



FREEDOM HR/C

Compact high resolution OEM spectrometers from Ibsen Photonics

Ibsen 
p h o t o n i c s



FREEDOM HR/C – high resolution spectroscopy with a small footprint

FREEDOM HR/C is a compact, high-resolution spectrometer platform from Ibsen Photonics, for measurements across a wavelength range from 178 nm in the deep UV to 1100 nm in the near-infrared region, depending on the model chosen. Packaged in a robust, compact, and athermal spectrometer design with a 0.11 numerical aperture, the spectrometer is optimized for use in a variety of applications, including LIBS, Raman spectroscopy, absorption spectroscopy, and laser-line characterization, among others. The spectrometers are available with electronics for standard USB or SPI communication, useful for most hardware integrations. Alternatively, they can be provided without electronics, allowing you full control over the electronics design and interface.

Key specifications of the FREEDOM HR/C platform

- Wavelength ranges: 178-409, 190-435, 360-830, or 475-1100 nm
- Can be used with either SMA fiber or free space coupling
- Resolution down to 0.3 nm (178-409), 0.15 nm (190-437), 0.3 nm (360-830) and 0.5 nm (475-1100)
- Numerical Aperture of 0.11 (f-number 4.5)
- Highly efficient transmission grating designs (Peak DE up to 85%)
- Four different detector types to choose from
- Cylindrical lens for improved focus of light on the detector plane
- Optional accompanying control electronics

Layout and design

Spectrometers in the FREEDOM HR/C platform are based on a Mirror-Grating-Mirror (MGM) design, utilizing collimating and focus mirrors, coated for minimum loss, in combination with Ibsen Photonics' in-house designed and manufactured transmission gratings, optimized for maximum broadband diffraction efficiency. The nature of the athermal design enables a very low temperature induced wavelength shift of $< 0.02 \text{ nm}/^\circ\text{C}$.

High resolution in a compact package

With options for four different wavelength ranges, four different detectors, two slit widths, and an additional cylindrical lens, depending on the model, the FREEDOM HR/C spectrometer platform offers a wide array of standard solutions. The FREEDOM HR-DUV (178-409 nm), can be supplied with valves for purging with an inert gas to enhance deep UV performance. All FREEDOM spectrometers accept either a standard SMA905 input fiber or free space coupling via a focus lens as the input.

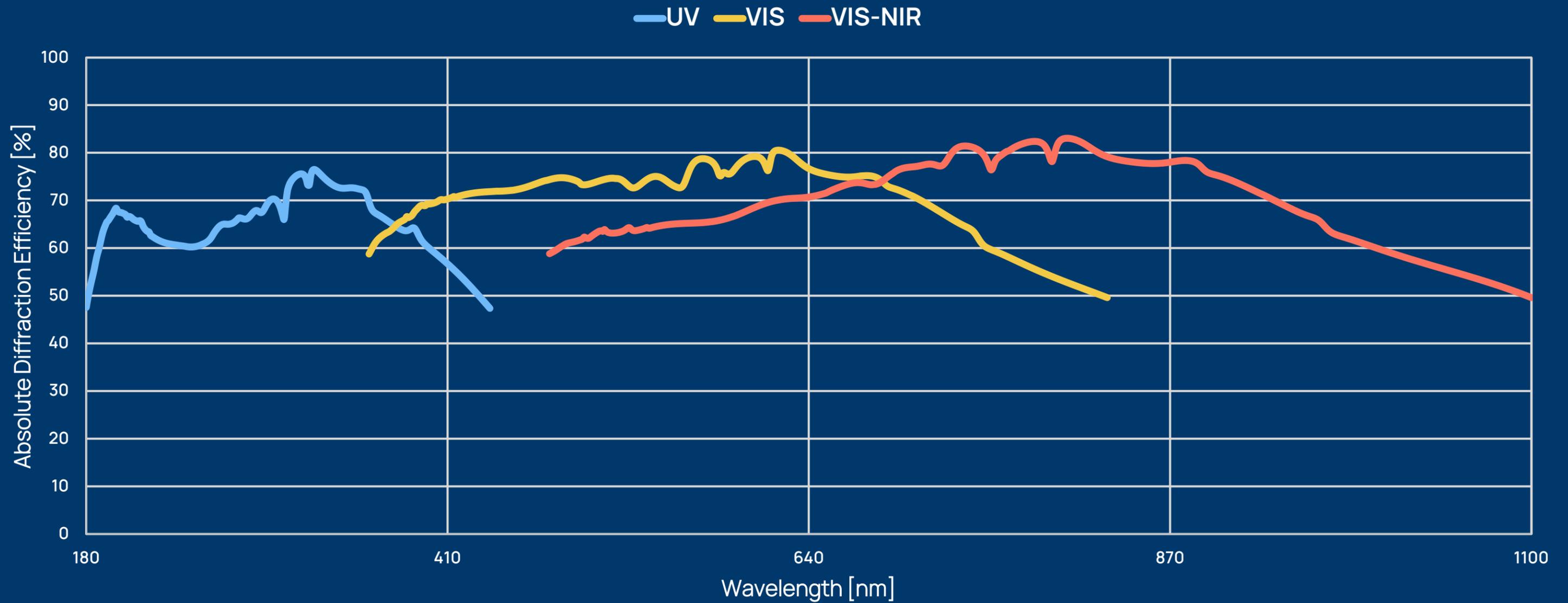
The four standard detector options allow for choices that prioritize cost-effectiveness, smaller pixels for optimal resolution, flat spectral response and low read-out noise, or high speed.

Ibsen can also build customized spectrometers to meet specific requirements. If the solution you are looking for is not available among our standard products, please reach out to our sales team to discuss the optimal solution for your spectrometer project.

Technical Specifications

		FREEDOM HR-DUV	FREEDOM HR/C-UV	FREEDOM HR/C-VIS	FREEDOM HR/C-VIS-NIR
Spectral range		178-409 nm	190-435 nm	360-830 nm	475-1100 nm
Wavelength accuracy		<0.24 nm	<0.24 nm	<0.24 nm	<0.24 nm
Resolution*	Slit width				
	5 µm (109 detector)		0.15 nm	0.30 nm	0.50 nm
	10 µm	0.30 nm	0.25 nm	0.45 nm	0.70 nm
	35 µm		0.55 nm	1.0 nm	1.3 nm
	70 µm		0.90 nm	1.6 nm	2.1 nm
Slit height		750 µm	750 µm	750 µm	750 µm
Numerical aperture		0.11	0.11	0.11	0.11
Stray light	Monochromatic input	<0.03 % (at +/- 10 x FWHM from peak)	<0.03 % (at +/- 10 x FWHM from peak)	<0.03 % (at +/- 10 x FWHM from peak)	<0.03 % (at +/- 10 x FWHM from peak)
Detector					
101 / 109	CMOS		Hamamatsu S11639N-01 / Hamamatsu S13496 2048 / 4096 x 1 pixels 14 / 7 x 200 µm pixel size SNR 380:1 Dynamic range 2150:1	Hamamatsu S11639N-01 / Hamamatsu S13496 2048 / 4096 x 1 pixels 14 / 7 x 200 µm pixel size SNR 380:1 Dynamic range 2150:1	Hamamatsu S11639N-01 / Hamamatsu S13496 2048 / 4096 x 1 pixels 14 / 7 x 200 µm pixel size SNR 380:1 Dynamic range 2150:1
315	BT-CCD		Hamamatsu S10420-1106 2048 x 64 pixels 14 x 14 µm pixel size	Hamamatsu S10420-1106 2048 x 64 pixels 14 x 14 µm pixel size	Hamamatsu S10420-1106 2048 x 64 pixels 14 x 14 µm pixel size
380	BT-CCD	Hamamatsu S11156-2048-02 2048 x 1 pixels 14 x 1000 µm pixel size	Hamamatsu S11156-2048-02 2048 x 1 pixels 14 x 1000 µm pixel size	Hamamatsu S11156-2048-02 2048 x 1 pixels 14 x 1000 µm pixel size	Hamamatsu S11156-2048-02 2048 x 1 pixels 14 x 1000 µm pixel size
Cylindrical lens		No	Optional	Optional	Optional
Interface		SPI or USB 2.0	SPI or USB 2.0	SPI or USB 2.0	SPI or USB 2.0
Temperature induced drift		<0.02 nm/°C	<0.02 nm/°C	<0.02 nm/°C	<0.02 nm/°C
Operating temperature range	Non-condensing	0 to +50 °C	0 to +50 °C	0 to +50 °C	0 to +50 °C
Storage temperature range	Non-condensing	-40 to +65 °C	-40 to +65 °C	-40 to +65 °C	-40 to +65 °C
Dimensions	Excluding electronics	61 mm x 65 mm x 19 mm	61 mm x 65 mm x 19 mm	61 mm x 65 mm x 19 mm	61 mm x 65 mm x 19 mm
Weight	Excluding electronics	119 grams	119 grams	119 grams	119 grams

*Typical values when configured with a cylindrical lens. FREEDOM HR-DUV typical resolution value is without a cylindrical lens.



Transmission Gratings

The FREEDOM HR/C spectrometer platform utilizes three different grating designs as standard for the UV, VIS, or VIS-NIR regions. All gratings provide high symmetrical diffraction efficiency, as shown by the absolute diffraction efficiency graph displayed above. A noteworthy specification is that all listed diffraction efficiencies are absolute values, accounting for any absorbance by the material or unwanted reflections from the grating's surface.

Additionally, the grating itself ensures great wavelength stability due to the inherent self-corrective nature of transmission gratings, compensating for any misalignment, shock, or vibrations that the spectrometer may experience. The designs also provide very low polarization dependence as an added benefit.

Every grating used in the FREEDOM HR/C spectrometer platform is a master grating, fabricated at Ibsen Photonics' clean-room facility in Denmark.

Spectrometer Input Coupling

Ibsen Photonics' FREEDOM HR/C spectrometer line-up, is equipped with a standard SMA905 fiber adapter and numerical aperture 0.11 input. This allows for the use of either a standard fiber coupling via SMA or free-space coupling using focusing optics.

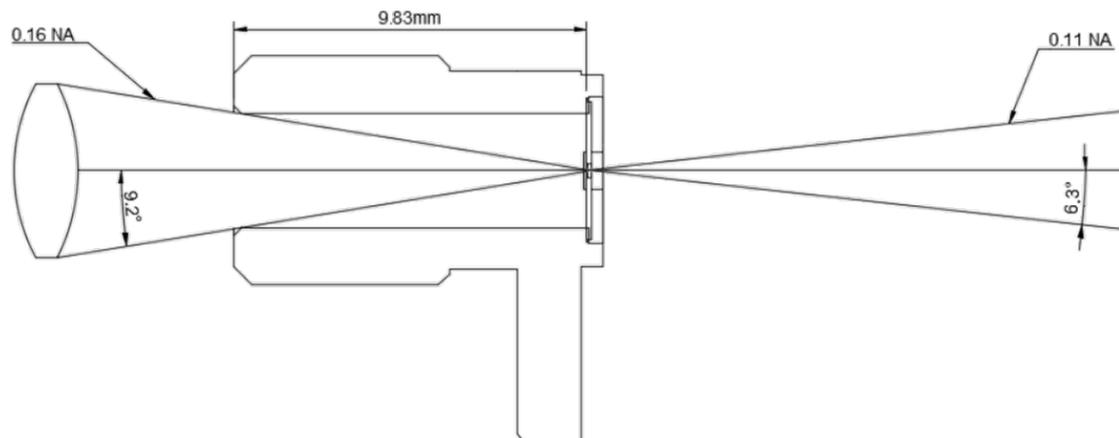
Depending on the model, the spectrometer can be equipped with a cylindrical lens to increase the optical throughput. The FREEDOM C spectrometer model has the cylindrical lens included, whereas the FREEDOM HR does not. The cylindrical lens can for some configurations provide throughput increases of up to a factor of 4 at certain wavelengths. The added cylindrical lens does however increase stray light and decrease resolution performance of the spectrometer slightly, as shown in the table below.

Slit width [μm]		FREEDOM C-UV	FREEDOM C-VIS	FREEDOM C-VIS-NIR
10	Typical	0.25 nm	0.45 nm	0.7 nm
		FREEDOM HR-DUV	FREEDOM HR-UV	FREEDOM HR-VIS-NIR
10	Typical	0.3 nm	0.2 nm	0.4 nm

To ensure maximization of the throughput of the spectrometer, it is required to fully illuminate the full slit and numerical aperture homogeneously. Over illumination of the spectrometer's 0.11 numerical aperture, such as using a 0.22 numerical aperture fiber, is perfectly valid and handled by internal apertures as part of the spectrometer's optical design.

Free Space Coupling

The illustration below displays a cross-section of the input SMA adapter used in a free space coupling setup, with a lens illuminating the slit. The physical dimensions of the adapter can at maximum accept a numerical aperture of 0.16, while internal apertures will limit the numerical aperture to 0.11. It is important to use a lens or other focusing optics to ensure proper even illumination of the spectrometer's numerical aperture.

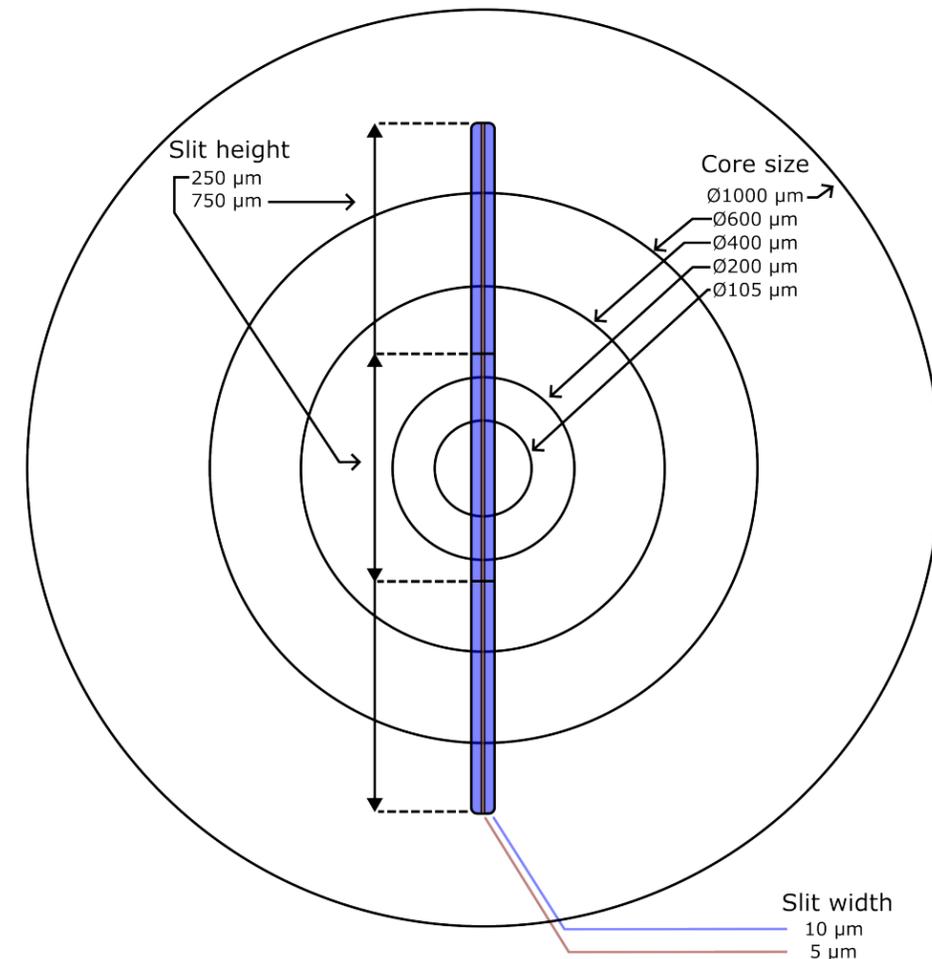


Optical Fiber Coupling

Optical fiber coupling is often used for its convenience concerning lack of alignment and ease of setup process.

For best signal strength, the diameter of the optical fiber core should be chosen such that the entire slit is illuminated evenly. The standard slit height of the FREEDOM HR/C spectrometer is 750 μm , and the optical fiber core size should be larger than this to ensure the best performance. Alternatively, a stacked fiber array can be used to likewise fill the entire height of the slit.

The common recommend size available would be 600 μm or 1000 μm diameter cores. In the below illustration, the figure on the left side shows the different optical fiber sizes. The figure on the right side shows the corresponding standard slit sizes offered for the FREEDOM HR/C spectrometer platform.



Detectors

The FREEDOM HR/C spectrometer platform supports four different types of detectors as standard, in order to cater to whichever requirements a particular application might have. These four different detectors are referred to via the last three numbers on the spectrometer product name, namely 101, 109, 315 or 380.

101/109 - Hamamatsu S11639N-01/ Hamamatsu S13496

Hamamatsu S11639N-01 and S13496 detectors provide well-rounded performance in a cost-effective package, making them a popular choice.

The S11639N-01 has a 2048 x 1 pixels layout, with 14 x 200 μm tall pixels to allow for better coupling with the spectrometer slit's dimensions. The S13496 used twice as many pixels, 4096, at half the width, 7 x 200 μm . The response curve, noise and general performance is virtually identical between the two detectors, with pixels count and size being the only difference. The larger number of pixels of the S13496 is ideally used in spectrometers, such as FCU, FCV, and FCT when using a slit width of 5 μm , that has a resolution high enough to benefit from the increased pixels count.

The quantum efficiency remains high, even down into the deep UV spectral region, while a high conversion factor and shallow well depth makes this particular detector especially sensitive. Combined with fast exposure times of down to 10.8 μs , robust nature, and simple CMOS readout logic, it makes it the detector of choice for most applications.

315 - Hamamatsu S10420-1106

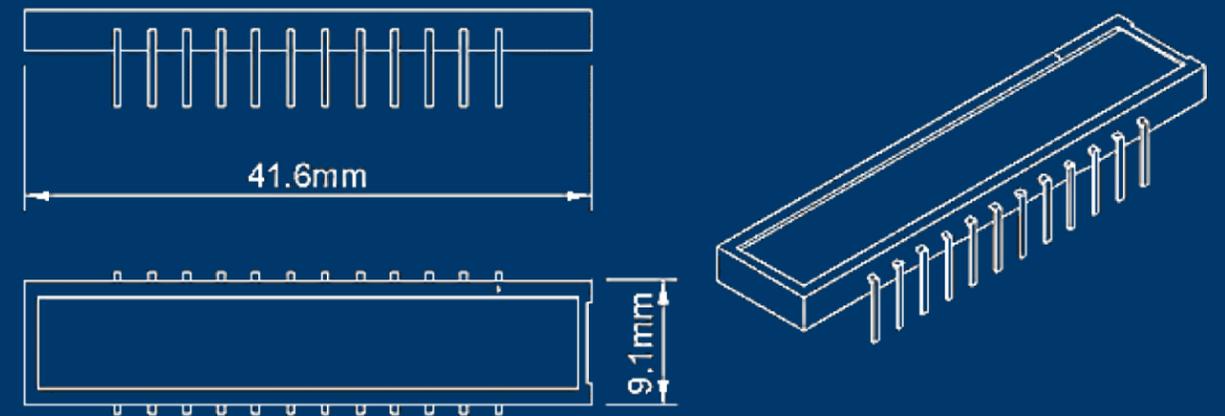
This Hamamatsu S10420-1106 detector is optimized towards low read-out noise, making it the detector of choice when working with applications where either signal strength is low or the signal-to-noise is the primary concern. The back-thinned CCD provides an excellent and smooth quantum efficiency throughout its entire spectral range while being optimized to exhibit a significantly reduced etalon effect compared to most back-thinned CCDs.

The detector has a 2048 x 64 pixels array, with square 14 x 14 μm pixels, creating an active array size of 28.772 x 0.896 mm.

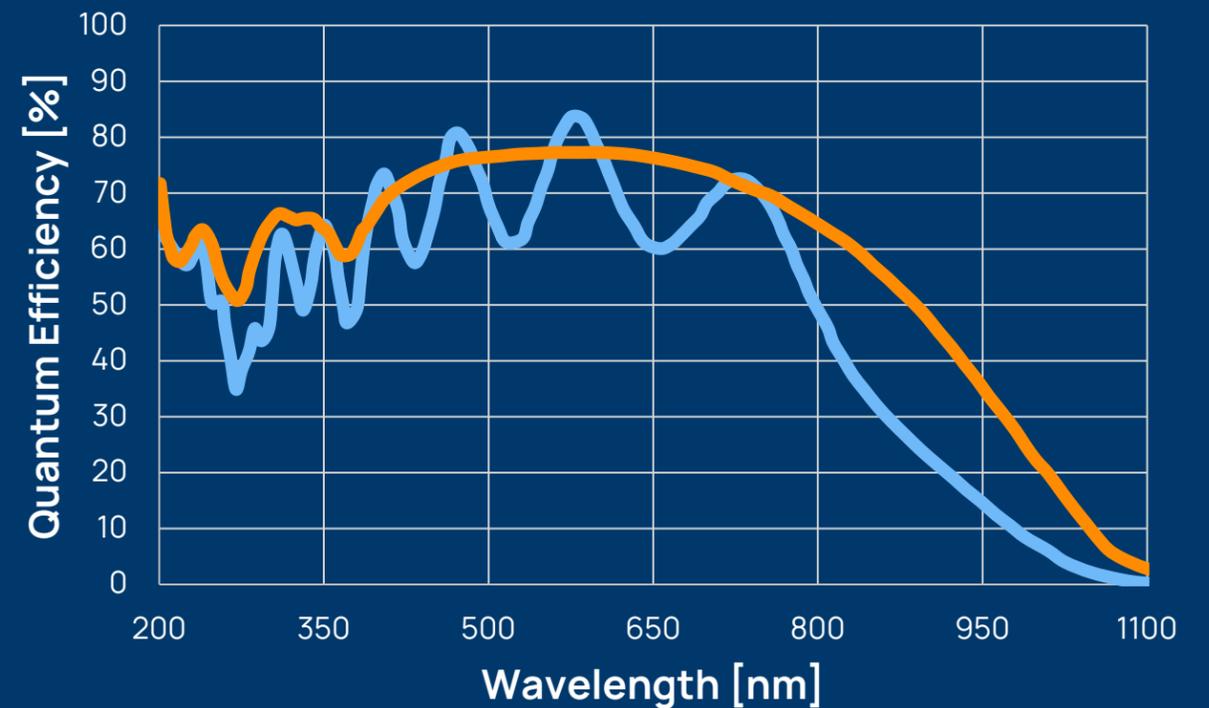
380 - Hamamatsu S11156-2048-02

The Hamamatsu S11156-2048-02 is the fastest detector available as a standard detector for the FREEDOM spectrometer platform. The back-thinned CCD, has a 1D array of 2048 x 1 pixels with very tall 14 x 1000 μm pixels, allowing for more light to be captured per pixel. The detector electronics layout is comprised of a double side horizontal shift register, that allows for the tall pixels to be read impressively fast, with exposure times down to 2 μs possible. This makes the S11156-2048-02 ideal for applications that require short and precise time-gating of the collected signals.

The exhibited quantum efficiency is identical to that of S10420-1106, with a smooth high level throughout the bandwidth and noticeably better performance at longer wavelengths compared to S11639N-01.



Detector response curve



— S11639-01/S13496 — S10420-1106/S11156-2048-02

Electronics

Every FREEDOM HR/C spectrometer can be supplied with one of four different electronic configurations depending on the desired level of integration.

The spectrometer can be purchased without any accompanying electronics, giving direct access to the pins on the chosen detector. Alternatively, Ibsen Photonics can supply its Digital Image Sensor Boards (**DISB**), designed to operate the detector of choice via hardware commands over a Serial Peripheral Interface (**SPI**). The DISB electronics can also be supplied with a **DISB to USB Bridge** board, which converts the SPI connection to a standard USB 2.0 for convenient connection to a PC.

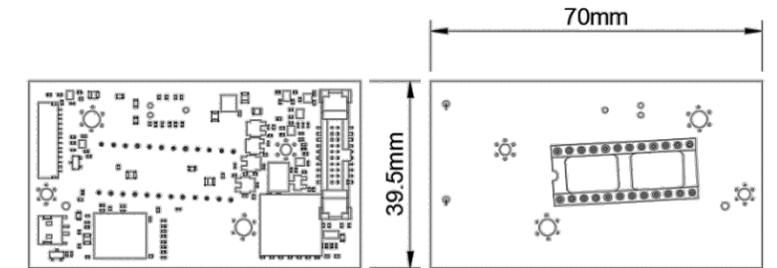
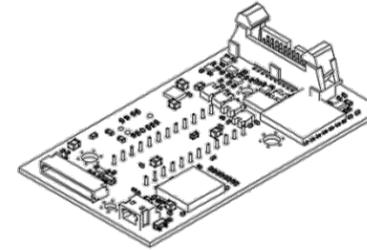
DISB electronics

Four different DISB board options are available to accommodate the series of detectors offered as standard for the FREEDOM HR/C spectrometer platform. For S11639N-01 (101), DISB-101T can be supplied. Detector S10420-1106 (315) utilizes DISB-315 and finally, S11156-2048-02 (380) should be used with DISB-380.

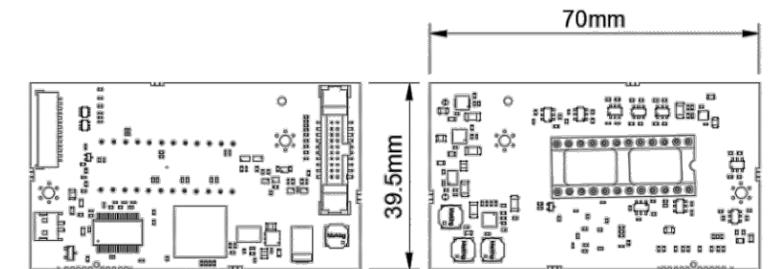
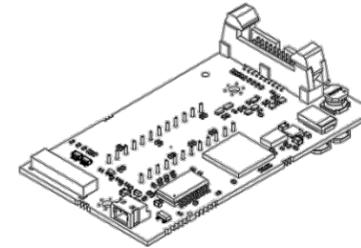
All DISB platforms utilize the same SPI communication protocol, making it straightforward to move from one platform to another without having to change the hardware interface or code.

	DISB-101T	DISB-315	DISB-380
Read-out speed	600 Hz 2048 pixels	300 Hz 4096 pixels	100 Hz (2048 pixels)
A/D bit depth	16-bit	16-bit	16-bit
Communication interface	SPI	SPI	SPI
Software trigger	Yes	Yes	Yes
Ext. Hardware trigger	Yes	Yes	Yes
Min. trigger delay	1.2 μ s	4.987 ms	360 ns
Trigger jitter	10 ns	20 ns	10 ns
Time increments	200 ns	2 μ s	200 ns
Exposure time	10.8 μ s – 859 s	4.987 ms – 8589 s	2 μ s – 859 s
On-Board calibration data	Yes	Yes	Yes
On-Board averaging	Yes	Yes	No
GPIO pinout	Yes	Yes	No
Programmable lamp control	Yes	Yes	No
Region of interest	Yes	Yes	No
Temperature sensor	Yes	Yes	Yes

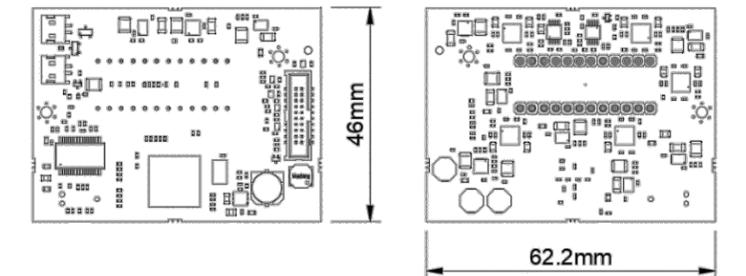
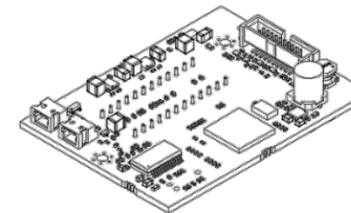
DISB - 101T



DISB - 315



DISB - 380



Software interfacing

The **DISB-to-USB bridge** board developed by Ibsen Photonics is an additional board that can be added to any spectrometer equipped with DISB electronics, to convert the DISB's SPI connection to a standard USB 2.0 connector, for convenient use via a standard PC.

The DISB-to-USB board is based around the **FTDI FT4222H** chipset, with drivers available for Windows, Linux, or Mac. The entire USB protocol is handled in the chip with no requirement for specific complicated USB firmware programming.

Ibsen Photonics supplies its LabVIEW-developed **Ibsen DISB-USB Evaluation software** as standard with the bridge board. This allows for the operation of the spectrometer and its features in a straightforward fashion using the Windows Operation system.

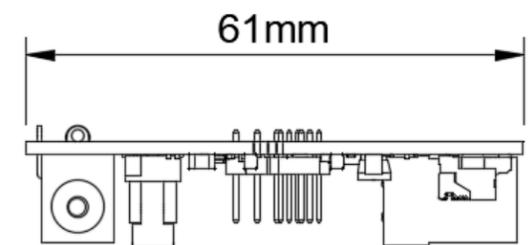
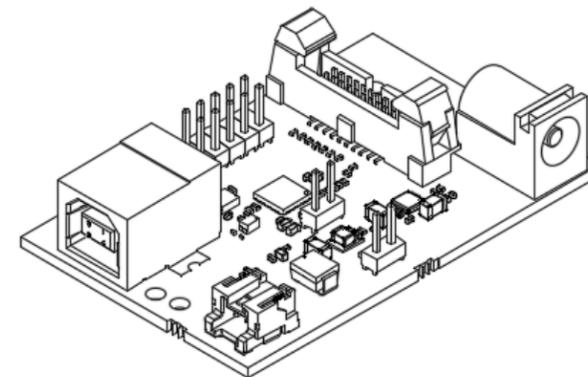
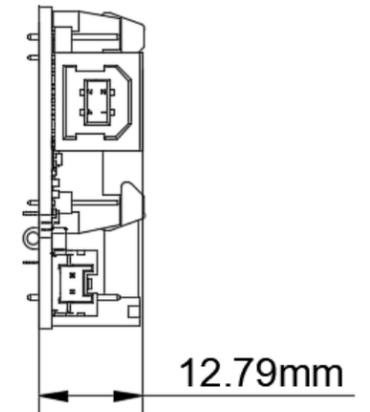
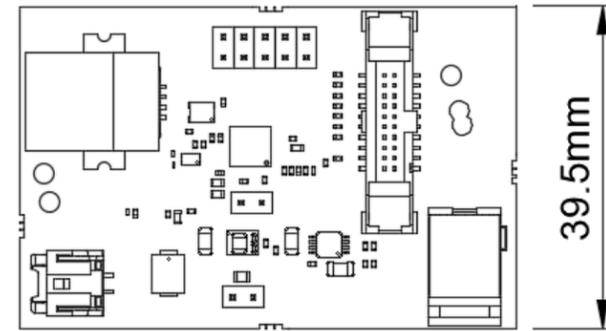
Additionally, an **SDK** is available for the Bridge board, allowing for simple, intuitive, and fast deployment of instruction sets and code via C/C++, C#, LabVIEW, Python, or MATLAB, via DLL and accompanying header files. The proprietary Ibsen command set allows for initialization, spectrum capturing, and closing of the spectrometer connection, with as little as three commands, as shown below.

`IBSEN_InitSpectrometer`

`IBSEN_produceSpectra`

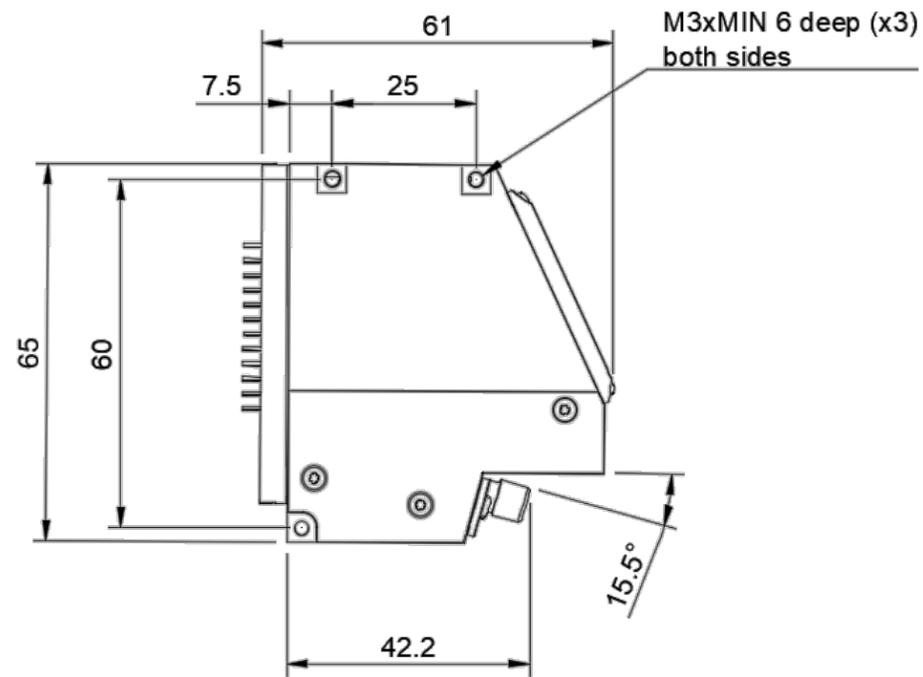
`IBSEN_closeDevice`

It is also possible to interface with the FT4222H library files directly. Code samples using C/C++, C#, LabVIEW, and Python are available, if you need it to develop your own implementation from the ground up.

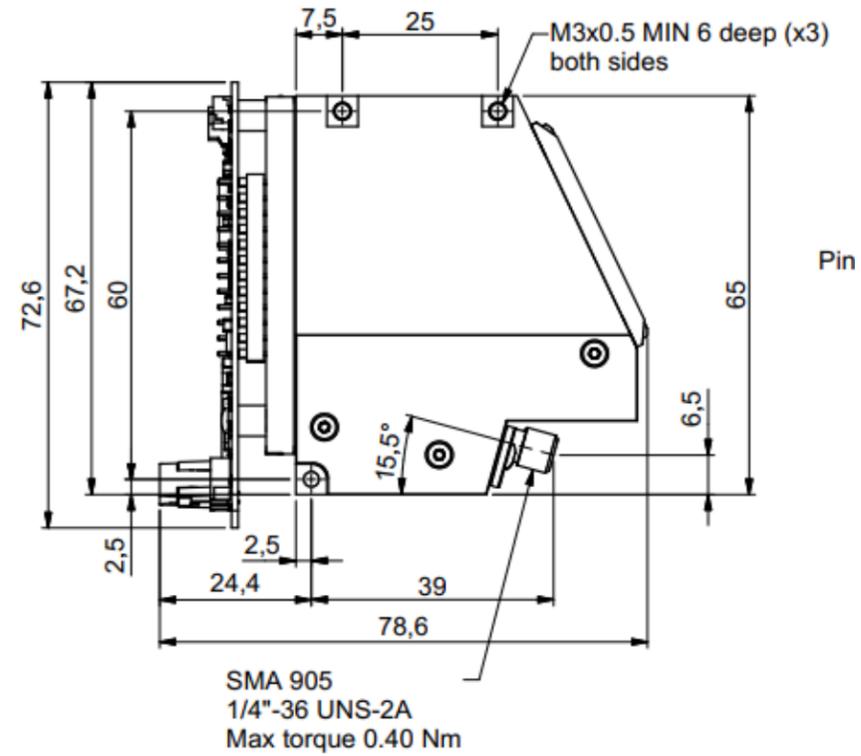


Mechanical Drawings

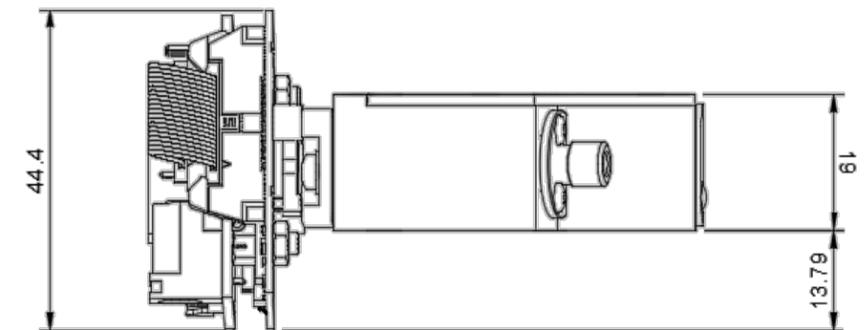
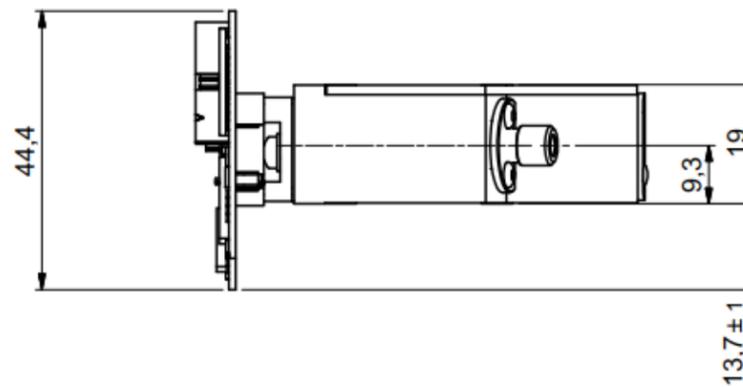
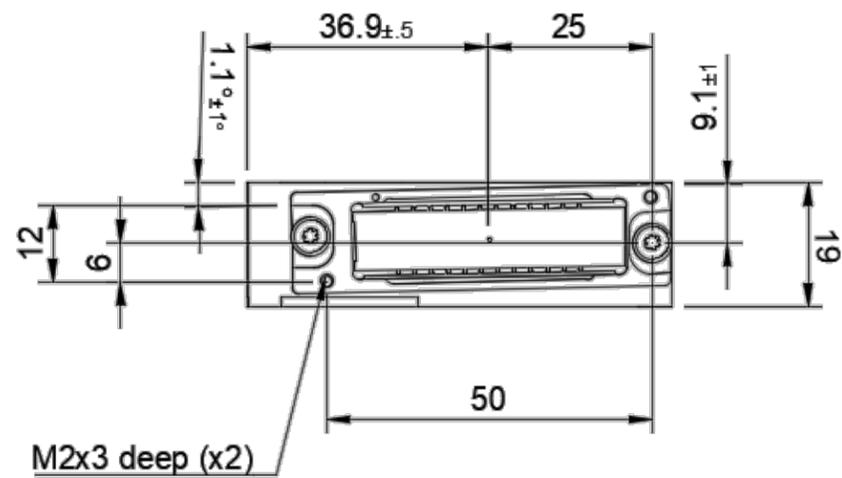
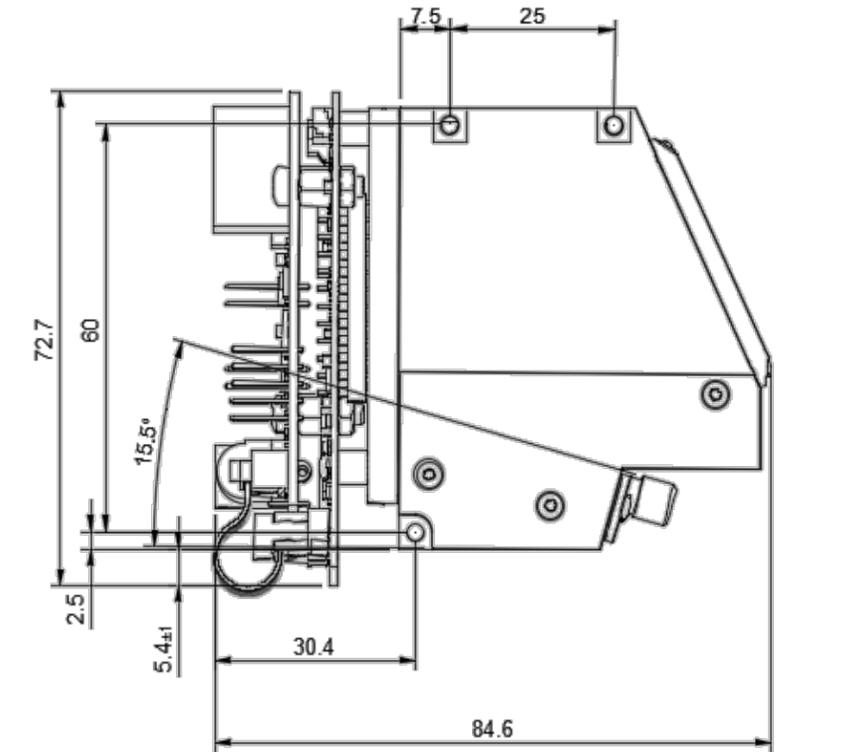
FREEDOM HR/C-UV, HR/C-VIS, HR/C-VIS-NIR
Excluding DISB



FREEDOM HR/C-UV, HR/C-VIS, HR/C-VIS-NIR
Including DISB-101T

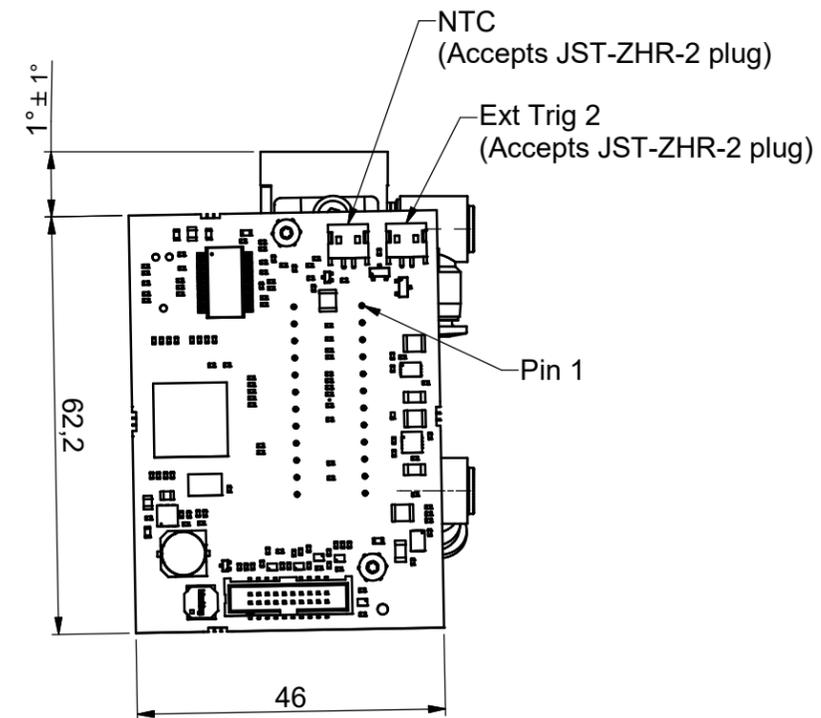
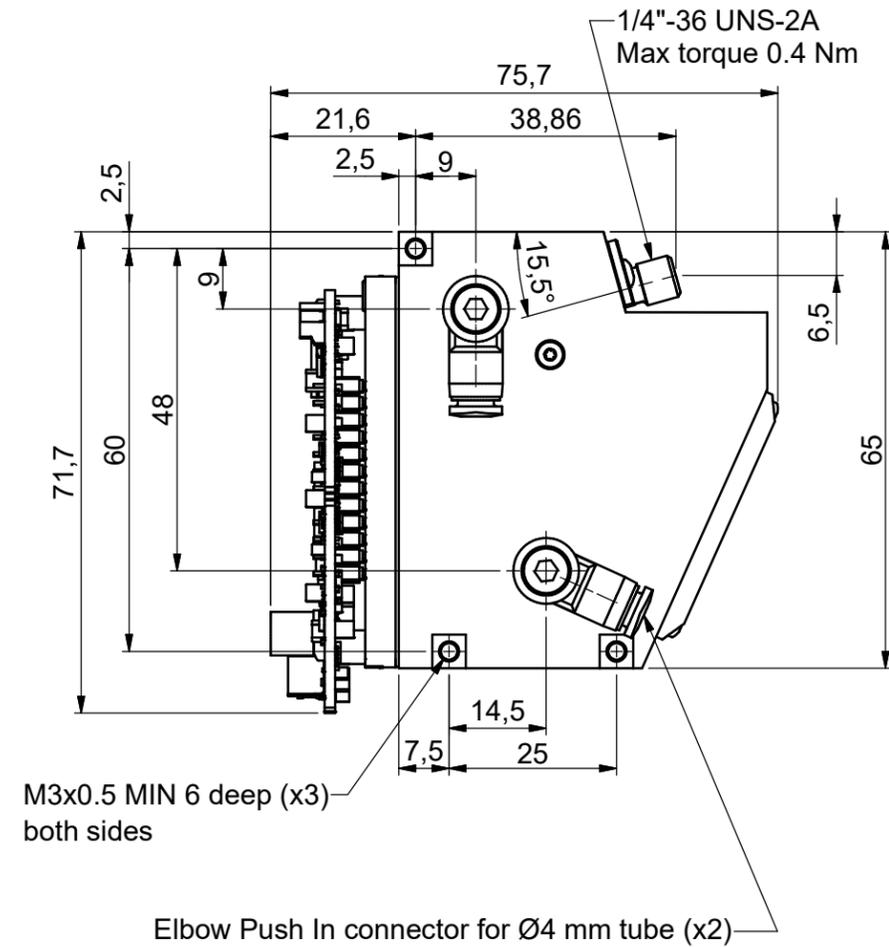
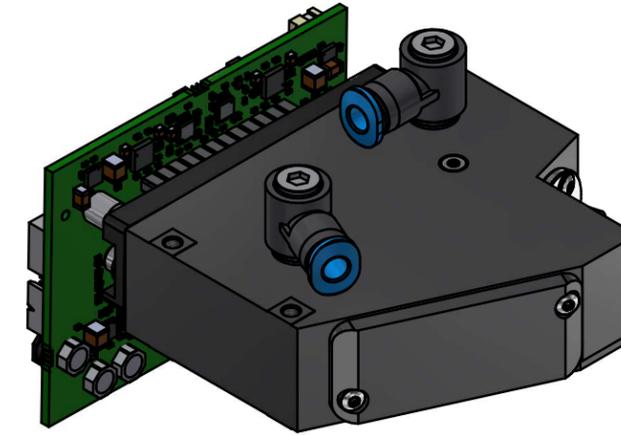
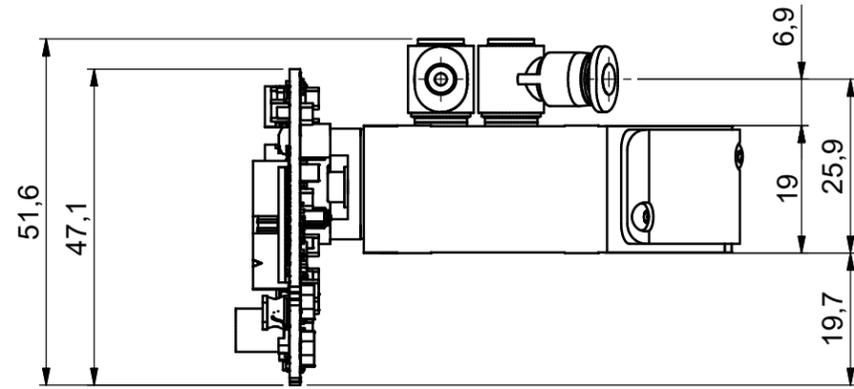


FREEDOM HR/C-UV, HR/C-VIS, HR/C-VIS-NIR
Including DISB-101T and DISB-USB



Mechanical Drawings

FREEDOM HR-DUV including DISB-380



About Ibsen Photonics

Ibsen was founded in 1991 by Per Ibsen under the name of Ibsen Micro Structures A/S. Today 88% of Ibsen Photonics' share is owned by Foss A/S, a world leader in analytical solutions for the Food and Agricultural industries. Ibsen management and employees hold the remaining 12 % of the shares.

The Ibsen spirit combines the dynamic, entrepreneurial culture of a medium size company with a disciplined, operational mentality of a large corporation. With an average employee tenure of more than 10 years, Ibsen makes for a very effective organization that builds on more than 30 years of experience as a company.

Ibsen employs more than 90 people at our R&D and manufacturing facility in Denmark and has achieved a turnover of more than 180 MDKK in 2022.

Working with Ibsen Photonics

The core expertise of Ibsen Photonics lies in the opto-mechanical design, grating technology and metrology. We master the cycle from optics, grating simulation and design, through optical and semiconductor production technologies, to high volume assembly, packaging and testing. Over the years we have developed many new designs, technologies and processes - many patented.

Our customers are large to medium-sized manufacturers of advanced optical devices and instruments, into which our products are integrated. With a highly organized production process, we are able to help customers obtain smooth instrument production, low unit-to-unit variation, high level of right first time, no field returns, and a low level of rework.

Our grating production facilities are world-class, including class 10 cleanroom facilities that we designed and built in 2000/2001, in which all environmental parameters are under continuous surveillance.

Our spectrometers are produced under strict quality control in our assembly facility in Denmark. We have been granted ISO 9001, ISO 13485, ISO 14001 and ISO 45001. This confirms Ibsen's' consistent capability to produce high quality products that meet market standards and all regulatory requirements.

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