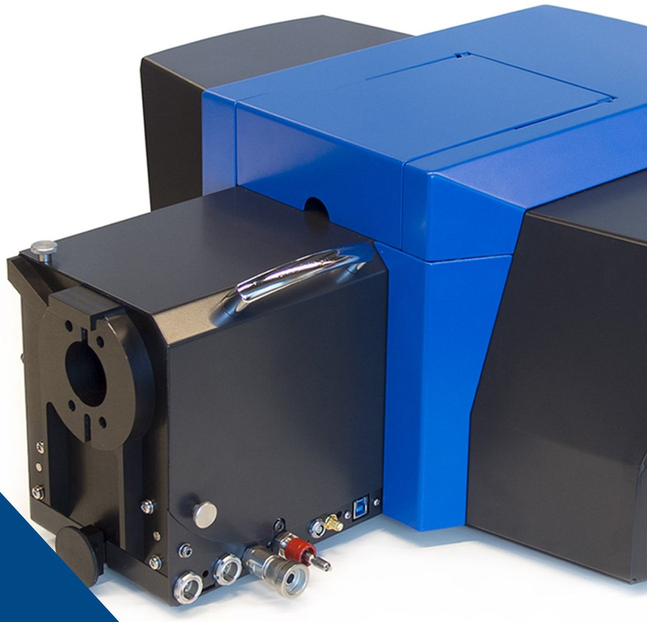

S P A R C

technical note

Polarization-Filtered Cathodoluminescence Imaging

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SPARC

technical note

Polarization-Filtered Cathodoluminescence Imaging

Light is a transverse electromagnetic wave: the electric and magnetic fields that compose the light wave always oscillate transversely to the propagation direction. Besides color (energy) and momentum (propagation direction), light is also characterized by a polarization which describes in what direction these electromagnetic fields oscillate. If the electromagnetic oscillations remain in the same plane, the polarization is referred to as linear but this plane can also rotate while the wave is propagating. In that case, the polarization is elliptical which can be either left - (anti-clockwise) or right-handed (clockwise) depending on the direction of rotation (circular polarization is a special case of elliptical polarization).

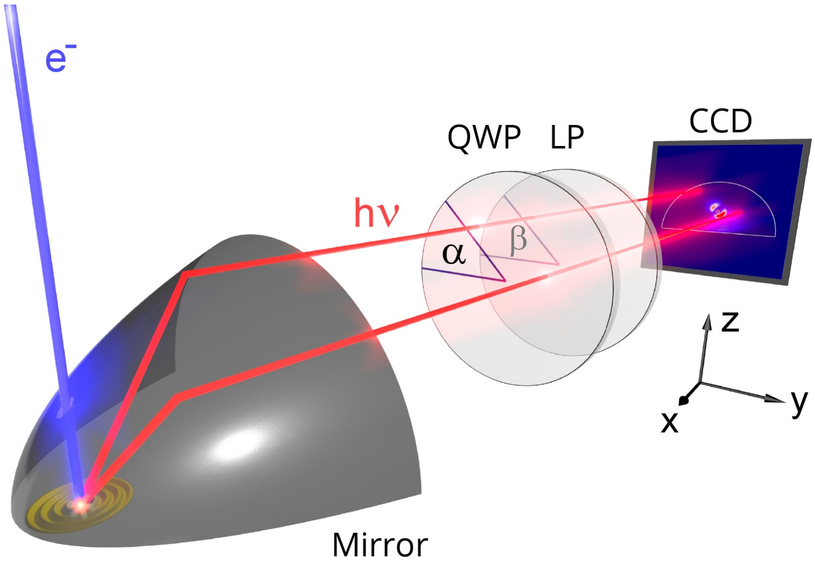

Figure 1 *Schematic representation of the angle-resolved polarimetry imaging mode. The CL is collected by the paraboloid mirror and then filtered by the polarization analyzer which consists of a quarter-wave plate and a linear polarizer. The CCD camera records the polarization filtered image. By recording this image for six different analyzer settings the full polarization state in the detector plane can be retrieved for every emission angle. By applying a correction for the distorting effect of the paraboloid the original emission polarization from the sample can be reconstructed.*

Polarization plays a key role in light-matter interactions and can be used to study coherence, scattering, birefringence, and chirality, for example. Additionally, it can be used to block spurious background radiation and to correct for aberrating effects in the collection optics. When light is emitted from a (nano)material the polarization is not necessarily the same for every emission angle. Fully comprehensive polarization studies have therefore to be performed in the Fourier-plane, i.e. angle-resolved mode. As the SPARC can perform angle-resolved imaging it is ideal to also study polarization effects.

The Stokes formalism provides a complete description of the polarization state (i.e. linear, elliptical, circular) of the light which is cast in the form of a Stokes vector. This stokes vector can be retrieved for every emission angle by using a polarization analyzer in conjunction with a 2D CCD or CMOS camera. The analyzer is composed of a quarter wave plate (QWP) and linear polarizer (LP). Figure 1 shows a schematic representation of this setup [1-3]. To gain full polarization information the measurement has to be performed for six analyzer settings. The measured Stokes vector comprises the polarization state at the detector. However, this polarization has been altered with respect to the polarization coming from the sample by the paraboloid collection optic inside of the SEM. By applying the appropriate correction the polarization distribution from the sample can be retrieved. Wavelength sensitivity can be included through bandpass filters.

An example of what can be done with this technique is shown in Figure 2 where we show the radial and azimuthal electric field amplitudes for different emission angles on a gold plasmonic bullseye grating, measured with CL polarimetry. With the electron beam we launch a circular plasmon wave in the center of the bullseye which is converted by the structure into a radially polarized coaxial beam. The azimuthal component is negligibly small for this geometry. The light is linearly polarized in this case but in principle the handedness can also be determined if the emission is elliptically polarized [2].

In addition to angle-resolved polarimetry it is also possible to perform polarization filtered hyperspectral imaging as is described in References [1] and [4]. In this imaging modality it is possible to obtain polarization-filtered nanoscale hyperspectral images. In conclusion, the modularity, the sensitivity, and the ability the measure the angular profile makes the SPARC the ultimate platform for versatile polarization studies at the nanoscale.

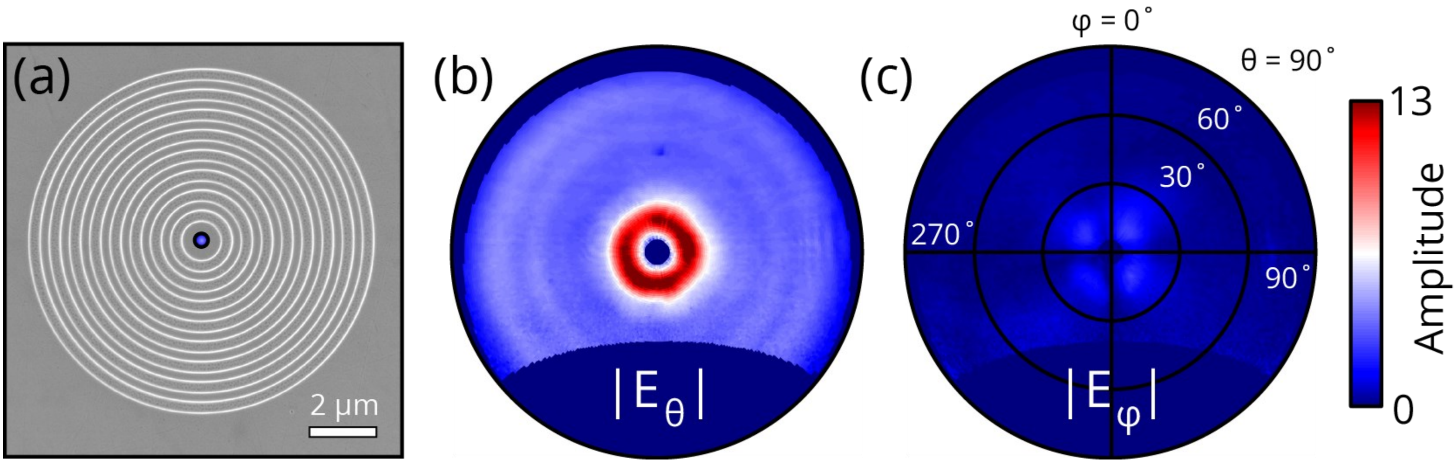

Figure 2 *(a) SEM of a plasmonic bullseye grating milled into a single-crystal of gold using focused-ion-beam milling. (b) Radial and (c) azimuthal field amplitudes as function of emission angles θ and φ for central electron beam excitation of the bullseye.*

References

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4. 4. E. J. R. Vesseur et al. Nano Lett. **11** (2011) 5524.

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

For more SPARC technical notes, see: delmic.com/sparc/technical_notes.php

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