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Realization of software based imaging energy analyzer on GPU

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ABSTRACT

Here, the realization of the Filtering the Effect of Chromatic Aberration (FECA) method is presented as Software Based Imaging Energy Analyzer (SBIEA) on an NVIDA Tesla K40 GPU. This method makes possible the correction of chromatic aberration and, therefore, spectrometry, as well as, real- and k-space monochromatic imaging by rapidly calculated spectral image sequences of monochromatic images in light and charged particle optics without the application of additional energy filters. The GPU accelerated realization of this method provides a good solution with reasonable calculation time on large size image sequences and opens new direction toward the better quality monochromatic real- and k-space imaging, as well as, the developments of software based instrumentation. The presented GPU accelerated realization of the FECA-SBIEA method provides promising alternative solution for making fast and accurate monochromatic spectral imaging that can be better than the usually applied electrostatic and magnetic analyzers due to the overlapping effect of different energy images especially in the case of large acceptance angle optics.

1. Introduction

In line with the scientific and technical progress there is an increasing interest for spectral imaging in nanoscale ranges where e.g. the Photoemission Electron Microscopy (PEEM) is one of the methods that can provide photoelectron spectra, as well as, restricted real- and k-space spectral imaging from small areas in many fields of physical, chemical and biological sciences, nanotechnology and semiconductor industry. The measured images contain a lot of information but disturbed by the lens aberrations that phenomena are known since the beginning of light and charged particle optics [1–3]. The imaging with Spherical Aberration (SA) Corrected (SAC) Wide Acceptance Angle (WAA) Electrostatic Lens (WAAEL) [4–11] and SAC WAAEL based Display Type Electrostatic Lens Analyzer (DELMA) (Fig. 1) [12], where WAA is necessary for the high resolution angular and spatial imaging, is a new method with new opportunities and of course with some newly arisen difficulties. Following the SA correction the CA is the next that has to be taken into account which effect in first order is proportional to the Acceptance Angle (AA) [2]. The CA in one way blurs and distorts the spectral images, as well as,

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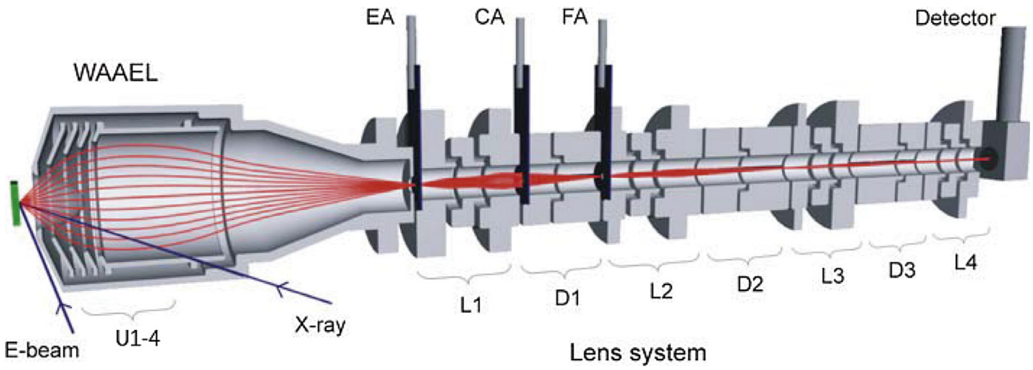

Fig. 1. The electrode arrangement and ray-paths of given E_{pass} energy electrons in a ±45° (0.59π sr) AA WAAEL based Display-type Ellipsoidal Mesh Analyzer (DELMA) (Fig. 11 of [12]).

decreases the spatial, angular and energy resolution but in the other way it makes possible the spectrometry and spectral imaging. By using apertures, accelerating voltages, different types of energy analyzers or different background subtraction and deconvolution methods, the mentioned effects could be decreased or applied in the cases of spectrometry, but these, natural or instrumental origin methods [2,13–16] are not so effective in imaging, especially in the case of WAAEL lenses where the different energy images overlap strongly e.g. in the case of applying Concentric Hemispherical Analizer (CHA) for monochromatic imaging.

One of the possible options to decrease this effect is the application of the recently developed FECA-SBIEA method [17,18] that in one way is a computationally intensive task, but by using supercomputers [19] or Graphics Processing Units (GPU) [20–22] the results can be calculated within a reasonable time, and in the case of GPUs the developed application can be very flexible and locally applicable near by the instrument. The FECA-SBIEA method, instead of applying additional energy filters, works on the taken CA distorted spectral image sequences and applies a large system of linear equations that describes the effects of the different energy-, direction- and coordinate monochromatic electron trajectories determined image points on each other (Fig. 1) [17,18]. Following the application of the iterative FECA-SBIEA method on the CA disturbed energy dependent image sequence, good quality CA free monochromatic images are resulted [17,18].

The recent GPU-s, like the NVIDIA Tesla K series [20], are fast and strong enough to be applied for the FECA-SBIEA calculations and allow to design unique and massively parallelized architectures. Its advanced interfaces allow easy integration into any computer system via the PCI express bus and utilize high bandwidth, as well as, fast and large enough internal memories. In this paper we describe a realized FECA-SBIEA method [17,18] on an NVIDIA Tesla K40 GPU and show some test results with an image sequence taken by the High Voltage (HV) SAC WAAEL based DELMA [12].

2. Description of the FECA-SBIEA and the applied parallel computation methods

The spatial-, angular- and energy resolutions are the main properties by what an imaging system can be characterized. However, these are strongly influenced by the lens's aberrations, which can be taken into account and eliminated not only by additional instruments, but by the help of calculations that can also give good starting points to develop new methods to decrease or eliminate the effects of different optical aberrations e.g. SA [4–6,12] and CA [17,18].

In the case of CA disturbed spectral imaging the specific energy (E_0) electrons form sharp monochromatic image points at the I_0 imaging plane, that intensity is influenced by the lower (E_-) and higher (E_+) energy electrons which in more or less degree, form sharp monochromatic images before and after the imaging plane, according to their energy.

In general, this phenomenon can be described as a nonlinear 3D parameter-space convolution. The CA free monochromatic spectral images can then be determined by the numerical solution of a nonlinear 3D parameter-space deconvolution for what the FECA-SBIEA method was developed [17,18]. The FECA-SBIEA method divides the solution into two parts, where the first determines the orbits of different initial energy (E), azimuthal and polar angles (θ, φ) and source coordinates (x, y) of the charged particles that leave the sample surface and determine their effects on the different image points of the different energy monochromatic spectral images. This e.g. in the case of electrostatic lenses, requires at first the numerical solution of the Poisson's equation to determine the electrostatic potential field and then requires ray tracing calculations of the relativistic charged particle motion on this pre-calculated field.

In the second part of the solution a sparse transmission matrix (**A**) of the optical system is created which elements (a_{ij}) are originated from the previously mentioned electron optical calculations. These elements describe the image points disturbing effects on the specific energy CA free ideal images (the intensities of the image points ordered into the **x** vector)