	Experiment title: Fast chemical element mapping by using x-ray ghost fluorescence at high photon energies	**Experiment number**: MI-1432
Beamline: ID15A	**Date of experiment**: from: 12/03/2022 to: 15/03/2022	**Date of report**: *Received at ESRF:*
Shifts: 9	**Local contact(s)**: Marco Di michiel	

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Report:

X-ray fluorescence imaging (XRFI) is an imaging tool that provides two-dimension (2D) chemical maps but in most cases requires focusing of the input beam and raster scanning of the sample, thus the measurement time is quite long. The extension to three-dimensional (3D) imaging is possible, however, it is very challenging since it requires high photon energies to enable the penetration through the sample and the measurement time is even longer than in 2D.

We tried to perform a proof-of-concept experiment that demonstrates a novel focusing free modality, which utilizes ghost imaging (GI) together with compressive sensing (CS) algorithms to reduce the measurement time significantly. The main advantages of our approach are that it does not require focusing and that the measurement time can be significantly reduced by using CS or artificial intelligence (AI) algorithms since our method requires a significantly smaller number of measurement points compared to standard techniques [1]. Our method therefore will open intriguing new possibilities for 3D chemical mapping of complex objects at high resolutions and large field of views. The feasibility of the proposed experiment is supported by the recent demonstration of the method with an x-ray tube for a simple 2D object [1] and by our recent feasibility study on ID19.

Our approach is based on the ghost imaging (GI) approach, which has been investigated extensively in a broad range of wavelengths and recently demonstrated in x-ray regime [2-4] and for CT [5]. In GI we irradiate the object with a set of different known intensity patterns and record the intensity after the object. The set of the intensity patterns is represented by a matrix A for which every row is a single intensity pattern. The intensity after the sample is represented by a vector T. The vector x is the transmission function of the object, thus the vector T is equal to the product of the matrix A and the vector x i.e. $T=Ax$. To find the vector x with a minimal number of realizations, and consequently to reduce the dose and measurement time, we utilize the CS approach.

In the experiment on ID15A, we used an unfocused monochromatic beam at 50 keV, silver mask with 5-micron resolution and a known object. The object is a mixture of the elements Ba, Gd and I. At first, we took pictures of the mask in order to measure its resolution and reassure its validity. After we where satisfied, we took pictures of the whole mask in order to use it in the reconstruction process. Later we measured the object with the pencil beam in order to take a picture of the object with spectral resolution in order to compare it with the reconstructed GI images. Finally, we took long measurements of the test data with the Ge detector provided by ID15A.

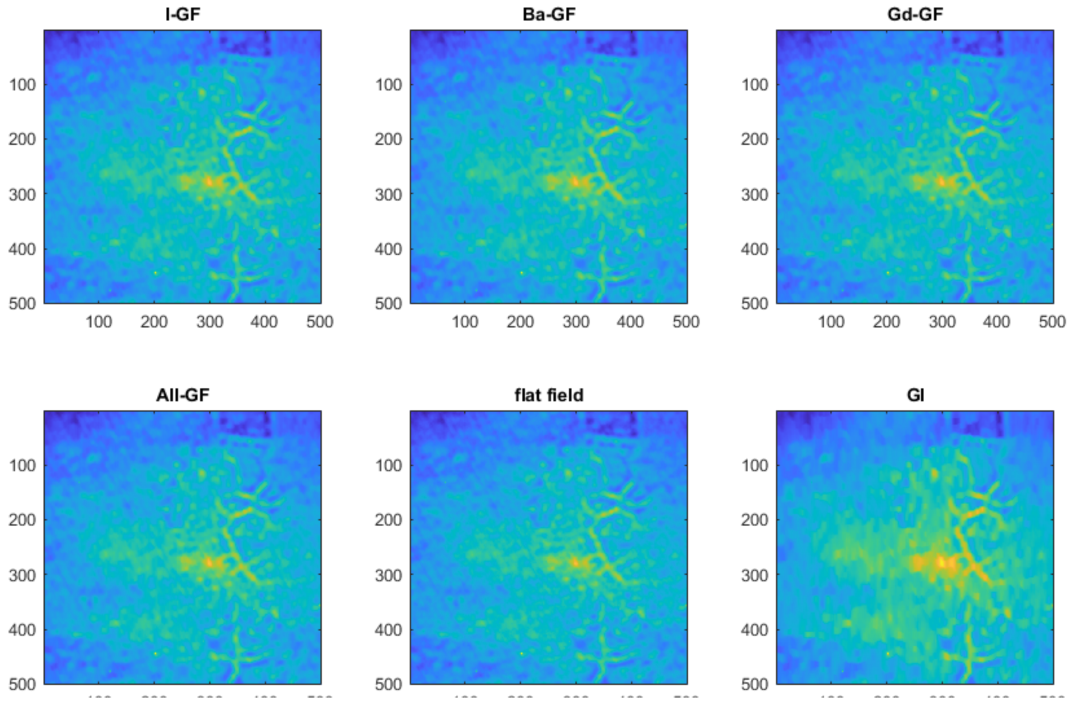

Figure 1: Reconstruction of each element fluorescence and traditional GI as compared to the flat field induced by the window.

During the beamtime we encountered a few major difficulties. The main problem was that the beam irradiating the sample had a strong moving intensity pattern that was induced by one of the windows in the pathway of the beam before the sample. Unfortunately, because the beam also passed through a monochromator, which was not stable enough due to temperature fluctuations of the crystals, an unpredictable movement was induced to the beam and moved the pattern. As a result, random, unpredicted, and dominant fluctuations were added to the test data and overshadowed the contrast changes induced by the mask. This phenomenon prevents the possibility of GI. Because the measured fluctuations induced by the mask plus the random pattern did not match the fluctuations which were induced to the object, the inherent concept of GI was not obtained and the algorithm could have not work. As a result, the reconstructions of all elements provide a reconstruction of the pattern in the beam before the sample. Examples of the attempts to reconstruct the shape of the elements are shown in Figure 1 for all three elements (Iodine, Barium, and Gadolinium) an for the combined object. The comparison with the shape of the beam (the flat field) reveals that we could only measure the shape of the and not the object. In addition, the following problems further hindered and complicated the GI reconstruction: (a) unreliable and faulty readings from the beam intensity monitor (namely: fpico3 and pico3); (b) vertical drift of the masks through-out the acquisition; (c) wires appearing in the Field-of-View when acquiring flat field images. Regarding point (a): fpico3 is a fast and supposedly accurate measurement of the incoming beam intensity, but it is rescaled at each acquisition to an arbitrary range, while pico3 is a slower and less accurate version of fpico3 in the correct intensity range. The first point of every fpico3 measurement was always wrong and visibly much more intense then all the following points, which was not physically possible. Moreover, using pico3 to rescale fpico3 measurements to the correct scale did not yield the expected result. Finally, fpico3 measurements exhibited wrong intensity decay profiles, which dealt wrong intensity normalization of the XRF signal. Regarding point (b): the measured masks / illumination patterns and the ones that produced the corresponding XRF intensities were shifted by an unknown number of pixels. Finally, regarding point (c): some flat-field images could not be used, because they would introduce further artefacts in the reconstruction.

In conclusion the experiment did not work because of the reasons mentioned above. We believe that the experiment will work after the above will be solved.

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