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INT
Institute of NanoTechnology

Laser Gas Detection

Last update:

Tuesday, February 11, 2020

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1 Basics

1.1 Introduction

Tunable diode laser absorption spectroscopy (TDLAS) is a technique for measuring the concentration of certain species such as methane, water vapor and many more, in a gaseous mixture using tunable diode lasers and laser absorption spectrometry. The advantage of TDLAS over other techniques for concentration measurement is its ability to achieve very low detection limits (of the order of ppb). Apart from concentration, it is also possible to determine the temperature, pressure, velocity and mass flux of the gas under observation.[1][2] TDLAS is by far the most common laser based absorption technique for quantitative assessments of species in gas phase.

A number of spectroscopic techniques have been developed for trace gas measurements. The traditional technique has been non-dispersive infrared (NDIR) where the transmission has been measured at two wavelength regions, one at absorbing and the other at non-absorbing wavelengths. This technique is suited for gases with broad absorption bands. In recent years new techniques has emerged such as Fourier transform infrared (FTIR), differential optical absorption spectroscopy (DOAS), laser-induced fluorescence (LIF) and tuneable diode laser absorption spectroscopy (TDLAS).

An overview of these techniques is given in [2]. There are several optical instruments commercially available for continuous emission monitoring based on these techniques. Some are extractive, where the gas has to be preconditioned before measurement in an internal cell, and others are insitu systems. These are broad-band spectroscopic instruments working in the infrared or ultraviolet. The middle infrared (MIR, 3–15 μm is a very rich spectral region where most of the interesting trace gases absorb on their fundamental rotational=vibrational modes. The absorption is so strong, particularly from H_2O and CO_2 molecules, that a very high spectral resolution is required to avoid interference between species. Tuneable diode lasers (TDL) have line widths of only a few MHz or less and are therefore well suited for highresolution spectroscopy. Lead-salt-based lasers are available in the middle infrared but both the TDLs and the detectors require cooling to around liquid nitrogen temperatures. In the near infrared (NIR, 0:8–3 mm we have the first and second overtones of the rotational=vibrationalmodes of the trace gases, and there are commercial III-V semiconductor lasers available up to approximately 2 mm that operate at room temperature. The absorption typically drops by an order of magnitude for every higher overtone, however, and a higher absorption sensitivity is required to obtain sufficiently low detection limits for many of the important gases. [1]

1.1.1 Working

Basic TDLAS setup consists of tunable diode laser light source, transmitting (i.e. beam shaping) optics, optically accessible absorbing medium, receiving optics and detector/s. The emission wavelength of the tunable diode laser, viz. VCSEL, DFB, etc., is tuned over the characteristic absorption lines of a species in the gas in the path of the laser beam. This causes a reduction of the measured signal intensity, which can be detected by a photodiode, and then used to determine the gas concentration and other properties as described later.[3]

Different diode lasers are used based on the application and the range over which tuning is to be performed. Typical examples are InGaAsP/InP (tunable over 900 nm to 1.6 μm), InGaAsP/InAsP (tunable over 1.6 μm to 2.2 μm), etc. These lasers can be tuned by either adjusting their temperature or by changing injection current density into the gain medium. While temperature changes allow tuning over 100 cm−1, it is limited by slow tuning rates (a few hertz), due to the thermal inertia of the system. On the other hand, adjusting the injection current can provide tuning at rates as high as ~10 GHz, but it is restricted to a smaller range (about 1 to 2 cm−1) over which the tuning can be performed. The typical laser linewidth is of the order of 10−3 cm−1 or smaller. Additional tuning, and linewidth narrowing, methods include the use of extracavity dispersive optics.[4]

1.1.2 Basic principle[1]

Concentration measurement

The basic principle behind the TDLAS technique is simple. The focus here is on a single absorption line in the absorption spectrum of a particular species of interest. To start with the wavelength of a diode laser is tuned over a particular absorption line of interest and the intensity of the transmitted radiation is measured. The transmitted intensity can be related to the concentration of the species present by the Beer-Lambert law, which states that when a radiation of wavenumber ($\tilde{\upsilon}$) passes through an absorbing medium, the intensity variation along the path of the beam is given by,[5]

$$I(\tilde{\nu}) = I_0(\tilde{\nu}) \exp(-\alpha(\tilde{\nu})L) = I_0(\tilde{\nu}) \exp(-\sigma(\tilde{\nu})NL)$$

Where,

$I(\tilde{\upsilon})$ is the transmitted intensity of the radiation after it has traversed a distance L through the medium,

$I_0(\tilde{\upsilon})$ is the initial intensity of the radiation,

$\alpha(\tilde{\upsilon}) = \sigma(\tilde{\upsilon})N = S(T)\varphi(\tilde{\upsilon} - \tilde{\upsilon}_0)$ is the absorbance of the medium,

$\sigma(\tilde{\upsilon})$ is the absorption cross-section of the absorbing species,

N is the number density of the absorbing species,

[1] https://en.wikipedia.org/wiki/Tunable_diode_laser_absorption_spectroscopy

$S(T)$ is the line strength (i.e. the total absorption per molecule) of the absorbing species at temperature T,

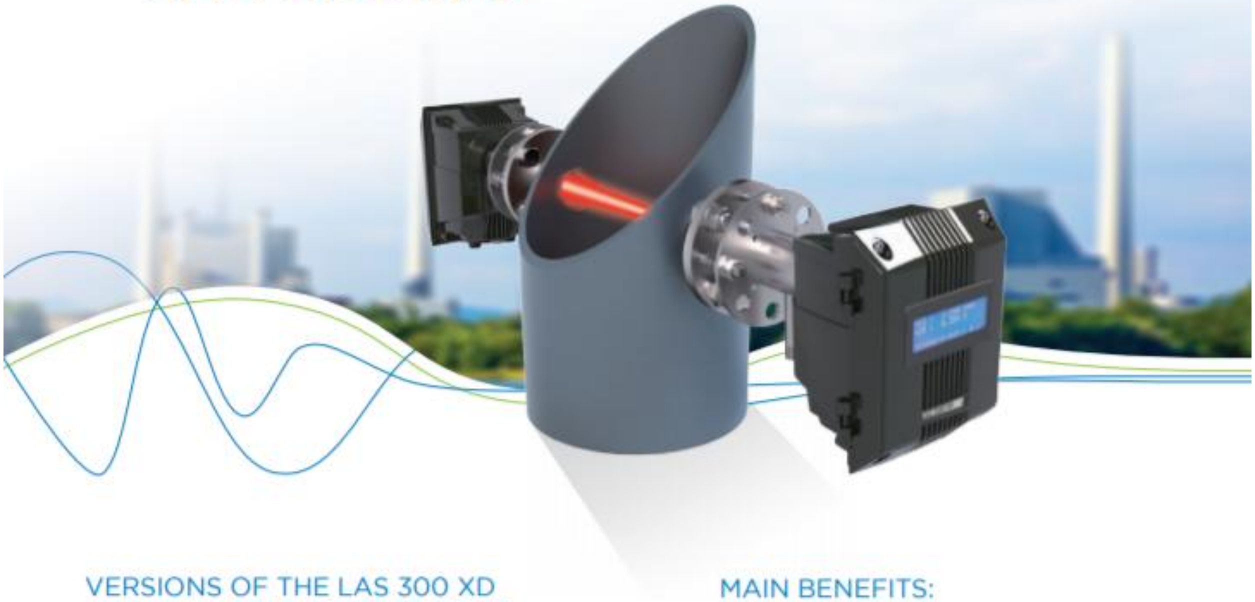
$\Phi(\tilde{\upsilon} - \tilde{\upsilon}_0)$ is the lineshape function for the particular absorption line. Sometimes also represented by $g(\tilde{\upsilon} - \tilde{\upsilon}_0)$,

$\tilde{\upsilon}_0$ is the center frequency of the spectrum.

1.2 Product LAS 300 XD[2]

[2] http://www.environnement-sa.com/products-page/en/las-300-xd-cross-duct-tdlas-laser-absorption-gas-analyzer/

LAS 300 XD



VERSIONS OF THE LAS 300 XD ARE AVAILABLE TO MEET YOUR ANALYTICAL REQUIREMENTS:

- LAS 300 XD **NH_3** for ammonia (NH_3) and water (H_2O) monitoring
- LAS 300 XD **CO** for low and high concentration carbon monoxide (CO) monitoring
- LAS 300 XD **HCl** for hydrochloric acid (HCl) and water (H_2O) monitoring
- LAS 300 XD **HF** for hydrofluoric acid (HF) monitoring
- LAS 300 XD **O_2** for oxygen (O_2) monitoring

including LaserTool® advanced software for setup and operations

MAIN BENEFITS:

- High sensitivity - ppb, ppm and % concentrations
- Interference-free gas measurements
- Large dynamic range
- Absolute measurements: no drift, no calibration, linear response
- Real-time - 1s response
- In-situ and non-invasive measurement
- Suitable for harsh environments. Unaffected by contaminants - no corrosion
- Small size
- No sample lines required, eliminating errors due to gas sampling
- Low maintenance and low cost of ownership

MAIN APPLICATIONS:

Process & emission monitoring for:

- Scrubber technology
- Combustion control
- Chemical industry
- Fertilizer plants
- Waste incinerators
- Cement industry
- Glass industry
- Pulp and paper
- Biomass boilers
- Petrochemical industry

Tunable Diode Laser Spectroscopy **LAS 300 XD**

Measurement ranges:	
$NH_3 + H_2O$	0 – 15 ppm / 0 – 500 ppm + 0 – 5% / 0 – 50%
$HCl + H_2O$	0 – 10 ppm / 0 – 3000 ppm + 0 – 5% / 0 – 50%
HF	0 – 100 ppm
CO (low)	0 – 500 ppm
CO (high)	0 – 100%
O_2	0 – 10% / 0 – 100%
Accuracy:	≤ ±2% of full scale
Response time (0–90%):	1s
Linearity:	≤ ±1% of full scale
Process gas (°C max):	
$NH_3 + H_2O$ / HCl + H_2O / HF	+400°C
CO (low) / CO (high) / O_2	+1200°C
Process gas pressure:	Typical max. 2 bar absolute
Display:	4 x 20 alphanumeric LED backlit LCD
Input signals:	Optional temperature and pressure inputs (4-20 mA)
Communication:	Modbus RTU
Output signals:	x2 analog outputs (4-20 mA), x2 relays
Power supply:	+ 24 V DC, ripple and noise 50 mV
Power:	15 W when starting-up the LAS 300 XD < 15 W in normal operation
Ambient operating (°C):	-10°C to +55°C
Enclosure rating:	IP65
Enclosure material:	Die-cast aluminium (polyester powder coated)
Mounting flange size:	DN40 PN20 or 1.5" 150lb ANSI
Mounting flange material:	SS 316 L
Air purge consumption:	10-50 L/min (depends on application conditions)
Stack temperature:	0-450°C (other temperatures upon request)
Stack diameter:	0.5 to 6 m

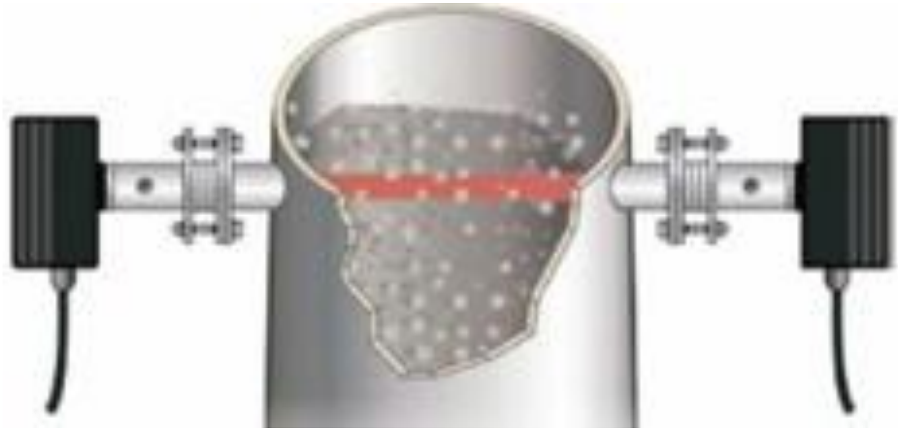
MAIN OPTIONS:

- IP67 Junction box (for power and signal)
- Purge air unit (blower, filters, flow meters, pressure regulator)
- Connecting cable (usb) RS485 or RS232
- In-line span check cell ①
- Weather protection covers
- Specific flanges (length / material / C°)
- Remote interface
- Audit cell (with tripod) ②
- Optical alignment tool ③

THE STANDARD LAS 300 XD IS SUPPLIED WITH:

- 1 signal cable, between the Transmitter and Receiver (10 m standard and 25 m optional)
- 2 cables for power supply and signal outputs (each 3 m long)
- 2 alignment bellows (type: ASME B16.6 class 150)
- LaserTool® software

Distributed by:



1.2.1 Exclusive features

The Tunable Diode Laser Spectroscopy (TDLS) is the perfect technology to use when you are looking for a selective measurement and a fast response time on some gas components as NH3, HCL, HF, low or high CO, or even O_2 when conditions are too rough for standard O_2 Zirconia In-Situ analysers. It uses a solid-state laser source with a wavelength that can be adjusted to the gas component unique spectrum, also called gas component “fingerprint”. TDLS method is a non-contact optical technology and therefore the emitter (laser source) as the sensor stays protected from any contamination or corrosion and so the maintenance operation and the cost of operation are very low compared to other technologies.

The LAS 300 XD uses a semiconductor laser light source that is rapidly tuned over the absorption peak of the gas being measured.

The LAS 300 XD uses fast, advanced signal processing electronics and Direct Absorption Spectroscopy (DAS). This combination leads to very low noise DAS measurements that are comparable or often better than those made using wavelength modulation spectroscopy (WMS).

Main advantages of LAS 300 XD technology:

Sensitive. With a large dynamic range

Accurate. The laser absorption relates directly to the quantity of gas being measured at a molecular level. This leads to extremely accurate measurements using fundamental and proven signal-processing algorithms in both single gas and multi-gas applications.

Linear. No complex calibration curves required. Unaffected by changes in background species.

Fast. Rapid laser tuning ensures an accurate measurement even with fast changing process conditions.

1.2.2 Specifications

LAS 300 XD gas analyzers are very easy to install. The two main parts are arranged on opposite sides of the duct. The Transmitter is on one side and the Receiver is on the opposite side.

The Transmitter contains the laser along with the signal processing and communication electronics. The Receiver contains a photodetector and is connected to the Transmitter unit by a cable.

Alignment of the two units is simple thanks to the alignment bellows supplied with the LAS 300 XD. For additional help with alignment, an alignment tool is available.

The LAS 300 XD includes a window purge system as standard. Options are available to help with the installation and arrangement of the purging system. For example: a complete purge system that includes blower/filter and regulator, when there is no instrument air available at the installation point.

Measurement ranges:

NH_3 + H_2O: 0 – 15 ppm / 0 – 500 ppm + 0 – 5% / 0 – 50%

HCl + H_2O: 0 – 10 ppm / 0 – 3000 ppm + 0 – 5% / 0 – 50%

HF: 0 – 100 ppm

CO (low): 0 – 500 ppm

CO (high): 0 – 100%

O_2: 0 – 10% / 0 – 100%

1.3 Sensor design

The developed sensor follows the classical in situ TDLAS design and consists of transmitter and receiver units. The transmitter unit contains a diode laser, collimating optics, a microprocessor board, and all input–output electronics. The transmitter unit also has a built in cell for H_2 validation. The receiver unit incorporates a photodetector, focusing optics, and signal detection electronics (amplifier, mixer, etc.). The sensor is based on the wavelength modulation spectroscopy (WMS) technique, which is well described in the literature [18–20]. This technique has been proven to be very useful in trace gas sensing due to its ability to perform very sensitive interference-free measurements directly in the process or across stacks without sample extraction and preconditioning. Since WMS provides nominally baseline-free absorption signals, it is especially suited for measuring weak absorbance. Recently published comparisons of WMS and direct absorption spectroscopy (DAS) techniques revealed that WMS is approximately one order of magnitude more sensitive [21–23]. Figure 1a shows a photograph of the LaserGas II sensor mounted on the demo pipe using DN50 flanges, and Figure 1b depicts a schematic diagram and the basic principle of the sensor operation.

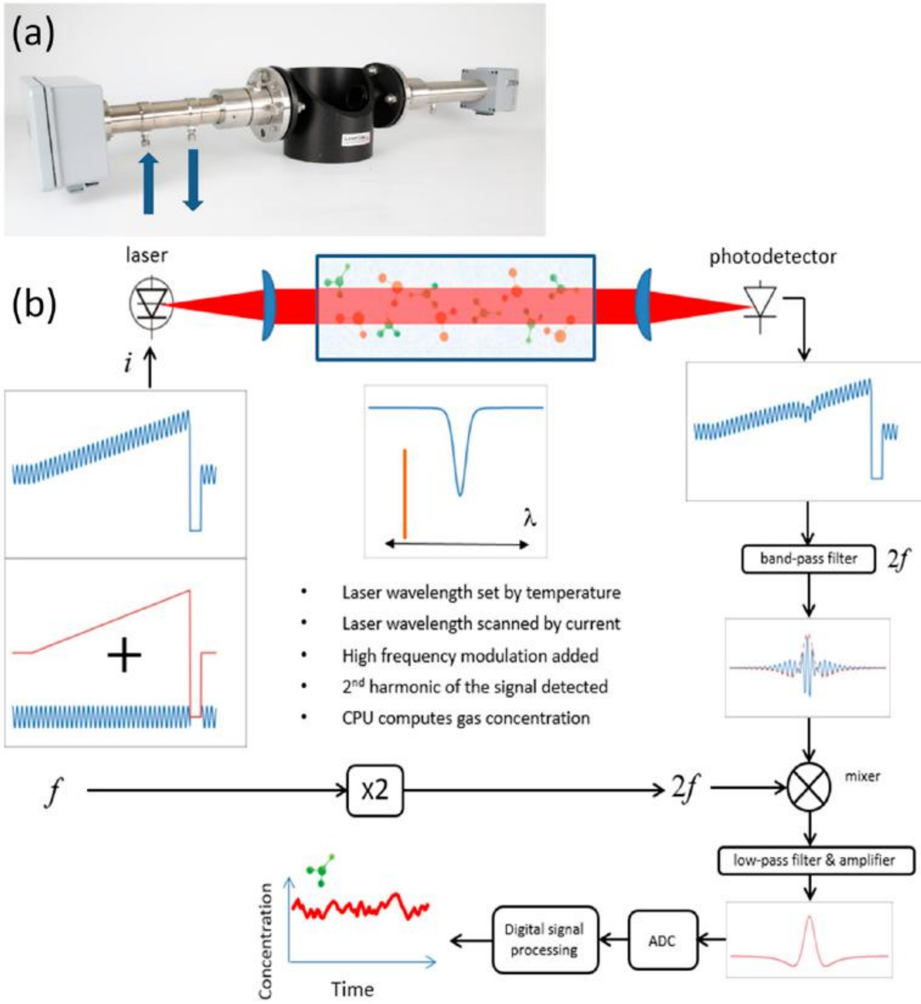


Figure 1. (a) Tunable diode laser absorption spectroscopy (TDLAS) H2 sensor mounted on a demo pipe. Transmitter unit is on the left and receiver unit on the right. Gas inlet and outlet of the built-in validation gas cell are indicated. (b) Schematic overview of the principles of sensor operation. A sinusoidally modulated current ramp is applied to the laser, which is swept in frequency across the transition of interest. After interacting with the sample, the absorption information is encoded in the transmitted intensity, which is measured using a photodetector. The photodetector signal is amplified, filtered, mixed, and digitized. Finally, digital signal processing is used to retrieve the concentration (and possibly other relevant parameters).

1.4 Diode lasers for spectroscopic applications [1][3]

The development of semiconductor diode lasers in the near infrared has been spurred by the development of CD players (0:78 µm) and fibre optic communication (1:3 µm, 1:55 µm). As technology has improved, lasers have been developed for new applications such as pumping of

[3] https://link.springer.com/article/10.1007%2Fs003400050509

solid-state (0:808 μm) and fibre (0:98 μm) lasers. In addition to wavelength, other important laser parameters are mode stability, in order to obtain single-frequency operation, current tuneability, and frequency drift. The Fabry–PKerot (FP) type lasers are unreliable with respect to mode jumping, therefore other types of lasers such as distributed feedback (DFB), distributed Bragg reflector (DBR) and vertical cavity surface emitting lasers (VCSEL) have been developed. Low current tuneability has to be compensated by higher current modulation which generally increase the RAM noise. It is beyond the scope of this paper to describe lasers in detail and we refer the reader to the literature (e.g. [14, 15]).

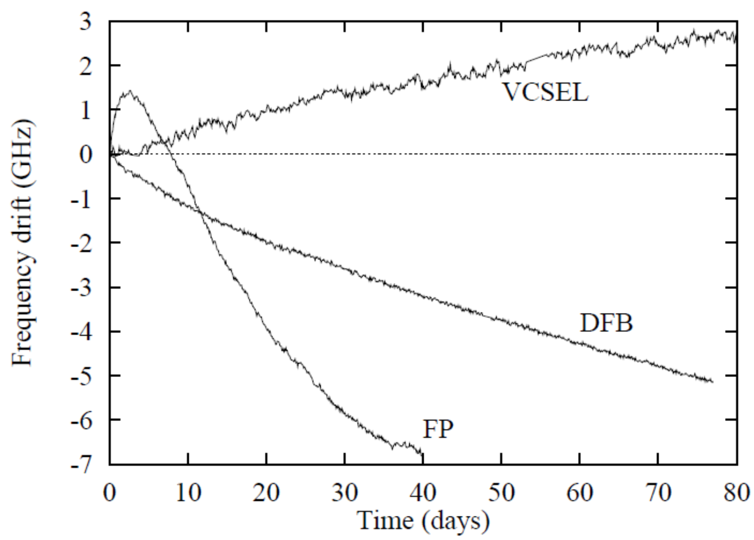


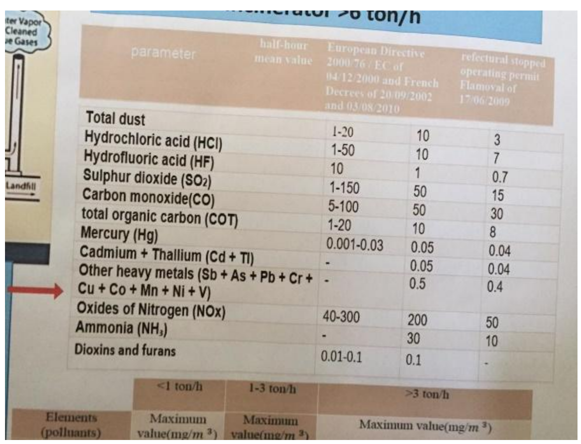
Fig. 6. Long-term frequency drift of some lasers at 760 nm. The lasers have passed "burn-in" tests prior to these measurements

Long-term frequency stability is one of the most important parameters for diode lasers used in industrial gas monitors. Most lasers have some frequency drift and Fig. 6 shows some long-term measurements for three lasers at 760 nm. We have observed a large spread in drift, both for lasers of the same kind, and for different types of lasers, but it is generally smaller in lasers at longer wavelengths. The drift is usually smaller after several months of operation, but a drift as shown in Fig. 6 may cause instrument failure during such a period. The drift can be overcome by adjusting the laser temperature such that the absorption line is always in the centre of the frequency scan. However, some applications normally have zero concentration and therefore no line to track (e.g. measurement of O_2 for explosion safety). In such cases one can introduce a gas cell temporarily or permanently in the measurement path, or in a split-off beam with a separate detector. However, such solutions will increase the optical noise and=or mechanical=electronical complexity. The monitors described in this paper use lasers which have been selected for low drift, but the testing is a costly and time consuming process. It is difficult to specify a maximum acceptable drift since this is coupled to the actual mechanical=optical solution. A large, persistent frequency drift is often accompanied by drift in other parameters such as output power and to some extent current tuneability. Such effects may result in drift in the measured gas concentration and short life time of the laser.

Most of the diode lasers mentioned above are used in high-volume products. Diode lasers for gas monitors are expected to be required in low volumes only [16], and until recently only gases with strong absorption lines near the above-mentionedwavelengths have been possible to measure. However, the advances in the manufacturing of diode lasers in recent years have made it possible to make lasers at other wavelengths, and several of the lasers used in the monitors described in this paper have been specially designed for the purpose of gas monitoring.

Table 1. Typical wavelengths and detection limits for some gases measured with the technique described in this paper. The detection limit for O_2 is not limited by electronic or optical noise, but by uncertainty due to air in the receiver and transmitter

Gas	Laser type	Wavelength /µm	Detection limit /ppm·m
O_2	FP, DFB, VCSEL	0.764, 0.760	1000
HF	DFB	1.28, 1.30	0.03
NH_3	DFB, DBR	1.51	0.2
CO	DFB	1.56	20
H_2S	DFB	1.57	5
HCl	DFB	1.74	0.1
NO	DFB	1.81	5



parameter	half-hour mean value	European Directive 2000/76 / EC of 04/12/2000 and French Decrees of 20/09/2002 and 03/08/2010	refectural stopped operating permit Flamoval of 17/06/2009
Total dust	1-20	10	3
Hydrochloric acid (HCl)	1-50	10	7
Hydrofluoric acid (HF)	10	1	0.7
Sulphur dioxide (SO_2)	1-150	50	15
Carbon monoxide(CO)	5-100	50	30
total organic carbon (COT)	1-20	10	8
Mercury (Hg)	0.001-0.03	0.05	0.04
Cadmium + Thallium (Cd + Tl)	-	0.05	0.04
Other heavy metals (Sb + As + Pb + Cr + Cu + Co + Mn + Ni + V)	-	0.5	0.4
Oxides of Nitrogen (NOx)	40-300	200	50
Ammonia (NH_3)	-	30	10
Dioxins and furans	0.01-0.1	0.1	-

Elements (polluants)	<1 ton/h Maximum value(mg/m^3)	1-3 ton/h Maximum value(mg/m^3)	>3 ton/h Maximum value(mg/m^3)

Table 1 lists some of the types of lasers and wavelengths we have used for some gases, and the corresponding detection limits obtained. Note that the detection limit for O_2 comes not from electronic or optical noise, but from uncertainty due to air in the receiver and transmitter. More extensive lists of suggested wavelengths for several gases can be found in [4, 17].

Standard wavelengths for hydrogen chloride detection HCl nanoplus offers various wavelengths to target the vibrational-rotational bands of hydrogen chloride. Literature recommends the following wavelengths for hydrogen chloride detection:

- 1742 nm
- 3395 nm

Standard wavelengths for sulfur dioxide detection (SO2)

nanoplus offers various wavelengths to target the vibrational-rotational bands of sulfur dioxide. Literature recommends the following wavelengths for sulfur dioxide detection:

- 2460 nm
- 4020 nm

Standard wavelengths for carbon monoxide detection (CO)

nanoplus offers various wavelengths to target the vibrational-rotational bands of carbon monoxide. Literature recommends the following wavelengths for carbon monoxide detection:

- 1568 nm
- 2330 nm
- 4610 nm

Standard wavelengths for nitrogen oxide detection (NOx)

nanoplus offers various wavelengths to target the vibrational-rotational bands of nitrogen oxides. Literature recommends the following wavelengths for nitrogen oxides detection:

- 1814 nm
- 2270 nm
- 2670 nm
- 2860 nm
- 3420 nm
- 4470 nm
- 5255 nm

1.5 Industrial applications of TDLAS[4]

Due to the short response time, industrial TDLAS monitors are ideal as process control tools in processes requiring a fast response, and they are also well suited for continuous emission monitoring of gases such as HCl and HF where the maximum permissible emission levels are in the low ppm range. Some typical examples are presented below, followed by measurements from real installations.

1.5.1 Process control

O2 measurement. The use of TDLAS offers for the first time a reliable and accurate method for measurement of oxygen by using spectroscopic techniques.While the O2 monitor can be used in most of the traditional applications for O2 measurements in combustion processes, the most challenging applications are found in process control and safety systems in chemical and petrochemical plants (i.e. flare gas explosion control), as well as safety systems in hazardous waste and solvents destruction plants.

The gas temperature is typically in the range 150 to 300 °C and the pressure can vary from a few millibar to 3–5 bar. For these processes the gas matrix mainly consists of hydrocarbons (25%−80%) with the rest being H_2O, CO and CO2 plus a low concentration of O2 (typically from 1% to 2%).

Another process control application which has now become feasible is the use of the O2 monitor to improve combustion control in high-temperature furnaces, such as steel and cement ovens. Performing high-temperature CO measurements at the same location will improve the combustion control even further. The temperature is typically 900–1200 °C and the gas matrix will in this case consist of O2, CO, CO2, N2, NO and H2O.

NH3 measuerement. At the moment there are no environmental emission standards for ammonia emissions from industrial processes. Ammonia is, however, widely used in power plants and incinerators to reduce NOx emissions. Two frequently used techniques are selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) in which NH3 is added to the flue gas. For such installations, monitoring NH3 is valuable for optimising the consumption of the gas, as well as reducing corrosion and environmental impact from excessive use. The NH3 slippage level should preferably be well below 5 ppm and should be measured as close as possible to the injection point. Typical conditions at this stage in the process are gas temperatures of 250–350 µC, dust levels of 10–20 g=m3 and a gas mix of 10%–20% CO2 , 10%–30% H2O, 3%–5% O2, with the rest being N2 and ppm levels of SOx , NOx and NH3.

CO measurement. Accurate and fast measurements of CO as close as possible to the process may be used for effective combustion control in high-temperature processes used in steel and cement ovens. The use of TDLAS offers for the first time a reliable and accurate method for this type of process control, by measuring the CO level at temperatures above 1000 °C.

H2S measurement. H_2S is a hazardous gas normally present in refineries and other petrochemical plants, which have facilities for reduction=destruction of it. The gas mix typically includes H_2, O_2, N_2, CH_4, CO_2 and H_2O, and monitoring H_2S on a continuous basis is an efficient tool for process optimisation.

1.5.2 Emission monitoring

The most important emission gases believed to have an impact on the environment are related to combustion processes. In an industrial context, emissions usually come from boilers (power plants), chemical industry, waste incinerators and furnaces such as aluminium smelters and steel and glass furnaces. Other significant sources of emission are cars, buses and other motor vehicles.

Continuous monitoring of gas emissions from industrial processes has traditionally been limited to measurement of carbon monoxide (CO) nitrogen oxides (NO and NO2) and sulphur dioxide (SO2), and the techniques for continuous measurements are well established. Limitations in performance=detection levels of the equipment available for continuous measurements of gases such as HF, HCl and NH3 has in practice prevented continuous monitoring for reporting of emissions. Standard practice has been sampling tests mentioned several spectroscopic methods which can be used for a large number of gases. However, for the gases that are particularly difficult to measure, TDLAS offers a new and unique method. Some examples are presented below.

HCl measurement. HCl is an emission depending mostly on the content of chlorine in the fuel. Experience from domestic waste incinerators [18] has shown that approximately 90% of the Cl in the fuel will end up as HCl in the flue gas. The maximum permissible emission level of HCl from industrial and domestic waste incinerators in Europe is now specified to not exceed 10 mg/m^3 (daily mean values). Only a few types of instrumentation can meet this requirement, the TDLAS being one of these, with a detection limit of approximately 0:1 ppm-m for the monitors described in this paper.

HF measurement. HF emissions come primarily from aluminium plants, glass works, tile manufacturers, incinerators and alkylation plants. For incinerators, typically 10% of the fluorine in the fuel will end up as HF in the flue gas [18]. The maximum permissible level is typically 1 to 10 mg/m^3, depending on the process and application. Until recently HF has been a gas which has been considered impossible to measure on a continuous basis at these low levels due to the lack of suitable instrumentation. The use of TDLAS has now changed this as HF proves to be one of the most suitable gases for the TDLAS technique with a detection limit of 30 ppb for a 1-m optical path length.

1.5.3 Measurement of O2, CO and HCl from a waste incinerator

In Fig. 7 we show some simultaneous time-series measurements from the stack of a 27-MW circulating fluidized bed (CFB) combined boiler and incinerator at a paper mill. The boiler produces a maximum of 40 tons of steam per hour at 210 °C and 20 bar. The steam is used in the paper mill production and may vary rapidly from 20% to 100% capacity. The boiler is designed to burn municipal waste, plastic, wood, paper, waste oil and coal. These fuels have greatly different calorific values and this puts high demands on both the process control and the abatement system.

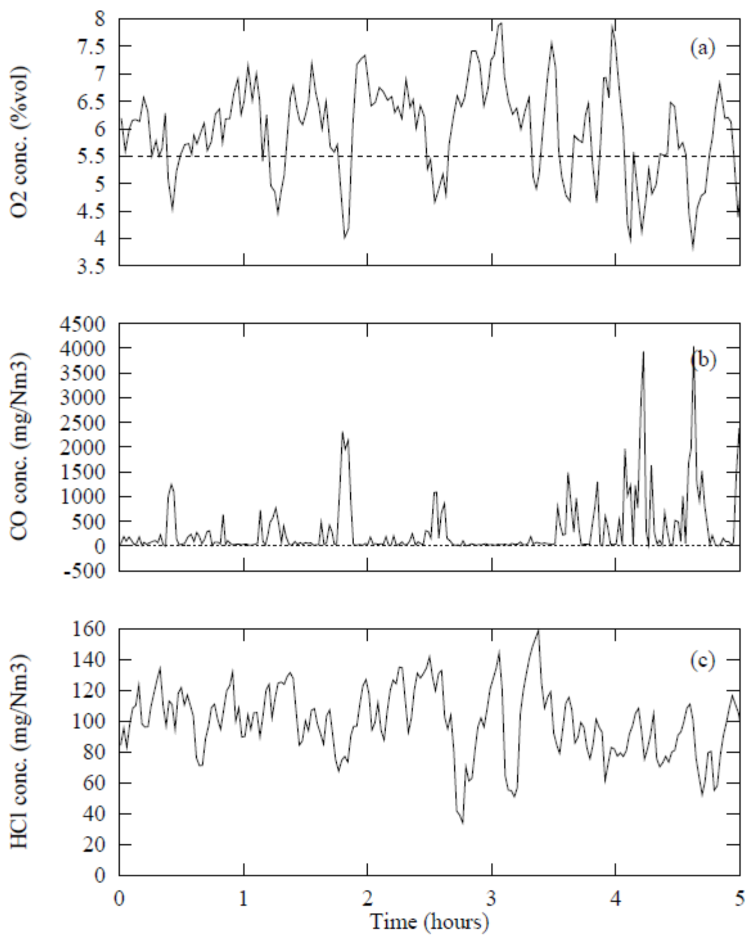


Fig. 7. Concentrations in flue gas from a waste incinerator measured over a period of 5 hours, where each sample is averaged over 60 seconds. The CO concentration peaks abruptly when the O_2 concentration drops below approximately 5.5 vol. % The HCl concentrations do not show a similar correlation

After the combustion in the CFB reactor the flue gas passes through two cyclones and the boiler before it is cleaned in a multi-cyclone and an electro-scrubber. The flue gas is then let out through a 40-m-high stack, where the gas monitors are located.

O2 and CO concentrations in the flue gas are the most importan gases for monitoring combustion efficiency. Complete oxidation can in practice be obtained only with an excessive amount of air Too much air, however, can cool down the combustion and increase the amount of CO in the flue gas. There exists an optimal amount of air. Figure 7a,b shows the O2 and CO concentrations for varying efficiency of the combustion. When the O2 concentration drops below approximately 5:5 vol:% the CO concentration peaks sharply to values as high as 4000 mg/Nm^3, and when the O2 concentration is approximately 6 vol:% to 7 vol:% the CO concentration is close to 50 mg/Nm^3. The fluctuations in CO concentrations are extremely fast and large. In Fig. 7 the concentrations have been averaged over 1min and we see changes from 50 to 2300 mg/Nm3 from one sample to the next. The fastest response of the CO monitor is 15 s, and we have seen cases where the concentration has changed from 100 to 9000 to 100 mg/Nm^3 in three successive samples at this sampling rate. It is difficult to understand how conditions can change this fast in such a large furnace, but considering a gas flow of up to 20 m^3/s, we realise that all the gas in the furnace has been replaced in less than 15 s. Such fast response measurements can therefore give valuable information that may be used in the process control of the furnace.

HCl was also measured in the flue gas from this waste incinerator. The concentration of HCl depends mostly on the content of chlorine in the fuel and is not expected to show much correlation with process-control-related parameters. This is consistent with the measurements shown in Fig. 7 where there is no correlation between the concentration of HCl and the other two gases. The content of chlorine in municipal waste can vary greatly, which is also seen in this figure. At the time of measurement the incinerator had no abatement system for removing HCl.

HF was also measured in the stack of the waste incinerator. In the analysed period the concentrations were generally very low and rarely above the detection limit, which was approximately 0:05 mg/Nm^3.

2 Gas analysis spectroscopy

2.1 Shematic

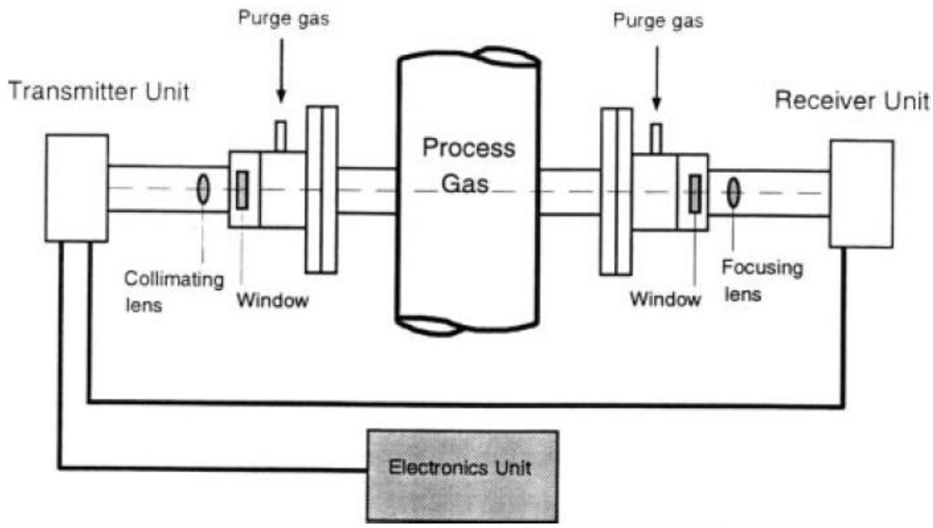
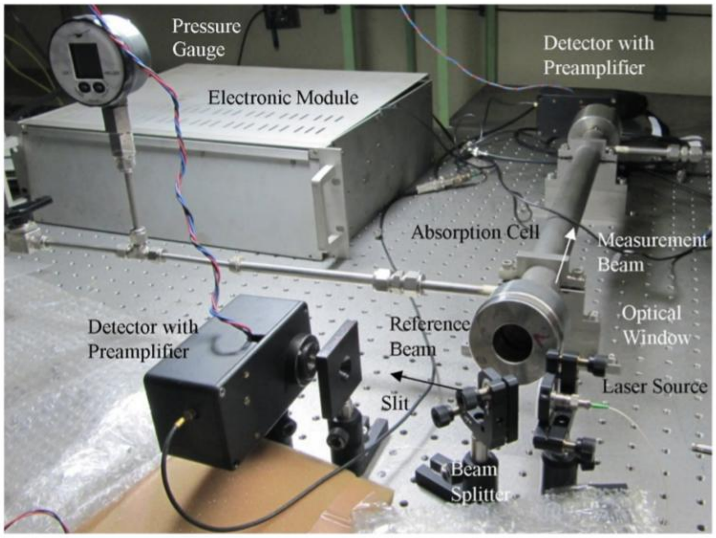


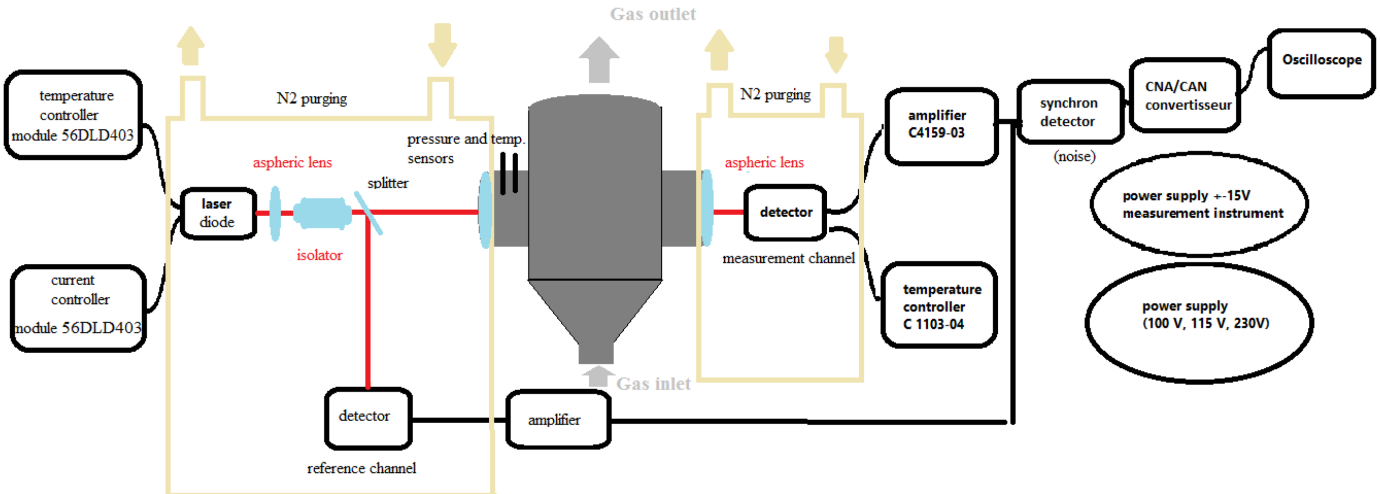
Fig. 2. Schematic drawing of the TDLAS gas monitors described in this paper

The mechanical layout of a monitor installed on a stack is shown in Fig. 2. The laser and detector are located in the transmitter and receiver units, respectively. Both units are mounted on the stack by using standard flanges purged with dry air to keep the optical windows clean. The detected signal is transmitted through a cable to the electronics unit, which contains signal-processing electronics. The measured concen- tration is displayed on an LCD display, and for data recording and logging it is sent through an RS232 digital output and a standard 4–20 mA analogue output.



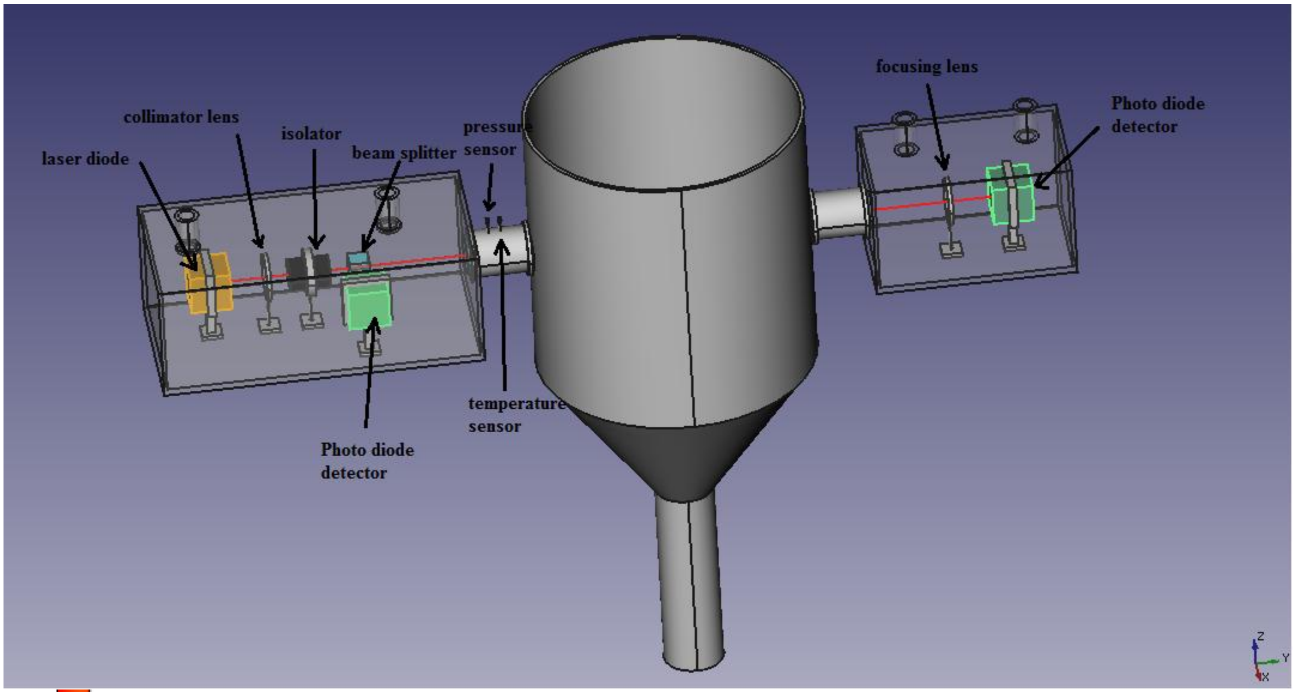
[5] https://aip.scitation.org/doi/abs/10.1063/1.5113968?journalCode=rsi

2.2 Design [6]



Optical path. The output from the laser diode is collimated by an aspheric lens before passing through an optical isolator. The isolator prevents reflected radiation from damaging the diode. After the optical isolator, the light enters a beam splitter with a typical transmission: reflection ratio of 90:10. The weaker reflected signal from the beam splitter is incident on a photodetector whose signal compared with the received photodetector signal.

- 6 https://espace.library.uq.edu.au/data/UQ_690617/s4111331_final_thesis.pdf?Expires=1578991666&Key-Pair-Id=APKAJKNBJ4MJBJNC6NLQ&Signature=IiK5vmsYt-GtLAfQynJTXcqGPrEgHmIDtGkVusuGTvSjr-AFU-6fP9HXXDe9KYya8xpM6Eo5lKMfKVw3~4KLhMVtvmEHC9yLxOH6IlfLLeIfl0g4D-a2S6aX3Ovfmc36eTYbESfhGqwtzBZlC5GPo-zwwCUo4nU2-ZxN8rIDP0DTynribbjF8ZpzMb96qOH-hekmrvx0PuvyrYxZ2IM-IxMBkuGLNB2JQAhkAze-C~PRedPTpbBtlR22PcGLUTmGs6SvATzIKWq9avUZhMIgFkskAjywiBGAcNJ84VlPRmz-IK3Ys2qiptwtOvCJ5rJ7YpFEo6WEU8pA5~QS-YcTuA



TDLAS.FCStd

2.3 Experimental setup[7]

2.3.1 Care of diode laser

Diode lasers are extremely sensitive to static electricity and surges in voltage. There are several concerns that must be kept in mind when dealing with diode lasers:

1. Never handle the diode laser with a tool (including fingers) that are not grounded. Static electricity may cause the diode laser to fail.
2. Take care never to drive the diode laser at voltages and currents beyond its capacity. The diode laser controller should be configured to restrict voltage, current, and case temperature.
3. Be sure to connect all equipment to a common ground to protect against ground loops.
4. Always configure the diode laser mounts to keep the diode voltage floating. Grounding the diode laser to earth ground will increase susceptibility to line power fluctuations and surges.

2.3.2 Alignment of Optics

There is no substitute for practice in learning to align optics. However, a few suggestions might be helpful.

[7] https://vtechworks.lib.vt.edu/bitstream/handle/10919/36293/MS_F_TDLASmanual.pdf?sequence=14

When aligning an optical setup for the first time, or if the optics have become badly out of alignment, place a visible He-Ne laser in place of the detector. Align the optics so that the visible laser shines directly on the head of the IR laser. Then, turn the IR laser on and adjust the IR laser so that the beam follows the same path as the visible laser.

In my experience, it is best to always work the laser to the detector when aligning optics. For the TDLAS setup,

1. Align the aspheric lens to achieve a well – collimated and symmetric beam.
2. Align the nearest mirror to direct the beam across the flame.
3. Adjust the mirror on the opposite side of the flame to direct the beam back across the flame.
4. Adjust the far mirror to direct the beam onto the detector.
5. Once the lasers are aligned on the correct path, small adjustments can be made to maximize the detector output.
6. The detector gain can then be adjusted to the desired output voltage.

The detector signal may begin to oscillate due to etalon effects (reflections) in the optical path. If this occurs, make small adjustments to the optical path until the oscillations are no longer observed.

2.4 Measurement procedure

2.4.1 Theoretical Lineshapes.

Theoretical lineshapes are calculated to identify attractive transitions and to determine physical parameters. The HITRAN database contains spectroscopic parameters for many important molecules. The HITEMP database includes parameters for high-temperature transitions. Many of the parameters are theoretical, although some have been experimentally verified. Using these parameters, theoretical lineshapes can be computed to compare with measured lineshapes. Also, the theoretical properties are used to calculate the temperature dependence of transitions (see Section 3.1.1). The Matlab program "spectra.m" calculates theoretical lineshapes based on the parameters in HITRAN and HITEMP.

2.4.2 Lineshape Data.

When a high-bandwidth measurement is not required, the wavelength of the laser is scanned over the entire absorption feature. The temperature and injection current is set through the laser controller to maintain the laser at the linecenter. A function generator is used to send a sawtooth waveform to the external modulation connection on the laser controller. Observing the lineshape on an oscilloscope, the case temperature and mean current can be adjusted to position the linecenter of the transition at the center of the waveform. The amplitude of the sawtooth wave should be adjusted so that at least 30% of the waveform is outside of the transition. For the setup at the VACCG, analog output channel 0 was connected to the modulation input on the diode laser controller. The Labview program “fungen.vi” was used to create a 50 Hz sawtooth waveform with amplitude of 0.2 Volts. Diode lasers can be modulated at up to 10 kHz. However, your data acquisition system must be able to record at atleast three times the modulation frequency. The Labview program “diagnostic_main.vi” was used to record the lineshape data. The data was processed by the Matlab program “v_scan.m”. This program fit baselines to the data to solve for the reference intensity (see Appendix B2) and plotted the resulting lineshape. The program also calculates the peak absorbance which is used in the temperature calculation.

By fitting theoretical lineshapes, using the data from the HITRAN database, to the measured lineshapes, species concentration, pressure, and broadening coefficients can be determined. The program “tst_voigtfit.m” was used to fit theoretical lineshapes to measured lineshapes.

MS_F_TDLASmanual.pdf

2.5 List of component (CO)

Thorlabs GmbH
Münchner Weg 1
85232 Bergkirchen
85232 Bergkirchen

Phone ...: +49 (0) 8131-5956-0
Fax .....: +49 (0) 8131-5956-99

Quotation

Number: **WEB N27W977793**
Purchase Order: **N27W977793**

Item Number	Description	Quantity	Price Each	Amount
L1575G1	1575 nm, 1.7 W, Ø9 mm, G Pin Code, MM Laser Diode	1	€ 295,10	€ 295,10 EUR
LTN330-C	Adjustable Collimation Tube with Optic for Ø5.6 and Ø9 mm Laser Diodes, f = 3.1 mm, NA = 0.68, AR Coated: 1050 - 1700 nm	1	€ 229,19	€ 229,19 EUR
SR9F	ESD Protection and Strain Relief Cable, Pin Codes F and G, 3.3 V	1	€ 49,19	€ 49,19 EUR
AD15NT	Ø1" Unthreaded Adapter for Ø15 mm Cylindrical Components	1	€ 22,13	€ 22,13 EUR
CP36	30 mm Cage Plate, Ø1.2" Double Bore for SM1 and C-Mount Lens Tubes	1	€ 20,06	€ 20,06 EUR
IOT-4-1550-VLP	Free-Space Tandem Isolator, 1550 nm, Ø3.6 mm Max Beam, 2.4 W Max	1	€ 1.418,42	€ 1.418,42 EUR
PDA10D2	InGaAs Fixed Gain Amplified Detector, 900 - 2600 nm, 25 MHz BW, 0.8 mm², Universal 8-32 / M4 Mounting Holes	2	€ 516,42	€ 1.032,84 EUR
POWER CORD EUROPE	PDA10D2:POWER CORD EUROPE : No Cost Accessory	2	€ 0,00	€ 0,00 EUR
CM1-BP108	Cube-Mounted Pellicle Beamsplitter, 8:92 (R:T), Uncoated, 400 - 2400 nm	1	€ 232,14	€ 232,14 EUR
LBF254-200-C	N-BK7 Best Form Lens, Ø1", f = 200 mm, ARC: 1050-1700 nm	2	€ 55,08	€ 110,16 EUR
LMR1/M	Lens Mount with Retaining Ring for Ø1" Optics, M4 Tap	2	€ 14,26	€ 28,52 EUR
WW31050	Ø1" Wedged Sapphire Window, Uncoated	2	€ 100,33	€ 200,66 EUR
BA2E	Flexure Clamping Base / Post Mount, Ø1/2" Double Bore, 2.00" x 3.00" x 0.48"	8	€ 30,54	€ 244,32 EUR
PH3-P5	Ø1/2" Post Holder, Spring-Loaded Hex-Locking Thumbscrew, L = 3", 5 Pack	1	€ 38,71	€ 38,71 EUR
TR30/M	Ø12.7 mm Optical Post, SS, M4 Setscrew, M6 Tap, L = 30 mm	3	€ 4,44	€ 13,32 EUR
PH3	Ø1/2" Post Holder, Spring-Loaded Hex-Locking Thumbscrew, L = 3"	3	€ 7,74	€ 23,22 EUR
TR30/M-P5	Ø12.7 mm Optical Post, SS, M4 Setscrew, M6 Tap, L = 30 mm, 5 Pack	1	€ 19,97	€ 19,97 EUR

General Manager: Dr. Bruno Gross
Email: europe@thorlabs.com - Web: www.thorlabs.com
HRB: 85345/Munich VAT-No.: DE 129 442 088
Please note our standard terms and conditions incl. WEEE
EAR: DE97581288

**** NOTE ** : Please note that the customs and duties charges are the responsibility of the customer.**

Subtotal: € 3.977,95
Shipping and Handling: 9.24
VAT: € 757,57
Grand Total: € 4.744,76 EUR

Component	Type	quantity	Price/supplier
Laser diode	L1575G1	1	**324.64$** https://www.thorlabs.com/thorproduct.cfm?partnumber=L1575G1
Collimator	LTN330-C	1	**252.13$** https://www.thorlabs.com/thorproduct.cfm?partnumber=LTN330-C
Isolator	IOT-4-1550-VLP	1	**1560.42 $** https://www.thorlabs.com/thorproduct.cfm?partnumber=IOT-4-1550-VLP
Beam splitter	CM1-BP108	1	**255.38$** https://www.thorlabs.com/thorproduct.cfm?partnumber=CM1-BP108
Focusing lens + Holder	LBF254-200-C	2	**60.59$/piece** https://www.thorlabs.com/thorproduct.cfm?partnumber=LBF254-200-C **15.69$/piece** https://www.thorlabs.com/thorproduct.cfm?partnumber=LMR1/M#ad-

	LMR1/M		image-0
Photodiode	PDA10D2-InGaAs	2	**568.12 $ / piece** https://www.thorlabs.com/thorproduct.cfm?partnumber=PDA10D2
Window	WW31050-φ1"	2	**110.37$ / piece** https://www.thorlabs.com/thorproduct.cfm?partnumber=WW31050
Holder	TR30/M TR30/M-P5	Pachage 1 Piece 3	**4.88$/piece** https://www.thorlabs.com/thorproduct.cfm?partnumber=TR30/M **21.97$/package**
Cable (diode)	SR9F	1	**54.11$** https://www.thorlabs.com/thorproduct.cfm?partnumber=SR9F
Adapter (collimator)	AD15NT CP36		**24.35$** https://www.thorlabs.com/thorproduct.cfm?partnumber=AD15NT **22.07$** https://www.thorlabs.com/thorproduct.cfm?partnumber=CP36
Base	BA2E	8	**33.60$** https://www.thorlabs.com/thorproduct.cfm?partnumber=BA2E#ad-image-0
Post holder	PH3 PH3-P5	Pieces 3 Package 1	**8.52$/piece** https://www.thorlabs.com/thorproduct.cfm?partnumber=PH3-P5#ad-image-0 **42.59$/package**
Total price			3,359.43$

Item	Image	Part Number	Ship Date	Qty	Price	Subtotal	Remove
2		L1575G1- **(WEIGHT (Total)):**0.02 Kgs 1575 nm, 1.7 W, Ø9 mm, G Pin Code, MM Laser Diode * **NOTE:** * L1575G1 is export controlled. To comply with US export laws, an End User Statement will be requested as part of the checkout process.	Today	1	295,10 €	295,10 €	
3		LTN330-C- **(WEIGHT (Total)):**0.04 Kgs Adjustable Collimation Tube with Optic for Ø5.6 and Ø9 mm Laser Diodes, f = 3.1 mm, NA = 0.68, AR Coated: 1050 - 1700 nm	Today	1	229,19 €	229,19 €	
4		SR9F- **(WEIGHT (Total)):**0.04 Kgs ESD Protection and Strain Relief Cable, Pin Codes F and G, 3.3 V	Today	1	49,19 €	49,19 €	
5		AD15NT- **(WEIGHT (Total)):**0.01 Kgs Ø1" Unthreaded Adapter for Ø15 mm Cylindrical Components	Today	1	22,13 €	22,13 €	
6		CP36- **(WEIGHT (Total)):**0.03 Kgs 30 mm Cage Plate, Ø1.2" Double Bore for SM1 and C-Mount Lens Tubes	3-5 Days	1	~~20,06 €~~* 20,06 €	20,06 €	
7		IOT-4-1550-VLP- **(WEIGHT (Total)):**0.17 Kgs Free-Space Tandem Isolator, 1550 nm, Ø3.6 mm Max Beam, 2.4 W Max	Today	1	1.418,42 €	1.418,42 €	
8		PDA10D2- **(WEIGHT (Total)):**1.98 Kgs InGaAs Fixed Gain Amplified Detector, 900 - 2600 nm, 25 MHz BW, 0.8 mm^2, Universal 8-32 / M4 Mounting Holes	Today	2	516,42 €	1.032,84 €	
9		CM1-BP108- **(WEIGHT (Total)):**0.09 Kgs Cube-Mounted Pellicle Beamsplitter, 8:92 (R:T), Uncoated, 400 - 2400 nm	Today	1	232,14 €	232,14 €	
10		LBF254-200-C- **(WEIGHT (Total)):**0.05 Kgs N-BK7 Best Form Lens, Ø1", f = 200 mm, ARC: 1050-1700 nm	Today	2	55,08 €	110,16 €	

11	LMR1/M- (WEIGHT (Total)):0.02 Kgs Lens Mount with Retaining Ring for Ø1" Optics, M4 Tap	Today	2	14,26 €	28,52 €	
12	WW31050- (WEIGHT (Total)):0.05 Kgs Ø1" Wedged Sapphire Window, Uncoated	Today	2	100,33 €	200,66 €	
13	BA2E- (WEIGHT (Total)):0.80 Kgs Flexure Clamping Base / Post Mount, Ø1/2" Double Bore, 2.00" x 3.00" x 0.48"	3-5 Days	8	30,54 €	244,32 €	
14	PH3-P5- (WEIGHT (Total)):0.48 Kgs Ø1/2" Post Holder, Spring-Loaded Hex-Locking Thumbscrew, L = 3", 5 Pack	Today	1	38,71 €	38,71 €	
15	TR30/M- (WEIGHT (Total)):0.08 Kgs Ø12.7 mm Optical Post, SS, M4 Setscrew, M6 Tap, L = 30 mm	Today	3	4,44 €	13,32 €	
16	PH3- (WEIGHT (Total)):0.25 Kgs Ø1/2" Post Holder, Spring-Loaded Hex-Locking Thumbscrew, L = 3"	Today	3	7,74 €	23,22 €	
17	TR30/M-P5- (WEIGHT (Total)):0.13 Kgs Ø12.7 mm Optical Post, SS, M4 Setscrew, M6 Tap, L = 30 mm, 5 Pack	Today	1	19,97 €	19,97 €	
* For Thorlabs Price and Discount Policy please see Thorlabs Price Policy . **WEIGHT (Total):** 4.22 Kgs				**TOTAL:**	**3.977,95 €**	

2.5.1 Laser diode

L1575G1 - 1575 nm, 1.7 W, Ø9 mm, G Pin Code, MM Laser Diode

Zoom

Complete Product Details

Part Number:	L1575G1 -Ask a technical question
Package Weight:	0.03 lbs / Each
Available:	Today
RoHS:	RoHS✓
Price:	$324.64
Add To Cart:	Qty : 1
	Add To Cart
Release Date:	Jul 6, 2018

Drawings and Documents:

Auto CAD PDF

Auto CAD DXF

Solidworks

eDrawing

Step

Spec Sheet

RoHS RoHS✓

REACH

Download all support documents

Download

SR9F - ESD Protection and Strain Relief Cable, Pin Codes F and G, 3.3 V

Zoom

Complete Product Details

Part Number:	SR9F -Ask a technical question
Package Weight:	0.08 lbs / Each
Available:	Today
RoHS:	RoHS✓
Price:	$54.11
Add To Cart:	Qty : 1
	Add To Cart
Release Date:	May 28, 2015

Drawings and Documents:

Auto CAD PDF	
Auto CAD DXF	
Solidworks	
eDrawing	
Step	
RoHS	RoHS✓
REACH	

Download all support documents

Download

AD15NT - Ø1" Unthreaded Adapter for Ø15 mm Cylindrical Components

Zoom

Complete Product Details

Part Number:	AD15NT -Ask a technical question
Package Weight:	0.03 lbs / Each
Available:	Today
RoHS:	RoHS✓
Price:	$24.35
Add To Cart:	Qty : 1 Add To Cart
Release Date:	Oct 7, 2009

Drawings and Documents:

Auto CAD PDF	
Auto CAD DXF	
Solidworks	
eDrawing	
Step	
RoHS	RoHS✓
REACH	

Download all support documents

Download

CP36 - 30 mm Cage Plate, Ø1.2" Double Bore for SM1 and C-Mount Lens Tubes

Zoom

Complete Product Details

Part Number:	CP36 -Ask a technical question
Package Weight:	0.06 lbs / Each
Available:	Today
RoHS:	RoHS✓
Price:	$22.07
Add To Cart:	Qty : 1 Add To Cart
Release Date:	Nov 11, 2019

Drawings and Documents:

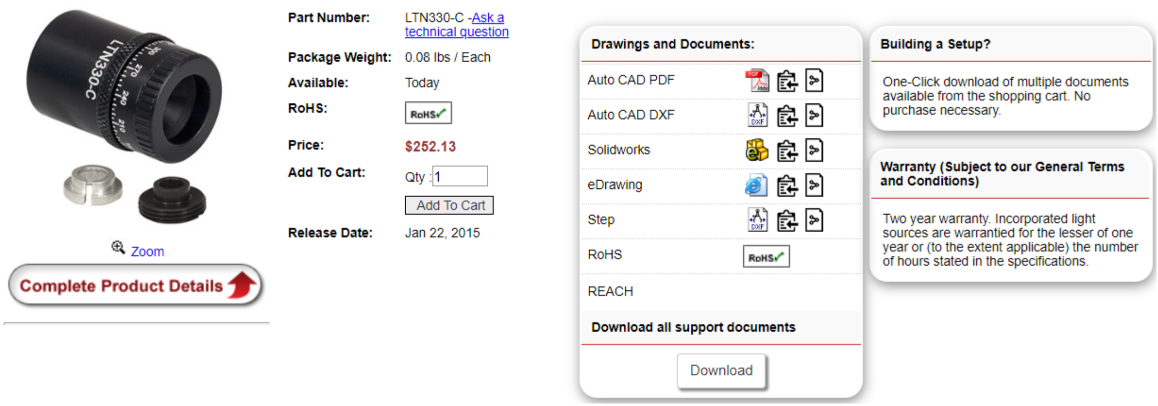
Auto CAD PDF	
Auto CAD DXF	
Solidworks	
eDrawing	
Step	
RoHS	RoHS✓
REACH	

Download all support documents

Download

2.5.2 Collimator

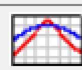
LTN330-C - Adjustable Collimation Tube with Optic for Ø5.6 and Ø9 mm Laser Diodes, f = 3.1 mm, NA = 0.68, AR Coated: 1050 - 1700 nm



Adjustable Lens Mount with Collimating Optic for our LD Sockets with Strain Relief Cables (Sold Below)

- 13/32"-40 Threaded Retaining Ring Secures Ø5.6 mm or Ø9 mm Laser Diode
- Aspheric Collimation Optic with One of Three Broadband AR Coatings:
  - A Coating: 350 - 700 nm
  - B Coating: 600 - 1050 nm
  - C Coating: 1050 - 1700 nm
- Rotating Cap with Locking Ring Provides 2.5 mm (0.1") of Lens Travel for an Adjustable Focus
- Includes Main Tube with Mounted Optic, Retaining Ring, and Adapter Kit for Ø5.6 mm Diode Packages
- Ø15 mm (Ø0.58") Tube Can be Mounted Using a Ø1" AD15NT Adapter or SM1-Threaded AD15F Adapter
- Laser Diode Retaining Ring Compatible with SPW301 and SPW801 Spanner Wrenches

2.5.3 Isolator

Click Image for Details	
Item #	IOT-4-1550-VLP
Type	Tandem Fixed Narrowband
Center Wavelength	1550 nm
Tuning Range	N/A
Operating Range	1500 - 1600 nm
Transmission[e]	85%
Isolation[e]	60 dB (Min)
Performance Graph (Click for Details)	
Max Beam Diameter[f]	3.6 mm
Max Power[g]	2.4 W
Max Power Density	Blocking: 50 W/cm^2

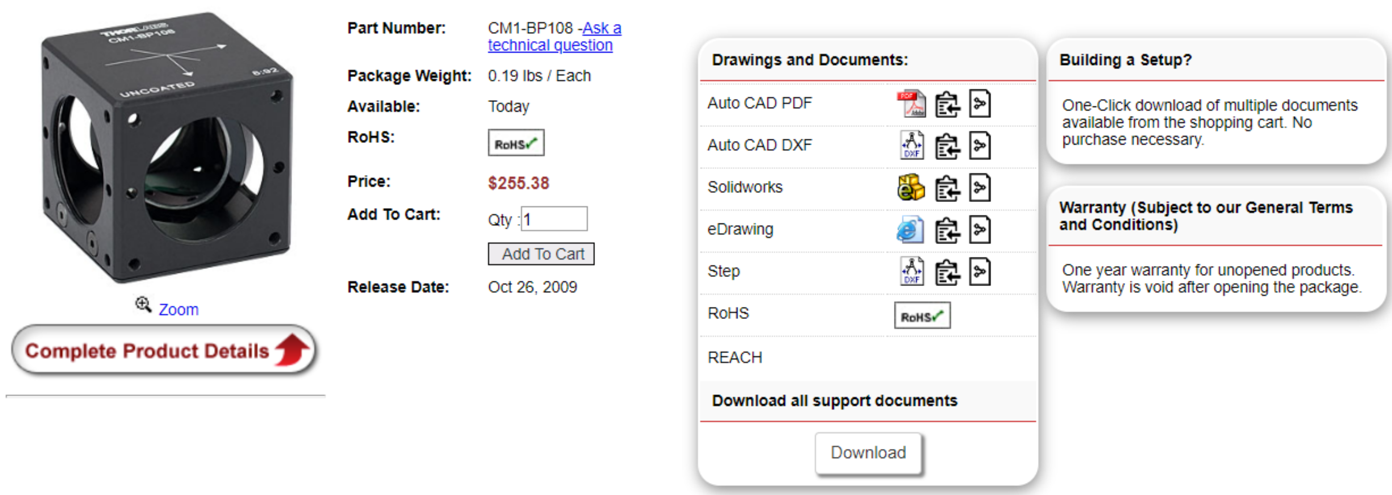
Optical isolators, also known as Faraday isolators, are magneto-optic devices that preferentially transmit light along a single direction, shielding upstream optics from back reflections. Back reflections can create a number of instabilities in light sources, including intensity noise, frequency shifts, mode hopping, and loss of mode lock. In addition, intense back-reflected light can permanently damage optics.

a. The input aperture is in the black end of the cylinder, while the output aperture is in the gold end of the cylinder.
b. This isolator can be supplied in an optic mount with twin steel dowel pins for our FiberBench systems by contacting Tech Support prior to ordering.
c. The mounting saddle contains an 8-32 tap. For an M4-threaded saddle, please contact Tech Support prior to ordering.
d. This isolator has two exit ports for rejected beams. Adequate beam traps should be selected and positioned to ensure safety.
e. Specified at center wavelength. See Performance Graph for wavelength dependence.
f. Defined as containing 100% of the beam energy.

g. The maximum power specification represents the maximum power for the combined forward and reverse directions. Therefore, the sum of the powers in the forward and reverse directions cannot exceed the maximum power specification.
h. The blocking power density corresponds to light polarized perpendicular to the transmission axis, while the transmission power density corresponds to light polarized parallel to the transmission axis.
i. Please see below for further details.
j. One SM087RC with an 8-32 tap is included with each of these isolators. For an isolator that includes an SM087RC/M with an M4 tap.
k. One SM1RC with an 8-32 tap is included with this isolator. For an SM1RC/M with an M4 tap.

2.5.4 Beam splitter

CM1-BP108 - Cube-Mounted Pellicle Beamsplitter, 8:92 (R:T), Uncoated, 400 - 2400 nm



- Eliminates Ghosting
- No Chromatic Aberration with Focused Beams
- Minimal Change in Optical Path Length
- SM1-Threaded Entrance and Exit Ports
- 30 mm Cage System Compatible

These beamsplitters virtually eliminate ghosting since the second surface reflection is superimposed on the first one. However, they are extremely fragile due to the nitrocellulose membrane being microns thick, which exhibits less than 1/2 wave of variation at 635 nm across its 25 mm diameter. To provide maximum protection from damage, these beamsplitters are housed inside a 30 mm cage-system-compatible cube. The cubes are post-mountable and have SM1-threaded access ports, making them compatible with our entire line of Ø1" lens tubes and accessories. The cubes are M6 x 0.5 threaded, but include 8-32 and M4 mounting adapters.

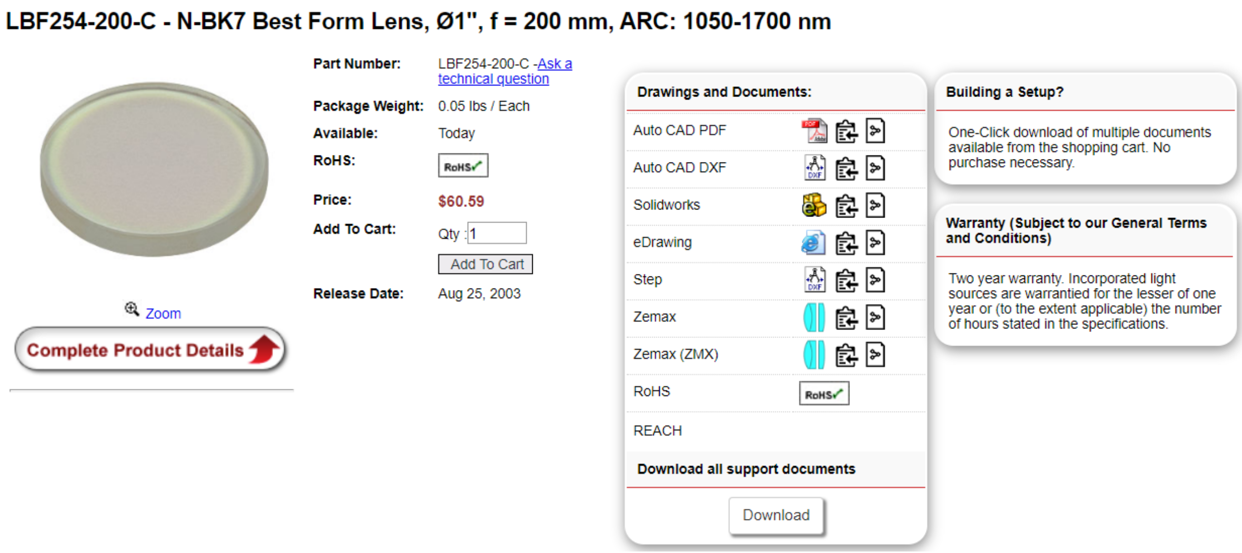
These Beamsplitter cubes can also be connected to other cage cubes with cage rods and our ERSCB adapters.

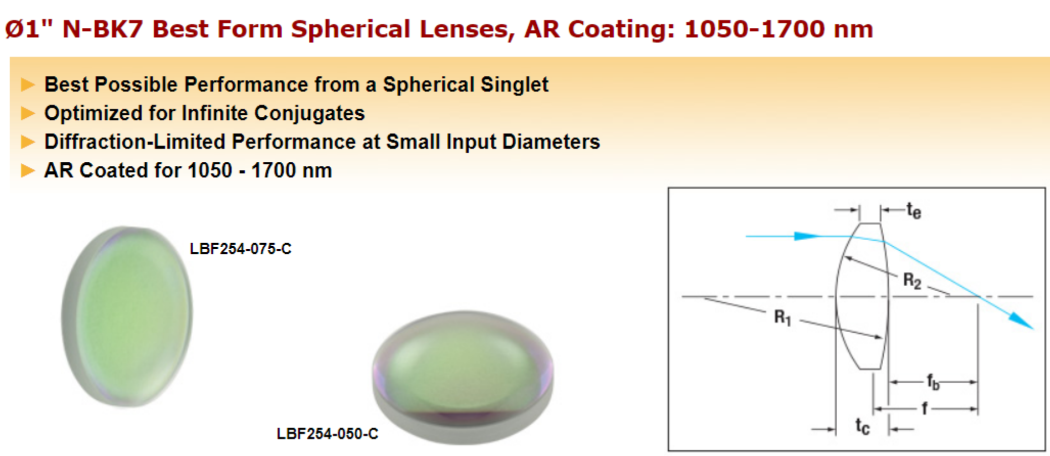
Handling Precautions

Our pellicle beamsplitters are manufactured from an extremely thin and fragile membrane. Please do not touch the membrane under any circumstances. Compressed or canned air can be used to clean these beamsplitters, but please exercise caution as the force of the air may be large enough to damage the membrane. Aim the stream of air such that it makes a small angle with the surface, and hold the can sufficiently far away to avoid damaging the membrane. If the pellicle becomes damaged, please contact tech support for information about replacement of the beamsplitter; in these cases, we only charge for the cost of the pellicle.

2.5.5 Focusing lens + holder

2.5.5.1 Focusing lens





Features

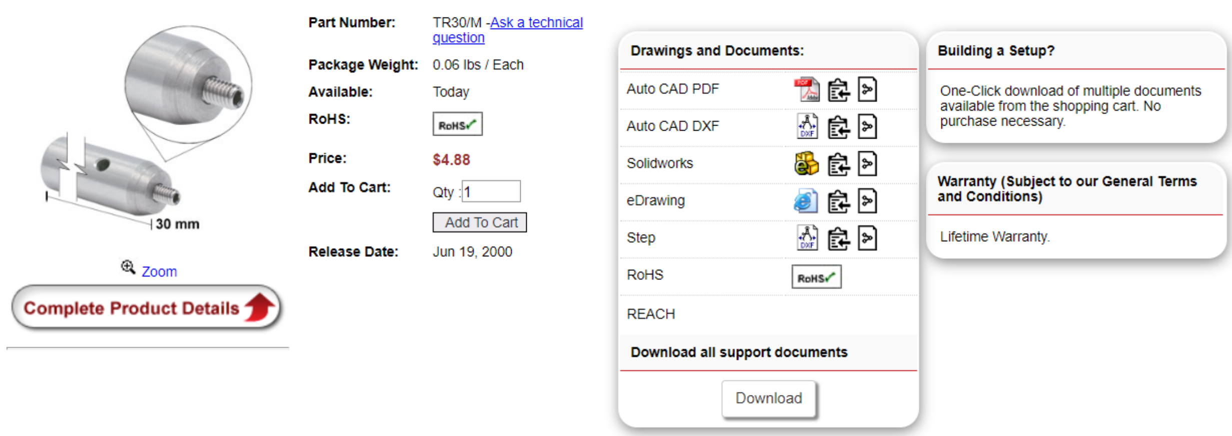
- Best Possible Performance from a Spherical Singlet
- 1050 - 1700 nm AR Coating Range
- Ideal for High-Power Applications
- Diffraction-Limited Performance at Small Input Diameters

Best Form lenses are designed to minimize spherical aberration while still using spherical surfaces to form the lens. Best form lenses are available with an AR coating for 1050 - 1700 nm to reduce the light reflected from each surface of the lens. Best Form Lenses are ideally suited for use at infinite conjugates in high-power applications where doublets are not an option.

Each side of the lens is polished so that it has a different radius of curvature, optimizing it for use at infinite conjugates. This process makes these lenses more expensive than plano-convex or bi-convex lenses. Since the lenses are optimized for minimum spot size, they can theoretically reach diffraction-limited performance for small input beam diameters

2.5.5.2 Holder

TR30/M - Ø12.7 mm Optical Post, SS, M4 Setscrew, M6 Tap, L = 30 mm

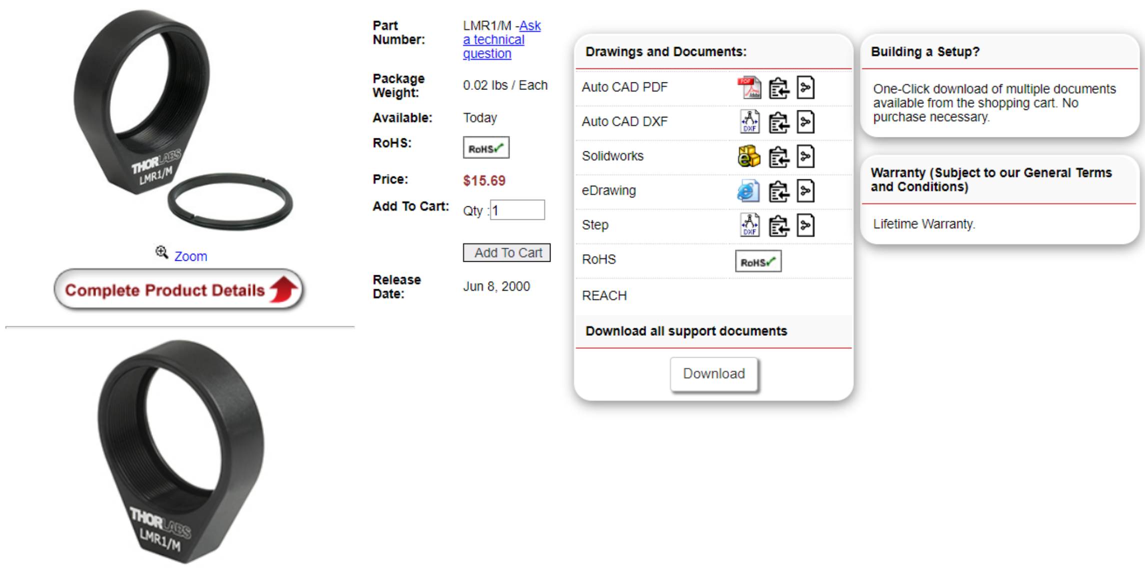


Features

- Precision-Ground Posts with 1/2" (12.7 mm) or 12 mm Diameters
    - Ø1/2" Imperial Posts: Bottom-Located 1/4"-20 Tapped Hole and Top-Located 8-32 Removable Setscrew
    - Ø12.7 mm Metric Posts: Bottom-Located M6 Tapped Hole and Top-Located M4 Removable Setscrew
    - Ø12 mm Metric Posts for Japanese Optomechanics: Bottom-Located M6 Tapped Hole and Top-Located M4 Removable Setscrew.
- Three Material Options Available
    - Standard Posts (303 Stainless Steel)
    - Vacuum-Compatible Posts (304L Stainless Steel)
    - Non-Magnetic, Low-Reflectivity Posts (Aluminum with Anodized Hard Coat)

- Available in a Variety of Lengths Ranging from 0.60" to 12" (15 mm to 300 mm for Metric Posts)
- Posts Available with Hex Tops Instead of Side-Located Bores
- Graduated Posts Available to Aid in Optic Alignment
- Post Spacers (Shims) to Achieve Intermediate Post Heights
- All Included Setscrews are Double-Ended (Except with Vacuum-Compatible Posts)

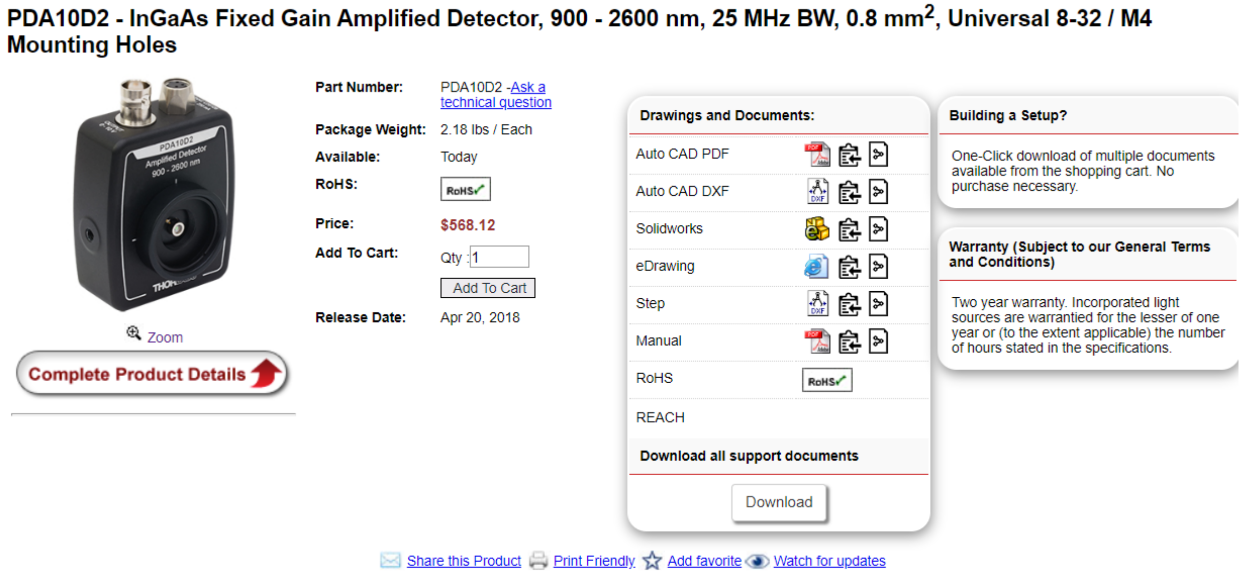
LMR1/M - Lens Mount with Retaining Ring for Ø1" Optics, M4 Tap



- ➢ Accommodates Various Optic Diameters from Ø5 mm to Ø4"
- ➢ Internally Threaded
- ➢ 8-32 (M4) Tapped Hole Allows for Mounting to Ø1/2" Posts
- ➢ Includes Compatible Retaining Ring for Mounting Optics
- ➢ Ø1/2", Ø1", and Ø2" Optic Mounts Available in 5 Packs

These Fixed Optic Mounts are our standard mounts for 20 distinct optic diameters ranging from Ø5 mm to Ø4". Each mount features internal threading, and ships with a retaining ring for securing the optic into place. The internal threading is deep enough to hold most unmounted optics or externally threaded components. The base of each mount features an 8-32 (M4) tapped hole, which allows for easy mounting to Ø1/2" Posts, as shown to the right. Additional retaining rings are sold separately below.

2.5.6 Photodiode



Features

- Wavelength Ranges within 800 to 2600 nm
- Low-Noise Amplification with Fixed or Switchable Gain
- Load Impedances 50 Ω and Higher for ≥3 kHz Bandwidth Versions
- Free-Space Optical Coupling

A selection of Indium Gallium Arsenide (InGaAs) Free-Space Amplified Photodetectors that are sensitive to light in the NIR wavelength range. Thorlabs' amplified photodetectors feature a built-in, low-noise transimpedance amplifier (TIA) which, for select detectors, is followed by a voltage amplifier. Menlo Systems' FPD series amplified photodetectors have a built-in radio frequency (RF) or transimpedance amplifier. We offer fixed-gain versions that possess a fixed maximum bandwidth and total transimpedance gain, as well as switchable-gain versions with two or eight gain settings.

Thorlabs' photodetectors are designed to meet a range of requirements, with offerings that include the 380 MHz PDA015C with an impulse response of 1 ns, the high-sensitivity PDF10C with a noise equivalent power (NEP) of 7.5 fW/Hz1/2, and the switchable-gain PDA20CS2 with eight switchable maximum gain (bandwidth) combinations from 1.51 kV/A (11 MHz) to 4.75 MV/A (3 kHz). The PDF10C with femtowatt sensitivity is a low-frequency device that should only be terminated into high impedance (Hi-Z) loads, while all other of our InGaAs PDA amplified photodetectors are capable of driving loads from 50 Ω to Hi- Z.

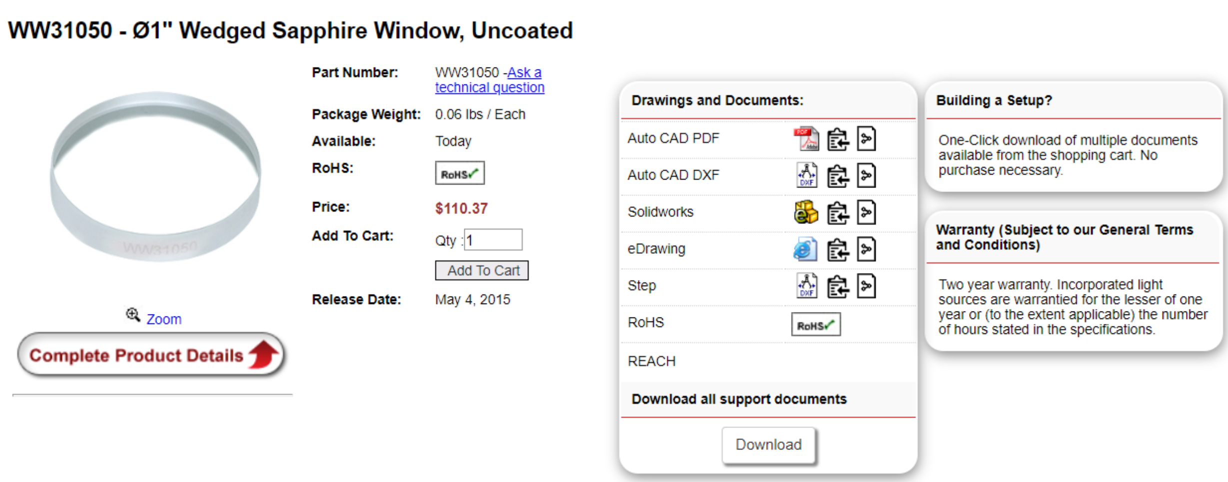
Every PDA and PDF detector has internal SM05 (0.535"-40) threading and external SM1 (1.035"-40) threading. Except for some select detectors, each unit's housing features 8-32 tapped holes (M4 for -EC and /M models). The PDA05CF2, PDA20C2, PDA10D2, PDA10CS2, and PDA20CS2 feature a new housing with two universal mounting holes that accept both 8-32 and M4 threads. For more information about the location of these mounting points and mounting these units

Menlo Systems' FPD series photodetectors are easy-to-use InGaAs-PIN photodiode packages with an integrated high-gain, low-noise RF (FPD310-FS-NIR) or transimpedance (FPD510-FS-NIR and FPD610-FS-NIR) amplifier. The FPD310-FS-NIR is recommended, in particular, for applications like pulse shape and low-noise radio frequency extraction. This photodetector is optimized for high gain, high bandwidths, extremely short rise times, and high signal-to-noise ratio. It has a 0.5 ns rise time and a switchable gain between two settings, allowing for an optimal performance for the user's application. The FPD510-FS-NIR and FPD610-FS-NIR have a fixed gain and are optimized for highest signal-to-noise-ratio for detection of low level optical beat signals at frequencies up to 250 MHz and 600 MHz, respectively. The FPD510-FS-NIR has a rise time of 2 ns, while the FPD610-FS-NIR has a 1 ns rise time. The 3 dB bandwidth of these DC-coupled devices is 200 MHz for the FPD510-FS-NIR and 500 MHz for the FPD610-FS-NIR. The compact design of the FPD detectors allows for easy OEM integration. The housing of each Menlo detector features one M4 tapped hole for post mounting.

Power Supply

A ±12 V linear power supply that supports input voltages of 100, 120, and 230 VAC is included with each amplified photodetector. Replacement power supplies are available separately below. Before connecting the power supply to the mains, ensure that the line voltage switch on the power supply module is set to the proper voltage range. The power supplies should always be powered up using the power switch on the power supply itself. Hot plugging the unit is not recommended.

2.5.7 Optical window



Features

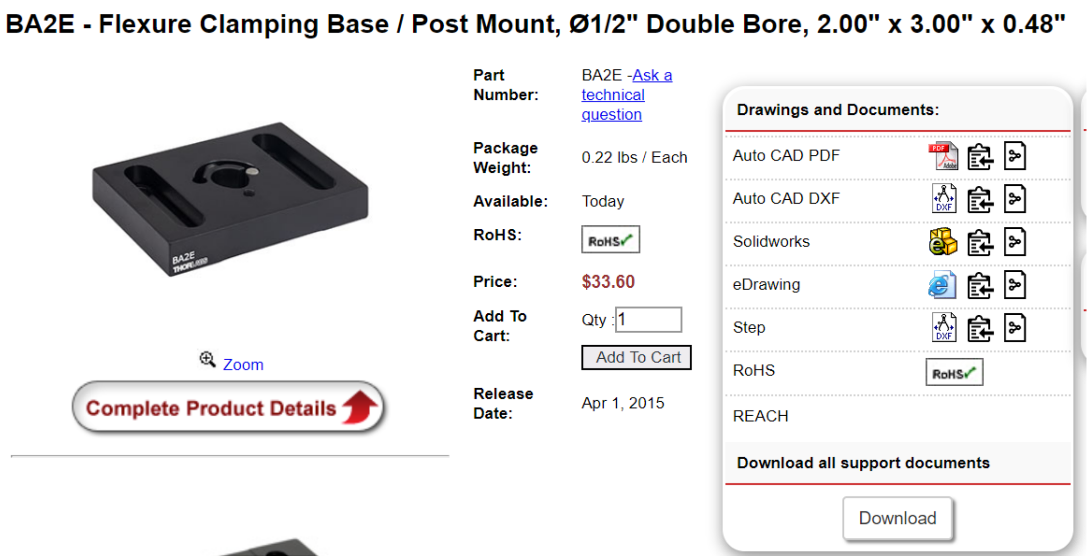
- 30 arcmin Wedged Windows

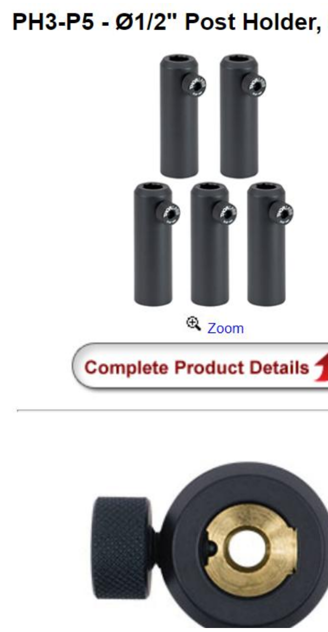
- Available Uncoated (150 nm - 4.5 µm) or with One of Two Broadband AR Coatings
- 1.65 - 3.0 µm (-D Coating Designation)
- 2.0 - 5.0 µm (-E1 Coating Designation)
- Ø1/2" and Ø1" Window

Sapphire is the material of choice for very demanding applications that benefit from reliability, strength, a broad transmission range, or low transmitted wavefront distortion at both high and low operating temperatures. Sapphire is transparent from the UV to the IR and can be scratched by only a few substances other than itself. It is chemically inert and insoluble in water, common acids, and alkalis at temperatures up to ~1,000 °C. Our sapphire windows are cut so that the c-axis of the crystal is parallel to the optical axis.

In addition to the sapphire wedged windows offered here, Thorlabs also offers wedged windows with other substrate materials (see the selection guide to the right). Wedged Laser Windows with AR coatings centered around common lasing wavelengths and wedged Beam Samplers with broadband AR coatings on only one face are also available

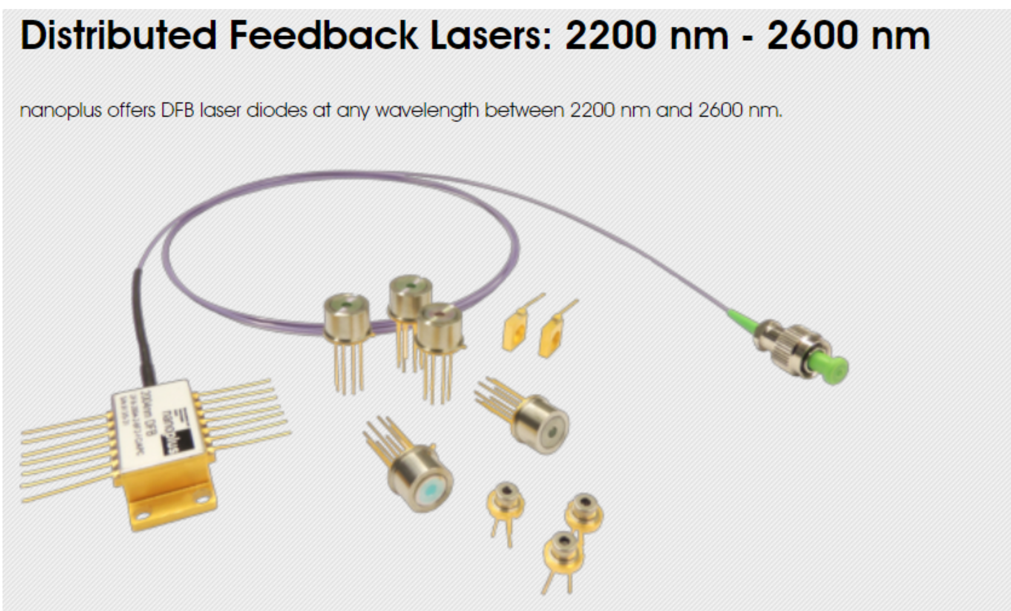
2.5.8 Component holders





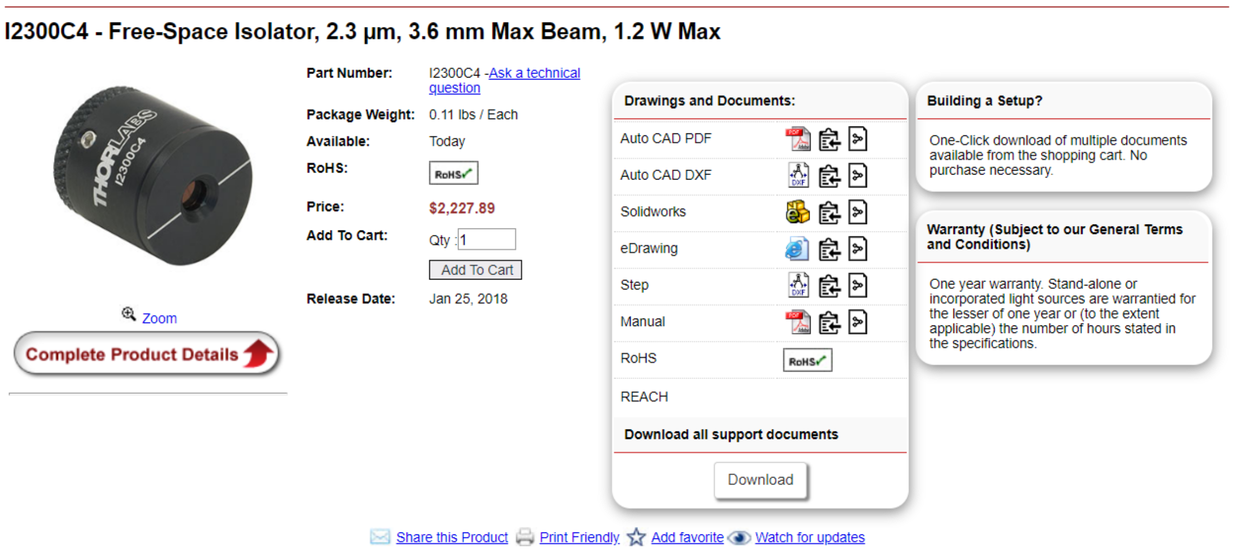
2.6 List of component NO

2.6.1 Laser diode (To do...)

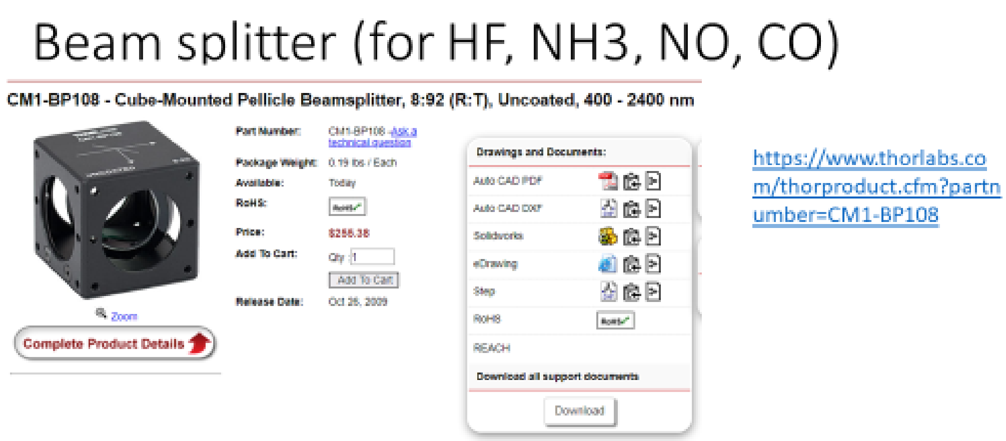


2.6.2 Collimator (To do…)

2.6.3 Isolator

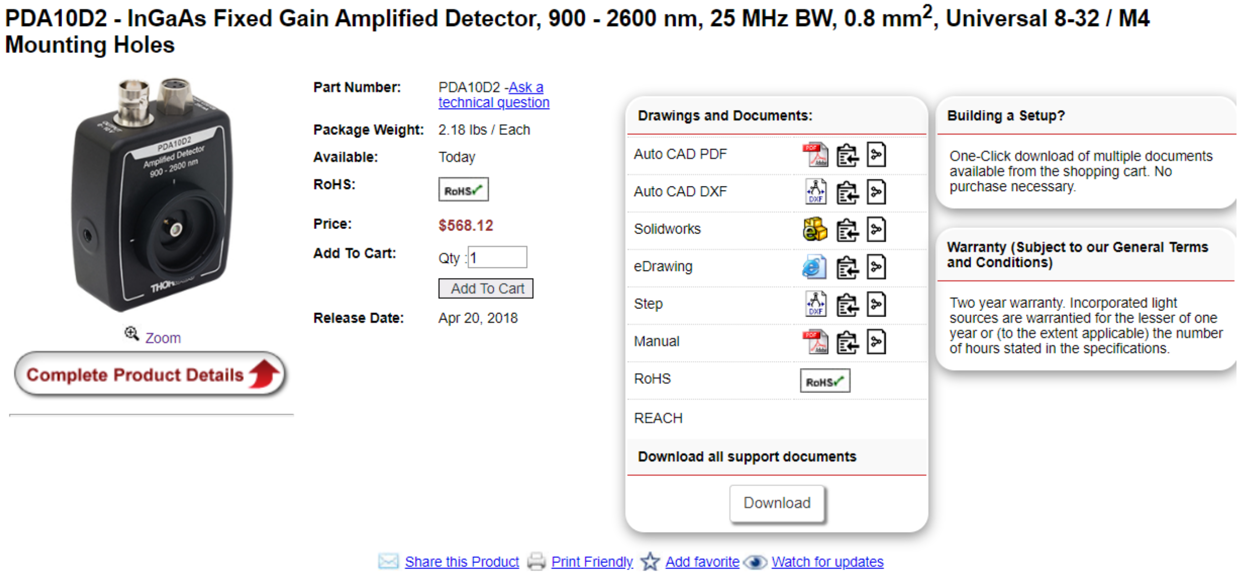


2.6.4 Beam splitter



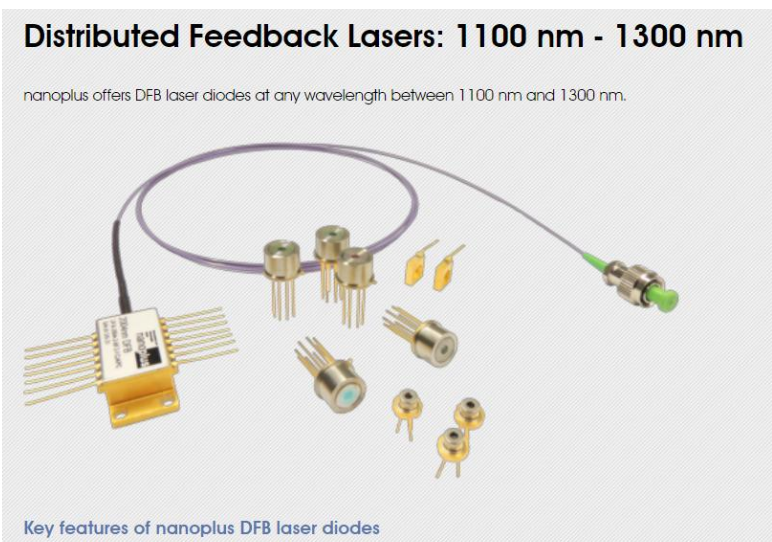
2.6.5 Focusing lens (To do...)

2.6.6 Photodiode



2.7 List of component HF

2.7.1 Laser diode (To do...)



2.7.2 Collimator

LTN330-C - Adjustable Collimation Tube with Optic for Ø5.6 and Ø9 mm Laser Diodes, f = 3.1 mm, NA = 0.68, AR Coated: 1050 - 1700 nm

Zoom

Complete Product Details

Part Number:	LTN330-C -Ask a technical question
Package Weight:	0.08 lbs / Each
Available:	Today
RoHS:	RoHS✓
Price:	$252.13
Add To Cart:	Qty 1 Add To Cart
Release Date:	Jan 22, 2015

Drawings and Documents:

- Auto CAD PDF
- Auto CAD DXF
- Solidworks
- eDrawing
- Step
- RoHS
- REACH

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Building a Setup?

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Warranty (Subject to our General Terms and Conditions)

Two year warranty. Incorporated light sources are warrantied for the lesser of one year or (to the extent applicable) the number of hours stated in the specifications.

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2.7.3 Isolator

IO-4-1310-VLP - Free-Space Isolator, 1310 nm, Ø3.6 mm Max Beam, 1.2 W Max

Zoom

Complete Product Details

Part Number:	IO-4-1310-VLP -Ask a technical question
Package Weight:	0.18 lbs / Each
Available:	Today
RoHS:	RoHS✓
Price:	$947.94
Add To Cart:	Qty 1 Add To Cart
Release Date:	Oct 24, 2007

Drawings and Documents:

- Auto CAD PDF
- Auto CAD DXF
- Solidworks
- eDrawing
- Step
- Manual
- RoHS
- REACH

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Warranty (Subject to our General Terms and Conditions)

One year warranty. Stand-alone or incorporated light sources are warrantied for the lesser of one year or (to the extent applicable) the number of hours stated in the specifications.

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2.7.4 Beam splitter

CM1-BP108 - Cube-Mounted Pellicle Beamsplitter, 8:92 (R:T), Uncoated, 400 - 2400 nm

Zoom

Complete Product Details

Part Number:	CM1-BP108 -Ask a technical question
Package Weight:	0.19 lbs / Each
Available:	Today
RoHS:	RoHS
Price:	$255.38
Add To Cart:	Qty : 1 Add To Cart
Release Date:	Oct 26, 2009

Drawings and Documents:

- Auto CAD PDF
- Auto CAD DXF
- Solidworks
- eDrawing
- Step
- RoHS
- REACH

Download all support documents

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2.7.5 Focusing lens

LBF254-200-C - N-BK7 Best Form Lens, Ø1", f = 200 mm, ARC: 1050-1700 nm

Zoom

Complete Product Details

Part Number:	LBF254-200-C -Ask a technical question
Package Weight:	0.05 lbs / Each
Available:	Today
RoHS:	RoHS
Price:	$60.59
Add To Cart:	Qty : 1 Add To Cart
Release Date:	Aug 25, 2003

Drawings and Documents:

- Auto CAD PDF
- Auto CAD DXF
- Solidworks
- eDrawing
- Step
- Zemax
- Zemax (ZMX)
- RoHS
- REACH

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2.7.6 Photodiode

PDA10D2 - InGaAs Fixed Gain Amplified Detector, 900 - 2600 nm, 25 MHz BW, 0.8 mm^2, Universal 8-32 / M4 Mounting Holes

Zoom

Complete Product Details

Part Number:	PDA10D2 -Ask a technical question
Package Weight:	2.18 lbs / Each
Available:	Today
RoHS:	RoHS✓
Price:	$568.12
Add To Cart:	Qty: 1 Add To Cart
Release Date:	Apr 20, 2018

Drawings and Documents:

Auto CAD PDF	
Auto CAD DXF	
Solidworks	
eDrawing	
Step	
Manual	
RoHS	RoHS✓
REACH	

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Warranty (Subject to our General Terms and Conditions)

Two year warranty. Incorporated light sources are warrantied for the lesser of one year or (to the extent applicable) the number of hours stated in the specifications.

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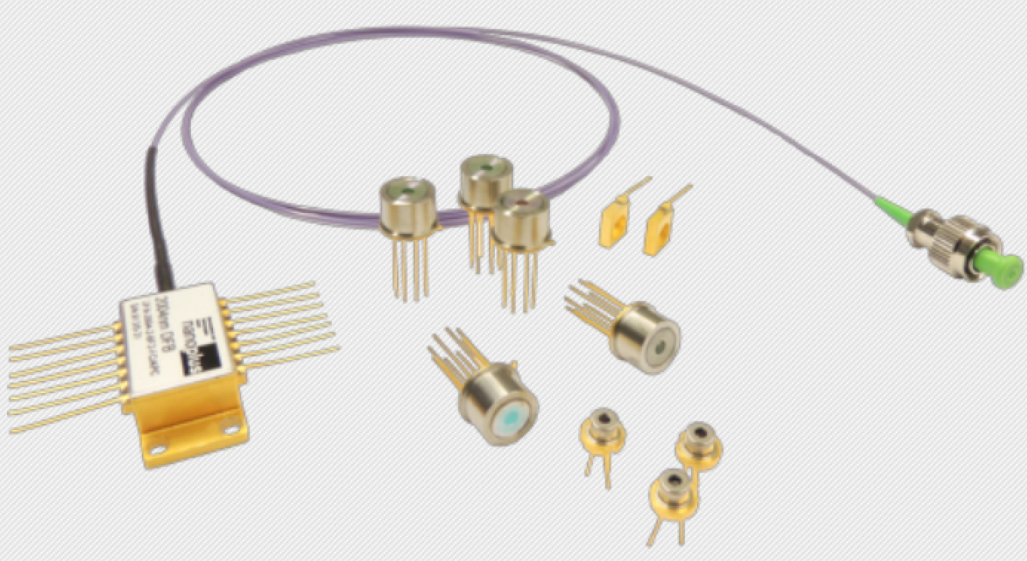
2.8 List of component SO2

2.8.1 Laser diode (To do...)

Distributed Feedback Lasers: 2200 nm - 2600 nm

nanoplus offers DFB laser diodes at any wavelength between 2200 nm and 2600 nm.



2.8.2 Collimator (To do...)

2.8.3 Isolator

I2500C4 - Free-Space Isolator, 2.5 µm, 3.6 mm Max Beam, 1.2 W Max

Zoom

Complete Product Details

Part Number:	I2500C4 -Ask a technical question
Package Weight:	0.11 lbs / Each
Available:	Today
RoHS:	RoHS✓
Price:	$3,193.31
Add To Cart:	Qty 1 Add To Cart
Release Date:	Jan 12, 2018

Drawings and Documents:

Auto CAD PDF	
Auto CAD DXF	
Solidworks	
eDrawing	
Step	
Manual	
RoHS	RoHS✓
REACH	

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2.8.4 Beam splitter (To do...)

2.8.5 Focusing lens (To do...)

2.8.6 Photodiode

PDA10D2 - InGaAs Fixed Gain Amplified Detector, 900 - 2600 nm, 25 MHz BW, 0.8 mm^2, Universal 8-32 / M4 Mounting Holes

Zoom

Complete Product Details

Part Number:	PDA10D2 -Ask a technical question
Package Weight:	2.18 lbs / Each
Available:	Today
RoHS:	RoHS✓
Price:	$568.12
Add To Cart:	Qty 1 Add To Cart
Release Date:	Apr 20, 2018

Drawings and Documents:

Auto CAD PDF	
Auto CAD DXF	
Solidworks	
eDrawing	
Step	
Manual	
RoHS	RoHS✓
REACH	

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Warranty (Subject to our General Terms and Conditions)

Two year warranty. Incorporated light sources are warrantied for the lesser of one year or (to the extent applicable) the number of hours stated in the specifications.

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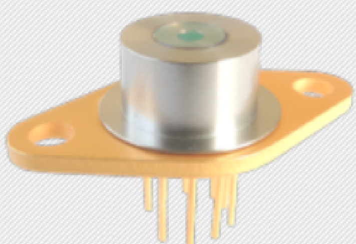
2.9 List of component HCL

2.9.1 Laser diode (To do...)

Distributed Feedback Lasers: 3000 nm - 6000 nm

nanoplus DFB interband cascade laser facilitates new TDLAS applications in mid-infrared

nanoplus offers a DFB interband cascade laser (ICL) at any target wavelength in the mid-infrared (MIR) between 3 µm and 6 µm. The device operates in continuous wave (cw) mode around room temperature. Specifications and behavior are very comparable to a nanoplus laser at lower wavelengths. When you set up an ICL-based analyzer, you can, hence, transfer the engineering knowledge you have gained from building short-wavelength gas sensors.



PRISM AWARDS WINNER

2.9.2 Collimator (To do...)

2.9.3 Isolator

I3400W4 - Free-Space Isolator, 3.4 µm, 3.6 mm Max Beam, 1.2 W Max

Zoom

Complete Product Details

Part Number:	I3400W4 - Ask a technical question
Package Weight:	0.11 lbs / Each
Available:	5-8 Days
RoHS:	RoHS
Price:	$2,652.25
Add To Cart:	Qty: 1 Add To Cart
Release Date:	Sep 17, 2018

Drawings and Documents:

Auto CAD PDF	
Auto CAD DXF	
Solidworks	
eDrawing	
Step	
Manual	
RoHS	RoHS
REACH	

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2.9.4 Beam splitter (To do...)

2.9.5 Focusing lens (To do...)

2.9.6 Photodiode (To do...)

3 References

[1] I. Linnerud, P. Kaspersen, T. Jæger, „Gasmonitoring in the process industry using diode laser spectroscopy," Applied Physics B, Skårer, Norway, 19 March 1998.