Vector Potential Photoelectron Microscopy: Early Results 2010-2012

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This is a collection of early results using the, proof-of–principle, first version, VPPEM microscope at the U4A beamline at NSLS. These are white light images. The U4A beamline is a bending magnet UV beam line focused to a 2-3 mm spot size incident at 15° to the microscope axis. The U4A spot size is comparatively large for microscopy. The UV white light photon flux is estimated at approximately 10^{13} photons/s, and therefore the photon flux density is $5x10^6$ photons/micron^2/s. Using monochromatic illumination with photons between 20-40 eV is in the range of $5x10^3$ photons/micron^2/s required us to develop fairly sophisticated data reduction for chemically specific imaging.

UV white light imaging using the photo-electron inelastic tail is straightforward, and effectively real time. Within the spectrometer energy window 100% of the photoelectrons emitted into the forward 2π steradians are collected. Using monochromatic illumination with photons between 20-40 eV, images can be collected within ten seconds. The images shown here used a fixed energy window of 1 eV, at the low energy peak of the secondary electron background.

The first image of a grid from 30 October 2010 is shown in figure 1. A short mpeg of several snapshots put together can be found at:

http://www.rbrowning.net/VPPEMfirstlight.mp4

Figure 1 shows results from a 600 mesh Au grid, 42 micron spacing. The microscope field of view is circular and approximately 80 microns. It was necessary to attach the Au grid above a hole in the microscope sample stub so that there was no background from the large depth of focus.

As we have said, the early version of the microscope was a prototype, and not free from defects. Figure 2 is of the same 600 line Au grid. The inset image in figure 2 has significant optical bloom associated with the multiple reflections of the CCD camera imaging though a viewport. This adds a

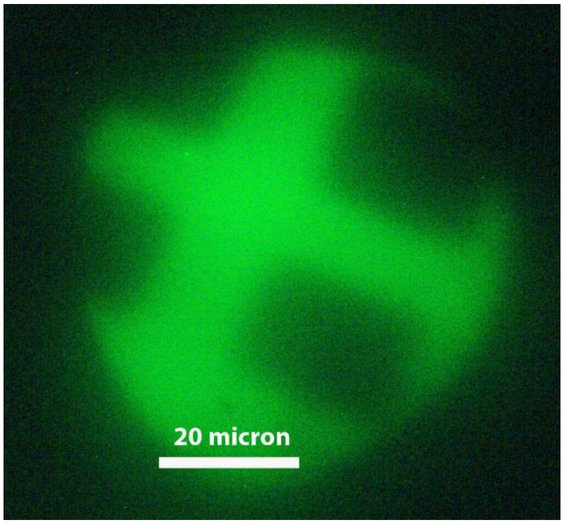

Figure 1. The first VPPEM image of a 600 line Au grid. 30 Oct 2010.

Gaussian background of 15-20 microns to the image, and that is apparent in the figure 2 image line scan. The 20-80% edge resolution across the Au bar is 5-6 microns which is in poor agreement with the calculated spatial resolution 1 eV electrons of 1.5 microns.

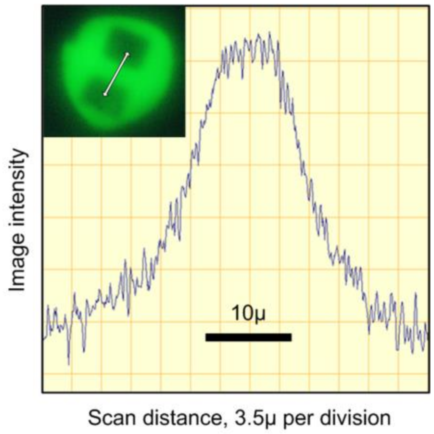

Figure 2 Averaged line scan across central bar of inset VPPEM image of 600 mesh Au grid.

We can estimate the signal to noise. The pixel to pixel signal to noise measured from a single line scan is approximately 30:1. The image collection time was 2 seconds. The pixel size is 0.1 micron. Assuming that 1% of the photoelectrons are in the 1 eV energy window, and a quantum efficiency of unity for UV photons, we would expect 10^5 electrons per micron^2, giving 10^3 electrons per pixel, and signal to noise of 30:1.

Figure 3 shows a white light illuminated photoelectron micrograph of Kyoto silk. The silk was frayed by scraping a silk thread with a razor blade to break the individual silk fibers, and then rolled into a pill. The silk pill was pushed into a hole in the microscope sample stub. The silk was not coated. This is a truly three dimensional object, and a good insulator. This sample did not charge more than a fraction of a volt, and showed no local areas of charging.

Figure 3a is an area with multiple crossed fibers. The image is a composite of images from mechanically scanning the sample. The actual image contrast is low because there is no large difference of intensity. The main contrast mechanism is shadowing of the fibers in the UV beam incident at 15°. This is a top down view, the equivalent 'depth of focus' is over a centimeter, and the fibers are not necessarily in the same plane. From the size and shape of the pill, we could expect the crossed fibers to be millimeters apart.

Figure 3b is a single silk fiber imaged over a void in the sample stub hole. The single fiber is almost certainly not running in the plane of the image, and the composite of images may represent a large depth of field. The inset extracts one enlarged image field from the composite for comparison. Locating and imaging a single fiber using VPPEM is straightforward. There is no focusing required, and the fibers are all in view. In comparison, optical imaging of this sample has only small sections of the fibers in focus.

The silk images shown here have been contrast enhanced. As indicated above, the detection scheme on the prototype instrument consists of MCP/Phosphor/CCD camera imaged through a standard UHV viewport. There is a large optical bloom, and the raw image contrast is low.

Steel wool which is a magnetic sample, and a single 10 micron tungsten wire suspended between electrodes were relatively straightforward to image using VPPEM. These are highly structured three dimensional objects that would be impossible with other techniques such as PEEM.

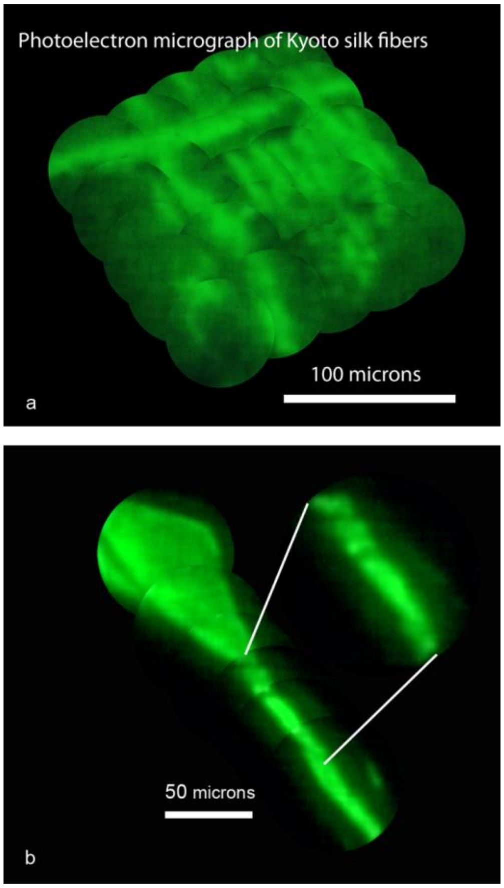

Figure 3. VPPEM micrographs of an uncoated silk fiber pill. a) An area of crossed fibers. The composite image was made from a set of images scanned manually using the micrometers of the sample stage. All the images were treated in the same way. Using image processing software the individual 80 micron circular images were trimmed to 60 microns to remove the edge fading, and overlapped to make up the composite. b) A single silk fiber. The composite image was created from a mechanically scanned set of images.

At present, we do not fully understand the charge neutralization, or what range of conditions it will hold for. It appears to work best when there is a local source of secondary electrons that can get trapped in the magnetic field. Figure 4 shows a borosilicate glass fiber held behind the 600 line Au grid, and there is little noticeable charging.

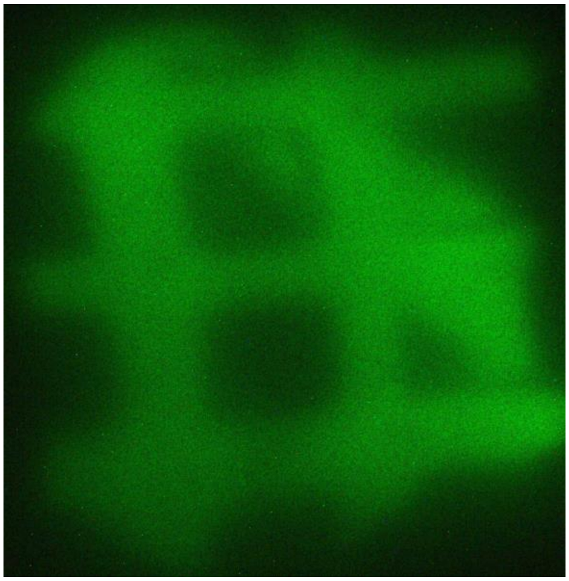

Figure 4. A borosilicate glass fiber held behind a 600 line Au grid. Illuminated with white light NSLA U4A.

We have not had the opportunity to follow up these results, but whatever the charge compensation process is, the demonstration is clear, single fibers of uncoated silk and glass have been imaged using a photoelectron microscope. This promises to open up a wide range of subjects that can be studied using PES.

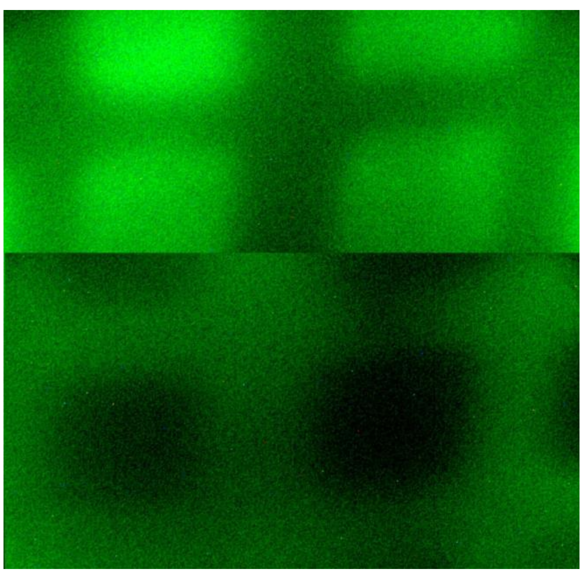

Figure 5. Contrast inversion from the change in workfunction of Au grid and Al foil

The use of white light means that no chemical imaging was possible, but the energy of the imaged secondary electrons can be changed to image differences in workfunctions. Figure 5 shows the contrast inversion from work function changes between a Au grid and an Al foil behind it.

In early 2013 the VPPEM was extensively upgraded. The original vacuum chamber, which was found to be magnetic was distorting the image, and was replaced by an all aluminum chamber with titanium conflats. The pure iron ring which is the field termination aperture was sent to have a very soft magnetic anneal. A sample introduction system was added with extra pumping, and an ion cleaning gun. The CHA input and output lenses were changed to give greater flexibility with magnification. The image detector was changed to a larger microchannel plate/phosphor detector which uses a fiber optic vacuum window. These changes made a large difference to the quality of the images. This can be seen in figure 6 from the same sample before and after.

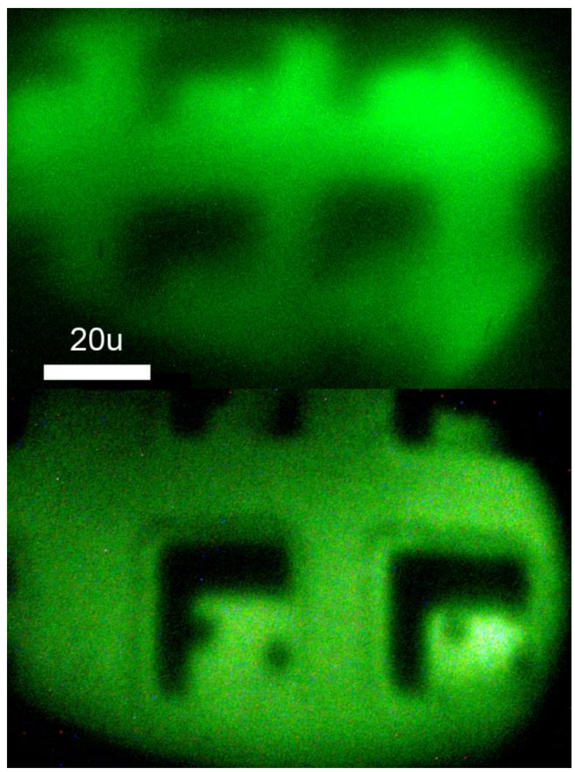

Figure 6. Before and after May 2013. 600 line Cu grid on top of a 2000 line Ni grid.