S P A R C

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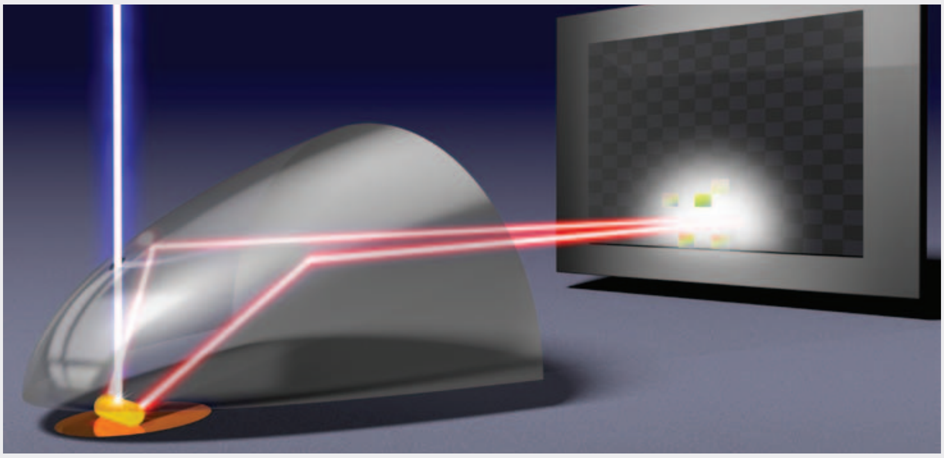
SPARC

is a cathodoluminescence imaging system for the study of nano- and micro-photonic structures that offers unsurpassed sensitivity, control and versatility.



High-resolution angle-resolved cathodoluminescence imaging spectroscopy

The SPARC system enables spatially-resolved cathodoluminescence (CL) imaging spectroscopy with less than 10 nm spatial resolution over the entire UV-VIS-IR spectral range. In addition, it offers angle-resolved spectroscopy of the emitted radiation. Equipped with a piezoelectrically controlled parabolic mirror alignment stage it enables quantitative measurements with high collection efficiency. No other commercial system offers this unique combination of features.

Cathodoluminescence spectroscopy: deep subwavelength spatial resolution

A scanning electron microscope's tightly focused electron beam effectively behaves like a radiating dipole source at the electron impact position. The electric field generated by the electron beam excites the photonic modes and resonances of a photonic nano and micro-structure over a spectral range spanning the entire UV-VIS-IR spectral range. Optical radiation from these modes and resonances is collected by a parabolic mirror placed between the sample and the electron beam column in the electron microscope. The electron beam can be easily focused to a spot size smaller than 10 nm. This technique enables optical spectroscopy at a spatial resolution smaller than 10 nm, which is 50-100 times smaller than the optical wavelength.

Spectral analysis: measuring the local density of optical states

The collected radiation from the excited sample is spectrally analyzed for every electron beam position. In that way a two-dimensional spectral map of the object's emission is recorded. This map is a direct measure of the local density of optical states (LDOS). The LDOS can be determined with a spatial resolution of less than 40 nm at virtually any wavelength.

SPARC capabilities

The SPARC system offers a truly unique method to investigate photonic nano- and micro- structures at deep-subwavelength resolution. It can be used to study metallic (plasmonic, Ag, Au, etc.), dielectric (SiO_2, Si_3N_4, TiO_2, etc.) and semiconductor (Si, GaAs, CdTe, etc.) micro- and nano-photonic structures and serves to investigate:

resonant mode spectra
modal field distributions
waveguide modal dispersion
photonic crystal band structure
photonic crystal cavity modes
localization of light
optical hot spots in nanostructures
emission from quantum dots
emission from rare-earth-doped structures
defects in optical materials
optical antenna radiation profiles
emission profiles from lasers, LEDs

Angular measurements: momentum spectroscopy

The SPARC system is also equipped with an imaging CCD camera that records the optical beam profile emitted from the mirror. From this profile the angle-resolved radiation pattern from the sample can be derived, enabling momentum spectroscopy: measuring the in-plane wave vector of light at every frequency and excitation position. Using this technique the local band structure of periodic and aperiodic structures can be determined with a spatial resolution less than 10 nm.

SPARC: new design for perfect alignment and high sensitivity

Efficient detection of the cathodoluminescence emission places stringent demands on the alignment and sensitivity of the collection and detection system.
The three unique design features of the SPARC system are:

The diamond-turned half-parabolic mirror has a very high collection angle (1.46 π sr.) and operates without major chromatic and surface aberrations over a large spectral bandwidth.

A 4-axis piezoelectric precision alignment system is used to align the focus of the collection mirror with the impact position of the electron beam. This is essential to perform quantitative measurements both in standard and angle-resolved CL modes.

Light that is collected from the sample is coupled to a multimode optical fiber that efficiently guides it to a spectrometer. This configuration separates the alignment of the mirror system from the alignment of the spectrometer and ensures a reliable high-yield collection system.

SPARC integration with SEM

The SPARC system is mounted on one of the flanges of the vacuum sample chamber of a scanning electron microscope (not included). A light-weight optical board is directly mounted on the SEM flange, ensuring that sample and SPARC optics are on the same vibrational platform. The titanium precision mirror stage is mounted onto the sample stage of the SEM inside the vacuum chamber. Mounting and unmounting the mirror stage can be done within five minutes. Special software for alignment is included. Detailed instructions for calibration are provided to enable quantitative CL measurements.

The SPARC system can be combined with almost any SEM. A dedicated flange assembly is designed corresponding to the SEM flange geometry. Driving signals for the SEM and SPARC software are interfaced with the external x-y scan input of the SEM.

User-friendly operation, dedicated analysis software

Cathodoluminescence spectroscopy provides very large data sets (x, y, wavelength, intensity, angle, polarization) in a relatively short period of time. Dedicated software is provided to make two-dimensional radiation maps, angular radiation profiles and other cross cuts through the data.

The SPARC system is based on the instrument developed at the FOM-Institute AMOLF in Amsterdam, the Netherlands (www.erbium.nl/arcis.html).
Three key publications are:

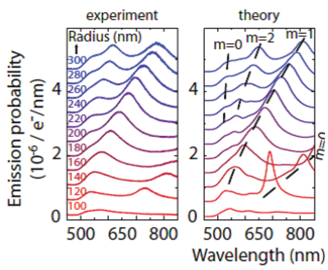
- Angle-resolved cathodoluminescence imaging spectroscopy
  T. Coenen, E.J.R. Vesseur, and A. Polman, Appl. Phys. Lett. 99, 143103 (2011)
- Plasmonic whispering gallery cavities as optical nanoantennas
  E.J.R. Vesseur and A. Polman, Nano Lett. 11, 5524 (2011)
- Deep-subwavelength spatial characterization of angular emission from single-crystal Au plasmonic ridge nanoantennas
  T. Coenen, E.J.R. Vesseur, and A. Polman, ACS Nano DOI: 10.1021/nn204750d (2012)

EXAMPLE MEASUREMENTS

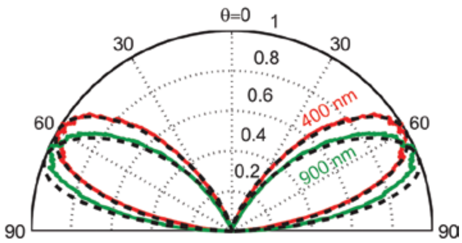
Demonstrating spectral, spatial and angle-resolved sensitivity.

SPARC is a truly versatile instrument that enables optical imaging and momentum spectroscopy at deep-subwavelength resolution

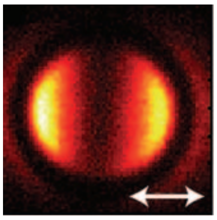
CL emission spectra from resonant plasmonic ring cavities with different diameters (note the absolute scale on the vertical axis) and the corresponding calculated spectra, showing good agreement



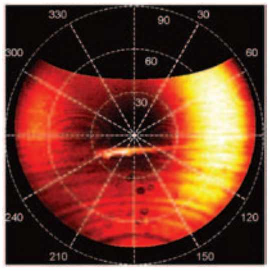
Angular emission distribution from a single-crystal Au surface (transition radiation) at two different wavelengths (400, 900 nm), reflecting a dipolar radiation pattern, experiment (color) and theory (dashed lines) are in excellent agreement



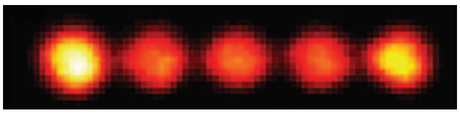
Spatially-resolved polarized emission at λ=800 nm from a plasmonic ring cavity on a Au surface, showing a dipolar mode (image size 800 x 800 nm)



Directional emission at λ=500 from a Au nanoparticle optical Yagi-Uda antenna excited at the left-outmost particle, with emission observed towards the right.



2D CL emission map at λ=600 nm from an optical Yagi-Uda antenna composed of five 100-nm-diameter Au particles (image size 200 x 800 nm)

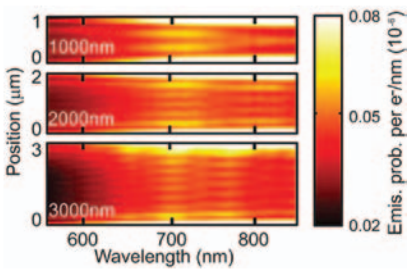


All measurements are taken using a 30 keV electron beam in an FEI XL-30 field-emission SEM.

All pictures courtesy of the Polman group, AMOLF.

It enables studies at the frontiers of optical science

CL line scan of plasmonic standing waves in Fabry-Perot cavities on a Au surface with three different cavity widths (1000, 2000, 3000 nm), a full CL spectrum is taken at every position



SPARC

Specifications & options

Mirror assembly

- Titanium precision translation/rotation stage with mirror mount
- Piezoelectric stepper motors with computer-controlled drivers:
  x, y accuracy < 10 nm; θ, φ accuracy < 1 μrad
- Diamond-turned Al-coated half-parabolic precision mirror, collection angle 1.46 π sr., surface roughness < 20 nm

Optical analysis system

- Lightweight optical board in light-tight enclosure with SEM mounting assembly
- High-quality coated mirrors and achromat lens (400-1700 nm)
- Electrically controlled flip mount for remote switching between imaging and angular CL modes
- Filter holder with filters for angle-resolved measurements (50 nm band pass)
- Polarization analyzer
- Fiber coupling assembly

Spectrometer/detectors

- Computer-controlled fiber-coupled Czerny-Turner optical spectrometer with 3 custom interchangeable gratings
- Thermoelectrically cooled ultraviolet-visible Si CCD array detector (λ=400–900 nm) and/or thermoelectrically cooled infrared InGaAs CCD array detector (λ=900–1700 nm)
- Photomultiplier tube for ultra-fast alignment and video-rate CL mapping (λ=300–900 nm)
- 1024 x 1024-pixel thermoelectrically cooled CCD camera system for angle-resolved CL acquisition

Data acquisition

- Spectroscopy mode
  - 1D and 2D hyperspectral imaging
  - Dwell time per e-beam position: 1 μs – 1 s
  - Spectral resolution: < 1 nm
- Angle-resolved mode
  - Angular collection range: up to 1.46π sr
  - Angular resolution: < 10 mrad
  - Spectral resolution: depending on filter band width (typically: 50 nm)
- Simultaneous acquisition of secondary electron and cathodoluminescence signals
- Measurement of polarization-resolved spatial and angular distributions

Hardware

- Design of a dedicated flange assembly for integration with the SEM
- Computer for spectrometer grating control, read-out of CCD detectors and imaging CCD camera, interfacing with SEM x-y external input, controlling mirror stage, and read-out of PMT.
- Drivers and power supplies for piezoelectric stepper motors, spectrometer, CCD detectors, CCD imaging camera, PMT.

Software / data analysis

- Control and alignment of mirror stage
- Plotting 1D and 2D spectral images, crosscuts through spatial and angular data, comparison with SEM images, plotting angular radiation distributions

All specifications are subject to change and may vary depending on SEM type. Please inquire whether your SEM is suitable for fitting with a SPARC system.

We aim to customize.

Contact Delmic
Please contact us for inquiries about availability.

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We are always interested in your comments and suggestions.