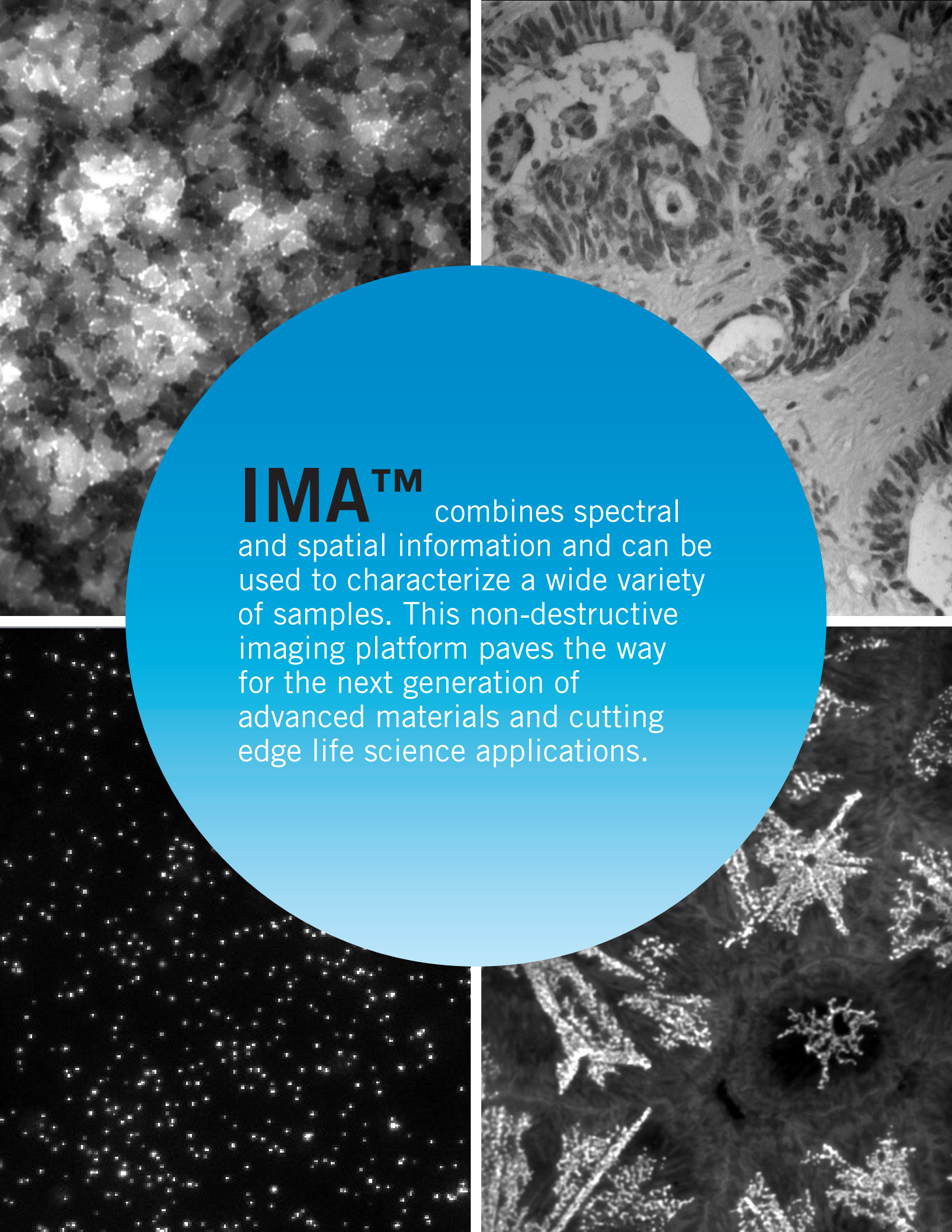
IMA™
Hyperspectral Microscope

State-off-the-art global hyperspectral imaging system based on a patented filtering technology

Photon etc
A spectrum of solutions



IMA™ combines spectral and spatial information and can be used to characterize a wide variety of samples. This non-destructive imaging platform paves the way for the next generation of advanced materials and cutting edge life science applications.

The hyperspectral imager provides spatial and spectral information, where each pixel of the field of view returns a spectrum. This technique can help map the sample composition, give feedback on its formation, identify defects, inhomogeneity, as well as fundamental physical properties such as photoluminescence, electroluminescence, fluorescence, and other optoelectronic properties.

This imaging system can be used to characterize materials from different families; organic, inorganic and hybrid semiconductors, carbon-based nanomaterials including fullerenes, carbon nanotubes, graphene and its derivatives, graphene oxide, nanodiamonds, and carbon-based quantum dots, perovskites and silicon-based materials. Moreover, this platform can also be used for the characterization of optoelectronic devices, for instance: photovoltaic solar cells, light emitting diodes, sensors and transistors. Additionally, it can be used for other kinds of samples for biological and life sciences applications.

Global Hyperspectral Imaging

↓

Efficiency %

↓

Orient fabrication method

IMA™ Intrinsic Configuration

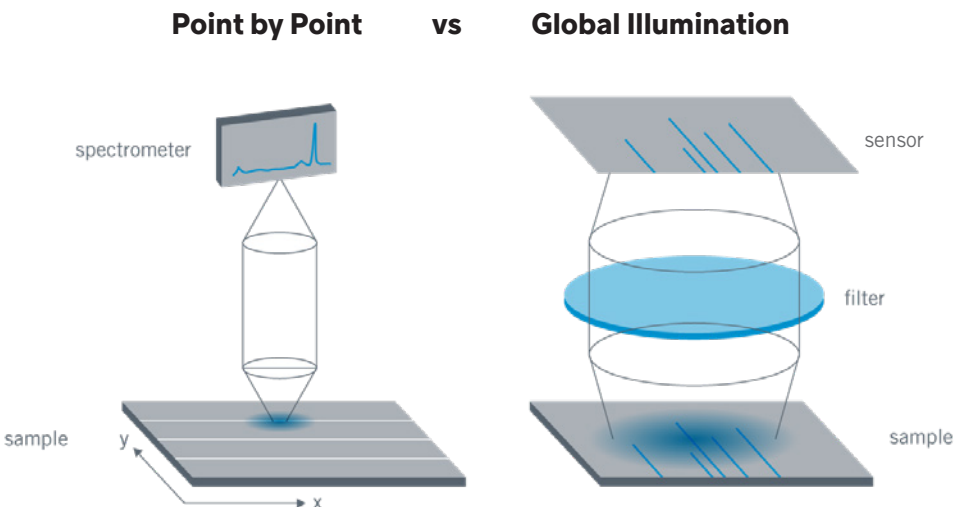
IMA is a hyperspectral microscope delivering spectral and spatial information. Based on high throughput patented global-imaging filters, IMA is faster and more efficient than standard point-by-point or line-scan-based systems.

IMA consists of an optical microscope coupled to high-power LEDs, broadband illumination sources and a hyperspectral filter, based on volume Bragg gratings (US patent 7557990 (B2)).

The hyperspectral filter is continuously tunable from 400 nm to 1000 nm or 900 nm to 1620 nm. It provides high spectral (< 2 nm (VIS), < 4 nm (SWIR)) and spatial resolution (~ 1 µm). A filter wheel is inserted before the camera allowing multispectral "snapshot" rapid measurements. This option "bypasses" the hyperspectral filter for faster but lower spectral resolution acquisitions. Broadband visualisation can also be performed with IMA. Our visible platform is equipped with an sCMOS camera and our SWIR platform is coupled with Photon etc.'s Alizé 1.7 or ZephIR 1.7 InGaAs camera. This set up can have accessories to acquire spatially and spectrally resolved photoluminescence (PL), electroluminescence (EL), bright field or darkfield transmittance, and reflectance data as well as an absolute photometric calibration module. Our intrinsic configuration also includes PHySpec, Photon etc.'s proprietary software for acquisition and analysis.

Global imaging capabilities (no image reconstruction)

Hyperspectral global imaging is a technique where the wavelength is being scanned and monochromatic images are acquired one after the other. In contrast, a spectral measurement performed with raster scanning technology is taken point by point or line by line by moving the sample, the sensor, or the excitation source. The number of acquisitions being much lower in global imaging (a few hundred wavelengths compared to several hundreds of thousands of points in scanning), the excitation density can be reduced while maintaining short measurement acquisition times. Global imaging therefore does not damage the sample, in addition to offering high spectral (~ nm) and spatial (~ µm) resolution. Also, since the whole field of view is imaged simultaneously, moving object trajectories can be reconstructed.



THE ADVANTAGE OF GLOBAL IMAGING IN THE FIELD OF PHOTOVOLTAICS

By design, global imaging, requires uniform illumination under the field of view.

In standard confocal setups, the excitation is done in one point (~1 µm^2) which leaves the surrounding area at rest. This leads to lateral diffusion of charges towards darker regions. This has the effect of reducing the PL signal intensity, hence the excitation power needs to be increased considerably in order to observe the signal. Also, this high-power density is far from what photovoltaics material will experience in real conditions. In fact, power densities used in confocal microscopy can reach up to 10^4 suns, far from operating conditions of solar cells, which complicates a deep interpretation of the results.

Whereas in global imaging, the uniform illumination reduces the charge diffusion. This uniform illumination allows carrying PL experiments in the range of 0.1 sun or up to 500 suns which is within the range of realistic operating mode of standard or concentrator photovoltaics.

Overview

400-1000 nm (VIS) or 900-1620 nm (SWIR)

Spectral resolution < 2 nm (VIS), < 4 nm (SWIR)

Spatial resolution < 1 µm (close to the diffraction limit)

Hyperspectral, multi-spectral and broadband visualisation modes

sCMOS (VIS) or InGaAs - Photon etc.'s ZephIR 1.7 or Alizé 1.7 cameras (SWIR)

Based on patented filtering technology - volume Bragg gratings.

Upright or inverted research grade microscopes configurations.

PHySpec Software: acquisition and analysis – unlimited licences included

Possibility to perform those measurements back to back over the same area

PL measurements: high-power LEDs

EL measurements: using your own probes and source meter

Transmittance and reflectance: with white light illumination

Filtering technology

Volume Bragg gratings

What is a volume Bragg grating?

A volume Bragg grating (VBG) is a diffraction grating in which there is a periodic modulation of the refractive index through the entire volume of a photosensitive material. This modulation can be oriented either to transmit or reflect the incident beam (see Figure below a and b respectively).

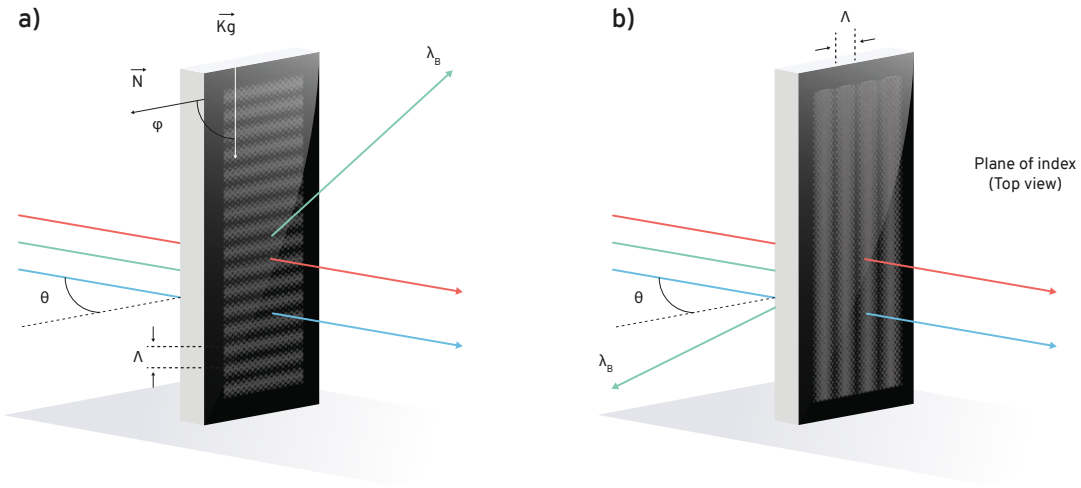


Illustration of a Bragg grating in transmission (a) and reflection mode (b).

Only a small fraction of the incident beam respects Bragg's law and will be diffracted. In order to select which wavelength will be diffracted, the angle of the filter is adjusted to meet Bragg's condition: $\lambda_B = 2n_0\Lambda\cos(\theta + \varphi)$, where λ_B is the diffracted wavelength. Only the diffracted wavelength will be detected by the camera.

What are the advantages of using Volume Bragg Gratings for IMA?

VBG possess a high throughput (> 90%), can be tuned over a wide spectral range (hundreds of nm) and provides a good spectral resolution. VBG can also be used to filtered images, allowing fast global imaging with no image reconstruction.

Where are the gratings located?

The VBG are inside in the hypercube (see IMA Intrinsic Configuration on p. 4) which is located between the microscope output and the camera to filter the signal coming from the sample (emission, transmittance, reflection). The sensor (sCMOS and/or InGaAs) is located on top of the hypercube.

Band-pass filters (multipsectral capabilities)

A filter wheel is inserted before the camera allowing multispectral measurements. This option "bypasses" the hyperspectral filter for faster but lower spectral resolution. Up to 6 positions can be available for the end users and custom filters can be added after acquiring the platform.

Illumination

IMA's intrinsic configuration comes with white light for standard reflectance (episcopic) and transmittance (diascopic) hyperspectral imaging as well as high-power ligh-emitting diodes (LEDs).

Up to 3 LEDs can be chosen with wavelengths ranging from 400 nm to 940 nm. Because of the divergence of the LEDs emission only 0.1% to 2% of the total LEDs output power can reach the sample depending on the excitation wavelength and the objective magnification. Hence, LEDs can be used for fluorescence or photoluminescence imaging when low power density is required (0.1 - 50 mW/mm^2).

Those illumination capabilities can be customized and even the intrinsic configuration can be tuned down if one of the illumination capability is not required.

Software - PHySpec

PHySpec is Photon etc.'s proprietary software for instrument and camera control. PHySpec provides a sequencer with measurement automation as well as analytical tools for rapid extraction of sample information. Its multithreaded architecture expedites processing complex algorithms as well as the acquisition, visualization, import, and export of data.

Every tool comes with a complete PHySpec user manual and with unlimited licences.

Please see below a few highlights of our software:

Broadband video recording (time stamp on each image)

Sequential acquisitions defined by the user via software:

Automatic data acquisitions, analysis and handling: parameters predetermined by user

Allows user to define custom spectral range, wavelength step size, exposure time

Hyperspectral imaging analysis toolbox:

Pixel-spectrum visualization tools

Hyperspectral data processing (dark subtraction, normalisation, smoothing, curve fitting, binning, cropping, spectral map)

Hyperspectral files exportable in HDF format (.H5) and fits (compatible with other softwares)

Spectrum data files exportable in HDF format (.H5) and CSV (excel compatible)

Image files exportable in HDF format (.H5), JPEG, PNG, FITS and BMP

Standard on-site technical requirements

While every IMA can be customized and have different dimensions/weight, our typical on-site requirements are listed below:

Optical table with passive anti-vibration isolation recommended

With LEDs-based illumination: 900 x 900 x 60 mm

With laser-based illumination:
900 x 1800 x 60 mm (36 x 72 x 2.4 inches) or

With laser-based illumination:
900 x 900 x 60 mm (36 x 36 x 2.4 inches) next to a 900 x 900 mm (36 x 36 inches) standard table

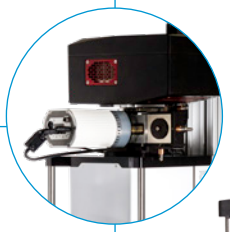
Height requirement above the optical table	1400 mm (55")
Power requirement	1000 W
Environmental condition requirements, which include room humidity and temperature ranges for equipment to function	standard laboratory conditions
Cooling requirements	N/A

NB: weight of the instrument (optical table weight to be added): around 85 kg (187 lbs).

Always confirm with our team that those requirements are adequate for your platform.

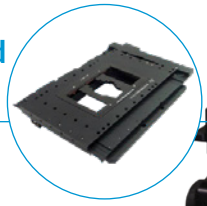
IMA™ Fundamental add-on

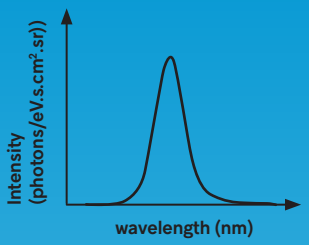
Extended spectral range option 400-1620 nm



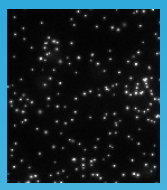
Additionnal epifluorescence illuminator and filters

XY motorized stage



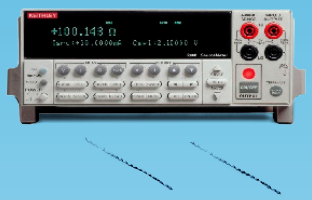


Absolute calibration module



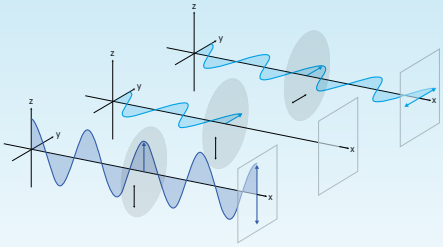
Darkfield hyperspectral imaging

Probes + sourcemeter can be used for electrolumienscence hyperspectral measurements and I-V curves



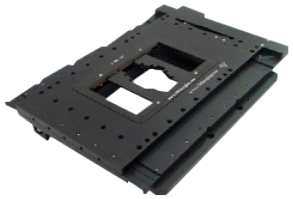
Laser-based photoluminescence illumination

Polarisation measurements



XY motorized stage

The motorized stage allows automated measurements as well as stitching to access optical information over a wider area.

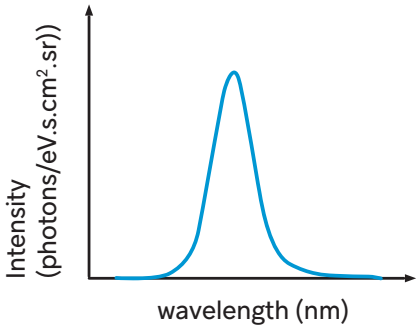


Our standard motorized stage is programmable along the X and Y axis and possess a 100 mm x 100 mm travel as well as a 0.022 µm resolution. It can be programmed with the sequencer of acquisition that is included in our proprietary software, PhySpec.

An unlimited number of images can be stitched or and it is also possible to stitch between 9 and 49 hyperspectral data cube, depending on their size.

Absolute calibration module

The photometric absolute calibration procedure, allows to determine the absolute number of photons emitted from every point of the surface of a sample, at every wavelength. With this feature, researchers obtain quantitative information instead of data in arbitrary units. This option allows the user to better understand the optical properties of their sample.



> Calibrated photoluminescence and electroluminescence data units are **photons/(eV.s.cm².sr).**

The absolute calibration module includes hardware (laser, white light, integrating sphere) and an upgraded version of our PHySpec software.

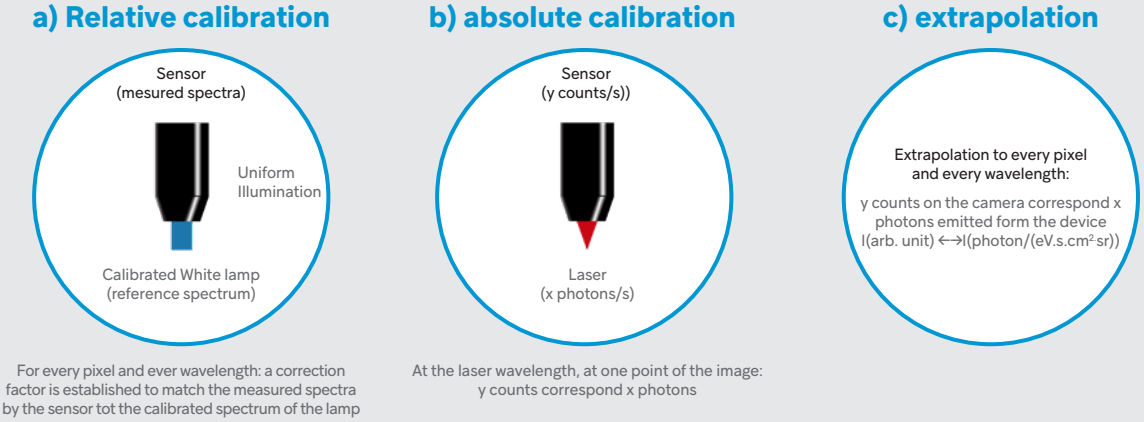
In order to get an absolute calibration of the intensity to get the number of photons, two steps are needed.[1]

FIRST, a relative calibration (see Figure below a)) is achieved on the entire field of view for each wavelength by imaging the output of an integrating sphere coupled to a calibrated halogen lamp. This setup provides a spatially uniform output with a known spectrum and allows the correction of sensitivity fluctuations across the field of view and the spectral range. For every pixel and wavelength, a correction factor is established to match the spectral output of the sensor to the calibrated spectrum of the lamp.

THEN, an absolute calibration is carried out for a given wavelength on a single point of the field of view. To do so, we image the output of an optical fiber in which a 915 nm laser is coupled and we compare with the intensity measured with a power meter.

FINALLY, combining the relative calibration of the entire field of view and spectral range to the absolute calibration at a given wavelength and point, we extrapolate the absolute calibration of the entire sample for every wavelength.

Schematic of the absolute calibration steps.



For every pixel and ever wavelength: a correction factor is established to match the measured spectra by the sensor tot the calibrated spectrum of the lamp

At the laser wavelength, at one point of the image: y counts correspond x photons

[1]Delamarre A. , Paire M., Guillemoles J.-F. and Lombez L., Quantitative luminescence mapping of Cu(In,Ga)Se2 thin-film solar cells, Progress in Photovoltaics, (2014).

Epifluorescence module

An epifluorescence module can be added to the system providing multiple excitation wavelengths at low power density. This option includes an epifluorescence illuminator and fluorescence filters (chosen by the customers).

Laser based photoluminescence illumination

If more power density is needed (1 mW/mm^2 - 10 W/mm^2) , high-power laser can be integrated into the system. Our laser enclosure can be design to accommodate two or three laser sources. Those sources can be purchased with the initial system or later on.

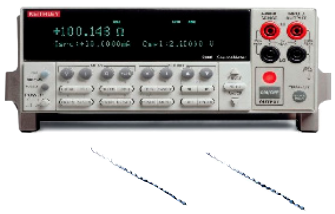
The lasers are injected into our flat-top beam shaping module to ensure homogenous illumination over the entire field of view:

- Homogenous illumination - no speckel
- 10-30% difference between middle and side

With this configuration, 10% to 40% of the total laser output power can reach the sample depending on the excitation wavelength and the objective magnification.

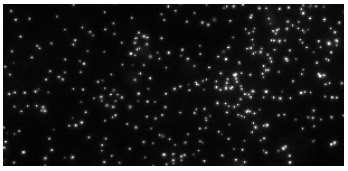
Computer-controlled safety shutters are included as well as specific filters that will remove any contribution from the laser after the excitation.

Electroluminescence station



When working with functional devices, electroluminescence (EL) can provide useful information on the fundamental properties of the samples. Probes and a source meter can be provided with IMA to perform hyperspectral EL imaging. Magnetic wings are added to the manual or motorized stage to position the probes. The source meter is controlled by Photon etc.'s proprietary software.

Darkfield option



The standard condenser of the microscope can be easily replaced by a darkfield condenser to transform the IMA into a darkfield hyperspectral microscope. Appropriate objectives have to be added to the configuration in order to fit the NA of the condenser. This platform is compatible with both dry and oil objectives.

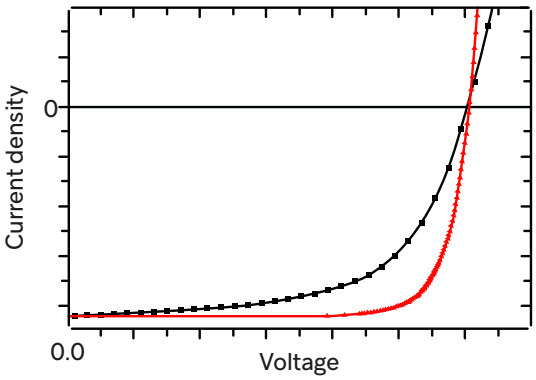
Extended spectral range

The intrinsic configuration covers either the VIS (400-1000 nm) or the SWIR (900-1620 nm) spectral range. It is possible to add gratings to your hyperspectral platform as well as a second camera port to cover a wider spectral range: 400-1620 nm. Both VIS and SWIR ranges become available and are covered by an sCMOS and InGaAs camera respectively.

This spectral range extension can be added later, but if we build the initial system knowing it can be upgraded in the future, the upgrade will be smoother (faster, and cheaper).

I-V curves

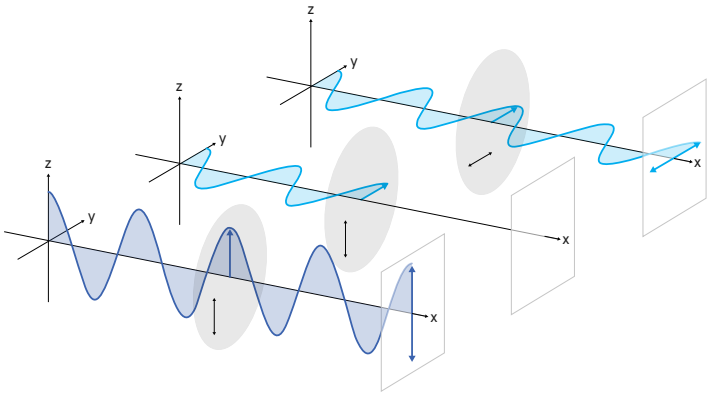
It is possible to perform I-V curves with the hyperspectral imager if probes and a source meter are added to the setup. Magnetic wings are added to the manual or motorized stage to position the probes. The source meter is controlled by Photon etc.'s proprietary software.



The measurement is performed by applying different voltages to the device. For each voltage, the current is measured. No image is provided for this measurement, only the I-V curves.

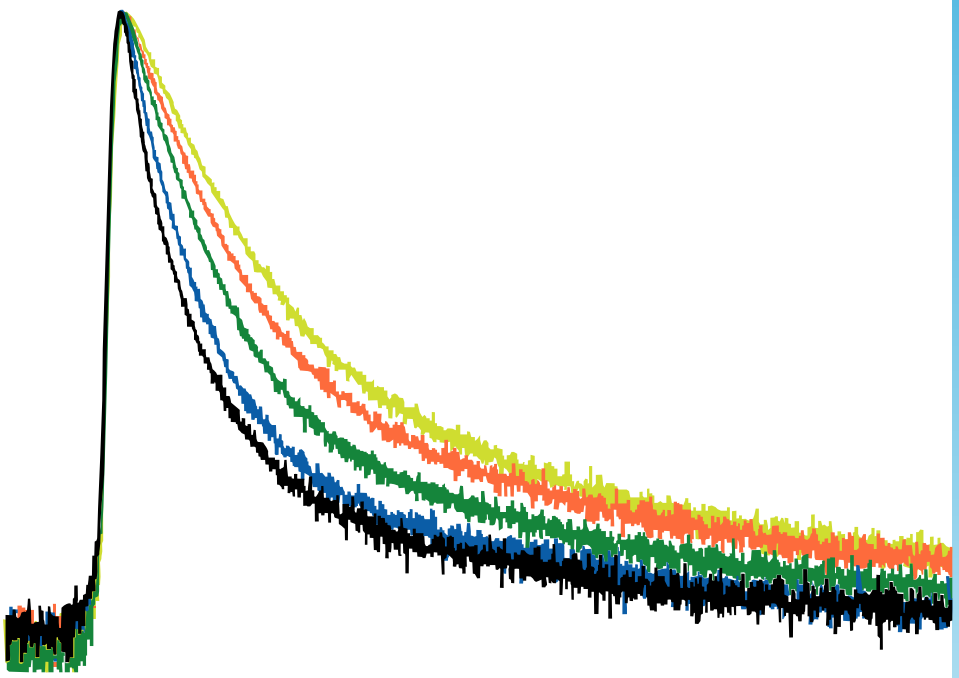
Polarisation measurements

Polarization measurements bring a new dimension to the hyperspectral imaging. It is possible to add polarisers in the optical path of the IMA to perform polarisation measurements. Polarisers can be added in the excitation and/or emission path. The polariser are chosen along with the customer to fit the specific needs of its research.



IMA™
Higher-level add-on

Time resolved measurements



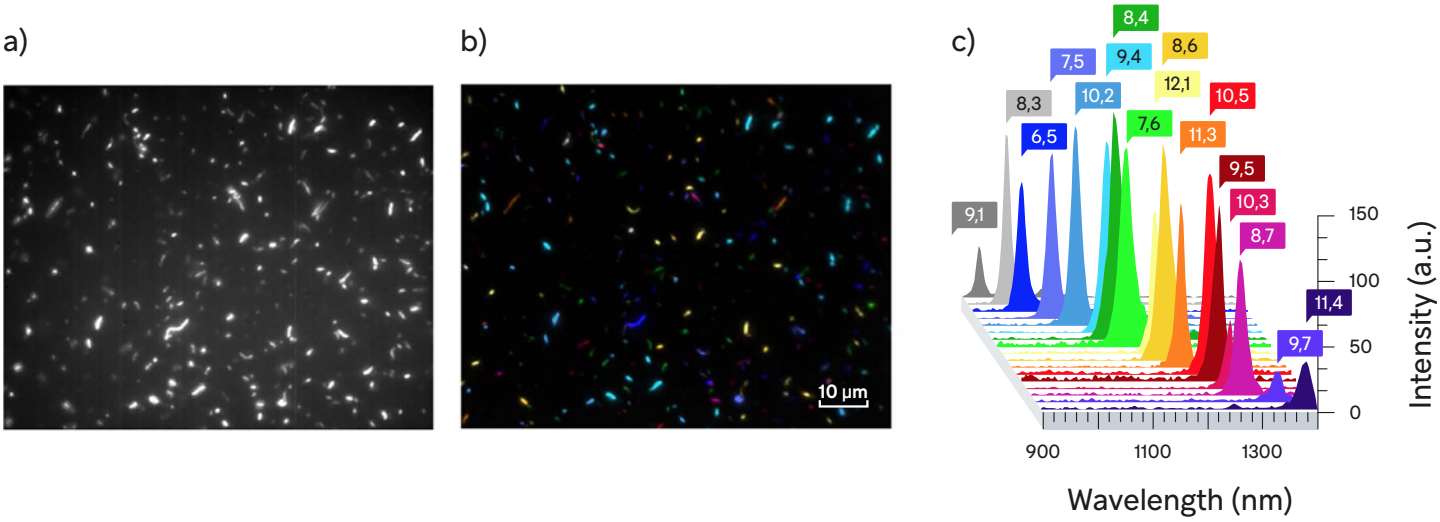
This imager can provide time-resolved photoluminescence measurements.

TRPL provides information on the carrier lifetime in a variety of advanced materials.

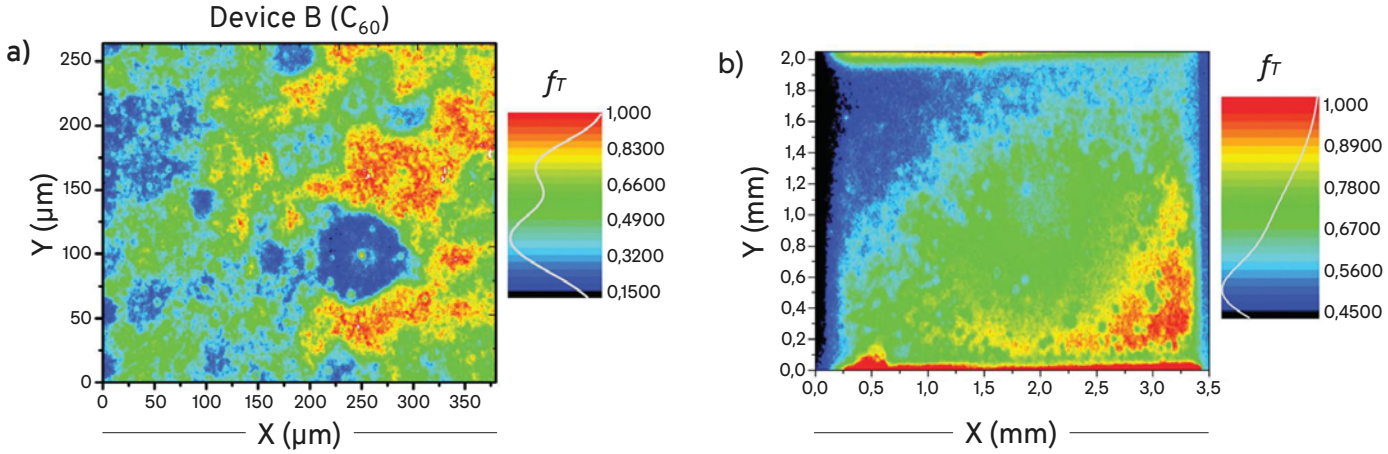
It is also possible to build the IMA with an additional input port that can accommodate fluorescence lifetime imaging microscopy (FLIM) module from other suppliers.

Cryostation - temperature dependent measurements

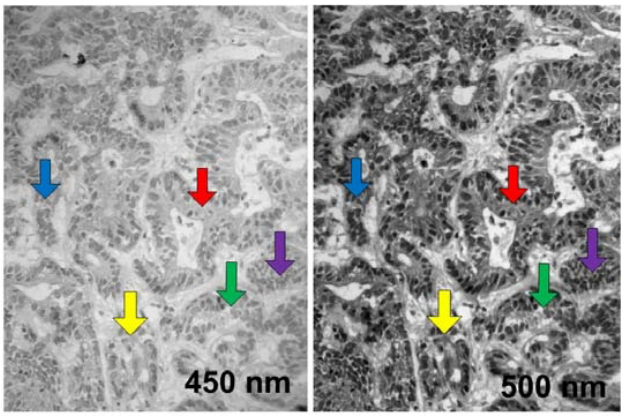
This imager can also be coupled with a cryostat for temperature controlled measurements (4K and up). Temperature dependence helps to understand the dynamics of carriers and the quenching of their radiative recombination. Measuring samples at 4 K also allows to observe fundamental optoelectronic properties that cannot be probed at room temperature (excitonic peaks, for example). Long-working distance objectives need to be included when a cryostation is included in the setup. The cryostation (cooling temperature/size/other features) and objectives are chosen in function of the client's research needs.



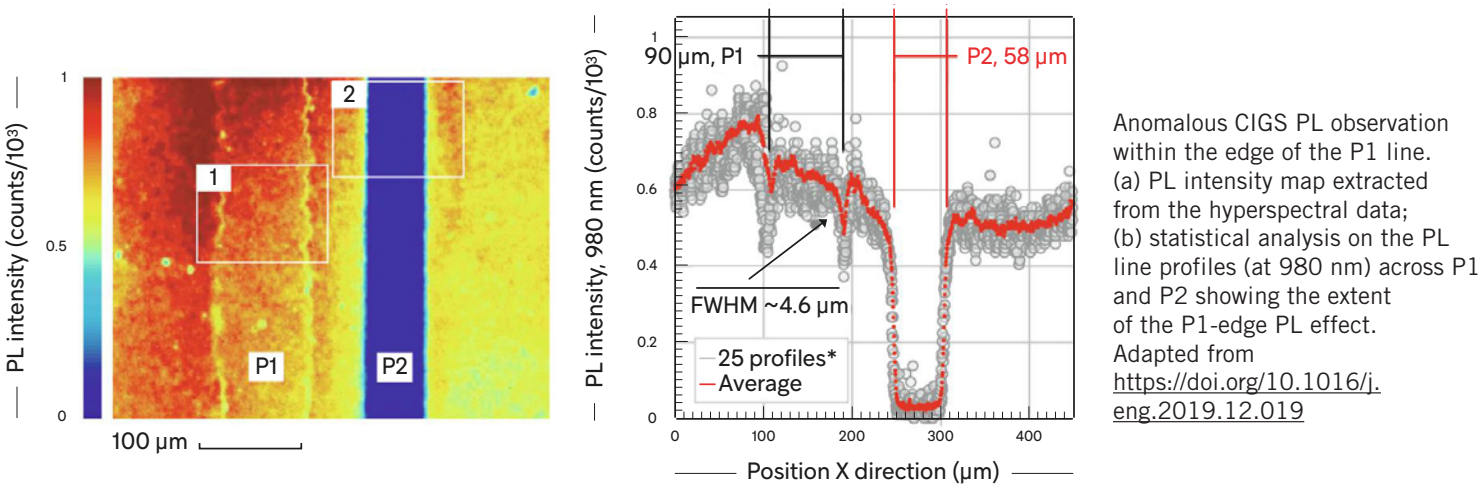
Hyperspectral microscopy of carbon nanotubes suspended with sodium deoxycholate. a) False-color image colored by nanotube chirality. b) A representative spectrum of a single nanotube of each of the 17 species detected in a 500 nm emission window.
Adapted from https://doi.org/10.1038/srep14167



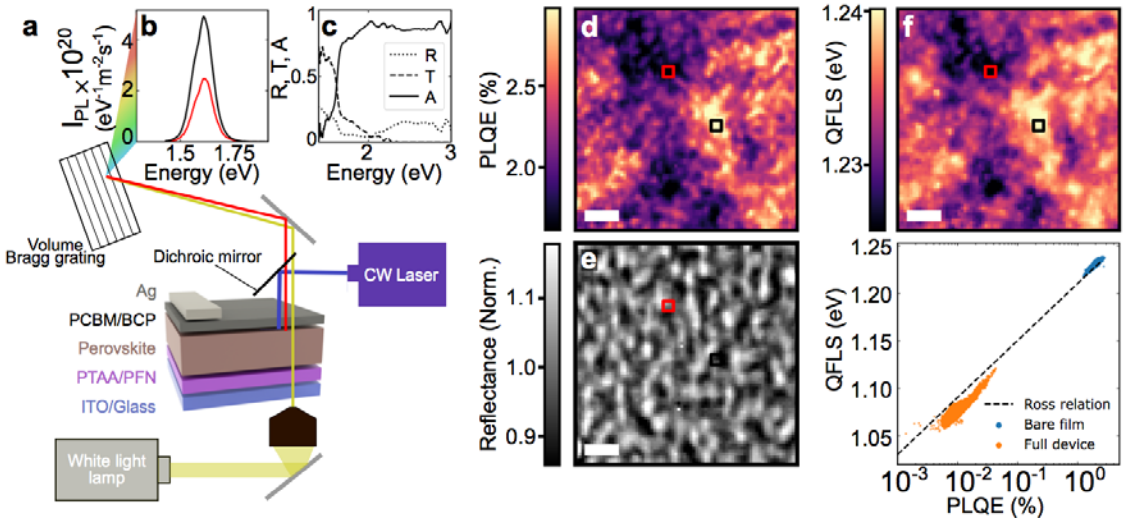
Mapping of the current transport efficiency fT calculated from EL hyperspectral images. fT mapping was performed at the microscale (a) and at the whole device level (b) for perovskite solar cells using C60 as the electron transport layer.
Adapted from https://doi.org/10.1039/C6EE00462H



Gray scale intensity images at specific wavelengths as part of a hyperspectral image cube of H&E stained specimen of human liver with metastasis of colon cancer. Corresponding cancer patterns are denoted in each image by an arrow of the same color.
Ref: https://doi.org/10.1117/12.2503907



Anomalous CIGS PL observation within the edge of the P1 line.
(a) PL intensity map extracted from the hyperspectral data;
(b) statistical analysis on the PL line profiles (at 980 nm) across P1 and P2 showing the extent of the P1-edge PL effect.
Adapted from https://doi.org/10.1016/j.eng.2019.12.019



Hyperspectral microscopy of perovskite solar cell device stacks.
d) Absolute PLQE, f) QFLS maps of a perovskite device stack (without the back metal contact). All scale bars represent 2 µm.
Adapted from: https://doi.org/10.1038/s41565-021-01019-7