ring will be done using eight separate charge sensitive preamplifiers. The present breadboard is assembled with two amplifiers (Fig. 4). The preamplifier circuits provide pulsed reset of the SDD to maintain high energy resolution at high counting rate. The FET drain voltage at the SDD chip is regulated using a slow feedback network from the preamplifier output as explained in Ref. [6]. Preamplifier signals are fed through a harness to the instrument's readout and control electronics in the rover body. In the final

* Corresponding author.
E-mail address: bernhardt@vh-s.de (B. Bernhardt).

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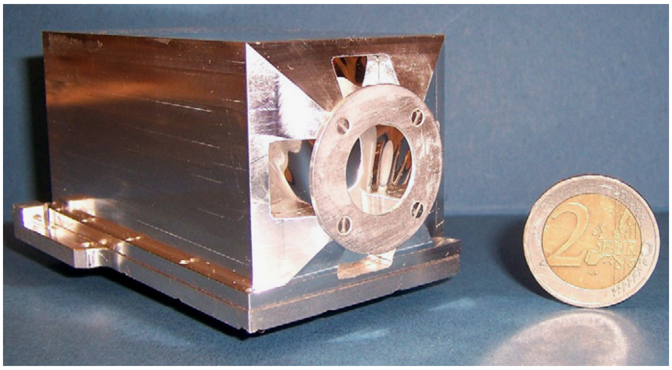

Fig. 1. MIMOS II sensorhead.

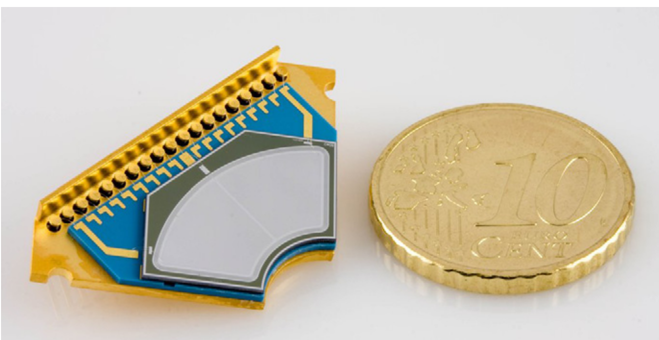

Fig. 2. MIMOS IIA SDD segment from PN Sensor GmbH.

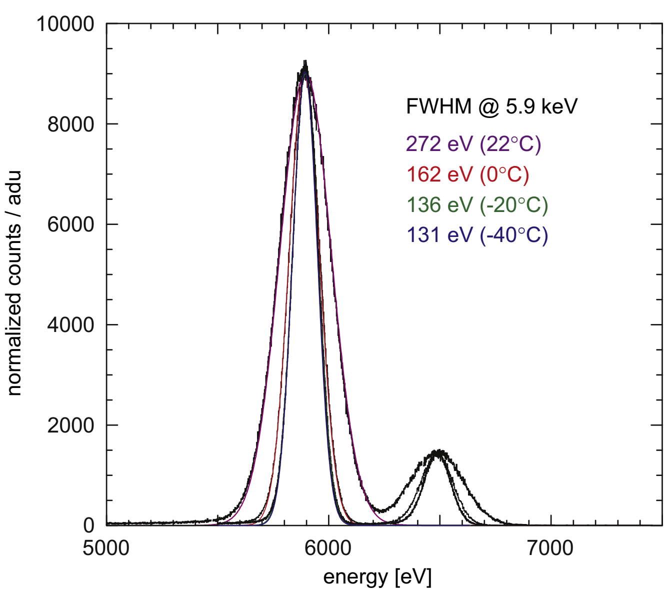

Fig. 3. ^{55}Fe spectrum acquired at PN Sensor GmbH.

configuration, 4 double ADCs sample the preamplifier signals. Parallel signal processing chains perform AC deconvolution and signal shaping in a single space qualified Actel FPGA. All XRF and MB histograms are built inside the FPGA and transferred to an onboard memory. A microcontroller IP in the FPGA eliminates the need for an additional space qualified controller part. The FPGA also operates the MB drive that generates the Doppler velocity of the ^{57}Co source. The whole instrument runs autonomously at a power consumption of 3 W, which is the same consumption as the precursor instrument but at significantly increased performance.

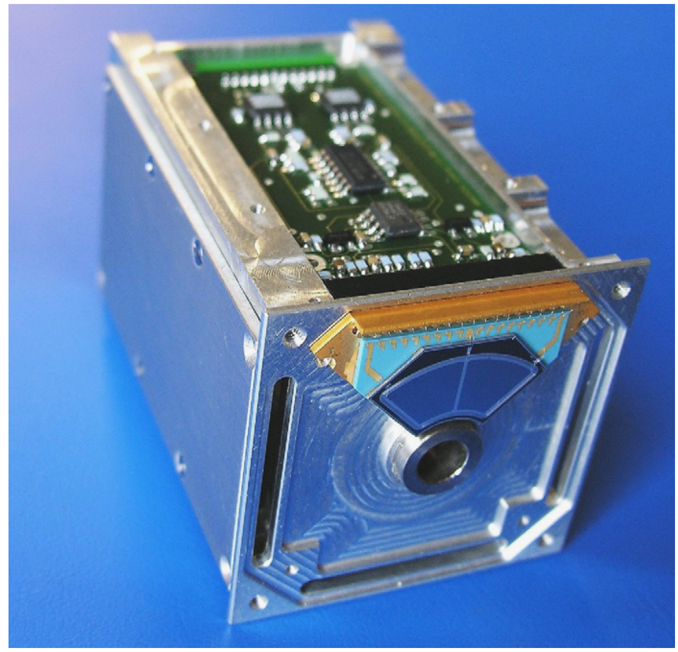

Fig. 4. MIMOS IIA sensorhead with one of four SDD quarters of the new ring detector and double preamplifier.

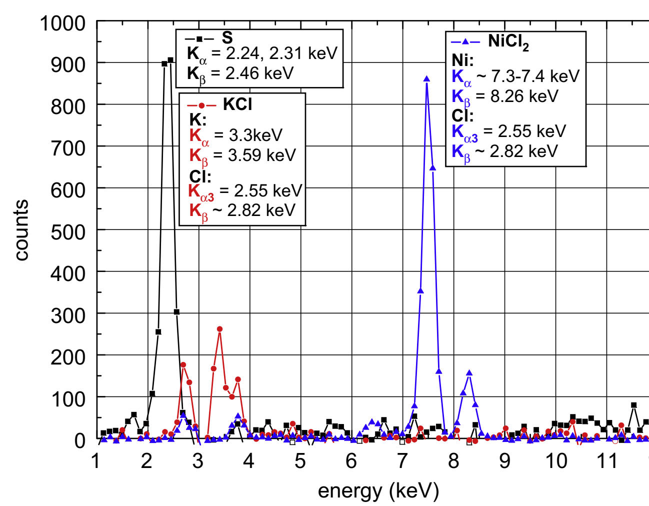

Fig. 5. XRF spectra of low Z elements measured with a commercial SDD unit. The surrounding material spectra are subtracted.

The control electronics interfaces to the spacecraft host for science and housekeeping data transmission.

4. Results

4.1. Preliminary studies

As a first verification of the improvement of the quality of Mössbauer-spectra, simultaneous measurements using a commercial SDD unit and MIMOS II have been done. The SDD is cooled with a Peltier cooler to $-30\,^{\circ}$C. In comparison to the PIN diodes used in MIMOS II, studies with the SDD unit on low Z elements (Na–P) show that X-rays down to ≈ 1 keV are detectable (Fig. 5). The plot shows the X-ray K-lines of the elements S, Cl, K, and Ni with their background removed. The Ca-line at 3.6 keV clearly reveals the two components, K_{α} and K_{β} line, of the K level

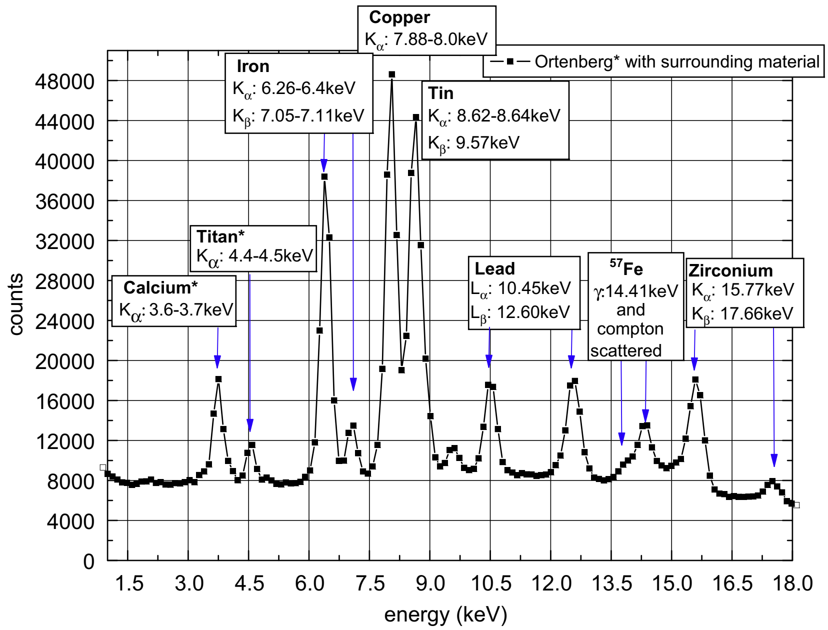

Fig. 6. X-ray spectra of Ortenberg basalt, surrounding material and ^{57}Co source measured with commercial SDD unit in backscattering geometry. The contribution of Ortenberg basalt is labeled *.

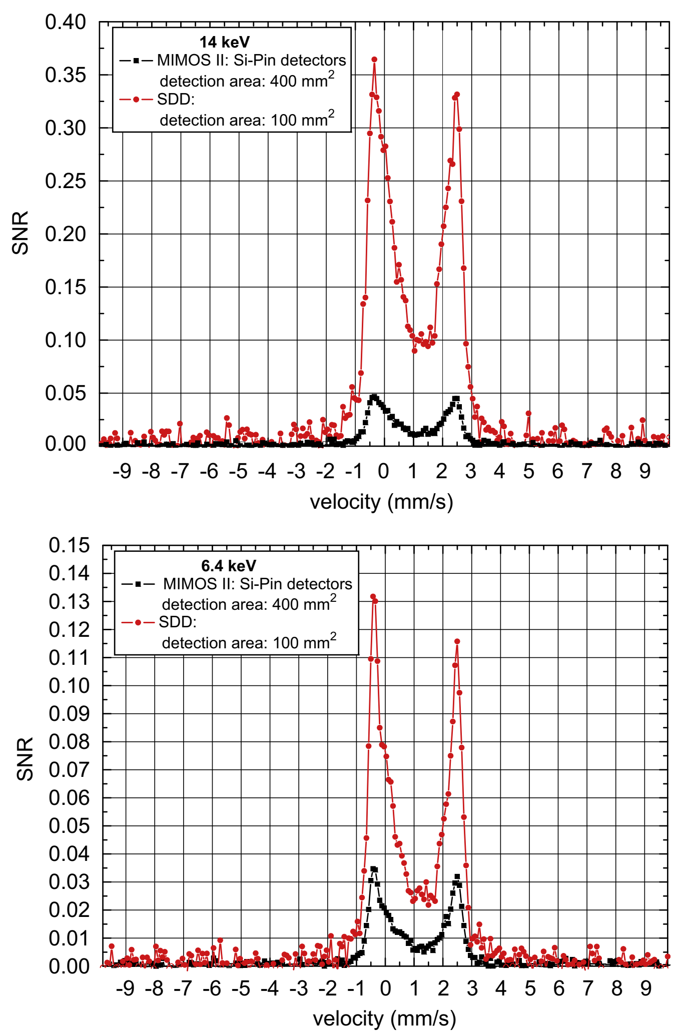

Fig. 7. Comparison of SNR of MB spectra of Ortenberg basalt taken at room temperature. Top: 14.4 keV spectra, and bottom: 6.4 keV spectra.

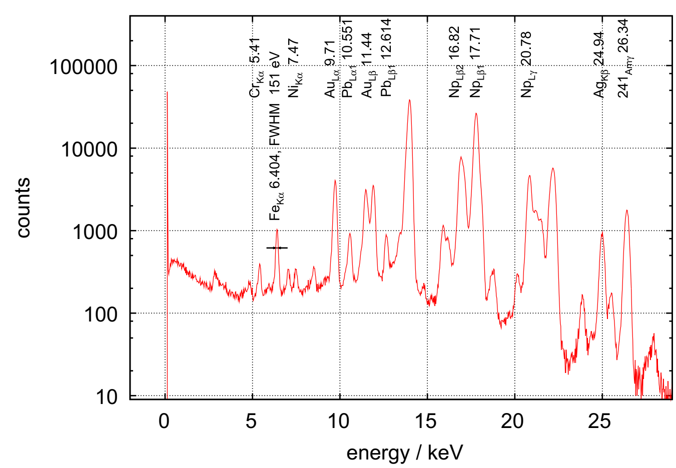

Fig. 8. ^{241}Am spectrum acquired with MIMOS IIA at −20 °C.

excitation, which points to the good energy resolution of the SDD. Furthermore, measurements with the SDD show a resolution of the 14 keV peak (from ^{57}Co source) and its Compton scattered peak (Fig. 6). In the 14 keV MB measurements done with the SDD, an optimal choice of the lower and upper threshold is possible, which removes Compton scattered events. The result is an increase of signal to noise ratio (SNR).

In Fig. 7 the SNR for the 6.4 keV K_α Fe-X-rays and the 14.4 keV MB-radiation is shown for simultaneous measurements of the MB-spectra of a basalt sample in backscattering geometry. Using the SDD gives a factor of four better SNR for 6.4 keV and a factor of seven for 14.4 keV radiation in comparison to MIMOS II. The use of the SDD ring with a total sensitive area of 360 mm^2 in MIMOS IIA will therefore reduce the acquisition time by at least a factor of seven.

4.2. MIMOS IIA spectra

The present MIMOS IIA miniaturised amplifier and readout electronics make use of nearly the full SDD performance. Fig. 8

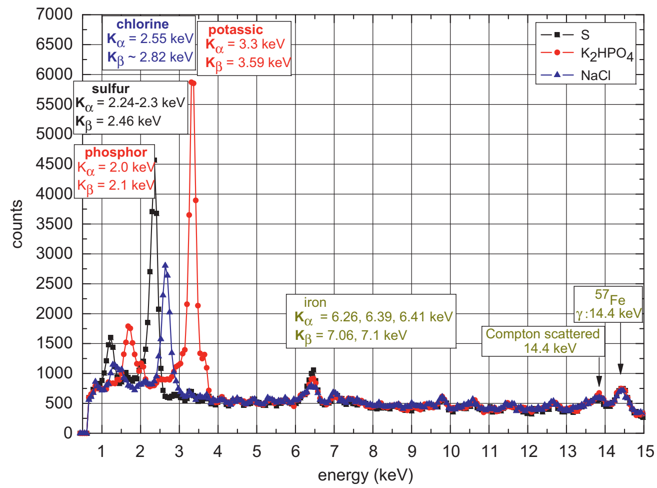

Fig. 9. Spectra of low Z elements measured with MIMOS IIA.

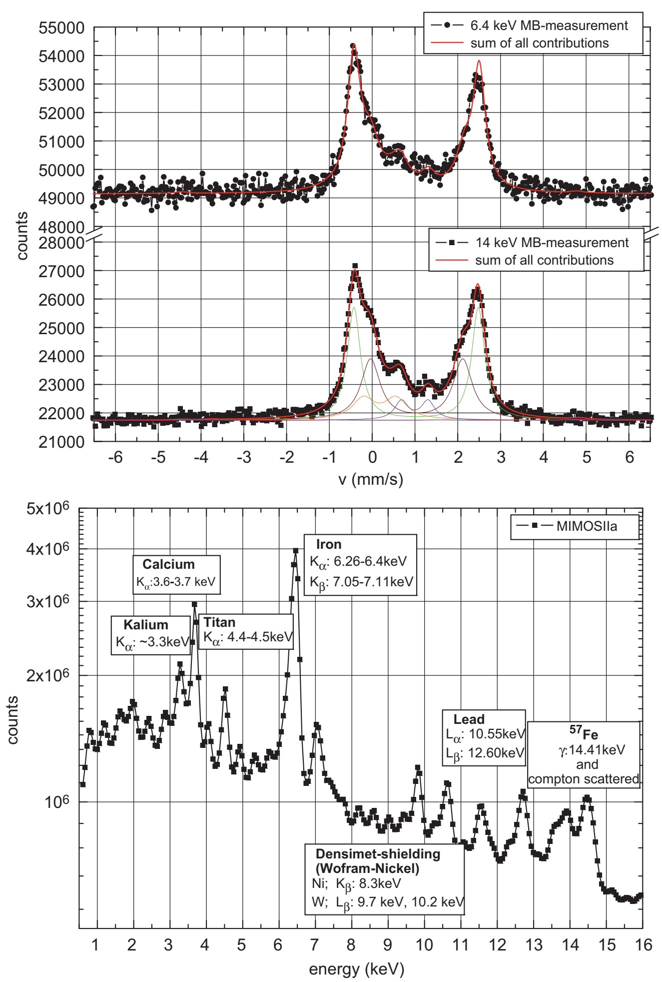

Fig. 10. Simultaneous acquisition of MB and XRF spectra using MIMOS IIA on a basalt sample.

provides an X-ray spectrum of an ^{241}Am source in front of the detector acquired with MIMOS IIA. The Fe X-ray line at 6.4 keV is resolved with 151 eV FWHM at −20 °C. This high energy resolution at 6 keV provides excellent resolution for low Z elements. Studies of the X-ray-spectra of low Z elements show, that with the excitation by ^{57}Co (6.4 and 14.4 keV) a detection of XRF-lines down to 1 keV is possible (Fig. 9). The different samples with simple compounds produce besides their major element line low-energy lines. The compound K_2HPO_4 emits the K-line at 3.3 keV, a weak line at 2 keV, which is produced by P, and a distinct line at ≈ 1.7 keV. This line is the escape line of the 3.3 keV line of K produced inside the Si material of the detector. The Sulfur sample shows the S-line at 2.3 keV and a line at ≈ 1.25 keV, which probably results from an Mg contamination. The NaCl salt gives rise to the 2.6 keV Cl K_{α}- line including a weak K_{β}- line.

A first simultaneous measurement of MB (14- and 6 keV) and XRF-spectra taken on a basalt sample from Ortenberg (Germany) shows the full functionality of the instrument (Fig. 10). Due to the small solid angle of backscattered radiation and good energy resolution the Compton scattered 14 keV γ radiation is clearly resolved at $-20\,^{\circ}$C.

5. Summary

MB spectroscopy is a powerful tool for planetary exploration. The advanced Mössbauer Spectrometer MIMOS IIA equipped with large area SDD technology and a high density FPGA significantly increases sensitivity and performance compared to its precursor MIMOS II. High energy resolution of the SDD allows XRF elemental analysis simultaneously to Mössbauer Spectroscopy. Example spectra of the existing instrument, developed and built for ESA's ExoMars rover mission are presented.

Acknowledgements

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