AvaSpec-2048x14 High UV-sensitivity back-thinned CCD Spectrometer

The AvaSpec-2048x14 Fiber Optic Spectrometers is a back-thinned type CCD spectrometer with high quantum efficiency and high UV sensitivity. The optical design is based on the AvaBench-75 symmetrical Czerny-Turner design with a 2048x14 pixels high UV sensitive CCD image sensor. The image sensor is used as a linear array of 2048 pixels binning the vertical 14 pixels to optimize efficiency. The spectrometer has a fiber optic entrance connector (standard SMA, others possible), collimating and focusing mirror and a diffractional grating. A choice of 16 different gratings with different dispersion and blaze angles enable applications in the 200-1160nm range. The AvaSpec-2048x14 comes with a 16 bit AD converter, and USB2.0 high speed interface. The AvaSpec-2048x14 is especially suitable for measuring low light, fluorescence and UV- applications. Digital IO ports enable external triggering and control of shutter and pulsed light sources from the Avantes line of instruments.

The new AvaSpec-2048x14 has a USB2 interface with fast data sampling of 450 spectra per second and data transfer in 2.24 msec and supports analog in-and outputs as well. Optional Bluetooth® (-BT) communication and an SD card for on-board saving of spectra can be added. The AvaSpec-2048x14-USB2 runs on USB power and comes with AvaSoft-basic, a complete manual and USB interface cable. Multiple (up to 127) USB2 spectrometers with different detector types can be externally coupled (see section multi-channel spectrometers, page 32).

AvaSpec-2048x14

NEW

Technical Data

Optical Bench	Symmetrical Czerny-Turner, 75 mm focal length
Wavelength range	200-1160 nm
Resolution	0.04 –20 nm, depending on configuration (see table)
Stray light	< 0.1%
Sensitivity (AvaLight-HAL, 8 µm fiber)	16,000 counts (16-bit AD)/µW -per ms integration time
UV Quantum efficiency	35-65% (200-300nm)
Detector	Back-thinned CCD image sensor 2048x14 pixels
Signal/Noise	500:1
AD converter	16 bit, 1.5MHz
Integration time	2.24 msec – 10 minutes
Interface	USB 2.0 high speed, 480 Mbps or RS-232, 115.200 bps
Sample speed with on-board averaging	2.24 msec / scan
Data transfer speed	2.24 msec / scan
Digital IO	HD-26 connector, 2 Analog in, 2 Analog out, 3 Digital in, 12 Digital out, trigger, synchronization
Power supply	Default USB power, 350 mA. Or with SPU2 external 12VDC, 350 mA
Dimensions, weight	175 x 110 x 44 mm (1 channel), 716 grams

Spectrometers

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Grating selection table for AvaSpec-2048x14

Use	Useable range	Spectral range (nm)	Lines/mm	Blaze (nm)	Order code
UV/VIS/NIR	200-1160**	900**	300	300	UA
UV/VIS	200-850	520	600	300	UB
UV	200-750	250-220*	1200	250	UC
UV	200-650	165-145*	1800	UV	UD
UV	200-580	115-70*	2400	UV	UE
UV	220-400	75-50*	3600	UV	UF
UV/VIS	250-850	520	600	400	BB
VIS/NIR	300-1160**	800**	300	500	VA
VIS	360-1000	500	600	500	VB
VIS	300-800	250-200*	1200	500	VC
VIS	350-750	145-100*	1800	500	VD
VIS	350-640	75-50*	2400	VIS	VE
NIR	500-1050	500	600	750	NB
NIR	500-1050	220-150*	1200	750	NC
NIR	600-1160**	500**	300	1000	IA
NIR	600-1160	500	600	1000	IB

** depends on the starting wavelength of the grating; the higher the wavelength, the bigger the dispersion and the smaller the range to select*
***please note that not all 2048 pixels will be used for the useable range*

Resolution table (FWHM) for AvaSpec-2048x14

	Slit size (µm)					
Grating (lines/mm)	**10**	**25**	**50**	**100**	**200**	**500**
300	0.8	1.4	2.4	4.3	8.0	20.0
600	0.4	0.7	1.2	2.1	4.1	10.0
1200	0.1-0.2*	0.2-0.3*	0.4-0.6*	0.7-1.0*	1.4-2.0*	3.3-4.8*
1800	0.07-0.12*	0.12-0.21*	0.2-0.36*	0.4-0.7*	0.7-1.4*	1.7-3.3*
2400	0.05-0.09*	0.08-0.15*	0.14-0.25*	0.3-0.5*	0.5-0.9*	1.2-2.2*
3600	0.04-0.06*	0.07-0.10*	0.11-0.16*	0.2-0.3*	0.4-0.6*	0.9-1.4*

** depends on the starting wavelength of the grating; the higher the wavelength, the bigger the dispersion and the better the resolution*

ORDERING INFORMATION	
AvaSpec-2048x14-USB2	Fiber Optic Spectrometer, 75 mm Avabench, 2048x14 pixel back-thinned CCD detector, USB powered high speed USB2 interface, incl AvaSoft-Basic, USB interface cable, specify grating, wavelength range and options
AvaSpec-2048x14-SPU2	Fiber Optic Spectrometer, 75 mm Avabench, 2048x14 pixel back-thinned CCD detector, high speed USB2 interface, incl. switch for USB power or external power for RS232/BT, AvaSoft-Basic, USB interface cable, specify grating, wavelength range and options
Options	
-SPU2-BT	Bluetooth® interface for USB2 platform only, including antenna and switch
SDXXX	Internal XXX MB SD card for on board data saving, for USB2 platform only
SLIT-XX	Slit size, please specify XX = 10, 25, 50, 100, 200, 500 µm
OSF-YYY	Order sorting filter for 2nd order effects filtering, please specify YYY= 375, 475, 515, 550, 600 nm
OSC	Order sorting coating with 590nm long pass filter for VA, BB (>350nm) and VB gratings in AvaSpec-2048x14
OSC-UA	Order sorting coating with 350 and 590nm longpass filter for UA gratings in AvaSpec-2048x14
OSC-UB	Order sorting coating with 350 and 590nm longpass filter for UB or BB (<350nm) gratings in AvaSpec-2048x14

Spectrometers

Introduction Fiber Optic Spectroscopy

Optical spectroscopy is a technique for measuring light intensity in the UV-, VIS-, NIR- and IR-region. Spectroscopic measurements are being used in many different applications, such as color measurement, concentration determination of chemical components or electromagnetic radiation analysis. For more elaborate application information and setups, please see further the Application chapter at the end of this catalog.

A spectroscopic instrument generally consists of entrance slit, collimator, a dispersive element, such as a grating or prism, focusing optics and detector. In a monochromator system there is normally also an exit slit, and only a narrow portion of the spectrum is projected on a one-element detector. In monochromators the entrance and exit slits are in a fixed position and can be changed in width. Rotating the grating scans the spectrum.

Development of micro-electronics during the 90's in the field of multi-element optical detectors, such as Charged Coupled Devices (CCD) Arrays and Photo Diode (PD) Arrays, enabled the production of low cost scanners, CCD cameras etc. The same CCD and PDA detectors are now used in the Avantes line of spectrometers, enabling fast scanning of the spectrum, without the need of a moving grating.

Thanks to the need for fiber optics in the communication technology, low absorption silica fibers have been developed. Similar fibers can be used as measurement fibers to transport light from the sample to the optical bench of the spectrometer. The easy coupling of fibers allows a modular build-up of a system that consists of light source, sampling accessories and fiber optic spectrometer.

Advantages of fiber optic spectroscopy are the modularity and flexibility of the system. The speed of measurement allows in-line analysis, and the use of low-cost commonly used detectors enable a complete low cost Avantes spectrometer system.

Optical Bench Design

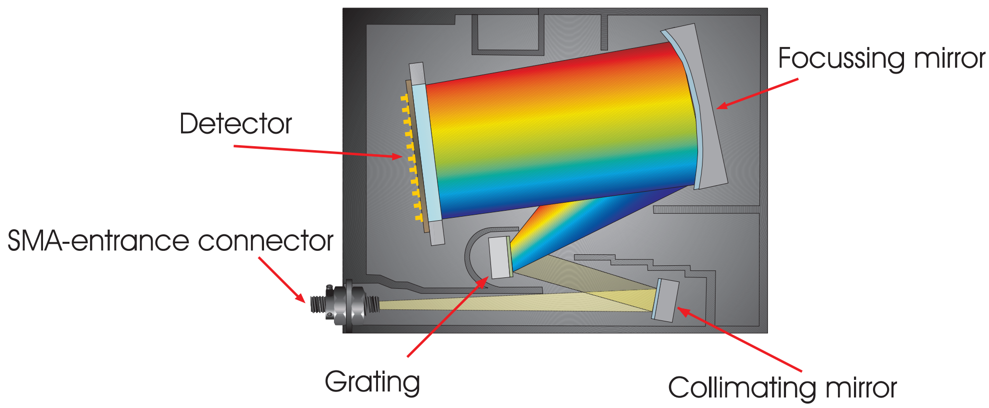


Figure 1 Optical bench design

The heart of the AvaSpec fiber optic spectrometer is an optical bench with 45, 50 or 75 mm focal length, developed in a symmetrical Czerny-Turner design (figure 1).

Light enters the optical bench through a standard SMA905 connector and is collimated by a spherical mirror. A plane grating diffracts the collimated light; a second spherical mirror focuses the resulting diffracted light. An image of the spectrum is projected onto a 1-dimensional linear detector array.

The optical bench has a number of components installed inside, allowing a wide variety of different configurations, depending on the intended application. The choice of these components such as the diffraction grating, entrance slit, order sorting filter, and detector coating have a strong influence on system specifications. Sensitivity, resolution, bandwidth and stray light are further discussed in the following paragraphs.

Spectrometers

How to configure a spectrometer for your application?

In the modular AvaSpec design a number of choices have to be made on several optical components and options, depending on the application you want to use the spectrometer for.
This section should give you some guidance on how to choose the right grating, slit, detector and other options, installed in the AvaSpec.

1. Wavelength Range

In the determination for the optimal configuration of a spectrometer system the wavelength range is the first important parameter that defines the grating choice. If you are looking for a wide wavelength range, we recommend to take an A-type (300 lines/mm) or B-type (600 lines/mm) grating (see Grating selection table in the spectrometer product section). The other important component is the detector choice, Avantes offers 9 different detector types with each different sensitivity curves (see figure 5). For UV applications the new 2048x14 pixel back-thinned CCD detector, the 256/1024 pixel CMOS detectors or DUV- enhanced 2048 or 3648 pixel CCD detectors may be selected. For the NIR range 3 different InGaAs detectors are available.
If you want to combine a wide range with a high resolution, a multiple channel spectrometer may be the best choice.

2. Optical Resolution

If you desire a high optical resolution we recommend to pick a grating that has 1200 or more lines/mm (C,D,E or F types) in combination with a narrow slit and a detector with 2048 or 3648 pixels, for example 10 µm slit for the best resolution on the AvaSpec-2048 (see Resolution table in the spectrometer product section)

3. Sensitivity

Talking about sensitivity, it is very important to distinguish between photometric sensitivity (How much light do I need for a detectable signal?) and chemometric sensitivity (What absorbance difference level can still be detected?)

a. Photometric Sensitivity

In order to achieve the most sensitive spectrometer in for example Fluorescence or Raman applications we recommend the 2048 pixel CCD detector, as in the AvaSpec-2048. Further we recommend the use of a DCL-UV/VIS detector collection lens, a relatively wide slit (100µm or wider) or no slit and an A type grating. For an A-type grating (300 lines/mm) the light dispersion is minimal, so it has the highest sensitivity of the grating types. Optionally the Thermo-electric cooling of the CCD detector (see product section AvaSpec-2048-TEC, page 30) may be chosen to minimize noise and increase dynamic range at long integration times (60 seconds).

For optimal UV sensitivity we recommend the back-thinned UV sensitive CCD detector, as implemented in the AvaSpec-2048x14.
For the different detector types the photometric sensitivity is given in table 4, the spectral sensitivity for each detector is depicted in figure 5.

b. Chemometric Sensitivity

To detect two absorbance values, close to each other with maximum sensitivity you need a high Signal to Noise (S/N) performance. The detector with best S/N performance is the 2048x14 pixel back-thinned CCD detector, next to the 256/1024 CMOS detector in the AvaSpec-256/1024. The S/N performance can also be enhanced by averaging over multiple spectra.

4. Timing and Speed

The data capture process is inherently fast with detector arrays and no moving parts. However there is an optimal detector for each application. For fast response applications, we recommend to use the AvaSpec- USB2 platform spectrometers. When datatransfer time is critical we recommend to select a small amount of pixels to be transferred with the UBS2 interface. Data transfer time can be enhanced by selecting the pixel range of interest to be transmitted to the PC; in general the AvaSpec-128 may be considered as the fastest spectrometer with more than 8000 scans per second.

The above parameters are the most important in choosing the right spectrometer configuration, please contact our application engineers to optimize and fine-tune the system to your needs. On the next page you will find a quick reference table 1 for most common applications, for a more elaborate explanation and configurations, please refer to the applications section in the back of this catalog.

In addition we have introduced in this catalog application icons, that will help you to find the right products and accessories for your applications.

- Biomedical Technology
- Chemistry
- Colorimetry
- Food Technology
- Inline Process Control
- Radiometry
- Thinfilm Analysis

Table 1 Quick reference guide for spectrometer configuration

Application	AvaSpec-type	Grating	WL range (nm)	Coating	Slit	FWHM Resolution (nm)	DCL	OSF	OSC
Biomedical	2048	NB	500-1000	-	50	1.2	-	475	-
Chemometry	1024	UA	200-1100	-	50	2.0	-	-	OSC-UA
Color	128	VA	360-780	-	100	6.4	X/-	-	-
	256	VA	360-780	-	50	3.2	-	-	-
	2048	BB	360-780	-	200	4.1	X/-	-	-
Fluorescence	2048	VA	350-1100	-	200	8.0	X	-	OSC
Fruit-sugar	128	IA	800-1100	-	50	5.4	X	600	-
Gemology	2048	VA	350-1100	-	25	1.4	X	-	OSC
High	2048	VD	600-700	-	10	0.07	-	550	-
resolution	3648	VD	600-700	-	10	0.05	-	550	-
High UV-Sensitivity	2048x14	UC	200-450	-	200	2.0	-	-	-
Irradiance	2048	UA	200-1100	DUV	50	2.8	X/-	-	OSC-UA
Laserdiode	2048	NC	700-800	-	10	0.1	-	600	-
LED	2048	VA	350-1100	-	25	1.4	X/-	-	OSC
LIBS	2048FT	UE	200-300	DUV	10	0.09	-	-	-
	2048USB2	UE	200-300	DUV	10	0.09	-	-	-
Raman	2048TEC	NC	780-930	-	25	0.2	X	600	-
Thin Films	2048	UA	200-1100	DUV	-	4.1	X	-	OSC-UA
UV/VIS/NIR	2048	UA	200-1100	DUV	25	1.4	X/-	-	OSC-UA
	2048x14	UA	200-1100	-	25	1.4	-	-	OSC-UA
NIR	NIR256-1.7	NIRA	900-1750	-	50	5.0	-	1000	-
	NIR256-2.2	NIRZ	1200-2200	-	50	10.0	-	1000	-
	NIR256-2.5	NIRY	1000-2500	-	50	15.0	-	1000	-

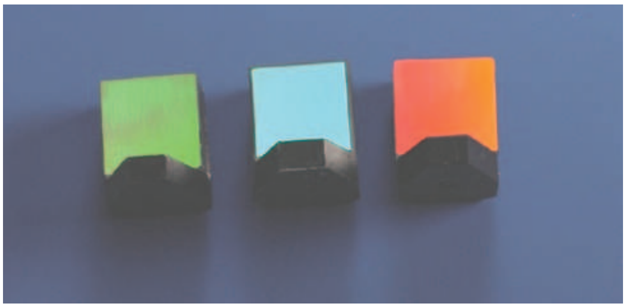
How to choose the right Grating?

A diffraction grating is an optical element that separates incident polychromatic radiation into its constituent wavelengths. A grating consists of series of equally spaced parallel grooves formed in a reflective coating deposited on a suitable substrate.

The way in which the grooves are formed separates gratings in two types, holographic and ruled. The ruled gratings are physically formed into a reflective surface with a diamond on a ruling machine. Gratings produced from laser constructed interference patterns and a photolithographic process are known as holographic gratings. In the Avaspec Spectrometers both ruled and holographic gratings are used.

The fiber optic spectrometer comes with a permanently installed grating that must be specified by the user. Further the user needs to indicate what wavelength range needs to reach the detector. Sometimes the specified usable range of a grating is larger than the range that can be projected on the detector. In order to cover a broader range, a dual or triple beam spectrometer can be chosen. Then master and slave(s) have different gratings. Similarly, a higher resolution over a wide range can be achieved by using a dual or triple spectrometer.

Different diffraction gratings



For each spectrometer type, a grating selection table is shown in the Spectrometer Platforms section. Table 2 illustrates how to read the grating selection table. The spectral range to select in Table 2 depends on the starting wavelength of the grating and the number of lines/mm; the higher the wavelength, the bigger the dispersion and the smaller the range to select. In Figure 2 their efficiency curves are shown.

When looking at the grating efficiency curves, please realize that the total system efficiency will be a combination of fiber transmission, grating and mirror efficiency, detector and coatings sensitivities. In Figure 3 the grating dispersion curves are shown for the AvaSpec-2048.

Table 2 Example of spectral range and gratings

Use	Useable range	Spectral range (nm)	Lines/mm	Blaze (nm)	Order code
UV/VIS/NIR	200-1100	900	300	300	UA
UV/VIS	200-850	520	600	300	UB
UV	200-750	250-220*	1200	250	UC
UV	200-650	165-145*	1800	UV	UD
UV	200-580	115-70*	2400	UV	UE
UV	220-400	75-50*	3600	UV	UF
UV/VIS	250-850	520	600	400	BB
VIS/NIR	300-1100	800	300	500	VA
VIS	360-1000	500	600	500	VB
VIS	300-800	250-200*	1200	500	VC
VIS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
NIR	500-1050	500	600	750	NB
NIR	500-1050	220-150*	1200	750	NC
NIR	[illegible]	500	[illegible]	[illegible]	[illegible]
NIR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

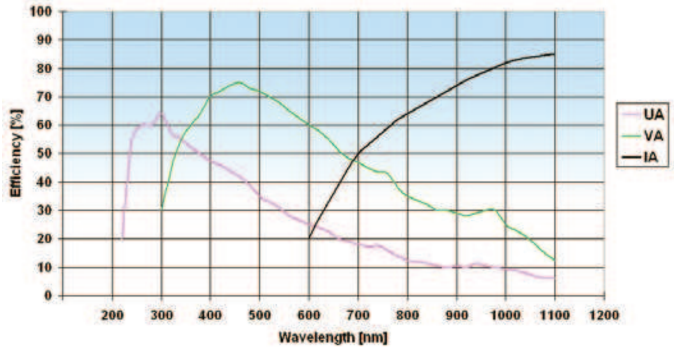
Please select Spectral range band-width from the useable Wavelength range, for example: grating UE (200-315nm)
***the spectral range depends on the starting wavelength of the grating; the higher the wavelength, the smaller the range.**
For example grating UE (510-580 nm)

The order code is defined by 2 letters: the first is the Blaze (U= 250/300nm or UV for holographic, B=400nm, V=500nm or VIS for holographic, N=750nm, I=1000nm) and the second the nr of lines/mm (Z=150, A=300, B=600, C=1200, D=1800, E=2400, F=3600 lines/mm)

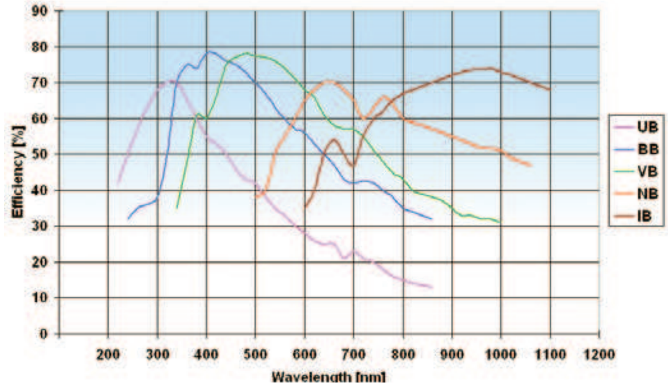
Spectrometers

Figure 2 Grating Efficiency Curves

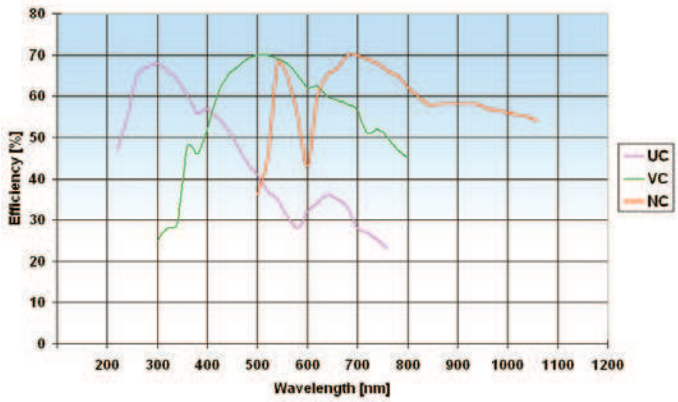
300 Lines/mm Gratings



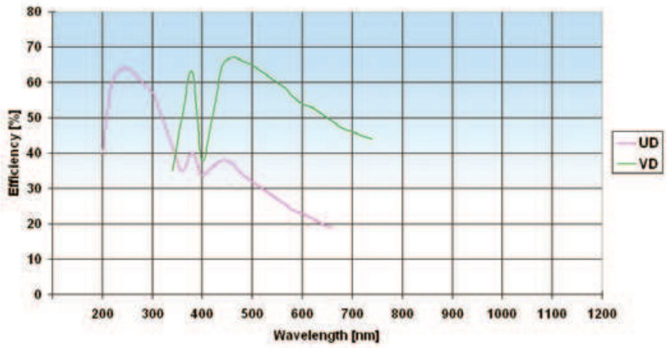
600 Lines/mm Gratings



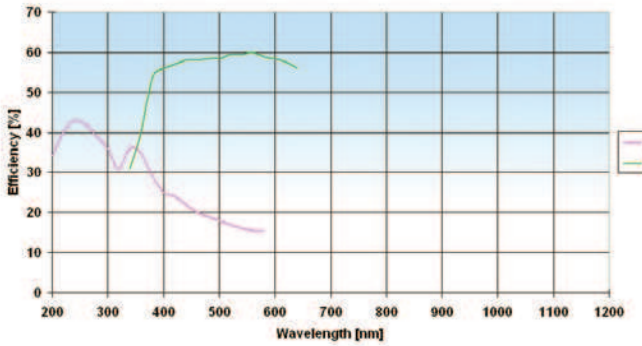
1200 Lines/mm Gratings



1800 Lines/mm Gratings



2400 Lines/mm Gratings



3600 Lines/mm Gratings

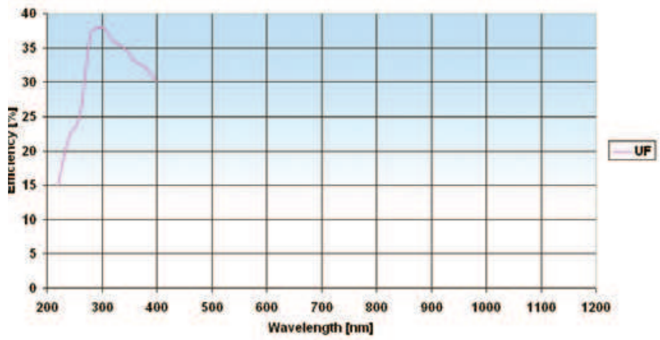
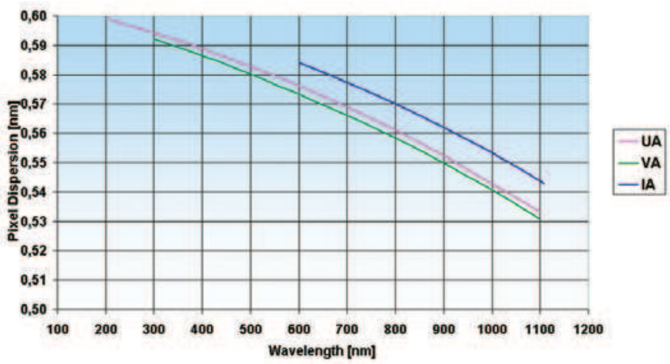
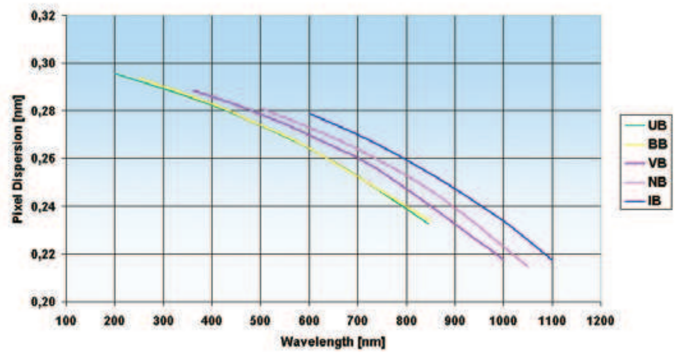


Figure 3 Grating Dispersion Curves

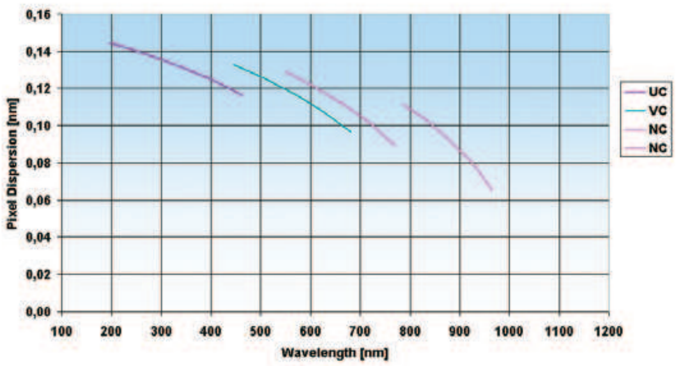
300 Lines/mm Gratings



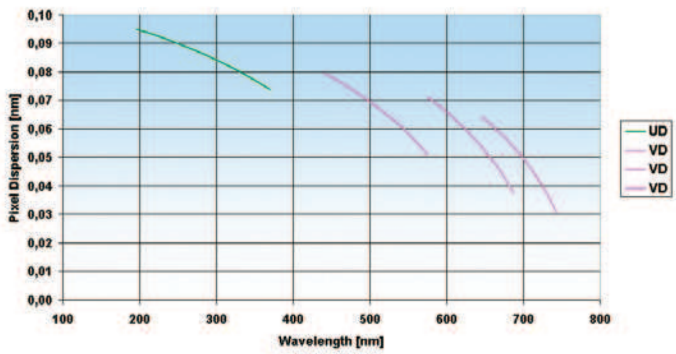
600 Lines/mm Gratings



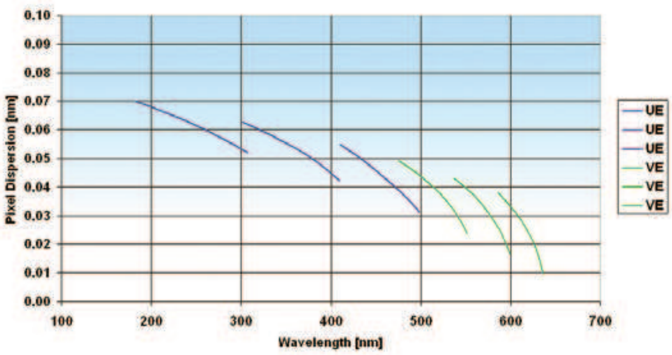
1200 Lines/mm Gratings



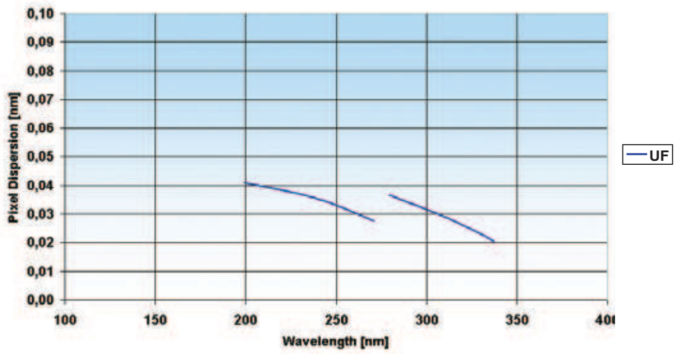
1800 Lines/mm Gratings



2400 Lines/mm Gratings



3600 Lines/mm Gratings

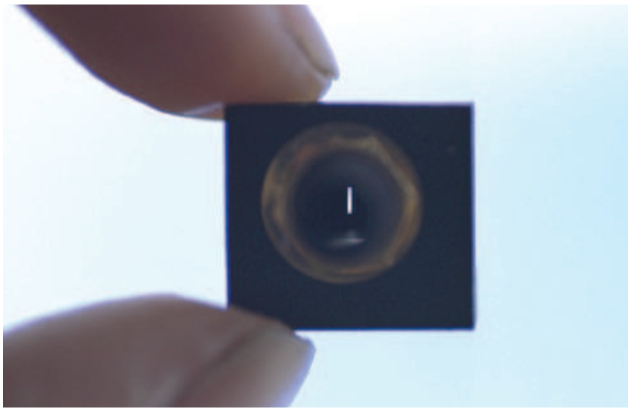


How to select optimal Optical Resolution?

The optical resolution is defined as the minimum difference in wavelength that can be separated by the spectrometer. For separation of two spectral lines it is necessary to image them at least 2 array-pixels apart. Because the grating determines how far different wavelengths are separated (dispersed) at the detector array, it is an important variable for the resolution.
The other important parameter is the width of the light beam entering the spectrometer. This is basically the installed fixed entrance slit in the spectrometer, or the fiber core diameter when no slit is installed.
The slits can be installed with following dimensions: 10, 25 or 50 x 1000 µm high or 100, 200 or 500 µm x 2000 µm high. Its image on the detector array for a given wavelength will cover a number of pixels. For two spectral lines to be separated, it is now necessary that they be dispersed over at least this image size plus one pixel. When large core fibers are used the resolution can be improved by a slit of smaller size than the fiber core. This effectively reduces the width of the entering light beam.

The influence of the chosen grating and the effective width of the light beam (fiber core or entrance slit) are shown in the tables at the product information. In Table 3 the typical resolution can be found for the AvaSpec-2048. Please note that for the higher lines/mm gratings the pixel dispersion varies along the wavelength range and gets better towards the longer wavelengths (see also Figure 3). The best resolution can always be found for the longest wavelengths. The resolution in this table is defined as F(ull) W(idth) H(alf) M(aximum), which is defined as the width in nm of the peak at 50% of the maximum intensity (see Figure 4).
Graphs with information about the pixel dispersion can be found in the gratings section as well, so you can optimally determine the right grating and resolution for your specific application.

Installed Slit in SMA Adapter



In combination with a DCL-detector collection lens or thick fibers the actual FWHM value can be 10-20% higher than the value in the table. For best resolution small fibers and no DCL is recommended.

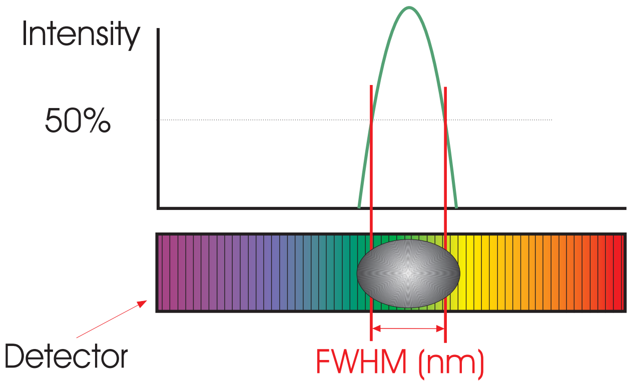


Figure 4 Full Width Half Maximum

Table 3 Resolution (FWHM in nm) for the AvaSpec-2048

	Slit size (µm)					
Grating (lines/mm)	**10**	**25**	**50**	**100**	**200**	**500**
300	0.8	1.4	2.4	4.3	8.0	20.0
600	0.4	0.7	1.2	2.1	4.1	10.0
1200	0.1-0.2*	0.2-0.3*	0.4-0.6*	0.7-1.0*	1.4-2.0*	3.3-4.8*
1800	0.07-0.12*	0.12-0.21*	0.2-0.36*	0.4-0.7*	0.7-1.4*	1.7-3.3*
2400	0.05-0.09*	0.08-0.15*	0.14-0.25*	0.3-0.5*	0.5-0.9*	1.2-2.2*
3600	0.04-0.06*	0.07-0.10*	0.11-0.16*	0.2-0.3*	0.4-0.6*	0.9-1.4*

* *depends on the starting wavelength of the grating; the higher the wavelength, the bigger the dispersion and the better the resolution*

Spectrometers

Detector Arrays

The AvaSpec spectrometers can be equipped with several types of detector arrays. Presently we offer silicon-based CCD, back-thinned CCD, CMOS and Photo Diode Arrays for the 200-1100 nm range. A complete overview is given in the next section "Sensitivity" in table 4. For the NIR range (1000-2500nm) InGaAs arrays are implemented.

CCD Detectors (AvaSpec-2048/3648)

The Charged Coupled Device (CCD) detector stores the charge, dissipated as photons strike the photoactive surface. At the end of a controlled time-interval (integration time), the remaining charge is transferred to a buffer and then this signal is being transferred to the AD converter. CCD detectors are naturally integrating and therefore have an enormous dynamic range, only limited by the dark (thermal) current and the speed of the AD converter. The 3648 pixel CCD has an integrated electronic shutter function, so an integration time of 10µsec can be achieved.

+ Advantages for the CCD detector are many pixels (2048 or 3648), high sensitivity and high speed.
- Main disadvantage is the lower S/N ratio.

UV enhancement

For applications below 350 nm with the AvaSpec-2048/3648 a special DUV-detector coating is required. The uncoated CCD-response below 350 nm is very poor; the DUV lumogen coating enhances the detector response in the region 150-350nm. The DUV coating has a very fast decay time, typ. in ns range and is therefore useful for fast trigger LIBS applications.

Back-thinned CCD Detectors (AvaSpec-2048x14)

For applications requiring high quantum efficiency in the UV (200-350nm) and NIR (900-1160nm) range, combined with good S/N and a wide dynamic range, the new back-thinned CCD detector may be the right choice. The detector is an area detector of 2048x14 pixels, for which the vertical 14 pixels are binned (electronically added together) to have more sensitivity and a better S/N performance.

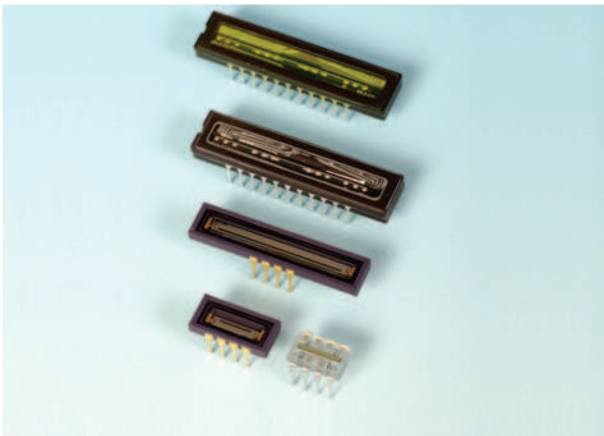
+ Advantage of the back-thinned CCD detector is the good UV and NIR sensitivity, combined with good S/N and dynamic range
- Disadvantage is the relative high cost

Photo Diode Arrays (AvaSpec-128)

A silicon photodiode array consists of a linear array of multiple photo diode elements, for the AvaSpec-128 this is 128 pixels. Each pixel consists of a P/N junction with a positively doped P region and a negatively doped N region. When light enters the photodiode, electrons will become excited and output an electrical signal. Most photodiode arrays have an integrated signal processing circuit with readout/integration amplifier on the same chip.

+ Advantages for the Photodiode detector are high NIR sensitivity and high speed.
- Disadvantages are limited amount of pixels and no UV response.

Different Detector Arrays



CMOS linear image sensors (AvaSpec-256/1024)

These so called CMOS linear image sensors have a lower charge to voltage conversion efficiency than CCD array sensors and are therefore less light sensitive, but have a much better signal to noise ratio.

The CMOS detectors have a higher conversion gain than NMOS detectors and also have a clamp circuit added to the internal readout circuit to suppress noise to a low level.

+ Advantages for the CMOS detectors are good S/N ratio and good UV sensitivity.
- Disadvantages are the low readout speed, low sensitivity, and relative high cost (1024 pixels).

InGaAs linear image sensors (AvaSpec-NIR256)

The InGaAs linear image sensors deliver high sensitivity in the NIR wavelength range. The detector consists of a charge amplifier array with CMOS transistors, a shift register and timing generator. 3 versions of detectors are available:

• 256 pixel non-cooled InGaAs detector for the 900-1750nm useable range
• 256 pixel 2-stage cooled Extended InGaAs detector for the 1000-2200nm range
• 256 pixel 2-stage cooled Extended InGaAs detector for the 1000-2500nm range

Sensitivity

The sensitivity of a detector pixel at a certain wavelength is defined as the detector electrical output per unit of radiation energy (photons) incident to that pixel. With a given A/D converter this can be expressed as the number of counts per mJ of incident radiation.
The relation between light energy entering the optical bench and the amount hitting a single detector pixel depends on the optical bench configuration. The efficiency curve of the grating used, the size of the input fiber or slit, the mirror performance and the use of a Detector Collection Lens are the main parameters. With a given set-up it is possible to do measurements over about 6-7 decades of irradiance levels. Some standard detector specifications can be found in Table 4 detector specifications. Optionally a cylindrical Detector Collection Lens (DCL) can be mounted directly on the detector array. The quartz lens (DCL-UV for AvaSpec-2048/3648) will increase the system sensitivity by a factor of 3-5, depending on the fiber diameter used.

In Table 4 the overall sensitivity is given for the detector types currently used in the UV/VIS AvaSpec spectrometers as output in counts per ms integration time for a 16-bit AD converter. To compare the different detector arrays we have assumed an optical bench with 600 lines/mm grating and no DCL. The entrance of the bench is an 8 µm core diameter fiber, connected to a standard AvaLight-HAL halogen light source. This is equivalent to ca. 1 µWatt light energy input.

In table 5 the specification is given for the NIR spectrometers, in figure 5 and figure 6 the spectral response curve for the different detector types are depicted.

Table 4 Detector specifications (based on a 16-bit AD converter)

Detector	**TAOS 128**	**HAM256**	**HAM1024**	**SONY2048**	**TOSHIBA3648**	**HAM2048x14**
Type	Photo diode array	CMOS linear array	CMOS linear array	CCD linear array	CCD linear array	Back-thinned CCD Array
# Pixels, pitch	128, 63.5 µm	256, 25 µm	1024, 25 µm	2048, 14 µm	3648, 8 µm	2048x14, 14 µm
pixel width x height (µm)	55.5 x 63.5	25 x 500	25 x 500	14 x 56	8 x 200	14x14 (total height 196 µm)
pixel well depth (electrons)	250,000	4,000,000	4,000,000	40,000	120,000	250,000
Sensitivity V/lx.s	100	22	22	240	160	200
Sensitivity Photons/count @600nm	100	440	440	40	60	50
Sensitivity (AvaLight-HAL, 8 µm fiber) in counts/µW per ms integration time	4000 (AvaSpec-128)	120 (AvaSpec-256)	120 (AvaSpec-1024)	20,000 (AvaSpec-2048)	14,000 (AvaSpec-3648)	16,000 (Avaspec 2048x14)
Peak wavelength	750 nm	500 nm	500 nm	500 nm	550 nm	650 nm
Signal/Noise	500:1	2000 :1	2000 :1	200 :1	350 :1	500:1
Dark noise (counts RMS)	60	28	60	35	35	50
Dynamic Range	1000	2500	2500	2000	2000	1300
PRNU**	± 4%	± 3%	±3%	± 5%	± 5%	± 3%
Wavelength range (nm)	360-1100	200-1000	200-1000	200*-1100	200*-1100	200-1160
Frequency	2 MHz	500 kHz	500 kHz	2 MHz	1 MHz	1.5 MHz

** DUV coated*

*** Photo Response Non-Uniformity = max difference between output of pixels when uniformly illuminated, divided by average signal*

Spectrometers

Figure 5 Detector Spectral sensitivity curves

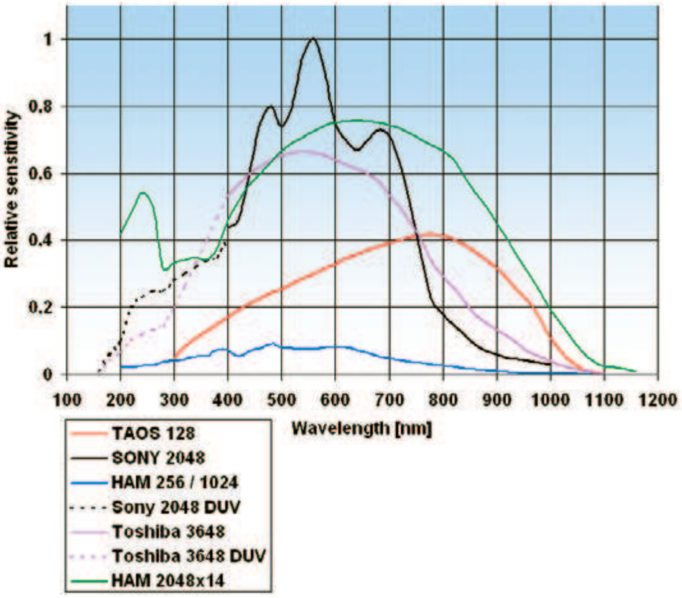


Figure 6 NIR Detector Sensitivity Curves

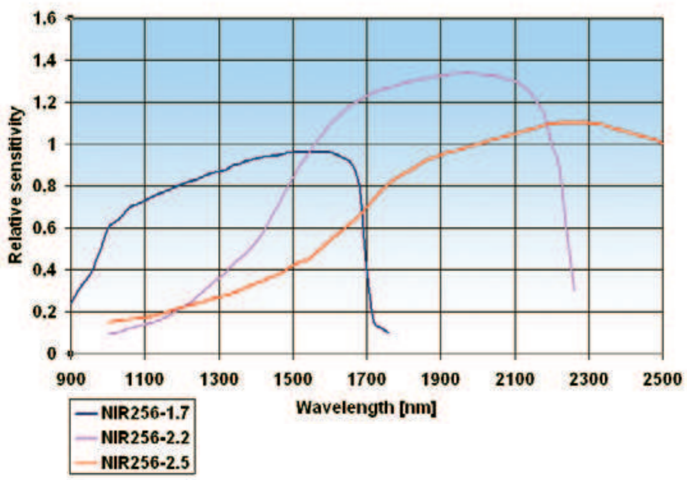


Table 5 NIR Detector Specifications

Detector	**NIR256-1.7**	**NIR256-2.2**	**NIR256-2.5**
Type	Linear InGaAs array	Linear InGaAs array with 2 stage TE cooling	Linear InGaAs array with 2 stage TE cooling
# Pixels, pitch	256, 50 µm	256, 50 µm	256, 50 µm
pixel width x height (µm)	50 x 500	50 x 500	50 x 500
Pixel well depth (electrons)	16,000,000	1,500,000	1,500,000
Sensitivity (AvaLight-HAL, 8 µm fiber) in counts/µW per ms integration time	350	250	200
Peak wavelength	1550 nm	2000 nm	2300 nm
Signal/Noise	4000:1	1200 :1	1200 :1
Dark noise (counts RMS)	12	40	40
Dynamic Range	5000	1600	1600
PRNU**	± 5%	± 5%	± 5%
Defective pixels (max)	0	12	12
Wavelength range (nm)	900-1750	1000-2200	1000-2500
Frequency	500 kHz	500 kHz	500 kHz

*** Photo Response Non-Uniformity = max difference between output of pixels when uniformly illuminated, divided by average signal*

Stray Light and Second Order Effects

Stray light is radiation of the wrong wavelength that activates a signal at a detector element. Sources of stray light can be:

- Ambient light
- Scattering light from imperfect optical components or reflections of non-optical components
- Order overlap

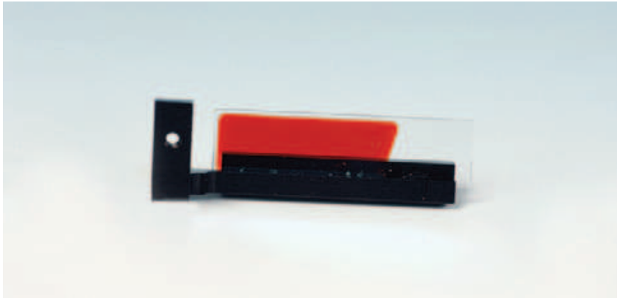
Encasing the spectrometer in a light tight housing eliminates ambient stray light.

When working at the detection limit of the spectrometer system, the stray light level from the optical bench, grating and focusing mirrors will determine the ultimate limit of detection. Most gratings used are holographic gratings, known for their low level of stray light. Stray light measurements are being carried out with a laser light, shining into the optical bench and measuring light intensity at pixels far away from the laser projected beam. Other methods use a halogen light source and long pass- or band pass filters.

Typical stray light performance is <0.05 % at 600 nm; <0.10 % at 435 nm; <0.10 % at 250 nm.

Second order effects, which can play an important role for gratings with low groove frequency and therefore a wide wavelength range, are usually caused by the grating 2^{nd} order diffracted beam. The effects of these higher orders can often be ignored, but sometimes need to be taken care of. The strategy is to limit the light to the region of the spectra, where order overlap is not possible. Second order effects can be filtered out, using a permanently installed long-pass optical filter in the SMA entrance connector or an order sorting coating on a window in front of the detector. The order sorting coatings on the window typically have one long pass filter (590nm) or 2 long pass filters (350 nm and 590 nm), depending on the type and range of the selected grating.

Order Sorting Window in holder



In Table 6 a wide range of optical filters for installation in the optical bench can be found. The use of following long-pass filters is recommended: OSF-475 for grating NB and NC, OSF-515/550 for grating NB and OSF-600 for grating IB.

In addition to the order sorting coatings we implement partial DUV coatings on Sony 2048 and Toshiba 3648 detectors to avoid second order effects from UV response and to enhance sensitivity and decrease noise in the Visible range.
This partial DUV coating is done automatically for the following grating types:

- UA for 200-1100 nm, DUV400, only first 400 pixels coated
- UB for 200-700 nm, DUV800, only first 800 pixels coated

Table 6 Filters installed in the AvaSpec spectrometer series

OSF-385	Permanently installed 1 mm order sorting filter @ 371 nm
OSF-475	Permanently installed 1 mm order sorting filter @ 466 nm
OSF-515	Permanently installed 1 mm order sorting filter @ 506 nm
OSF-550	Permanently installed 1 mm order sorting filter @ 541 nm
OSF-600	Permanently installed 1 mm order sorting filter @ 591 nm
OSC	Order sorting coating with 590nm long pass filter for VA, BB (>350 nm) and VB gratings in AvaSpec-1024/2048/3648/2048x14
OSC-UA	Order sorting coating with 350 and 590nm longpass filter for UA gratings in AvaSpec-1024/2048/3648/2048x14
OSC-UB	Order sorting coating with 350 and 590nm longpass filter for UB or BB (<350 nm) gratings in AvaSpec-1024/2048/3648/2048x14