ZEISS Spectrometer Modules
Compendium of products, electronic components and software solutions
The moment you discover that your expectations have been exceeded.  
This is the moment we work for.
Introduction

Your application is our motivation

A traditional spectrometer and/or a traditional monochromator consists of a dispersive medium, an entrance and an exit slit and imaging elements which generate a parallel beam path. To capture a spectrum, a detector behind the exit slit must capture the light sequentially while the dispersive element or the exit slit is moved. This sort of mechanical movement requires time and is prone to interference. However, short measuring times and insensitivity to external influences are quite advantageous for many applications – especially in industry. That is why ZEISS began developing the diode array spectrometers at the end of the 1970s. In place of the exit slit, these spectrometers have a diode array and, through this replacement, capture a complete spectrum simultaneously in a fraction of a second, making moving components unnecessary. The design of the spectrometer module family from ZEISS is based on reducing the optical-mechanical design and the number of components to the physical minimum while using the greatest possible number of identical components for different versions.

In the last few years, ZEISS has developed a large number of diverse spectrometer modules for very different applications and requirements. All of these modules offer a key benefit: all spectrometer parts are permanently affixed to each other. This ensures a very high degree of insensitivity to mechanical vibrations and thus a high level of reliability. Moreover, the entire design is maintenance-free, i.e. recalibration is not necessary. The foundation for the high quality of the spectrometer is the technological know-how at ZEISS for mathematical designs, structuring (grating manufacture and replication), coatings and material processing. Ultimately, the joining technology is decisive for ensuring a high degree of insensitivity to influences such as vibrations and, especially, temperature fluctuations.

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.
Click on the respective wavelength range to reach the technical data of the corresponding product.
MMS Family
Monolithically compact

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 (slit height determined by the number of individual fibers; the slit 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 the theoretical limit. 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.
MMS 1
Technical Data

**Optical entrance**
- **Input:** round
- **Output:** linear
- Fiber bundle consists of 30 quartz glass fibers with a 70 µm core diameter, designed as a cross-section converter
- Diameter: 0.5 mm
- NA = 0.22 (homogeneous illumination of the acceptance angle)
- Mounted in an SMA connector
- 70 µm x 2500 µm (entrance slit)

**Grating**
- Fair field, 386 l/mm (in the center)

**Diode array**
- **Manufacturer:** Hamamatsu
- **Type:** S 3904-256Q in special housing (S 5713)
- (S 8381-256Q for the MMS 1 NIR enhanced)
- Number of pixels: 256

**Spectral range**
- 310 nm – 1100 nm
- Specifications for the range
  - 360 nm – 900 nm (UV-VIS enhanced)
  - 400 nm – 1000 nm (NIR enhanced)

**Wavelength accuracy**
- 0.3 nm

**Temperature drift**
- ≤ 0.01 nm/K

**Spectral pixel distance**
- ∆λPixel = 10 nm

**Resolution**
- ∆λFWHM = 7 nm

**Sensitivity**
- ≈ 10^11 Vs / J

**Stray light**
- ≤ 0.8 % with deuterium lamp for UV-VIS enhanced
- ≤ 0.2 % with halogen lamp for NIR enhanced

**Dimensions**
- With housing
- 70 x 50 x 40 mm³
- Standard: 240 mm, available up to 1 m

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

**Optical entrance**
- **Input:** round
- **Output:** linear
- Fiber bundle consists of 30 quartz glass fibers with a 70 µm core diameter, designed as a cross-section converter
- Diameter: 0.5 mm
- NA = 0.22 (homogeneous illumination of the acceptance angle)
- Mounted in an SMA connector
- 70 µm x 2500 µm (entrance slit)

**Grating**
- Fair field, 386 l/mm (in the center), blazed for approx. 220 nm

**Diode array**
- **Manufacturer:** Hamamatsu
- **Type:** S 3904-256Q in special housing
- 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**
- ∆λPixel = 2.2 nm

**Resolution**
- ∆λFWHM = 7 nm

**Sensitivity**
- ≈ 10^11 Vs / J

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

**Dimensions**
- With housing
- Cross-section converter (outer length)
- 67 x 60 x 40 mm³
- Standard: 240 mm, available up to 1 m
**MMS UV**

**Technical Data**

<table>
<thead>
<tr>
<th>Optical entrance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber bundle consists of approx. 15 quartz glass fibers with a 70 µm core diameter, designed as a cross-section converter. Diameter: 0.4 mm, NA = 0.22 (homogeneous illumination of the acceptance angle). Mounted in an SMA connector. 70 µm x 1250 µm (entrance slit).</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat-field, 1084 lines/mm (in the center), blazed for approx. 220 nm</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Diode array</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer: Hamamatsu Type: S 3904-256N in special housing Number of pixels: 256</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spectral range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>195 nm – 390 nm Specifications for the 220 nm – 390 nm range</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wavelength accuracy</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 nm</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature drift</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.005 nm/K</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spectral pixel distance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>∆λPixel = 0.8 nm</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>∆λFWHM = 3 nm</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 10&lt;sup&gt;6&lt;/sup&gt; V/W</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stray light</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 0.3 % deuterium lamp</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>With housing: Cross-section converter (outer length) 70 x 60 x 40 mm&lt;sup&gt;3&lt;/sup&gt; Standard: 240 mm, available up to 1 m</td>
<td></td>
</tr>
</tbody>
</table>

### Order Information

<table>
<thead>
<tr>
<th>Order number</th>
<th>Name</th>
<th>Wavelength range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>224002-9020-000</td>
<td>MMS UV</td>
<td>195 – 390 nm</td>
<td>PDA with 256 pixels, 240 mm external fiber length</td>
</tr>
<tr>
<td>000000-1392-178</td>
<td>MMS UV</td>
<td>195 – 390 nm</td>
<td>PDA with 256 pixels, 240 mm external fiber length, low solarization</td>
</tr>
</tbody>
</table>

[www.zeiss.com](http://www.zeiss.com)
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 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.

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>

**Technical Data**

- On-site electronics
- MCS FLEX Family
- PGs Family

**Software**

- Areas of application
- Definitions and explanations

**Introduction**

- Wavelength ranges
- MMS Family
- CGS Family
  - Technical Data
  - On-site electronics

**On-line electronics**

**MCS FLEX Family**

**PGs Family**

**Areas of application**

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<td>190 – 1015</td>
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<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</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 µm optical slit (can be varied upon request)</td>
<td></td>
</tr>
<tr>
<td>NA = 0.22 (homogeneous illumination of the acceptance angle)</td>
<td></td>
</tr>
<tr>
<td>600 µm mono-fiber interface recommended for customer</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grating</th>
<th>Flat field</th>
</tr>
</thead>
<tbody>
<tr>
<td>534 l/mm (in the center), blazed for approx. 230 nm</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spectral range</th>
<th>190 nm – 1015 nm</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Resolution (FWHM) with 50 µm slit</th>
<th>UV-VIS &lt; 2.2 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIR &lt; 2.5 nm</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Streak light (ASTM 387-04)</th>
<th>3 AU at 240 nm with deuterium lamp (absorption A₁₀ of NaI)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Integration time (dependent on on-site electronics)</th>
<th>min. 30 µs</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Hamamatsu S11156, back-thinned CCD, 2048 pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector height: 1 mm</td>
<td></td>
</tr>
<tr>
<td>Pixel pitch: 14 µm</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Housing size L x W x H</th>
<th>78 x 30 x 35 mm³</th>
</tr>
</thead>
</table>

CGS UV-NIR PDA

Technical Data

<table>
<thead>
<tr>
<th>Optical entrance</th>
<th>SMA connector</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 µm optical slit (can be varied upon request)</td>
<td></td>
</tr>
<tr>
<td>NA = 0.22 (homogeneous illumination of the acceptance angle)</td>
<td></td>
</tr>
<tr>
<td>600 µm mono-fiber interface recommended for customer</td>
<td></td>
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<tr>
<th>Spectral range</th>
<th>190 nm – 935 nm</th>
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</thead>
</table>

<table>
<thead>
<tr>
<th>Resolution (FWHM) with 50 µm slit</th>
<th>UV-VIS &lt; 2.0 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIR &lt; 2.0 nm</td>
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<table>
<thead>
<tr>
<th>Streak light (ASTM 387-04)</th>
<th>3 AU at 240 nm with deuterium lamp (absorption A₁₀ of NaI)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Integration time (dependent on on-site electronics)</th>
<th>min. 500 µs</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Hamamatsu S3903, 1024 pixels</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Housing size L x W x H</th>
<th>78 x 30 x 75 mm³</th>
</tr>
</thead>
</table>

Order number | Name | Wavelength range | Description |
-------------|------|------------------|-------------|
000001-794-791 | CGS UV-NIR CCD | 190 – 1015 nm | Back-thinned CCD, 2048 pixels |

Order number | Name | Wavelength range | Description |
-------------|------|------------------|-------------|
000000-2034-897 | CGS UV-NIR PDA | 190 – 935 nm | Hamamatsu S3903, NMOS linear image sensor, 1024 pixels |
ZEISS Spectrometer Modules
Compendium

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
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CGS UV-NIR PDA
On-site electronics

Configuration: an overview

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.
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.

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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 optoelectronic 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 $a \approx 13 \times 10^{-6}$). 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 $NA = 0.22$.

**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 in 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.
MCS FLEX PDA
Technical Data

Optical entrance
Cross-section converter

Cross-section converter
Diameter: 0.5 mm
NA = 0.22 (consistent illumination of the acceptance angle)
Mounted in an SMA connector

Grating
Flat field
248 l/mm (in the center), blazed for approx. 250 nm

Diode array
Manufacturer: Hamamatsu
Type: S 3904-1024Q
Number of pixels: 1024

Spectral range
190 – 1015 nm
Wavelength accuracy
≤ 0.5 nm
Temperature drift
≤ 0.009 nm/K
Spectral pixel distance
Δλ_{pixel} = 0.8 nm
Resolution
Δλ_{FWHM} = 3 – 4 nm
Stray light
≤ 0.1% at 340 nm with deuterium lamp
(Transmission of NaNO₂ solution, 50 g/l, 1cm)
Housing size L x W x H
160.3 x 62 x 122.2 mm

MCS FLEX CCD
Technical Data

Optical entrance
Cross-section converter

Cross-section converter
Diameter: 0.5 mm
NA = 0.22 (consistent illumination of the acceptance angle)
Mounted in an SMA connector

Grating
Flat field
248 l/mm (in the center), blazed for approx. 250 nm

Diode array
Manufacturer: Hamamatsu
Type: S 7031-1006
Number of pixels: 1044 x 64

Spectral range
190 – 980 nm
Wavelength accuracy
≤ 0.5 nm
Temperature drift
≤ 0.009 nm/K
Spectral pixel distance
Δλ_{pixel} = 0.8 nm
Resolution
Δλ_{FWHM} = 3 – 4 nm (UV-NIR version)
Stray light
≤ 0.1% at 340 nm with deuterium lamp
(Transmission of NaNO₂ solution, 50 g/l, 1cm)
Housing size L x W x H
160.3 x 62 x 122.2 mm

Order number Name Wavelength range Description
000000-1459-276 MCS FLEX CCD UV-NIR 190 – 1015 nm PDA with 1024 pixels
000000-1423-352 MCS FLEX CCD UV-NIR 190 – 980 nm with Hamamatsu CCD detector S7031 with 1024 (1044) x 64 pixels, short cross-section converter
000000-1701-305 MCS FLEX CCD UV-NIR 190 – 980 nm with Hamamatsu CCD detector S7031 with 1024 (1044) x 64 pixels, long cross-section converter
Introduction

Wavelength Ranges

MMS Family
CGS Family
MCS FLEX Family

Technical Data

On-site electronics

PGS Family

Software

Areas of application

Definitions and explanations

Email

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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). 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/or 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>960 – 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>

[Image of spectrometer module]
### PGS NIR 1.7-512

**Technical Data**

- **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

- **Input:** round
- **Output:** linear

- **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**
  - ∆λ_{pixel} ≈ 1.5 nm
- **Resolution**
  - ∆λ_{FWHM} ≈ 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**

- **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

- **Input:** round
- **Output:** linear

- **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**
  - ∆λ_{pixel} ≈ 3 nm
- **Resolution**
  - ∆λ_{FWHM} ≈ 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**
---|---|---|---
000001-1007-412 | PGS NIR 1.7-512 | 960 – 1690 nm | NIR spectral sensor, Peltier cooled, InGaAs PDA up to 1.7 µm, 512 pixels, dispersion: 1.5 nm/pixel, external fiber length: 300 mm

**Order number** | **Name** | **Wavelength range** | **Description**
---|---|---|---
000001-1381-397 | PGS NIR 1.7-256 | 960 – 1690 nm | NIR spectral sensor, Peltier cooled, InGaAs PDA up to 1.7 µm, 256 pixels, dispersion: 3.0 nm/pixel, external fiber length: 300 mm
### PGS NIR 2.0-256

**Technical Data**

**Optical entrance**
- Fiber consists of Infrasil quartz glass
- Diameter: 3.6 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. 1.4 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

**Order number**
- 000000-1396-757

**Name**
- PGS NIR 2.0

**Wavelength range**
- 1340 – 2000 nm

**Description**
- 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**
- Fiber consists of Infrasil quartz glass
- Diameter: 3.6 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

**Order number**
- 000000-1332-256

**Name**
- PGS NIR 2.2

**Wavelength range**
- 1000 – 2150 nm

**Description**
- NIR spectral sensor, Peltier cooled
- Extended InGaAs PDA up to 2.2 µm
- 256 pixels, dispersion: 5 nm/pixel, external fiber length: 300 mm

---

### Order numbers

**Order number**
- 000000-1396-757

**Name**
- PGS NIR 2.0

**Wavelength range**
- 1340 – 2000 nm

**Description**
- 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

---

**Order number**
- 000000-1332-256

**Name**
- PGS NIR 2.2

**Wavelength range**
- 1000 – 2150 nm

**Description**
- NIR spectral sensor, Peltier cooled
- Extended InGaAs PDA up to 2.2 µm
- 256 pixels, dispersion: 5 nm/pixel, external fiber length: 300 mm

---

**Email**

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# PGS NIR 1.7-256 UC

## Technical Data

<table>
<thead>
<tr>
<th><strong>Optical entrance</strong></th>
<th><strong>Input:</strong> round</th>
<th><strong>FSM A 905</strong></th>
</tr>
</thead>
</table>
| **Output:** linear | **FSCA 905**<br>**Nk = 0.22 (homogeneous illumination of the acceptance angle)**<br>**Mounted in an SMA connector**<br>**UV width: 80 µm**<br><br>**Filter**<br><br>**Grating**<br><br>**Plane grating, 484 l/mm, Blazed for approx. 1.2 µm**<br><br>**Diode array**<br><br>**Manufacturer:** Hamamatsu<br>**Type:** G9211-01SP<br>**Number of pixels:** 256<br><br>**Spectral range:** 960 – 1690 nm<br>**Wavelength accuracy:** ± 1 nm<br>**Temperature drift (10 – 40°C):** ≤ 0.012 nm/K<br>**Spectral pixel distance:** Δλ_{Pixel} ≈ 3 nm<br>**Resolution:** Δλ_{FWHM} ≈ 8 nm<br>**Stray light:** ≤ 0.1% at transmission of 10 mm of water at 1405 nm (measured using a halogen lamp)<br><br>**Weight:** approx. 590 g<br>**Operating temperature:** 0 – 40°C (standard, depending on cooling electronics)<br>**Storage temperature:** -40 – +70°C

## Order number

<table>
<thead>
<tr>
<th>Order number</th>
<th>Name</th>
<th>Wavelength range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>000000-2109-070</td>
<td>PGS NIR 1.7-256 UC</td>
<td>960 – 1090 nm</td>
<td>NIR spectral sensor, uncooled Extended InGaAs PDA up to 1.7 µm 256 pixels, dispersion: 3 nm/pixel, external fiber length: 300 mm</td>
</tr>
</tbody>
</table>
Introduction
Wavelength ranges
MMS Family
CGS Family
MCS FLEX Family
PGS Family
Technical Data
On-site electronics
Software
Areas of application
Definitions and explanations

Configuration: an overview

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 as 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). The fast FEE-1M requires high-speed USB communication. All electronic circuit boards designed to be integrated into a customer’s housing.

PGS On-site electronics

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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.

### Software Solutions

**Directly in the process**

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.
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. Compares and invariancy to external influences are crucial so that modules can be installed in close proximity to production. An on-lime control option is provided in most of the applications mentioned below.

Measuring principles:
1. Emission
2. Diffuse reflection
3. Reflection
4. Transmission – absorption
5. White light interference

Emission

A part of the light is injected into the spectrometer to determine the spectral emission of a light source. In many cases, the coupling fiber bundle only needs to be brought close to the light source because of the high light sensitivity. An achromatic converging lens can be used for optimization.

Examples
- Monitoring illuminators (aging)
- Luminescence, fluorescence
- Monitoring the solar spectrum, discharges or emissions
- Determining the wavelength of LEDs or tunable lasers
- Performing layer thickness measurement on photoresists

Requirements
- The wavelength accuracy is very high for the size of the module.
- Spectral resolution available in close proximity to production. An on-line control option is provided in most of the applications mentioned below.

Diffuse reflection

The diffuse reflection (from rough surfaces) provides information on the color of the surface. In addition to the spectrometer, the light source and the placement (angle to surface normal) of the spectral sensor are important. In most cases, a light source with a wide-band emission is used, e.g. a halogen lamp. In this case, it is usually sufficient to bring the cross section conversion entrance close to the surface to be measured without an additional optic.

Examples
- Color measurements on diverse surfaces (materials)
- Determining paper quality
- Determining the fat content in meat and sausages
- Determining the sugar and alcohol content in beverages
- Determining the moisture content in humidity in grains, food and cellulose

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 thicknesses 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 \(\alpha\) (\(I_G\), radiated intensity, \(I_0\) transmitted intensity). Immersion prisms connected to a light source and a spectrometer module via fibers are the simplest way to measure the concentration \(c\) of liquids. The concentration is related to the absorption constant via the extinction coefficient \(e\). Otherwise, setting up a collimated beam path is recommended. However, it is also possible to work with the cross section converter entrance in direct contact with the object to be measured.

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

Reflection

Reflection is a special case of diffuse reflection and refers to the directionally reflected light from rough or low scatter surfaces. A light source is also required in addition to the sensor. Please note that the reflectivity depends strongly on the angle. A simple setup for measurements under 18° is possible by using a special light guide which both supplies the light and transmits it to the detector.

Examples
- Displaying paper quality
- Determining the temperature \(T\) as per Wien’s displacement law: \(n \approx T \approx 2.8978 \times 10^6 \text{ m K}\)

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 thicknesses 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).

E.g. MMS 1, \(n = 1.5\)

\[d_{\text{min}} = 25 \mu m, d_{\text{max}} = 0.2 \mu m\]

\[2 \pi n d = n \pi (\lambda_2 - \lambda_1)\]
Definitions and Explanations of Terms

One of the most important criteria when selecting a spectrometer is the spectral range which the spectrometer must cover. It is usually clear what range is required. However, the two other important criteria for a spectrometer – the spectral and the intensity-related (dynamical) 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 determining the line width of a line or a band
3. Measuring a line with respect to peak wavelength and intensity at the maximum – e.g. determining emissions.

Spectral resolving power

The Rayleigh criterion is relevant for splitting spectral lines as per DIN. This shows how large the spectral distance of two lines must be so that each line can be recognized as separate and not merged with each other. The spectral width of the individual lines \( \Delta \lambda_{\text{FWHM}} \) (see above) must be significantly less than their distance. This is the only significant definition for the spectral resolving power.

\[ \text{Spectral resolving power} = \frac{\text{Line distance}}{\text{Line width}} \]

Special features of diode array spectrometers (DAS)

1. Wavelength accuracy
   - To determine the absolute spectral position \( \lambda \), with a certain accuracy \( \Delta \lambda_{\text{abs}} \), an individual line, a spectrometer with at least this absolute wavelength accuracy \( \Delta \lambda_{\text{abs}} \) is required. The parameter depends on the position accuracy of the readout elements (pixels or slits/detectors) and the stability of this position.
   - 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 spectral sensor depends on the mechanical stability and the temperature-determined wavelength drift. The former is completely non-critical for spectrometer modules and the drift is practically negligible.

2. Spectral line width
   - The Rayleigh criterion is relevant for splitting spectral lines as per DIN. This shows how large the spectral distance of two lines \( \Delta \lambda_{\text{FWHM}} \) must be so that each line can be recognized as separate from each other. The spectral width of the individual lines \( \Delta \lambda_{\text{FWHM}} \) (see above) must be significantly less than their distance. This is the only significant definition for the spectral resolving power.

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 \( \Delta \lambda_{\text{FWHM}} \) can be measured. It is important to know the expansion \( \Delta \lambda_{\text{FWHM}} \) created by the spectrometer. This property is related to the Rayleigh criterion.

\[ \Delta \lambda_{\text{FWHM}} = \frac{1}{2} \lambda \left( \frac{\text{pixel peak intensity}}{2} - \frac{\text{pixel valley intensity}}{2} \right) \]

3. Dispersion
   - The specification \( \Delta \lambda_{\text{pixel}} \) is 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 \( \Delta \lambda_{\text{FWHM}} \).

\[ \Delta \lambda_{\text{FWHM}} = 3 \times \Delta \lambda_{\text{pixel}} \]

4. Special properties of diode array spectrometers (DAS)

   a. Wavelength accuracy
      - The position of the maxima corresponds relatively exactly to the central wavelengths of the pixels displayed.
      - If, however, the maximum of a line is imaged onto the dividing line of two pixels \( \lambda_{i}, \lambda_{j} \), then four pixels are required to establish a clear reduction in pixel intensities. Both pixels exhibit roughly the same intensity so that a reduction to 81% is only displayed in the next pixel \( \lambda_{i+1} \). In this case, the real maxima are separated by less than three pixels. However, the DAS displays a spectral distance of \( 3 \times \Delta \lambda_{\text{pixel}} \) because a diode array only captures discrete values with the step size of the pixel dispersion. A total of four pixels are required for the evaluation.

5. Spectral resolution
   - Determined by the fixed position of the pixels and the wavelength of the radiation, the resolution is different on monochromators/spectrometers with movable elements. Resolution is also defined by ‘splitting two adjacent lines’ – depends on the relative position of these lines with respect to the pixels.

\[ \Delta \lambda_{\text{FWHM}} = \frac{1}{2} [b/(2a)]^2 - \frac{[c - \text{peak intensity}]/a}{2a} \]

6. Intensity resolution
   - The following equation can be used to calculate the intensity resolution of a diode array spectrometer.

\[ \text{Intensity resolution} = \frac{\text{Relative peak intensity}}{\text{Peaks} - \text{Baseline}} \]

7. Spectral line width
   - The Rayleigh criterion is relevant for splitting spectral lines as per DIN. This shows how large the spectral distance of two lines \( \Delta \lambda_{\text{FWHM}} \) must be so that each line can be recognized as separate from each other. The spectral width of the individual lines \( \Delta \lambda_{\text{FWHM}} \) (see above) must be significantly less than their distance. This is the only significant definition for the spectral resolving power.

\[ \text{Spectral line width} = \frac{1}{2} \lambda \left( \frac{\text{pixel peak intensity}}{2} - \frac{\text{pixel valley intensity}}{2} \right) \]

8. Special features of diode array spectrometers (DAS)
   - Determined by the fixed position of the pixels and/or the wavelength of the radiation, the resolution is different on monochromators/spectrometers with movable elements. Resolution is also defined by ‘splitting two adjacent lines’ – depends on the relative position of these lines with respect to the pixels.

\[ \Delta \lambda_{\text{FWHM}} = \frac{1}{2} [b/(2a)]^2 - \frac{[c - \text{peak intensity}]/a}{2a} \]

9. Spectral resolution
   - The position of the maxima corresponds relatively exactly to the central wavelengths of the pixels displayed.
   - If, however, the maximum of a line is imaged onto the dividing line of two pixels \( \lambda_{i}, \lambda_{j} \), then four pixels are required to establish a clear reduction in pixel intensities. Both pixels exhibit roughly the same intensity so that a reduction to 81% is only displayed in the next pixel \( \lambda_{i+1} \). In this case, the real maxima are separated by less than three pixels. However, the DAS displays a spectral distance of \( 3 \times \Delta \lambda_{\text{pixel}} \) because a diode array only captures discrete values with the step size of the pixel dispersion. A total of four pixels are required for the evaluation.

\[ \Delta \lambda_{\text{FWHM}} = \frac{1}{2} [b/(2a)]^2 - \frac{[c - \text{peak intensity}]/a}{2a} \]

10. Intensity resolution
   - The following equation can be used to calculate the intensity resolution of a diode array spectrometer.

\[ \text{Intensity resolution} = \frac{\text{Relative peak intensity}}{\text{Peaks} - \text{Baseline}} \]
**Definitions and explanations**

**Accuracy**
Measurements of minimal changes and stability depend directly on each other and are essentially determined by the noise within the electronics because most spectrometers ensure a stable ‘light path’. As with all sizes, it is important how a value – in the present sense of the word - is determined. For the spectrometer module specifications, e.g. a 10 µm integration time is selected and the standard deviation Δσ is calculated above 25 captures. This supplies a measure for the accuracy Δσ which can be used to determine an intensity value.

\[ \Delta I = I_{\text{meas}} - I_{\text{true}} \]

**Dynamics and intensity changes**

The dynamic is understood as the relationship between the saturation level ΔI and the noise ΔI. It corresponds to the signal-to-noise ratio S/N. (The usable range is still reduced by ΔI.

\[ S/N = I_{\text{sat}} / I_{\text{noise}} \]

Or 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 16384 steps or increments – and a noise of ΔI = 1 count, a signal (fully controlled) can actually be divided into 2^14 = 16384 steps. The smallest measurable change is then 1/16384 of the saturation signal. There is an uncertainty of four counts with a noise of four counts, i.e. only 0.6% of the saturation signal can be measured as a definitive change and/or the signal can be meaningfully divided into 4096 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.

\[ \text{Dynamic} = \text{Range ADC} / \text{ΔI} \]

**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 illumination. The admissible deviation must be specified for quantitative information to be obtained. Fortunately, modern semiconductor detectors exhibit almost perfect linear behavior over many ranges. Before reaching saturation (the extreme case of non-linearity), however, the increase in the electricity supplied (information carrier for intensity) is no longer linear to the number of photons hitting the photo-sensitive 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 1000 °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 1.5 ppm, even for InGaAs photo-diode 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<sub>d</sub> increases with rising temperature, resulting in a reduction of the dynamic range. This is why detectors – in particular InGaAs photo-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.

**Optical interface**

The etendue is the result of the numeric aperture (NA).

\[ \text{Etendue} = \text{NA}^2 \times \text{NA} \]

or the opening or spatial angle of 70 µm individual fibers for the QSW on the MMS modules are nearly perfect for a pixel width of 25 µm. The number of fibers must be specified for quantitative information to be obtained. A 4% Fresnel reflection loss (index jump at the glass fiber). The photodiode arrays used do not show any deterioration in the signal-to-noise ratio. Only the dark current I<sub>d</sub> increases with rising temperature, resulting in a reduction of the dynamic range. This is why detectors – in particular InGaAs photo-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.

**Transmission increase**

The transmission increase is calculated above 20 captures.

\[ \text{Transmission increase} = \frac{I_{\text{true}}}{I_{\text{meas}}} \]

**Sensitivity**

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 very narrow bandwidth, as featured with most lasers. The situation is at least clear if the bandwidth is significantly smaller than the spectrometer bandwidth. The MMS value of over 10^7 counts/s/Hz has been measured with a red Helio 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 155-175 nm.

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 module, 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 nm, R<sub>G</sub> 850 filter and 10 mm water absorption.

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 at 1 ppm, a 10% change in the effective radiation means a change of 10° °. The causative radiation is not used, then the proportion can be further reduced via filtering. In the example described, a blockage of 10% leads to a total change of 10°. There are only small limitations to measuring minute 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 SBA plug-in connection – such as that used on all models – is a useful mechanical interface in the plastic, resulting in a clear interfacing along with the well-defined etendue of a fiber bundle.

**Emission**

The light etendue G is the product of the light entrance surface F and the opening or spatial angle θ of the light bundle where by the calculation index n must still be observed. The first factor corresponds to the fiber (bundle) cross section. The second factor is the result of the numeric aperture (NA).

\[ G = F \times \pi \times \theta \]

In the MMS family, the etendue is calculated at G = 0.157 mm² for

\[ \text{NA} = \sin (\theta) \]

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 to 4.4% Fresnel reflection loss (index jump at the glass fiber) must be divided.

**Transmission increase**

Assuming the beam is round, then an increase in transmission of \(\Delta I / I_{\text{true}}\%\) is achieved by using a cross-section converter (CSC) 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 CSC, the transmitted portion through the fill factor is \(\pi \times d_{\text{eff}}^2 / 4\). The fill factor is defined as an optically effective surface \(A_{\text{eff}}\) with respect to the illuminated entire surface \(A_{\text{ill}}\). In the case of the QSW, the product of the fiber core cross-section with the diameter \(d_{\text{core}}\) 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 \(d_{\text{eff}} = h\).

### Diode array spectrometer optimization

In addition to selecting extremely efficient components (blazed gratings, in the ideal case, perfect dispersion, imaging properties, entrance slit, pixel size and pixel distances must be considered as well). What is the most crucial is that - with monochromatic light – more than 2 pixels are illuminated for the spectral resolution. The grating images 1:1 in the first approximation, e.g. the entrance 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. That is why the selection of 70 µm individual fibers for the QSW on the MMS modules are nearly perfect for a pixel width of 25 µm. The number of fibers is the result of the pixel height divided by the external diameter of the individual fibers.
Introduction

Wavelength ranges

MMS Family
CGS Family
MCS FLEX Family
PGS Family

Software

Areas of application

Definitions and explanations

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