ZEISS Spectrometer Modules
Compendium of products, electronic components and software solutions

Information on interactivity on this page
Explanatory product video on youtube.com
Page navigation
Previous page | Next page
Introduction

Wavelength ranges

MMS Family
CGS Family
MCS FLEX Family
PGS Family

Software

Areas of application

Definitions and explanations

The moment you discover that your expectations have been exceeded.
This is the moment we work for.
The following spectrometer module families have been developed at ZEISS:

- **MMS** Monolithic Miniature Spectrometer
- **CGS** Compact Grating Spectrometer
- **MCS FLEX** Multi-Channel Spectrometer
- **PGS** Plane Grating Spectrometer

At ZEISS, the complete solution is consistently aligned with the customer’s application. Not only is the corresponding module family available for every measuring job, but the electronics, interface and processing software are always optimally configured. Furthermore, this approach ensures that the customer enjoys a consistently high level of performance and quality for all system components.

Determine the measuring method
Criteria for the spectrometer system

**ZEISS**

- Spectrometer modules
- Electronic components for spectrometer modules
- Interface module
- Driver / software development

**Customer**

- Area of application
- Specific system solution
The extremely compact design is significant for the spectrometers in the MMS family. Small sizes are available because high repeatability rather than a high resolving power is necessary for many applications.

### Optical components in the MMS family

- **Imaging grating**
- **A fiber cross-section converter as an optical entrance**
- **Diode array as an opto-electronic output port**

These elements are arranged around and attached to a central body. Depending on the version, the central body is designed as either a glass body or a titanium hollow body. The two components important for the interfaces – the cross-section converter and the detector – are retained.

#### Central body

On the MMS 1, the central body is a glass body resembling a lens. The imaging grating is replicated directly on this glass body so that it cannot be moved and is optimally protected against dust and gases. An optically denser medium also enables the use of smaller gratings because of the larger aperture, reducing aberrations.

On the UV-sensitive modules, the large glass body has been replaced by a hollow body for reasons of transmission. The grating and detector are affixed to this hollow body. The overall stability is not impaired by the tube design; the temperature-dependent drift of the wavelength has even been reduced.

#### Gratings

The gratings for the MMS family are holographically blazed flat-field gratings for optimized effectiveness. At ZEISS, these gratings are manufactured using the threshold value method and achieve significantly higher effectiveness (for unpolarized light) than sinusoidal gratings. In addition to the dispersive function, the grating must image the entrance slit on the detector array. Via the groove density and curved grooves, comma errors are corrected and the focal curve is evened out (flat field) so that it is optimally adjusted for the flat detector structure. Spectra of over 6 mm long are achieved – even with the small focal length available. Thus the same grating design can be used for the VIS- and the UV-VIS versions. The original grating has an efficiency maximum of approx. 220 nm. The efficiency curve is offset by the factor of the refractive index on the VIS module due to the greater optical thickness.

#### Cross-section converter

A fiber bundle cross-section converter further optimizes the light intensity. The linear arrangement of individual fibers creates the entrance slit (slot height determined by the number of individual fibers; the slot width determined by the core diameter). This is adjusted to the pixel size of the diode array used and to the dispersion properties of the flat-field grating, enabling light intensities to reach theoretical limits. The cross-section converter is an integral part of the spectrometer design and therefore cannot simply be changed. There is, however, the possibility of changing the length of the fiber and the design of the entrance. It must also be noted that quartz fibers, such as those used on older MMS UV modules (VIS), create so-called solarization centers when irradiated with deep UV light under 220 nm. This means the transmission of the fibers is reduced when irradiated with high-energy light. This effect occurs more strongly and more often the shorter the wavelength (higher photon energy), the shorter the intensity and the longer the brightness time. The transmission can also be limited above 220 nm up to 250 nm. This solarization effect can only be partially reversed but can be corrected via frequent reference measurements. For measurements below 225 nm, it is possible to equip the MMS module with solarization-stable fibers. Using a WG 225 filter with 3 mm thickness is an absolute must with standard modules.

### Detector

MMS

In the MMS family, the silicon diode array S3904-256Q from Hamamatsu is integrated. Only the MMS 1 NIR enhanced uses the Hamamatsu type S8381-256Q. By using a shorter special housing, the split-off angle is very small, enabling an efficient grating design. This and the 6 mm spectrum length must be considered when switching to another detector. The diode array is coated directly with a dielectric edge filter to suppress the second order.

The following modules are available:

<table>
<thead>
<tr>
<th>Module</th>
<th>Spectral range (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMS 1</td>
<td>310 – 1100</td>
</tr>
<tr>
<td>MMS UV-VIS</td>
<td>195 – 780 or 250 – 780</td>
</tr>
<tr>
<td>MMS UV</td>
<td>195 – 810</td>
</tr>
</tbody>
</table>

---

**Visit the ZEISS Spectrometer Modules Compendium page for more details and specifications.**

---

**Contact Information**

Email: www.zeiss.com
**MMS 1**

**Technical Data**

**Optical entrance**
- Input: round
- Output: linear

**Grating**
- Flat field, 366 l/mm (in the center)

**Diode array**
- Manufacturer: Hamamatsu
- Type: S 3904-256Q in special housing (S 5713), S 3904-256Q (for the MMS 1 NIR enhanced)
- Number of pixels: 256

**Spectral range**
- UV-VIS I: 190 nm – 720 nm
- UV-VIS II: 250 nm – 780 nm

**Wavelength accuracy**
- 0.5 nm

**Temperature drift**
- ≤ 0.006 nm / K

**Spectral pixel distance**
- \( \Delta \lambda_{\text{pixel}} \approx 2.2 \text{ nm} \)

**Resolution**
- \( \Delta \lambda_{\text{FWHM}} \approx 7 \text{ nm} \)

**Sensitivity**
- \( \approx 10^{3} \text{ Vs} / \text{ J} \)

**Stray light**
- ≤ 0.3 % with deuterium lamp
- Transmission at 365 nm with NaNO₂ solution (50 g/l)

**Dimensions**
- With housing: 67 x 60 x 40 mm³
- Standard: 240 mm, available up to 1 m

---

**MMS UV-VIS I / UV-VIS II**

**Technical Data**

**Order number**
- 224000-9001-000
- 000000-1410-176
- 000000-1090-197

**Name**
- MMS UV-VIS I
- MMS UV-VIS II

**Wavelength range**
- UV-VIS I: 190 nm – 720 nm
- UV-VIS II: 250 nm – 780 nm

**Description**
- PDA with 256 pixels, 240 mm external fiber length
- PDA with 256 pixels, 240 mm external fiber length
- PDA with 256 pixels, 240 mm external fiber length

---

**Order number**
- 224000-9001-000
- 000000-1410-176
- 000000-1090-197

**Name**
- MMS UV-VIS I
- MMS UV-VIS II

**Wavelength range**
- NIR enhanced: 310 nm – 1100 nm

**Description**
- PDA with 256 pixels, 240 mm external fiber length
- PDA with 256 pixels, 240 mm external fiber length
- PDA with 256 pixels, 240 mm external fiber length

---

**Order number**
- 224000-9001-000
- 000000-1410-176
- 000000-1090-197

**Name**
- MMS 1 NIR enh.

**Wavelength range**
- 310 nm – 1100 nm

**Description**
- S8381 PDA with 256 pixels, 240 mm external fiber length
- S8381 PDA with 256 pixels, 240 mm external fiber length
- PDA with 256 pixels, 240 mm external fiber length

---

**Order number**
- 224001-9001-000
- 224001-9011-000
- 000000-1233-038

**Name**
- MMS 1 UV-VIS enh.
- MMS 1 UV-VIS enh.
- MMS 1 NIR enh.

**Wavelength range**
- 310 – 1100 nm
- 310 – 1100 nm
- 310 – 1100 nm

**Description**
- PDA with 256 pixels, 240 mm external fiber length
- PDA with 256 pixels, 240 mm external fiber length
- S8381 PDA with 256 pixels, 240 mm external fiber length

---

**Order number**
- 224000-9001-000
- 000000-1410-176
- 000000-1090-197

**Name**
- MMS UV-VIS I
- MMS UV-VIS II

**Wavelength range**
- 190 nm – 720 nm
- 250 nm – 785 nm

**Description**
- PDA with 256 pixels, 240 mm external fiber length
- PDA with 256 pixels, 240 mm external fiber length
- PDA with 256 pixels, 240 mm external fiber length

---

**Order number**
- 224000-9001-000
- 000000-1410-176
- 000000-1090-197

**Name**
- MMS 1 NIR enh.

**Wavelength range**
- 310 nm – 1100 nm

**Description**
- S8381 PDA with 256 pixels, 240 mm external fiber length
- PDA with 256 pixels, 240 mm external fiber length
- PDA with 256 pixels, 240 mm external fiber length
MMS UV
Technical Data

<table>
<thead>
<tr>
<th>Optical entrance</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Input: round</td>
<td>Fiber bundle consists of approx. 15 quartz glass fibers with a 70 µm core diameter, designed as a cross-section converter</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diameter: 0.4 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>for λ = 0.22 (homogeneous illumination of the acceptance angle)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mounted in an SMA connector</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>70 µm x 1250 µm (entrance slit)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output: linear</td>
<td>Grating</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flat-field, 1084 l/mm (in the center), blazed for approx. 220 nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diode array</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Manufacturer: Hamamatsu</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Type: S 3904-256N in special housing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number of pixels: 256</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectral range</td>
<td>Spec 195 nm – 390 nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Specifications for the 220 nm – 390 nm range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wavelength accuracy</td>
<td>0.2 nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature drift</td>
<td>≤ 0.005 nm/K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectral pixel distance</td>
<td>Δλpixel = 0.8 nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resolution</td>
<td>ΔλFWHM = 3 nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity</td>
<td>≈ 10² V/µJ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stray light</td>
<td>≤ 0.3 % deuterium lamp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimensions</td>
<td>70 x 60 x 40 mm²</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Standard: 240 mm, available up to 1 m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Order number | Name | Wavelength range | Description |
-------------|------|------------------|-------------|
224002-9020-000 | MMS UV | 195 – 390 nm | PDA with 256 pixels, 240 mm external fiber length |
00000-1392-178 | MMS UV | 195 – 390 nm | PDA with 256 pixels, 240 mm external fiber length, low solarization |
USB and ethernet electronics are available for the standard PC interfaces. The USB based electronics are powered externally through an additional power supply (self-powered USB device). The PC is connected via a standard USB cable. We recommend a hi-speed USB port (USB 2.0 or 3.0). All electronic circuit boards are designed to be integrated into a customer’s housing. The user must provide external ±12 VDC and +5 VDC supply voltages.
The CGS UV-NIR spectrometers are a class unto themselves. They are extremely compact and robust and are available with a PDA or CCD detector upon request. These spectrometers enable users to measure with maximum quality and optimal spectral efficiency.

**Optical components in the CGS family**

- Imaging grating
- Optical entrance
- CCD or PDA as an opto-electronic exit port

The CGS comprises an imaging grating, an optical entrance and an uncooled CCD receiver array or a silicon photodiode array (PDA). The CCD receiver array has an electric shutter function which requires minimal integration times and consequently enables high sensitivity. The PDA requires an extremely low noise, ensuring a high signal-to-noise ratio – even in low lighting conditions. The core of the spectrometers is a blazed flat-field grating for light dispersion and imaging. The overall configuration results in a spectral pixel distance of 0.4 nm/pixel with a CCD detector and 0.7 nm/pixel with the PDA detector. A spectral resolution smaller than 3 nm is achieved in accordance with the Rayleigh criterion. The optical entrance is an optical slit on the module side (available in different widths) and an SMA connector on the customer side. All optical components are mounted in a housing made of aluminum.

The spectrometer modules are compact and thermally stable, making them ideal for industrial applications. Their excellent thermal stability and a very low amount of stray light ensure reliable measuring results – even in rough environments. The CGS spectrometer modules extend the MMS and MCS spectrometer module product families.

The new CGS spectrometer combines the benefits of the MMS and MCS spectrometers:

- High resolution
- High sensitivity
- Very good signal-to-noise ratio
- High dynamic range
- Small size

Areas of application

The areas of application for these spectrometers are diverse because of their flexible design. They can be classified in accordance with measurement principles, areas of application or the materials to be analyzed. Yet their most important advantage is their compactness and insensitivity to external influences so that the modules can be installed in very close proximity to production. An option for on-line inspection is available for most of the applications mentioned below.

**Areas of application**

The following modules are available:

<table>
<thead>
<tr>
<th>Module</th>
<th>Spectral range (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CGS UV-NIR CCD</td>
<td>190 – 1015</td>
</tr>
<tr>
<td>CGS UV-NIR PDA</td>
<td>190 – 935</td>
</tr>
</tbody>
</table>

**CGS UV-NIR Family**

More than you'd think
## CGS UV-NIR CCD

**Technical Data**

<table>
<thead>
<tr>
<th>Optical entrance</th>
<th>SMA connector, 50 µm optical slit (can be varied upon request)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA = 0.22 (homogeneous illumination of the acceptance angle)</td>
<td></td>
</tr>
<tr>
<td>Grating</td>
<td>Flat field</td>
</tr>
<tr>
<td>Spectral range</td>
<td>190 nm – 1015 nm</td>
</tr>
<tr>
<td>Resolution (FWHM) with 50 µm slit</td>
<td>UV-VIS &lt; 2.2 nm</td>
</tr>
<tr>
<td></td>
<td>NIR &lt; 2.5 nm</td>
</tr>
<tr>
<td>stray light (ASTM 387-04)</td>
<td>3 AU at 240 nm with deuterium lamp (absorption A₁₀ of NaI)</td>
</tr>
<tr>
<td>Integration time (dependent on on-site electronics)</td>
<td>min. 30 µs</td>
</tr>
<tr>
<td>Sensor</td>
<td>Hamamatsu S11156, back-thinned CCD, 2048 pixels</td>
</tr>
<tr>
<td>Detector height</td>
<td>1 mm</td>
</tr>
<tr>
<td>Pixel pitch</td>
<td>14 µm</td>
</tr>
<tr>
<td>Housing size L x W x H</td>
<td>78 x 30 x 75 mm³</td>
</tr>
</tbody>
</table>

## CGS UV-NIR PDA

**Technical Data**

<table>
<thead>
<tr>
<th>Optical entrance</th>
<th>SMA connector, 40 µm optical slit (can be varied upon request)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA = 0.22 (homogeneous illumination of the acceptance angle)</td>
<td></td>
</tr>
<tr>
<td>Grating</td>
<td>Flat field</td>
</tr>
<tr>
<td>Spectral range</td>
<td>190 nm – 935 nm</td>
</tr>
<tr>
<td>Resolution (FWHM) with 50 µm slit</td>
<td>UV-VIS &lt; 2.0 nm</td>
</tr>
<tr>
<td></td>
<td>NIR &lt; 2.0 nm</td>
</tr>
<tr>
<td>stray light (ASTM 387-04)</td>
<td>3 AU at 240 nm with deuterium lamp (absorption A₁₀ of NaI)</td>
</tr>
<tr>
<td>Integration time (dependent on on-site electronics)</td>
<td>min. 500 µs</td>
</tr>
<tr>
<td>Sensor</td>
<td>Hamamatsu S3903, 1024 pixels</td>
</tr>
<tr>
<td>Detector height</td>
<td>1 mm</td>
</tr>
<tr>
<td>Pixel pitch</td>
<td>14 µm</td>
</tr>
<tr>
<td>Housing size L x W x H</td>
<td>78 x 30 x 75 mm³</td>
</tr>
</tbody>
</table>
**CGS UV-NIR PDA**

**On-site electronics**

**Configuration: an overview**

<table>
<thead>
<tr>
<th>CGS UV-NIR PDA</th>
<th>Interface electronics</th>
<th>Power supply unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>with preamplifier DZA-S3901-4 1M/03</td>
<td>PD-USB or PD-ETH</td>
<td>(power supply voltage)</td>
</tr>
<tr>
<td></td>
<td>FEE-16/16A06S-1 MMB</td>
<td>CAB-PS4/ STD</td>
</tr>
</tbody>
</table>

USB / ethernet configuration

USB and ethernet electronics are available for the standard PC interfaces. The interface electronics (USB and/or ethernet) are powered externally via a power supply unit (self-powered). USB-based electronics are connected with the PC via a standard USB cable. A hi-speed USB port (USB 2.0 or 3.0) is required for this configuration.

Ethernet-based configurations are connected to networks via a standard ethernet cable (patch cable) or directly to PCs or laptops via a cross-over ethernet cable. All electronic circuit boards are designed to be integrated into a customer’s housing. The user must provide the external + 5 VDC supply voltage.
Introduction
Wavelength ranges
MMS Family
CGS Family
Technical Data
On-site electronics
MCS FLEX Family
PGS Family
Software
Areas of application
Definitions and explanations

Email
www.zeiss.com

CGS UV-NIR CCD
On-site electronics

USB / ethernet configuration

USB and ethernet electronics are available for the standard PC interfaces. The interface electronics (USB and/or ethernet) are powered externally via a power supply unit (self-powered). USB-based electronics are connected with the PC via a standard USB cable. A hi-speed USB port (USB 2.0 or 3.0) is required for this configuration.

Ethernet-based configurations are connected to networks via a standard ethernet cable (patch cable) or directly to PCs or laptops via a cross-over ethernet cable. All electronic circuit boards are designed to be integrated into a customer’s housing. The user must provide the external +5 VDC supply voltage.

Configuration: an overview

USB and ethernet electronics are available for the standard PC interfaces. The interface electronics (USB and/or ethernet) are powered externally via a power supply unit (self-powered). USB-based electronics are connected with the PC via a standard USB cable. A hi-speed USB port (USB 2.0 or 3.0) is required for this configuration.

Ethernet-based configurations are connected to networks via a standard ethernet cable (patch cable) or directly to PCs or laptops via a cross-over ethernet cable. All electronic circuit boards are designed to be integrated into a customer’s housing. The user must provide the external +5 VDC supply voltage.
The spectrometers in the MCS FLEX family feature a good resolving power in addition to their high repeatability. All optical components are firmly affixed via a central body, ensuring a robust design.

**Optical components in the MCS FLEX family**
- Imaging, aberration-corrected grating
- Fiber cross-section converter or slit as an optical entrance
- Diode array and/or a cooled back-thinned CCD as the opto-electronic exit port

In the MCS FLEX family, the different design of the central body determines the system's application. The cross-section converter and detector are used in all the different versions.

#### Central body
The central body of the MCS FLEX spectrometers consists of a special aluminum alloy to ensure thermal stability (expansion coefficient $\alpha \approx 13 \times 10^{-6}$). The aberration-corrected grating, the cross-section converter (or the mechanical slit) as an optical port and the detector are connected via the central body, ensuring excellent stability and reliability. The hollow body means the MCS FLEX can be used for the complete spectrum of the UV-NIR.

#### Gratings
The gratings for the MCS FLEX family are also holographically blazed flat-field gratings for optimized effectiveness. Maximum grating efficiency has been optimized for different wavelength ranges through additional ion beam etching. Even spectra over a length of 25 nm are achieved through the aberration correction of the gratings. The grating surface is dimensioned in such a way that light from the fiber can be imaged with $\text{NA} = 0.22$.

#### Cross-section converter
A fiber bundle cross-section converter further optimizes the light intensity. The linear arrangement of individual fibers forms the entrance slit (slit height is determined by the number of individual fibers, the slit width is determined by the core diameter). The slit is adjusted to the pixel size of the diode array used and to the imaging dispersion properties of the flat-field grating, enabling light intensities to reach the theoretical limit.

The cross-section converter is an integral part of the spectrometer design and therefore cannot simply be altered. There is, however, the possibility of changing the length of the fiber and the entrance design. Please note that quartz fibers, such as those used on older MCS FLEX UV modules (VIS), create so-called solarization centers when irradiated with deep UV light under 220 nm. This means that the transmission of the fibers is reduced when irradiated with high-energy light. This effect is stronger and occurs more often, the shorter the wavelength (higher photon energy), the greater the intensity and the longer the exposure time. The transmission can also be limited above 220 nm up to 250 nm. This solarization effect can only be partially reversed but can be corrected via frequent reference measurements. For measurements below 225 nm, it is possible to equip the MCS FLEX modules with solarization stabilized fibers. Using a WG 225 filter with 3 mm thickness is an absolute must with standard modules.

**Detector**
- **MCS FLEX PDA**
  - The MCS FLEX PDA modules use the silicon diode array S3904-1024Q installed by Hamamatsu. The diode array is coated directly with dielectric edge filters to suppress the 2nd order.

**Module** | Spectral range (nm)
--- | ---
MCS FLEX PDA | 190 - 1015

- **MCS FLEX CCD**
  - Back-thinned CCDs S7031-1006Q from Hamamatsu are installed on the MCS FLEX CCD modules. Back-thinned CCDs are distinguished by direct sensitivity to UV light. To reduce the dark current, this detector has an integrated Peltier element which must be controlled externally. On the MCS FLEX CCD, the warmth discharged by the Peltier element reaches the fan-cooled heat sink via a copper block.

**Module** | Spectral range (nm)
--- | ---
MCS FLEX CCD | 190 - 980
MCS FLEX PDA
Technical Data

Optical entrance
Cross-section converter
Cross-section converter
Grating
Diode array
Spectral range
Wavelength accuracy
Temperature drift
Spectral pixel distance
Resolution
Stray light
Housing size L x W x H

MCS FLEX CCD
Technical Data

Optical entrance
Cross-section converter
Cross-section converter
Grating
Diode array
Spectral range
Wavelength accuracy
Temperature drift
Spectral pixel distance
Resolution
Stray light
Housing size L x W x H

Order number | Name | Wavelength range | Description
--- | ---: | ---: | ---
000000-1459-276 | MCS FLEX UV-NIR | 190 – 1015 nm | PDA with 1024 pixels

Order number | Name | Wavelength range | Description
--- | ---: | ---: | ---
000000-1423-352 | MCS FLEX CCD UV-NIR | 190 – 980 nm | With Hamamatsu CCD detector S7031
000000-1761-535 | MCS FLEX CCD UV-NIR | 190 – 980 nm | With Hamamatsu CCD detector S7031
Configuration: an overview

- **MCS FLEX PDA**
  - DZA-S3901-4 1M/STD
  - FEE-1M/NI3DS-01
  - USB/ethernet

- **DZA-S3901-4 1M/STD**
  - FEE-1M/NI3DS-1
  - USB/ethernet

### USB / ethernet configuration

USB and ethernet electronics are available for the standard PC interfaces. The USB-based electronics are powered externally through an additional power supply (a self-powered USB device). The PC is connected via a standard USB cable. We recommend a hi-speed USB 2.0 port (compatible with a standard USB 1.1).

High-speed USB communication is required to use the fast FEE-1M. All electronic circuit boards designed to be integrated into a customer's housing. The user must provide the external +5 VDC supply voltage.

#### On-site electronics

**MCS FLEX PDA**
- 16 bit / 100 kHz
- 16 bit / 1 MHz

**DZA-S3901-4 1M/STD**
- DZA-S3901-4 1M/STD
- FEE-1M/NI3DS-1
- USB/ethernet

**Front end electronics**
- FEE-1M/NI3DS-1

**Interface electronics**
- PD-USB or PD-ETH

**On-site electronics (supply voltage)**
- +5 VDC
- USB/ethernet cable
- PD-USB or PD-ETH cable

**Control / status**
- DC supply
- Interface electronics

**DC supply**
- Interface electronics

**Video**
- MCS FLEX PDA with DZA-S3901-4 1M preamp/11or
USB / ethernet configuration

USB and ethernet electronics are available for the standard PC interfaces. The USB-based electronics are powered externally through an additional power supply (a self-powered USB device). The PC is connected via a standard USB cable. We recommend a high-speed USB 2.0 port (compatible with a standard USB 1.1). All electronic circuit boards designed to be integrated into a customer’s housing. The user must provide the external + 5 VDC supply voltage.
The spectrometers in the PGS family are designed to be used in NIR. InGaAs (indium gallium arsenide) is used as a detector material in this wavelength range. The special combination of an aspheric collimator lens and a focusing lens enables the use of optimized plane gratings for NIR while retaining good flat field correction of the spectral imaging. To ensure long-term stability, all optical components are firmly affixed to each other.

**Optical components in the PGS family**

- Blazed plane grating
- Aspheric lenses
- Mono fiber with a slit as an optical entrance
- Cooled InGaAs photodiode array as an optoelectronic output

**Central body**

In the PGS family, a special aluminum alloy (expansion coefficient $\alpha \approx 13 \times 10^{-6}$) is used for the central body. This body is the carrier for the blazed grating and the aspheric collimator and focusing lens. The input fiber and the detector are firmly affixed to the central body, guaranteeing excellent stability.

**Gratings**

The gratings used in the PGS family are mechanically ruled or holographically exposed. The maximum of the efficiency is modified to the special wavelength range in NIR. With the free diameter, the grating surface is dimensioned in such a way that the light from a fiber can be imaged with a NA of up to 0.37.

**Input fiber**

The light is generally coupled via a mono quartz fiber. These fibers have a diameter of 600 µm and a NA = 0.22. There is a slit at the end of the fiber with a height of 500 µm (NIR 1.7) and 250 µm (NIR 2.2). The slit heights are adjusted to the pixel heights in the InGaAs arrays. A cross-section conversion of the light for creating a higher entrance slit, such as on modules with silicon detectors, is not necessary because of the lower detector height of the InGaAs arrays.

**Detector**

InGaAs detectors are used in the near infrared range. For the PGS NIR modules, arrays with InGaAs are used for the range up to 1.7 µm and modules with extended InGaAs are used for the range up to 2.2 µm. Arrays are also available with an element number of 256 or 512 (only 1.7 µm pixels). For the extended InGaAs arrays, an order-sorting filter is applied to the array, depending on the wavelength range, to suppress the 2nd diffraction order.

The following modules are available:

<table>
<thead>
<tr>
<th>Module</th>
<th>Spectral range (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PGS NIR 1.7-256 UC</td>
<td>960 – 1690</td>
</tr>
<tr>
<td>PGS NIR 1.7-256</td>
<td>960 – 1690</td>
</tr>
<tr>
<td>PGS NIR 1.7-512</td>
<td>500 – 1690</td>
</tr>
<tr>
<td>PGS NIR 2.0-256</td>
<td>1340 – 2000</td>
</tr>
<tr>
<td>PGS NIR 2.2-256</td>
<td>1000 – 2150</td>
</tr>
</tbody>
</table>

PGS Family
The NIR specialists
## PGS NIR 1.7 -512

### Technical Data

<table>
<thead>
<tr>
<th>Order number</th>
<th>Name</th>
<th>Wavelength range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>000000-1307-412</td>
<td>PGS NIR 1.7 -512-512</td>
<td>960 – 1690 nm</td>
<td>NIR spectral sensor, Peltier cooled, InGaAs PDA up to 1.7 µm, 512 pixels, dispersion: 1.5 nm/pixel, external fiber length: 300 mm</td>
</tr>
</tbody>
</table>

### Optical entrance

- Fiber consists of Infrasil quartz glass
- Diameter: 0.6 mm
- Length: 300 mm
- NA = 0.22 (homogeneous illumination of the acceptance angle)
- Mounted in an SMA connector
- Slit width: 80 µm

### Filter

- 950 nm edge filter

### Grating

- Plane grating,
- 484 l/mm, blazed for approx. 1.2 µm

### Diode array

- Manufacturer: Hamamatsu
- Type: S9204
- Number of pixels: 512

### Spectral range

- 960 – 1690 nm

### Wavelength accuracy

- ± 1 nm

### Temperature drift (10 – 40°C)

- < 0.012 nm/K

### Spectral pixel distance

- ∆λPixel ≈ 1.5 nm

### Resolution

- ∆λFWHM ≈ 7 nm

### Stray light

- ≤ 0.1 % as transmission of 10 mm of water at 1405 nm (measured using a halogen lamp)

### Weight

- approx. 590 g

### Operating temperature

- 0 – 40°C (standard, depending on cooling electronics)

### Storage temperature

- -40 – +70°C

---

## PGS NIR 1.7 -256

### Technical Data

<table>
<thead>
<tr>
<th>Order number</th>
<th>Name</th>
<th>Wavelength range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>000000-1381-397</td>
<td>PGS NIR 1.7 -256-256</td>
<td>960 – 1690 nm</td>
<td>NIR spectral sensor, Peltier cooled, InGaAs PDA up to 1.7 µm, 256 pixels, dispersion: 3.0 nm/pixel, external fiber length: 300 mm</td>
</tr>
</tbody>
</table>

### Optical entrance

- Fiber consists of Infrasil quartz glass
- Diameter: 0.6 mm
- Length: 300 mm
- NA = 0.22 (homogeneous illumination of the acceptance angle), mounted in an SMA connector
- Slit width: 80 µm

### Filter

- 950 nm edge filter

### Grating

- Plane grating,
- 484 l/mm, blazed for approx. 1.2 µm

### Diode array

- Manufacturer: Hamamatsu
- Type: S9203-256
- Number of pixels: 256

### Spectral range

- 960 – 1690 nm

### Wavelength accuracy

- ± 1 nm

### Temperature drift (10 – 40°C)

- < 0.012 nm/K

### Spectral pixel distance

- ∆λPixel ≈ 3 nm

### Resolution

- ∆λFWHM ≈ 8 nm

### Stray light

- ≤ 0.1 % as transmission of 10 mm of water at 1405 nm (measured using a halogen lamp)

### Weight

- approx. 590 g

### Operating temperature

- 0 – 40°C (standard, depending on cooling electronics)

### Storage temperature

- -40 – +70°C
PGS NIR 2.0-256
Technical Data

Optical entrance
Input: round
Output: linear
Fiber consists of Infrasil quartz glass
Diameter: 0.6 mm
Length: 300 mm
NA = 0.22 (homogeneous illumination of the acceptance angle)
Mounted in an SMA connector
Slit width: 80 µm

Filter
1350 nm edge filter

Grating
Plane grating, 484 l/mm, blazed for approx. 1.4 µm

Diode array
Manufacturer: Hamamatsu
Type: G 9206
Number of pixels: 256

Spectral range
1340 – 2000 nm

Wavelength accuracy
± 1 nm

Temperature drift (10 – 40°C)
< 0.012 nm / K

Spectral pixel distance
∆λPixel = 3 nm

Resolution
∆λFWHM ≈ 8 nm

Stray light
≤ 0.1 % as transmission of 10 mm of water at 1405 nm (measured using a halogen lamp)

Weight
approx. 590 g

Operating temperature
0 – 40°C (standard, depending on cooling electronics)

Storage temperature
-40 – +70°C

Order number Name Wavelength range Description
000000-1396-757 PGS NIR 2.0 12 1340 – 2000 nm NIR spectral sensor, Peltier cooled
Extended InGaAs PDA up to 2.2 µm
256 pixels, dispersion: 1.5 nm/pixel, external fiber length: 300 mm

PGS NIR 2.2-256
Technical Data

Optical entrance
Input: round
Output: linear
Fiber consists of Infrasil quartz glass
Diameter: 0.6 mm
Length: 300 mm
NA = 0.22 (homogeneous illumination of the acceptance angle)
Mounted in an SMA connector
Slit width: 80 µm

Filter
950 nm edge filter

Grating
Plane grating, 300 l/mm, blazed for approx. 1.4 µm

Diode array
Manufacturer: Hamamatsu
Type: G 9206
Number of pixels: 256

Spectral range
1000 – 2150 nm

Wavelength accuracy
± 1 nm

Temperature drift (10 – 40°C)
< 0.012 nm / K

Spectral pixel distance
∆λPixel = 5 nm

Resolution
∆λFWHM ≈ 16 nm

Stray light
≤ 0.1 % as transmission of 10 mm of water at 1405 nm (measured using a halogen lamp)

Weight
approx. 590 g

Operating temperature
0 – 40°C (standard, depending on cooling electronics)

Storage temperature
-40 – +70°C

Order number Name Wavelength range Description
000000-1332-256 PGS NIR 2.2 12 1000 – 2150 nm NIR spectral sensor, Peltier cooled
Extended InGaAs PDA up to 2.2 µm
256 pixels, dispersion: 5 nm/pixel, external fiber length: 300 mm

-
PGS NIR 1.7-256 UC

Technical Data

Optical entrance  Input: round
Output: linear
FSMA 905
NA = 0.22 (homogeneous illumination of the acceptance angle)
Mounted in an SMA connector
Slit width: 80 µm
Filter
950 nm edge filter
Grating
Plane grating,
484 l/mm, Blazed for approx. 1.2 µm
Diode array
Manufacturer: Hamamatsu
Type: G9211-01SP
Number of pixels: 256
Spectral range
960 – 1690 nm
Wavelength accuracy
± 1 nm
Temperature drift (10 – 40°C)
< 0.012 nm/K
Spectral pixel distance
ΔλPixel = 3 nm
Resolution
∆λFWHM = 8 nm
Stray light
≤ 0.1 % as transmission of 10 mm of water
at 1405 nm (measured using a halogen lamp)
Weight
approx. 590 g
Operating temperature
0 – 40°C (standard, depending on cooling electronics)
Storage temperature
-40 – +70°C

<table>
<thead>
<tr>
<th>Order number</th>
<th>Name</th>
<th>Wavelength range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>000050-2109-070</td>
<td>PGS NIR 1.7-256 UC</td>
<td>960 – 1690 nm</td>
<td>NIR spectral sensor, uncooled</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Extended InGaAs PDA up to 1.7 µm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>256 pixels, dispersion: 3 nm/pixel, 250 nm of water</td>
</tr>
</tbody>
</table>
Configuration: an overview

PGS NIR 1.7-256 UC
PGS NIR 1.7-512
PGS NIR 2.0-256
PGS NIR 2.2-256
FEE-1M/NIR-4
USB/ethernet

USB / ethernet configuration

USB and ethernet electronics are available for the standard PC interfaces. The USB-based electronics are powered externally through an additional power supply (a self-powered USB device). The PC is connected via a standard USB cable. We recommend a high-speed USB 2.0 port (compatible with a standard USB 1.1). The fast FEE-1M requires high-speed USB communication. All electronic circuit boards designed to be integrated into a customer’s housing.

On-site electronics

PGS NIR 1.7-256 UC
PGS NIR 1.7-512
PGS NIR 2.0-256
PGS NIR 2.2-256
FEE-1M/NIR-4
USB/ethernet

Exposed to a 10 kHz high frequency signal, it is insensitive to the variations in power supply voltage. The PGS NIR 1.7-256 UC is an example of this technology. The high-frequency signal is created by the Peltier element, which is also used to control the temperature of the detector.

*Not necessary for PGS NIR 1.7-256 UC
The architecture of the software products for capturing and processing spectral data is based on a modular structure. This ensures that the software meets diverse, customer-specific specifications and enables different hardware configurations to be adjusted flexibly. For the various operating electronics units, device drivers are available for Windows 2000, XP and Vista.

The universal Aspect Plus program package featuring comprehensive functions is available along with the drivers for the PC bus interface. A programming interface for the SDACQ 32 MP function library is also offered to ensure easy integration into customer-specific applications. This interface directly supports C/C++, Visual Basic and Delphi, and a LabVIEW® driver for programming in a LabVIEW® environment. It is possible to program with finished menu structures for data capture by using the SDPROC32 function library for data capture, configuration and entering parameters.

The SDACQ32MP function library directly addresses these device drivers and supplies a hardware-independent collection of functions, enabling the configuration of the on-site electronics and spectral data capture.

**Aspect Plus software package + driver**

- **Interface**
  - SDACQ32MP and SDPROC32P function libraries
  - Instrument driver for LabVIEW®
  - User-specific applications

- **Instrument driver**
  - Aspect Plus driver for PCs and USBs
  - Aspect Plus driver for Windows 2000 and XP tec5 electronics

**Order number**

- 263259-5020-026 Aspect Plus Windows spectrometer software
- 000000-1242-401 Aspect Plus driver for PCs and USBs

**Benefits**
- Available in multiple languages (English, French, German, Italian, Portuguese, Spanish), other languages to follow
- More than one spectrometer can be controlled simultaneously
- Supports calibrations (chemometric models) created using standard chemometric software such as GRAMS, UNSCRAMBLER® or UCAL
- Filter function eliminating outlying spectra
- Communication via OPC for integration into production line inspection
- Use of pre-defined products or creation of user-specific products, as required
- Calculation, evaluation and integration into an upstream process environment
- Control of results via Digital I/O
Areas of application

The areas of application for these spectrometers are diverse because of their flexible design. They can be classified in accordance with measurement principles, areas of application or the materials to be analysed. Compliance with these requirements enables production and environmental testing to be performed with a high degree of accuracy. The spectrometer modules are not suitable for analyzing emissions which contain many spectrally adjacent lines. A high wavelength accuracy is necessary for the size of the module, enabling, through a sub-pixel resolution procedure, an exact identification of the wavelength from light sources which emit a line, e.g. LEDs (sabretooth). The spectrometer modules are not suitable for analyzing emissions which contain many spectrally adjacent lines. A high wavelength accuracy is necessary for the size of the module, enabling, through a sub-pixel resolution procedure, an exact identification of the wavelength from light sources which emit a line, e.g. LEDs (sabretooth). The spectrometer modules are not suitable for analyzing emissions which contain many spectrally adjacent lines. A high wavelength accuracy is necessary for the size of the module, enabling, through a sub-pixel resolution procedure, an exact identification of the wavelength from light sources which emit a line, e.g. LEDs (sabretooth).

Requirements

The spectrometer modules have been specially developed for color measuring technology. Their high repeatability and light intensity at a moderate spectral resolution meet the specifications exactly.

Reflection

Reflection is a special case of diffuse reflection and refers to the directionally reflected light from a smooth low-scatter surfaces. A spectral resolution of one period. A simple setup for measurements under 0°C is possible by using a special light guide which both supplies the light and transmits it to the detector.

Requirements

In many cases, a very high spectral resolution is once again less important than a good spectral resolving power. Thus absolute wavelength accuracy is often significantly more important than a good spectral resolving power.

White light interference

Interference are the result of radiating white light on optically transparent interfaces because, for certain wavelengths, the optical path difference is exactly the multiple of the optical layer thicknesses

\[ d \cdot \text{refractive index} = \lambda _1 \cdot \lambda _2 / (\lambda _1 - \lambda _2) \]

Requirements

High absolute accuracy of the wavelength is also necessary to accurately determine the thickness. The maximum measurable thickness is coupled with the spectral resolving power (split of two interference maxima). The minimal thickness with the spectral range to be captured display of at least a half-period. Absolute intensity values must be known to determine even thinner layers (performing an evaluation of less than a half-period).

Transmission

Radiographing material with the thickness d provides information on the spectral dependence of the absorption constant \( \alpha (\lambda) \) (\( \lambda _1 \), \( \lambda _2 \), position of the extrema; distance: one period). If the refractive index n is known, then the geometric layer thickness \( d \) can be determined. The fiber interface ensures easy coupling to microscopes or flanging onto coating systems. Inversely: if layer thickness \( d \) is known, then the dispersion \( n (\lambda) \) can be determined.

Requirements

Examples

• Measuring filters (color filters, interference filters)
• Determining the concentration of liquids
• Determining the sugar and alcohol content in beverages
• Performing quality assurance in the petrochemical industry

Wavelength ranges

The wavelength ranges can be found in the following sections.

**Introduction**

**Wavelength ranges**

**Requirements**

High absolute accuracy of the wavelength is also necessary to accurately determine the thickness. The maximum measurable thickness is coupled with the spectral resolving power (split of two interference maxima). The minimal thickness with the spectral range to be captured display of at least a half-period. Absolute intensity values must be known to determine even thinner layers (performing an evaluation of less than a half-period).

**Transmission**

Radiographing material with the thickness d provides information on the spectral dependence of the absorption constant \( \alpha (\lambda) \) (\( \lambda _1 \), \( \lambda _2 \), position of the extrema; distance: one period). If the refractive index n is known, then the geometric layer thickness \( d \) can be determined. The fiber interface ensures easy coupling to microscopes or flanging onto coating systems. Inversely: if layer thickness \( d \) is known, then the dispersion \( n (\lambda) \) can be determined.

Requirements

Examples

• Measuring filters (color filters, interference filters)
• Determining the concentration of liquids
• Determining the sugar and alcohol content in beverages
• Performing quality assurance in the petrochemical industry

**Wavelength ranges**

The wavelength ranges can be found in the following sections.
Definitions and Explanations of Terms

One of the most important criteria when selecting a spectrometer is the spectral range within which the spectrometer must cover. It is usually clear which range is required. However, the two other important criteria for a spectrometer – the spectral and the intensity-related (dynamic) resolution – are not usually clearly defined.

Spectral resolution

The following four terms refer to ‘spectral’ resolution:

1. Rayleigh criterion – \( \Delta \lambda_{\text{Rayleigh}} \) (DIN standard)
2. Line width, mostly half-value width or full width at half maximum – \( \Delta \lambda_{\text{FWHM}} \)
3. Sub-pixel resolution (also called ‘software resolution’)
4. Pixel dispersion – \( \Delta \lambda_{\text{pixel}} \)

A meaningful definition results from the application. A spectrometer is essentially used to perform three different jobs. These tasks may, of course, overlap:

1. Splitting two or more lines within a spectrum – analyzing compounds
2. Determining the line form – usually by evaluating the spectrometer’s resolving power
3. Measuring a line with respect to peak wavelength and intensity at the maximum – e.g. determining emissions

The widening of the line via the spectrometer must be less than the spectral width of the line itself so that the width of a spectral line \( \Delta \lambda_{\text{spectrometer}} \) can be measured. It is important to know the expansion \( \Delta \lambda_{\text{spectrometer}} \) related to the spectrometer. This property is related to the Rayleigh criterion:

\[
\Delta \lambda_{\text{spectrometer}} = \frac{h \Delta \lambda_{\text{FWHM}}}{2} = \frac{h \Delta \lambda_{\text{Rayleigh}}}{2} = \frac{\Delta \lambda_{\text{FWHM}}}{2} = \frac{\Delta \lambda_{\text{Rayleigh}}}{2}
\]

Spectral line width

The widening of the line via the spectrometer must be less than the spectral width of the line itself so that the width of a spectral line \( \Delta \lambda_{\text{spectrometer}} \) can be measured. It is important to know the expansion \( \Delta \lambda_{\text{spectrometer}} \) related to the spectrometer. This property is related to the Rayleigh criterion:

\[
\Delta \lambda_{\text{spectrometer}} = \frac{h \Delta \lambda_{\text{FWHM}}}{2} = \frac{h \Delta \lambda_{\text{Rayleigh}}}{2} = \frac{\Delta \lambda_{\text{FWHM}}}{2} = \frac{\Delta \lambda_{\text{Rayleigh}}}{2}
\]

Spectral resolution

Determined by the fixed position of the pixels and/or the wavelength of the radiated light, the resolution is different on monochromators/spectrometers with movable elements. Resolution – as defined by ‘splitting two adjacent lines’ – depends on the relative position of these lines with respect to the pixels:

If two closely adjacent lines are imaged onto the pixels in such a way that the minimum falls on the middle pixel (\( h \)) and the maxima fall on the two neighboring pixels (\( h \pm 1 \)), the lines can be split if the displayed intensity \( I_{\text{pixel}} = 0.81 \times I_{\text{max}} \). A \( \Delta \lambda_{\text{pixel}} \) is exactly two pixels (\( 2 \times \Delta \lambda_{\text{pixel}} \)).

Wavelength accuracy

To determine the absolute spectral position \( \lambda \) – with a certain accuracy \( \Delta \lambda_{\text{FWHM}} \) – of an individual line, a spectrometer with at least this absolute wavelength accuracy \( \Delta \lambda_{\text{FWHM}} \) is required. This parameter depends on the position accuracy of the readout elements (pixels or diode detector) and the stability of this position (see below) characterized by the repeatability. In contrast, the absolute wavelength accuracy only depends indirectly on the dispersive and focal properties of the spectrometer and is not a ‘resolution’ in the traditional sense. The stability (or repeatability) of a spectrometer is based on the mechanical stability and the temperature-determined wavelength drift. The former is completely noncritical for spectrometer modules and the drift is practically negligible.

Dispersion

The specification \( \Delta \lambda_{\text{pixel}} \) has nothing to do with spectral resolution. Instead, it is just the linear dispersion of a diode array spectrometer. Pixel dispersion and spectral resolution are linked via the width of the entrance slit and the imaging properties: if the entrance slit is imaged on approx. 3 pixels, triple the pixel dispersion corresponds approximately to \( \Delta \lambda_{\text{spectrometer}} \).

Sub-pixel resolution

The peak wavelength \( \lambda_{\text{pixel}} \) (and/or peak intensity \( I_{\text{pixel}} \)) requires that the spectral line to be measured be imaged onto at least three pixels. With three intensity value pairs per pixel \( I_{\text{pixel}} \) and the central wavelength of the corresponding pixels \( \lambda_{\text{pixel}} \), the line can be e.g. relatively easily modified using a parabola. The parabola equation provides the vertex with the information on the peak wavelength and peak intensity. The accuracy of this method depends primarily on the absolute accuracy of the central wavelength. In principle, this wavelength can be determined with almost any degree of accuracy on a diode array spectrometer. If necessary, each pixel can be individually calibrated. However, stability is crucial. Otherwise, the wavelength specification will only remain valid until the next shock or temperature change. No extreme value determination can be performed if the imaging (and the dispersion) of a DiAS is selected in such a way that fewer than three pixels are illuminated. This results in a parabola seemingly more advantageous situation – a line is very narrow at the exit – leads to significantly greater inaccuracy. If, for example, a line is imaged onto only one pixel, the spectral uncertainty is \( \Delta \lambda_{\text{spectrometer}} \).

Parabola equation

\[
(D) \quad y = ax^2 + bx + c
\]

Coefficients:

\[
a = \frac{I_1 - I_3}{4 \Delta \lambda} - \frac{I_2}{2 \Delta \lambda^2}
\]

\[
b = \frac{I_1 - I_3}{2 \Delta \lambda} - 2ax - \frac{I_2}{2 \Delta \lambda^2}
\]

\[
c = I_2 - ax^2 - \frac{I_1 - I_3}{2 \Delta \lambda}
\]

Maximum at \( x = \frac{-b}{2a} \)

Determining the half-value width

The parabola fit also provides qualitative information on the half-value width. To perform a parabola fit \( \lambda_{\text{FWHM}} \) just needs to be inserted into the parabola equation. The half-value width of a parabola only deviates slightly from the half-value width of a Gaussian fit.

The half-value width displayed by a DiAS depends on the relative position of a line to the individual pixels and is a periodic function of this position with a 1 pixel period length. Our specifications are based on ‘worst case’ values.

More suitable – but also more complex – are fits with Gaussian and Lorentz curves which better correspond to the real spectral distributions. These also have the benefit that the resulting calculated half-value width is not dependent on the relative position to the pixels.

\[
\Delta \lambda_{\text{FWHM}} = 2\sqrt{2} \times \Delta \lambda_{\text{FWHM}}\text{fit}
\]

Intensity resolution

The following properties are of interest for measuring intensities:

- Relative
- Smallest detectable change
- Signal stability
- Detection range or dynamics
- Uncertainty

Absolute

- Lowest detectable light quantity or sensitivity
Accuracy
Measurements of minimal changes and stability depend directly on each other and are essentially determined by the noise with the electronics because most spectrometers ensure a stable ‘light path’. As well as all sizes, it is important how a value — in the transit sense of the word — is determined. For the spectrometer module specifications, e.g. a 10 ms integration time is selected and the standard deviation $\sigma$ is calculated above 25 captures. This supplies a measure for the accuracy $A$ which can be used to determine an intensity value.

$$A = 2\sigma $$

Dynamic and intensity changes
The dynamic is understood as the relationship between the saturation level $\text{SL}$ and the noise level $\text{NL}$, and corresponds to the signal-to-noise ratio $\text{SNR}$. (The usable range is still reduced by the dark current.) The $\text{SNR}$ depends not only on the detector but also the digitization which provides the small step width into which a suitable signal can be separated.

$$\text{Dynamic} = \text{SNR} = \frac{\text{NL}}{\text{NL}}$$

Of course the weakest link in the chain determines the signal-to-noise ratio to be achieved. With a 14 bit converter e.g. this corresponds to $16\,384$ steps or increments — and a noise of $\text{DNL} = 1$ count, a signal (fully controlled) can actually be divided into $16\,384$ steps. The slightest measurable change is thus $1/16\,384$ of the saturation signal. There is an uncertainty of four counts with a noise of four counts, i.e. only $4/16\,384$ of the saturation signal can be measured as a definitive change and/or the signal can be meaningfully divided into $4069$ steps.

At this point it should be noted that a higher dynamic range is only useful if the detector is adjusted so that it is equally high that you should always try to reach a high level of light so that the high sensitivity of the ZEISS spectrometers is beneficial.

$$\text{Dynamic} = \text{Range} = A \cdot \text{DNL}$$

Linearity
These statements only apply to an ideal detector linearity and the connected electronics, i.e. if the measured charge is linearly dependent on the intensity of the light. The admisible deviation must be specified for quantitative information to be obtained. Unfortunately, modern semi-conductor detectors exhibit almost perfect linear behavior over many ranges. Before reaching saturation (the extreme case of non-linearity), however, the increase in the electrically supplied (information carrying for intensity) is no longer linear to the number of photos hitting the photosensi-

tive material. The linearity range is consequently smaller than the dynamic range.

External influences
As the graphic shows, a change of temperature $T$ does not cause any change in sensitivity. In the range up to $1100$ °C, the sensitivity even increases as the temperature rises. At temperatures between $50$ and $50$ °C, the sensitivity changes by less than $1\%$ in the range of $1$ to $1.55\,\mu\text{m}$, even for InGaAs photodiode arrays. Only outside of the specified range is a stronger temperature influence caused by a different coating. (Falling temperatures cause reduced sensitivity on the band edge.)

The photodiode arrays used do not show any deterioration in the signal-to-noise ratio. Only the dark current $I_{\text{DC}}$ increases with rising temperature, resulting in a reduction of the dynamic range. This is why detectors — in particular InGaAs diode arrays are often cooled. With this in mind, it should be noted that the light quantities to be measured are also subject to fluctuations. The instability of the illumination source is often the limiting factor. The ‘smallest detectable change’ is a relative specification. It is significantly more difficult to specify the smallest detectable quantity of light at all. Or how many photons are needed so that the detection electronics detect a change? The difficulties stem from determining the light intensity of a light source and the coupling efficiency. There are also dependent on the wavelength: first because all components have wavelength-dependent efficiencies, including the coupling: second because the bandwidth for the sensitivity measurements are of crucial importance. The simplest case is a light source with a very narrow band as, with most lasers. The situation is at least clear if the bandwidth is significantly smaller than the spectrometer bandwidth. The MMS value of over $10^3$ counts/W has been measured with a red Helie laser.

Stray light
Specifying the stray light value only makes sense in conjunction with the measuring instructions. Stray light values for the spectrometer modules are determined with three different light sources to determine the different spectral components in stray light and/or false light: a deuterium lamp for the UV range and a halogen lamp for the VIS-IR range.

The stray light level is the ratio between the respective measurement with a GG495 or KG3 filter and the maximum useful signal. Thus the stray light given is for the shortwave range, showing that, on the spectrometer modules, the essential stray light proportion comes from the NIR. This is beneficial because these spectrally ‘remote’ components can be easily filtered out. For the PGS NIR, the stray light value is reduced to 0.1% measured with a halogen lamp at $1450\,\text{nm}$, RG50 filter and $10\,\text{mm}$ working distance.

Stray light affects the dynamic range because the full dynamic range is no longer available due to false light. Changes in the causative radiation only break through in relation to the stray light proportion. E.g. if the stray light proportion is $1$ per mill, a $10\%$ change in the effective radiation means a change of $10\%$. If the causative radiation is not used, then the proportion can be further reduced via filtering. In the example described, a blockade of $10\%$ leads to a total change of $10\%$. There are only small limitations to measuring measurable changes because the noise is usually much stronger. The stray light proportion can be ‘calculated out’ if the cause of the signal is known.

Optical interface
Interfaces must be defined mechanically and optically. The SMA plug in connection — such that used on all models — is a useful mechanical interface in the practical, resulting in a clear interface along with the well-defined etendue of a fiber bundle. In order to optimally modify an existing light source (fiber, lamp, imaging system), it is recommended that the corresponding etendue be determined first. The following coupling efficiency can be estimated through the comparison with the MMS etendue. Due $4.4\%$ Fresnel reflection losses (index jump at the glass fiber) must be determined.

Transmission losses
Assuming the beam is round, then an increase in transmission of $\eta_1 \cdot \eta_2 \cdot \text{SNR}$ is achieved by using a cross-section converter (ESC) as compared to the classical slit. This can be calculated using the ratio of the light transmitted via the QSW to the light transmitted via a rectangular slit.

With the ESC, the transmitted portion through the fill factor is $\eta_{\text{ESC}}$. The fill factor is defined as an optically effective surface $A_{\text{eff}}$ with respect to the illuminated entire surface $A_{\text{apt}}$. In the case of the QSW, the product of the fiber core cross section with the diameter $d_{\text{fiber}}$ and the number of fibers $N$ at the slit, the surface from slit width $b$ and the slit height $h$. The entire surface is the circular surface with a diameter $d_{\text{fiber}}$.

$$\text{ESC} = \frac{N \cdot d_{\text{fiber}}^2}{b \cdot h}$$

Diode array spectrometer optimization
In addition to selecting especially efficient components (a blazed grating, a correct selectivity, dispersion, imaging properties, entrance slit, pixel size and pixel distances must be evaluated) is another important factor — that with monochromatic light — more than $2$ pixels are illuminated for the spectral resolution. The grating images $1.1$ to the first approximation, e.g. the entry slit should be $2$ to $3$ pixels wide. If more pixels are illuminated, the signal-to-noise ratio and the sensitivity become worse ($1$ pixel captures a bandwidth that is too narrow). If fewer than $3$ pixels are illuminated, the wavelength accuracy becomes worse. This is why e.g. the selection of $70\,\mu\text{m}$ individual fibers for the QSW on the MMS modules are nearly perfect for a pixel width of $25\,\mu\text{m}$. The number of fibers is the result of the pixel height divided by the external diameter of the individual fibers.
Introduction

Wavelength ranges

MMF Family
CGS Family
MCS FLEX Family
PGS Family

Software

Areas of application

Definitions and explanations

The moment you achieve absolute confidence. This is the moment we work for.
<table>
<thead>
<tr>
<th>Introduction</th>
<th>Wavelength ranges</th>
<th>MMS Family</th>
<th>CGS Family</th>
<th>MCS FLEX Family</th>
<th>PGS Family</th>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areas of application</td>
<td>Definitions and explanations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>