Compact laboratory micro-CT/micro-XRF scanner for non-destructive 3D imaging of internal chemical composition

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We developed a compact laboratory scanner, which combines X-ray microtomography (micro-CT) with X-ray microfluorescence (micro-XRF). This dual-modality scanner opens the possibility for nondestructive three-dimensional analysis of internal local chemical composition, enhanced by morphological information provided by the built-in micro-CT system.

Unlike known micro-XRF methods based on a collimated beam and detector [1,2], our micro-XRF scanner uses full field (two-dimensional) acquisition with a 512x512 pixels energy sensitive detector operated in photon counting mode. It allows detecting two-dimensional photon energy maps in the range of 3 to 20keV. The detector uses hourglass shaped pinhole optics.

The scanner contains two parts: (1) a micro-CT part with a microfocus X-ray source and a cooled 1.3Mp X-ray camera and (2) a micro-XRF part with two powerful (2x200W) X-ray sources for excitation and a photon counting full-field detector. The object is mounted on the rotation stage which is supported by a long-travel elevation stage, allowing the sample to be moved between the micro-CT and the micro-XRF parts of the scanner.

The operator can select up to 8 sets of energy windows to collect fluorescent X-rays independently and simultaneously. By rotating the object the scanner acquires all necessary angular two-dimensional views in transmission and fluorescence modes for following 3D reconstruction. The system acquires data in such a way that the micro-CT scans and the micro-XRF scans match each other exactly in position, magnification and spatial orientation. This makes image registration much easier and more accurate. Micro-CT data are reconstructed with a modified Feldkamp algorithm (filtered back-projection) [3]. Micro-XRF data are reconstructed by a maximum likelihood iterative algorithm [4]. The micro-CT images provide information for absorption correction during micro-XRF reconstructions. After reconstruction 3D morphological information and 3D chemical composition match each other exactly. For visualization of results chemical information shown in colors overlays the micromorphology shown in grayscale.

Good performance of the system has been demonstrated using phantom measurements and real objects. Micro-CT and micro-XRF reconstructions from one of the phantom samples are shown in Fig.1. The sample contains copper and vanadium wires wrapped in titanium foil and inserted in steel cylinder with holes. The top row in Fig.1 shows one of the angular projections, while the bottom row depicts reconstructed slices from the position marked in the left top image. The left column shows a micro-CT projection and reconstructed slice, followed by (left to right) micro-XRF projections and reconstructed slices for the characteristic lines of Fe, Ti, Cu and V correspondingly. The right most column shows a combined micro-CT/XRF projection and reconstructed slice portraying absorption information overlapped by color-coded chemical composition. Fig.2 shows an application example: the 3D distribution of chemical composition in a piece of corroded antique glass.

As clearly seen, lead corrosion covers both surfaces of the glass sample, but calcium and iron particles are mainly distributed inside the glass body.

Our tests confirm that the developed scanner opens prior unavailable possibilities for non-destructive 3D imaging and mapping of the internal chemical composition of samples from different application areas.

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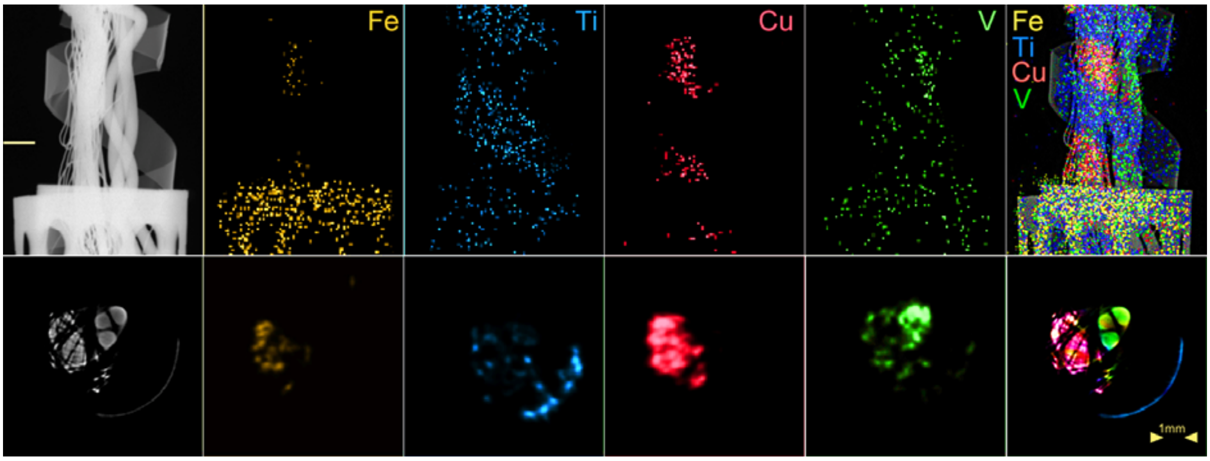

Figure 1. 3D distribution of the chemical composition in a phantom containing several different metals (explanations in text).

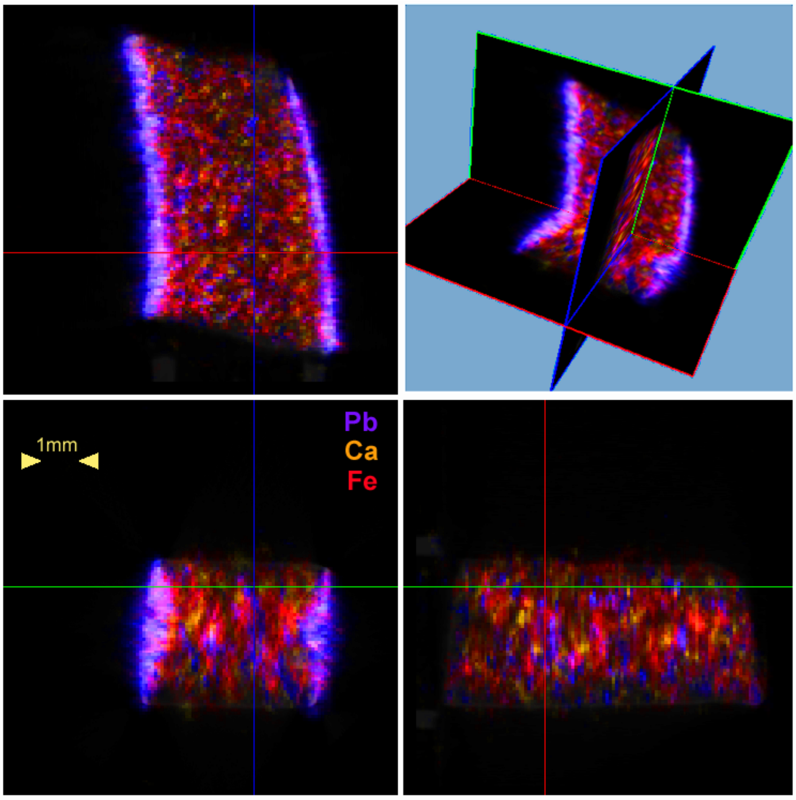

Figure 2. Internal chemical composition of a glass sample with surface corrosion. Three orthogonal sections show that both surfaces of the sample are covered by Pb layers, but Ca and Fe particles are homogeneously distributed inside the glass body.

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