Energy-momentum cathodoluminescence microscopy for nanophotonics

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Cathodoluminescence (CL) microscopy has gained significant interest last years as a technique for probing the nanoscale optical properties of dielectric, semiconductor, and metallic (nano) photonic materials. In particular, the high spatial resolution, radiative LDOS sensitivity, and broad band character (both in energy and momentum) are appealing for studying such materials. In "conventional" hyperspectral CL imaging the electron beam is raster scanned over the material and a full emission spectrum is obtained at every position. These spectra can contain information on various physical properties including band edge emission, material defects, optical (plasmon) resonances, guided modes etc. More recently, angle-resolved CL was developed where an angular profile is collected by measuring a Fourier image with a 2D array detector, enabling CL studies in momentum space.

Here, we present a novel cathodoluminescence imaging technique, energy-momentum (E-k) CL imaging, in which we merge hyperspectral and angle-resolved CL imaging [2]. To that end, we project the CL Fourier pattern onto the slit of a spectrograph after which the light is dispersed by a diffraction grating and imaged with a 2D CCD array. This yields a hybrid 2D image in which the horizontal direction corresponds to wavelength/energy and the vertical direction corresponds to a range of polar angles/momenta (see Figure a,b). The benefit of this approach is that one can achieve high spectral (< 1 nm) and high angular (< 20 mrad) resolution in a single measurement. This makes it complementary to the angle-resolved method in reference [1] where a complete angular/momentum profile is collected in one shot but averaged over a significant wavelength band as defined by the band pass filter used.

To validate the technique we performed measurements on bulk crystalline silicon and bulk MoS_2 for disentangling coherent and incoherent CL contributions with high energy resolution. Furthermore, we fully map diffraction from a TiN grating (1.6 m pitch) in E-k space [2]. Finally, we demonstrate that it is possible to construct a full 3D dataset containing a large range of momenta and wavelengths by scanning the Fourier pattern over the input slit of the spectrograph using the motorized lenses in the CL system (lens 1 and 2 in Figure a). The presented technique is of interest for a large range of applications including material dispersion mapping, separation of coherent and incoherent CL contributions, probing diffraction in (a)periodic plasmonic and photonic crystals, and gaining insight into photonic topological systems.

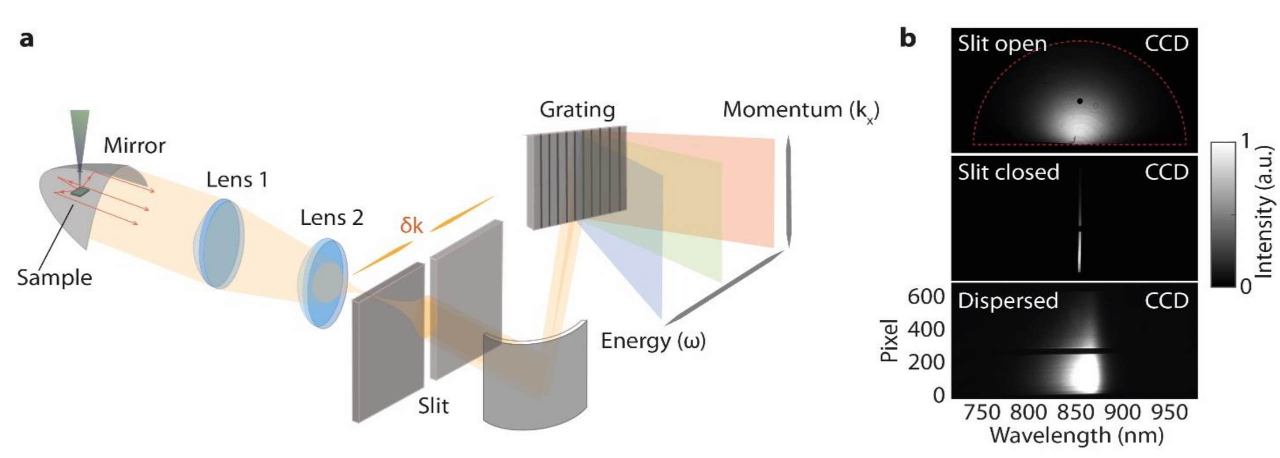

Figure: (a) Experimental realization of the E-k momentum imaging. **(b)** Images of a CL Fourier pattern from a GaAs crystal measured with slit open, slit closed and dispersed by the grating. The latter corresponds to a hybrid E-k image.

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[2] S. Mignuzzi, M. Mota, T. Coenen, Y. Li, A. P. Mihai, P. K. Petrov, R. F. M. Oulton, S. A. Maier, and R. Sapienza, ACS Photonics, **DOI:** 10.1021/acsphotonics.7b01404 (2018).