Multi-energy X-ray imaging for high-Z elements identification

Daniela Doubravova [a], Jan Jakubek [a], Eliska Trojanova [a], Stepan Polansky [a]

[a] ADVACAM s.r.o., U Pergamenky 12, Prague, Czech Republic

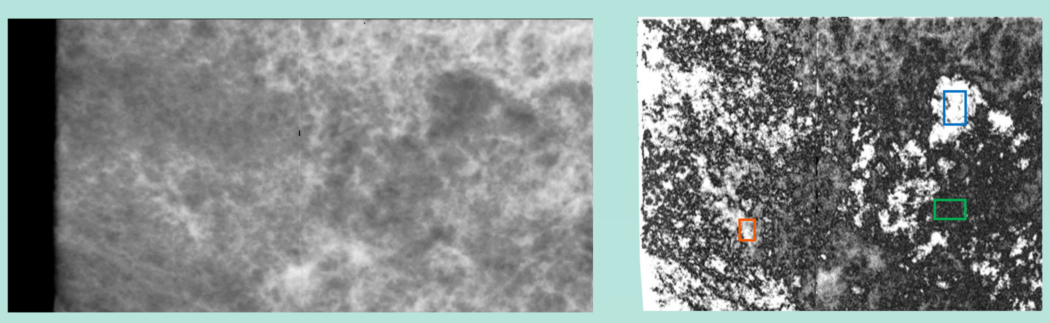
Introduction

Material decomposition of sample components using multi-energy or multi-threshold X-ray imaging can be performed using the hybrid semiconductor pixel detectors of the Medipix family. The K-edge imaging method gives even more analytic approach to identification of a specific element within the unknown sample matter. It is based on the fact that there is a sudden increase of the X-ray absorption at certain energy (absorption edge), which is characteristic for given element. The exact implementation of this method depends on the type of sample and number of elements to be identified. Especially for high-Z elements, where also high-Z sensor material is required for efficient detection (e.g. CdTe), the K-edge imaging becomes difficult to implement due to spectrum distortions caused by high absorption combined with Compton scattering in both the sample and the detector as well as the X-ray fluorescence within the sensor material.

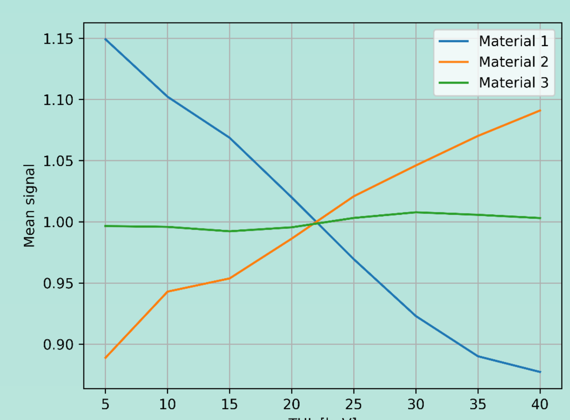
We demonstrate that various types of materials can be identified based on their material response extracted from several images measured with different energy thresholds. Next, the K-edge based identification of selected high-Z element within a material mixture is demonstrated. The sample image is decomposed into components and the content of the selected element is calculated.

Multi-threshold imaging for material decomposition

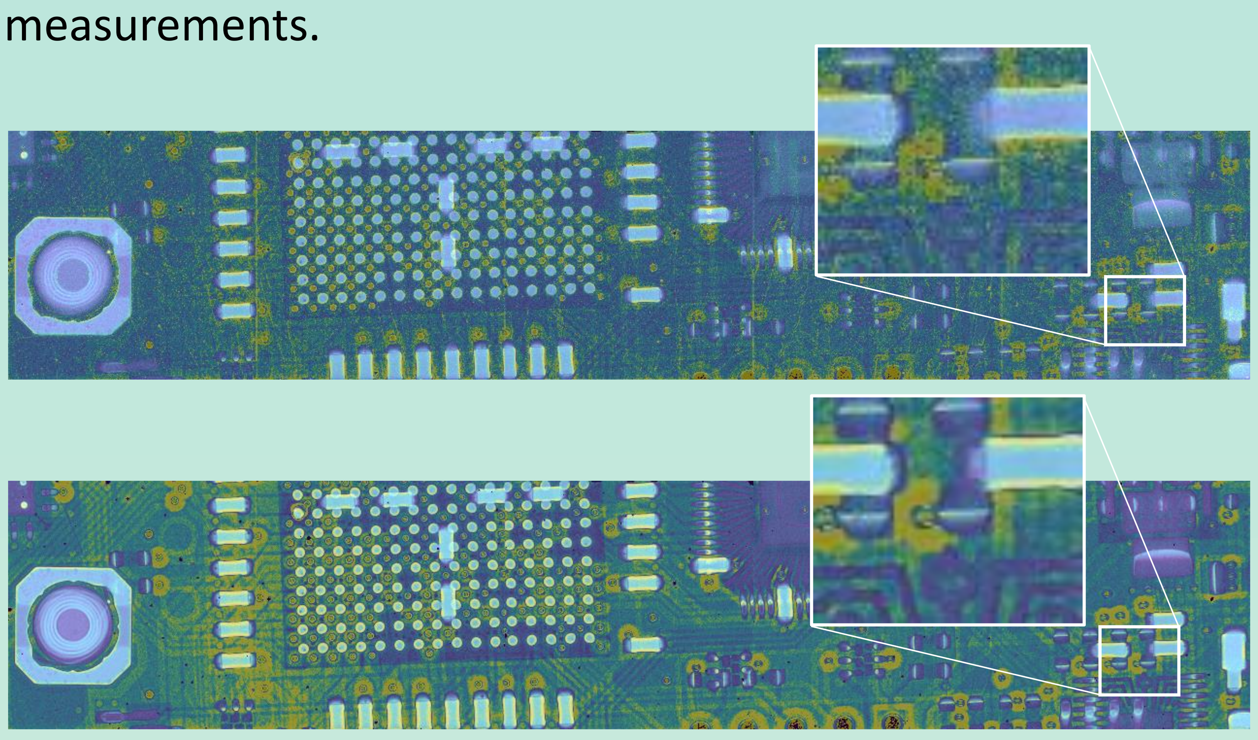
Various types of materials can be identified in the sample based on their response extracted from two or more images measured with different energy thresholds.



XRT image of rock slice after beam hardening correction, material variation and material response curves of three selected regions of the sample. Sample of Zn ore was by provided by Lovisagruvan mine.



X-rays of higher energies are needed for inspection of high-Z elements which is problematic from the detection efficiency point of view. One of the goals of this work was to study the benefits of the Charge Summing Mode (CSM) of Medipix3. The results verified that CSM provides better performance for spectral measurements.



Spectral images of PCB which represents well defined sample containing many elements. Different colors signify different material properties.
Comparison of results measured with Medipix3 detector using:
(a) conventional approach of Single Pixel Mode
(b) Charge Summing Mode intended for spectral imaging

Hybrid pixel detectors of the Medipix family

Single photon counting detectors of the Medipix family consist of a semiconductor sensor layer connected to the readout chip using the bump-bonding technology. The main advantages in comparison to the conventional X-ray imaging detectors are high contrast and spectral information of the radiation that allows material specific information to be displayed in colors. Pixel size is 55 µm and sensitive area depends on detector type (e.g. 70 × 70 mm in case of WidePIX 5×5).

Medipix3 operates in counting mode, however the spectral information can be measured using a threshold scan. Besides the classic Single Pixel Mode (SPM), the chip also implements Charge Summing Mode (CSM). This feature suppresses the charge sharing effect and thus allows better imaging properties at higher energies. Several operation modes are available and the number of adjustable energy thresholds varies according to the selected mode. Modified „spectroscopic" variant of the chip assembly with 110 µm pixel pitch provides up to 8 thresholds.

Timepix3 chip can be operated in event-based mode, where all information about the interacting particle (position, time of arrival and energy) is recorded at the same time. This approach allows to get images for all spectral channels within one acquisition. Moreover, the unwanted effects can be suppressed and the original spectra can be reconstructed.

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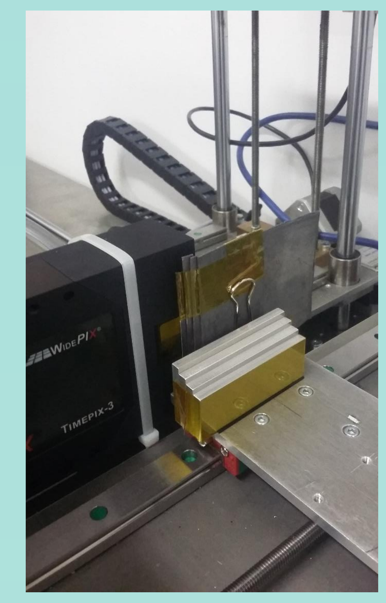
K-edge imaging

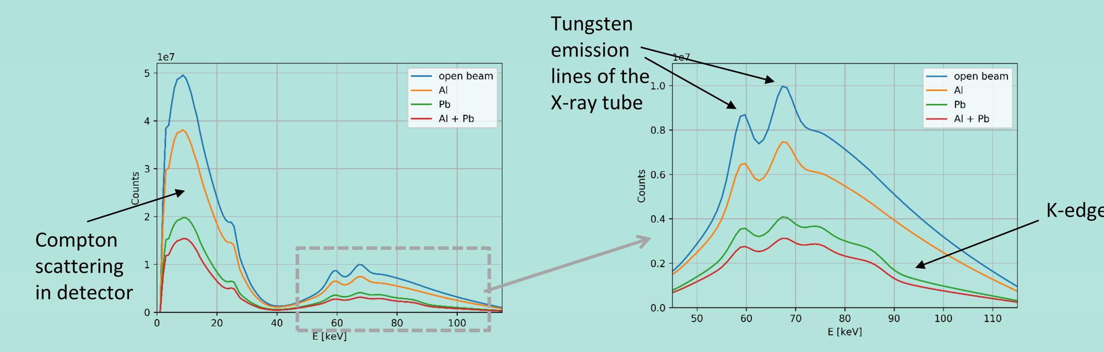
The aim of the method is to decompose the transmission X-ray image to two components – the first represents the high-Z element content, the second corresponds to the light elements that have no absorption edge in the spectral region of interest.

The method is illustrated with lead K-edge at 88.005 keV using Timepix3 and Medipix3 detectors. Step calibration samples (Pb + Al) were prepared in order to get the relation between the transmission spectra and the lead / aluminum thickness. Aluminum substitutes the light component.

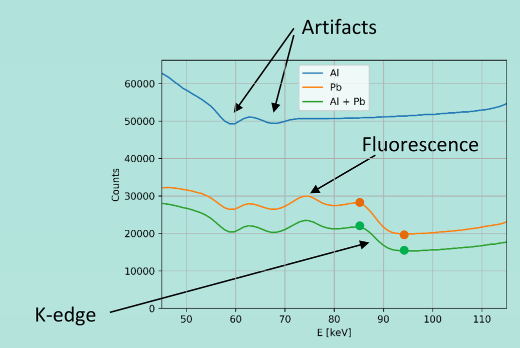


K-edge based identification using fully spectral imaging

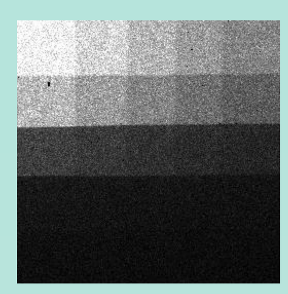
The calibration samples were measured using Timepix3 device. K-edge of lead is clearly visible in the measured spectra. As for K-edge imaging only two channels corresponding to energies below and above lead K-edge are needed, two images of the sample combination (Pb + Al) were selected for further processing. Calibration curves of lead thickness were calculated and applied to every pixel of the images.



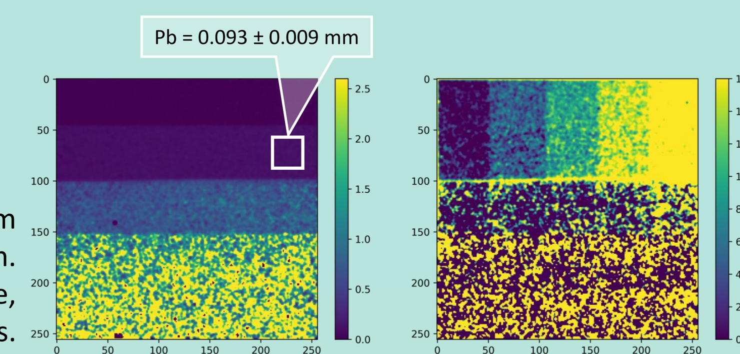
Global spectra of calibration samples measured with Timepix3 detector



Spectra after flat field correction



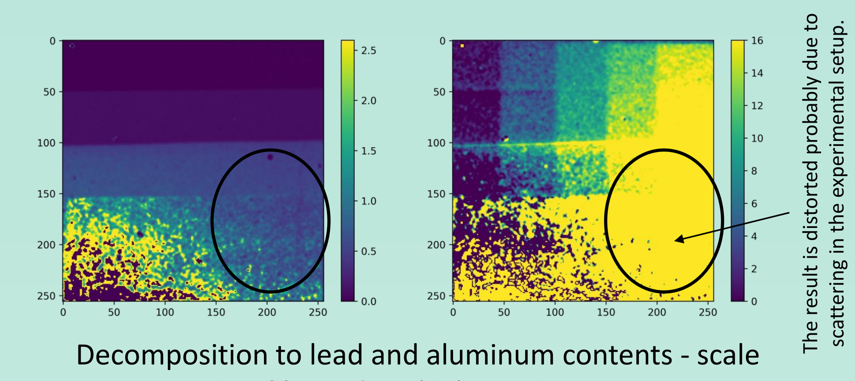
X-ray transmission image of the calibration samples combination



Decomposition to lead and aluminum contents - calibrated to thickness in mm. For lead of thickness above certain value, the result is distorted due to poor statistics.

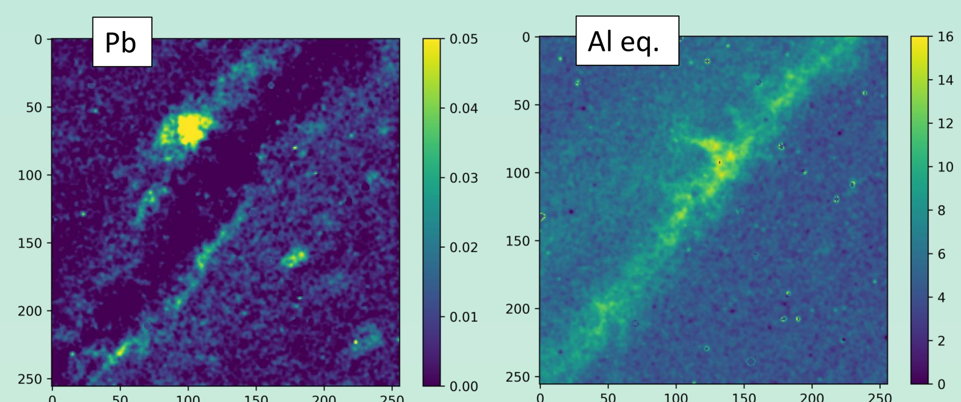
K-edge imaging using multi-threshold measurement

The second approach uses Medipix3 detector in Charge Summing Mode which is more suitable for this application. Since the threshold cuts off all energies below the set value, two images at different thresholds are needed to get one energy channel as their difference. The sample was measured in CSM to get the images below (channel from 78 to 83 keV) and above (from 94 to 104 keV) the K-edge. Then the calibration curves of lead thickness were calculated and applied to every pixel.



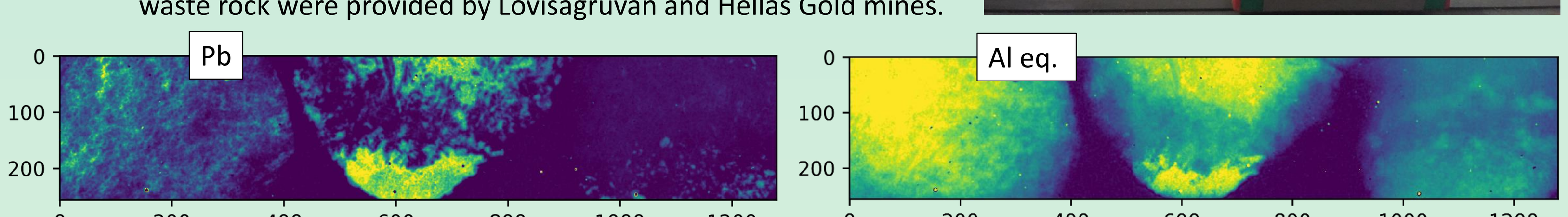
Decomposition to lead and aluminum contents - scale is calibrated to thickness in mm.

The same curves were used for other samples to extract the lead content out of material mixture.



Decomposition to fraction of lead and fraction of light elements (aluminum equivalent) of rock slice sample - scale is calibrated to thickness in mm.
Sample of waste rock was provided by Lovisagruvan mine. Even when the sample was classified as waste, it contains small amount of lead.

Decomposition to fraction of lead and fraction of light elements (aluminum equivalent) of rock samples of general shape - scale is calibrated to thickness in mm. Samples of Zn and Pb ore and waste rock were provided by Lovisagruvan and Hellas Gold mines.



Conclusion

We have proven that various types of materials can be identified based on their material response extracted from two or more images measured with different energy thresholds. The K-edge imaging can be used as a method for extracting the high-Z element content from the transmission X-ray image of mixed material. It was shown that determination of lead content within sample of general shape is possible using 2D spectral imaging with high precision, e.g. in 16 mm thick rock the lead content of **2.4% is determined with precision 0.2%**. K-edge imaging of high-Z elements can be performed very effectively using Medipix3 detector operated in Charge Summing mode. Four thresholds need to be measured, so it is achievable by single measurement using the Medipix3 device with 110 µm pixel pitch.

Both demonstrated approaches can be used for inspection of element occurrence within ore in the mining industry and in other practical applications. The K-edge decomposition method reaches its limit for higher content of the high-Z elements since the sample looses its transparency.