Assessing Color Cathodoluminescence Imaging in the Scanning Electron Microscope

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Historically, color cathodoluminescence (CL) images were obtained in the luminoscope and visualized by direct examination, film exposure, or combining red, green, and blue (RGB) filtered images collected sequentially using a greyscale CCD camera [1]. Scanning electron microscope-based CL systems offer advantages with respect to higher spatial resolution and lower electron dose/dose-rate imaging. Despite these advantages many SEM-based CL systems output only the sum of photons of all energies to form a panchromatic greyscale image by way of a photomultiplier tube (PMT) detector. Some PMT systems are modified to include RGB filtering. Such RGB images are a useful, if simplistic, color representation of the specimen. However, these long band pass images do not necessarily faithfully represent the entire spectrum of luminesced photons in the visible.

Images for this study were initially collected using a Gatan ChromaCL2. This system uses a high collection efficiency parabolic mirror and disperses luminesced light onto a segmented PMT. Sixteen PMT segments are then binned into four UV-VIS images resulting in multispectral image output (Fig. 1). These dispersive multispectral (DMS) images can be collected with pixel dwell times in the range of 100s of microseconds, shorter than CCD-based systems typically limited to millisecond read-out rates. The higher image collection speed make higher pixel density, and therefore higher spatial resolution, imaging practical. In order to evaluate the spectral fidelity of DMS CL imaging, full spectroscopic imaging using a Gatan MonoCL4 Elite was also performed. True color CL images were generated from the hyperspectral datasets according to chromaticity response curves representing spectral sensitivity for human vision [e.g. 2].

A CL reference sample [3] was examined where α-quartz (SiO₂) from the St. Peter sandstone displayed evidence of electron beam damage (15 kV/~2 nA), even at relatively short (200 μs) pixel dwell times (Fig. 2). The Seneca sandstone was also examined and α-quartz showed no such radiation sensitivity. DMS CL imaging reveals a quartz sub-grains with a reddish interiors (Fig 3a). A true color image derived from a full spectroscopic image of one such region within Fig. 3a is noticeably blue-shifted relative to the DMS CL image (Fig. 3b, 3c). Additional color references throughout the visible are required for a complete evaluation of the spectral fidelity of the multispectral image output. For simple images, a color correction of the DMS CL image relative to the true color image is feasible. The spectral shift correction could be applied based upon the difference between average RGB values of the images on a kernel by kernel basis.

References:
Figure 1. Microscope signals collected in parallel during dispersive multispectral CL using a 15 kV/~2 nA beam: a) backscattered electron (BSE), b) panchromatic CL, c) red, green, and blue (RGB) CL, d) ultraviolet (UV) CL, and e) composite RGB-UV CL.

Figure 2. Evidence for electron beam damage in RGB CL of α-quartz using a pixel dwell time of 200 μs.

Figure 3. Evaluating the color output of two CL systems for α-quartz from the Seneca sandstone: a) PMT-based dispersive RGB CL, b) CCD-based true color image of highlighted region in A derived from spectroscopic imaging data cube, c) sum spectrum from interior region of B (blue line); representation of spectral shift for the DMS CL image (dashed line).