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TRUE COLOUR SEM IMAGING FOR PHASE RECOGNITION AMD X-RAY MICROANALYSIS

Peter J.Statham
Oxford Instruments Microanalysis Group

Secondary (SE) and backscattered electron (BSE) signals in the SEM provide high resolution monochrome images. BSE signal strength is modulated by mean atomic number and 'false" colour can be introduced to enhance material contrast. Colour can also be introduced using multiple SE detectors, each with a different sensitivity to topographic and compositional information: by controlling signal mixtures and colours, the operator effectively has access to a powerful "studio" to generate aesthetically pleasing colour images.[1] In both these examples, the correspondence between local elemental content and colour is entirely arbitrary and under subjective control of the operator. Elemental x-ray maps can be acquired and combinations colour coded to reveal phase distributions.[2] For large numbers of maps and images, chemometric techniques such as PCA may be used to discover common relationships and assist the process of colour coding.[3] Images derived from x-ray maps are usually low resolution and the analyst has to decide which elements to include and do a fair amount of data manipulation before any conclusions can be drawn. Furthermore, local topography effects perturb any multivariate statistical analysis. This paper presents a novel imaging technique which addresses these limitations.

In cathodoluminescence (CL), the sample emits visible light, and images can be coded to reflect the "true colour", as would be seen in an optical microscope.[4] By analogy, we can use the emitted x-ray signal to generate a true colour image. Figure 1 shows the normal human visual response to light with wavelengths from about 400 to 700 nm. To offset the visual response into the x-ray region, an energy dispersive x-ray detector and analysis system (i.e., Link ISIS) is used to assign colour to photons based on their effective wavelengths using a rainbow colour scale. For example, with a 300 eV x-ray assigned red and a 5 keV photon assigned blue, the offset visual response appears as in the lower graph in Figure 1. While the electron beam is resting on a point on the sample, as each photon is detected, its energy is measured and converted to a colour (r,g,b) with the condition r+g+b=1 and the results added to three colour accumulators which maintain totals R,G,B. At the end of the acquisition period, R,G,B effectively represents the colour sensation to the emitted x-ray spectrum which can be reproduced by display on a colour monitor. This process is repeated for all the pixels in a rectangular grid over the field of view to build up a complete full colour image in approximately 1 minute; the acquisition can be extended for further frames to improve counting statistics. The resultant colour x-ray image effectively provides a low bandwidth chrominance signal which is combined with a high resolution monochrome electron image previously acquired from the same field of view using the same beam control hardware. As in conventional broadcast television, the combination is designed to maintain the same luminance as the electron image and thus retain high resolution image detail and topographic appearance.[5,6]

Figure 2 still exhibits the topography and fine detail of the SE image. After the true x-ray colour is added, the tungsten-rich balls appear green, the titanium-rich balls appear blue and the carbon cement substrate is tinged red. If the red, green and blue components for each pixel are plotted on a ternary diagram the resulting scatter plot reveals clusters corresponding to the regions of similar colour (Figure 3). In a multiphase sample, the numbers of pixels in each cluster can be used to calculate area % for each phase.

The multidimensional information corresponding to individual spectra at every pixel point is effectively compressed into a single true colour image and although separation of phases into different colours is not always dramatic, phase recognition is considerably easier and more intuitive than multivariate statistical analysis. Provided the same energy response band is used, the colour will be reproduced on any microscope under similar conditions so compounds will

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appear in memorable colours which can be learned for CL microscopy. Unlike pseudo-colour encoding of BSE images or signal mixing techniques, the colour is independent of beam current, insensitive to local geometry and no user intervention is required to calibrate thresholds. Unlike conventional x-ray mapping techniques, there is no need to choose specific elements and set appropriate windows. The augmented image is intuitive and easy to interpret yet contains a considerable amount of encoded information equivalent to a multitude of x-ray images. A single image can be acquired in about one minute with sufficient statistics to give an informative "first look" at a sample. Faced with a complex analytical problem, the analyst can use this true colour x-ray imaging technique to give a useful cue for positioning the probe for subsequent microanalysis, obtain area % of phases or simply to compress topographical and compositional information into a single image for archiving.[7]

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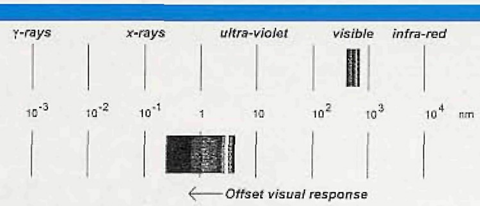
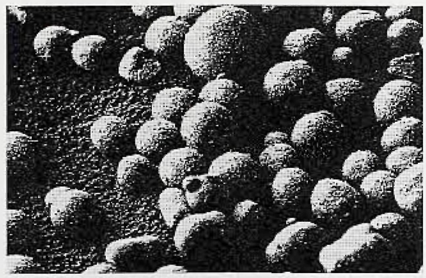
7. I am grateful to my colleagues, particularly Neville Cox for software implemetation and Judith Root, Mohinder Dosanjh and Pierre Rolland for experimental work.





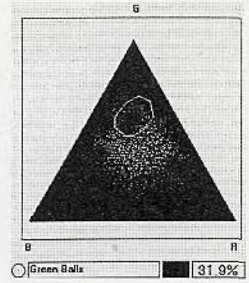


Figure 1: Electromagnetic spectrum showing region where human visual sensors normally operate to give the sensation of colour. Offsetting this visual response allows us to see a true colour x-ray image.

Figure 2: Monochrome reproduction of colour augmented image. 20 kV. field width 1000 µm, acquire time 3 min.

Figure 3: Ternary scatterplot showing colour distribution for fig.2. Outlined region gives total area for W phase.

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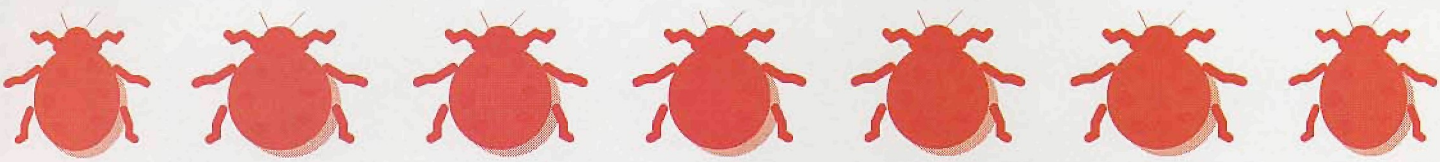

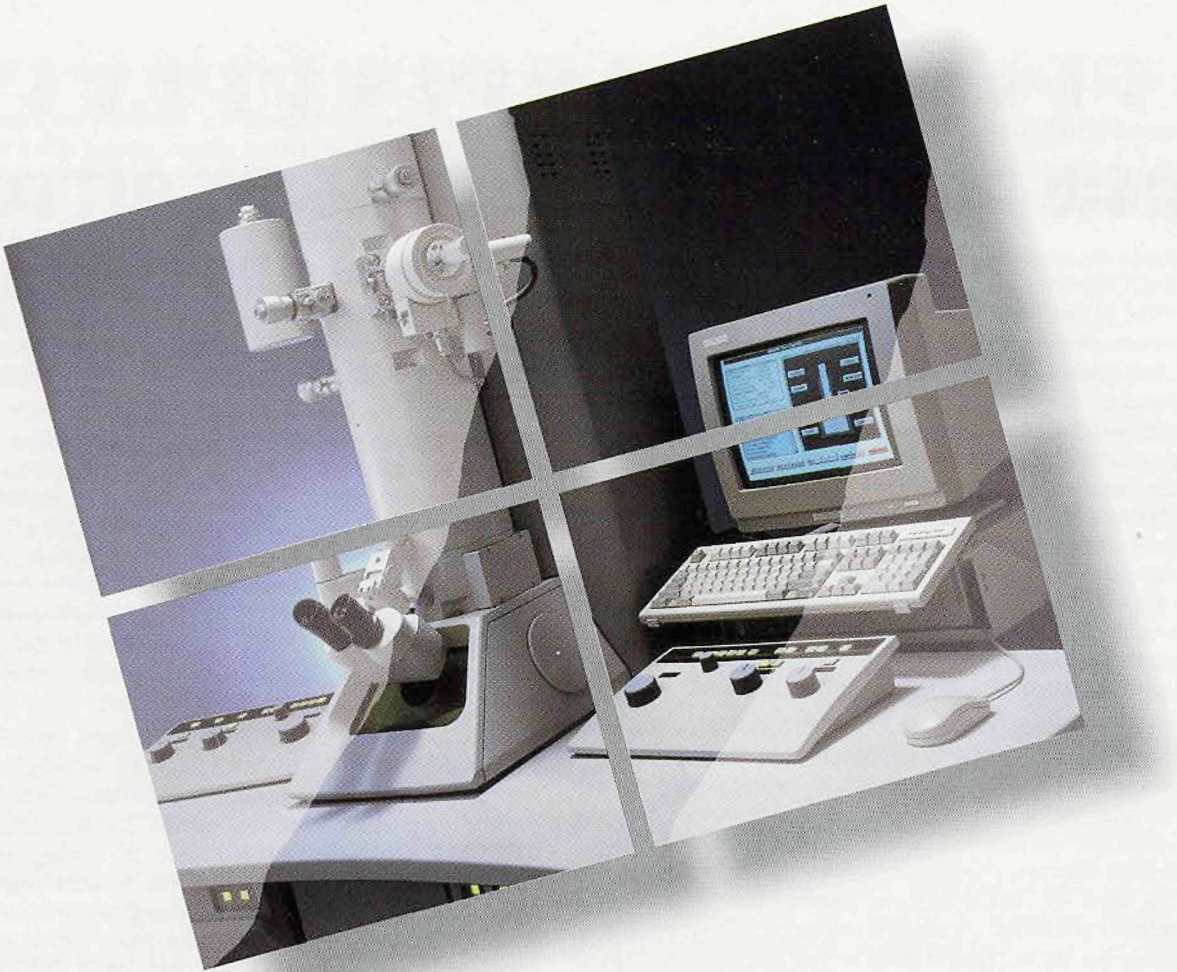

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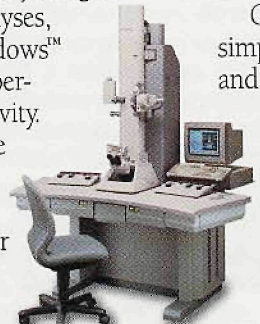

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