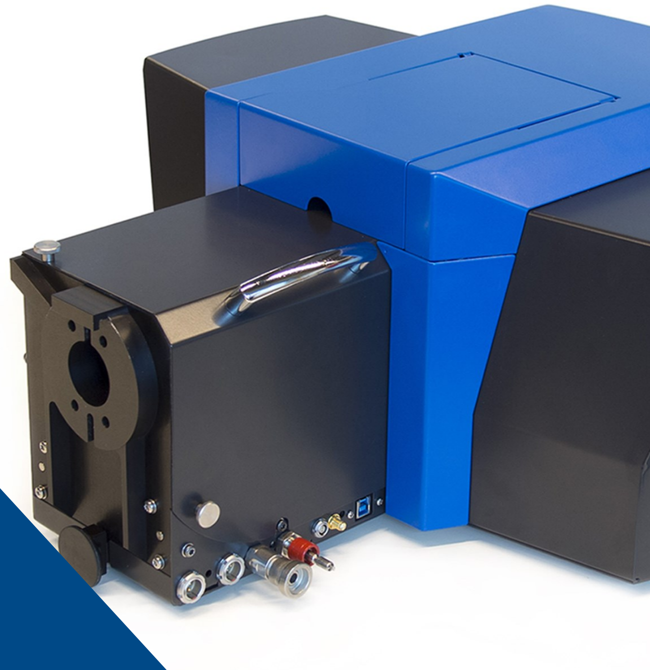

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Angle-Resolved Cathodoluminescence Imaging

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Angle-Resolved Cathodoluminescence Imaging

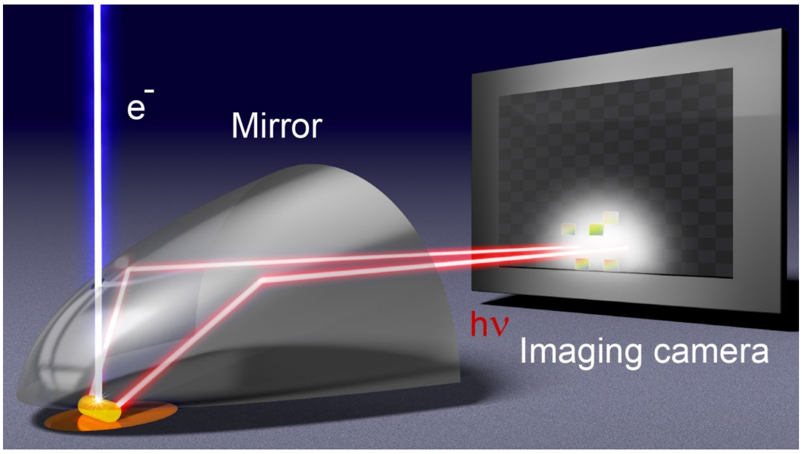

Figure 1 *Graphical representation of the angle-resolved CL imaging mode (image by Tremani).*

In cathodoluminescence (CL) imaging the wavelength-dependent intensity (spectrum) is often studied. In addition to the wavelength (color) of the emission, light is also characterized by a wave vector which describes its momentum and propagation direction. The direction in which light is emitted often contains valuable information on how a (nanostructured) object emits and scatters light and can also be an important performance metric for antenna structures.* It also gives insight into the band structure of periodic systems.** In the SPARC CL system it is possible to probe this feature of light as well.

The concept is illustrated in Figure 1. The CL emission is collected by an aluminium paraboloid mirror and redirected out of the SEM chamber toward a 2D CCD or CMOS imaging array in a parallel CL beam. This allows full retrieval of the beam intensity profile. An example of such a profile measured on single-crystal gold substrate is shown in 2(a). Every point within this profile can be directly associated with a specific emission angle in the upper angular hemisphere from which CL is collected. Such imaging is also known in optics as 'Fourier' imaging, referring to the fact that one images momentum (angular) space rather than real space.

* See application note on plasmonic antennas.
** See application note on photonic crystals.

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The emission angle is described by a zenithal angle θ and an azimuthal angle φ and every point in the beam profile corresponds to a combination of these angles. The images in 2(b) and (c) show how different positions within the beam can be related to θ and φ, respectively. As a final step, a solid angle correction is applied to convert the data to photon flux per unit of solid angle. The standard SPARC mirror collects 1.46π sr of the upper hemisphere, equivalent to a NA of 0.96, and is able to collect zenithal angles up to 88º. In figure 2(e) the result is shown from the angular mapping and solid angle correction on the raw image in (a). The angular profile of gold corresponds to a toroidal pattern because the CL emission is dominated by transition radiation (TR). The black area on the bottom of the pattern corresponds to the open end of the paraboloid where light is not collected. The theoretical TR angular pattern is shown in 2(f) and matches very well with the experiment.

In the optical beam path there is space for color filters to isolate certain spectral features which is important as the angular profile can change profoundly for different emission wavelengths. Additionally, polarizers can be included to study polarization effects*.

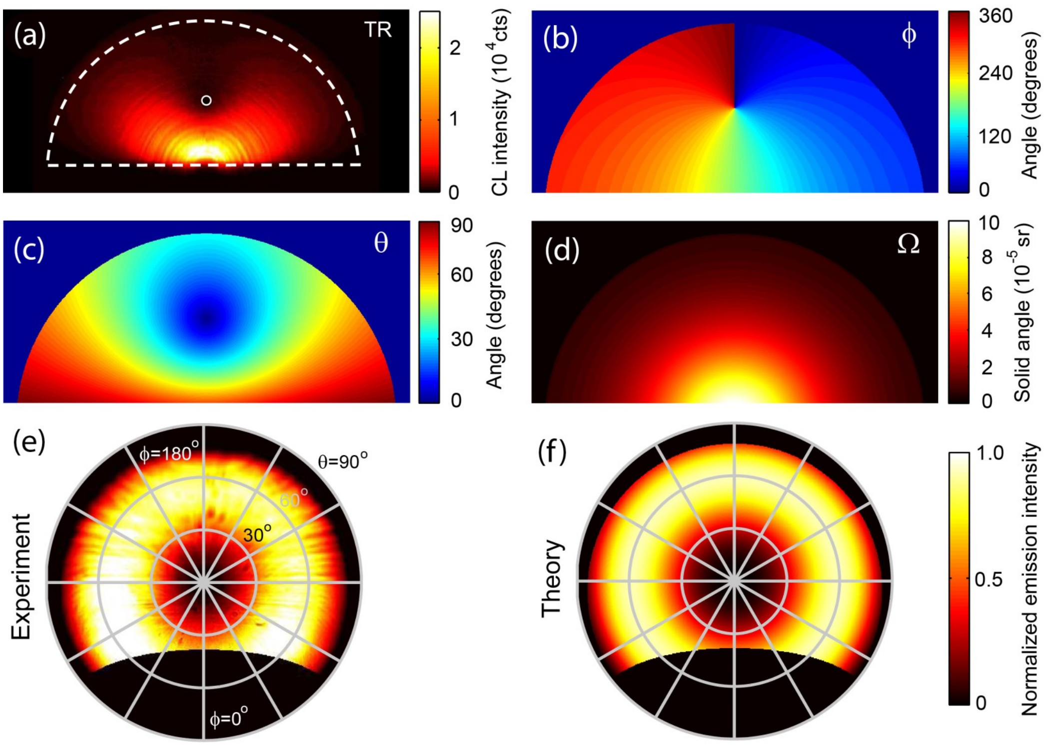

Figure 2 *(a) Raw panchromatic CCD image, measured on a single-crystal gold substrate. The white dashed line indicates the mirror contour, and the white circle indicates the position of the hole in the mirror. Maps relating pixel position in the CCD image to (b) zenithal angle θ, (c) azimuthal angle φ, and (d) the solid angle per pixel, allowing conversion to an absolute radiation pattern. (e) Normalized measured panchromatic emission pattern as a function of emission angle. (f) Normalized theoretical emission pattern for gold. Images are taken from Ref. [1]*

References

1. T. Coenen et al., Appl. Phys. Lett. **99** (2011) 143103.

* See technical note on polarization.

DELMIC B.V. is a company based in Delft, the Netherlands that produces correlative light and electron microscopy solutions. DELMIC's systems cater to a broad range of researchers in fields ranging from nanophotonics to cell biology.

The SPARC is a high-performance cathodoluminescence detection system produced by DELMIC. The system is designed to optimally collect and detect cathodoluminescence emission, enabling fast and sensitive material characterization at the nanoscale.

For questions regarding this note, contact our SPARC Application Specialist at: coenen@delmic.com

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