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QCL BASED PHOTOACOUSTIC SPECTROMETER FOR FOOD SAFETY

RT/2019/1/ENEA

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L. Fiorani, G. Giubileo, S. Mannori, A. Puiu, W. Saleh

Abstract

The Diagnostics and Metrology Laboratory (FSN-TECFIS-DIM) of the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) applied for years photoacoustic spectroscopy with CO2 lasers to food safety. In order to make available to control authorities a portable and user-friendly instrument, smaller lasers and automated controls are necessary. This report presents a new instrument, based on a QCL source, in which each measurement is fully managed by a dedicated software. Then, some characterizations of the whole system and its components are provided. Finally, its first results in the framework of the Metrofood project are briefly described.

Key words: *QCL applications, Laser spectroscopy, Photoacoustic technique, Agro-food chain, Food safety*

Riassunto

Il Laboratorio Diagnostiche e Metrologia (FSN-TECFIS-DIM) dell'Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile (ENEA) ha applicato da anni la spettroscopia fotoacustica con laser CO2 alla sicurezza alimentare. Allo scopo di rendere disponibili alle autorità di controllo uno strumento portatile e di facile utilizzo, sono necessari laser più piccoli e controlli automatici. Questo rapporto presenta un nuovo strumento, basato su una sorgente QCL, in cui ogni misura è completamente gestita da un software dedicato. Quindi, alcune caratterizzazioni dell'intero sistema e delle sue componenti sono fornite. Alla fine, i suoi primi risultati nel quadro del progetto Metrofood sono brevemente descritti.

Parole chiave: Applicazioni del QCL, Spettroscopia laser, Tecnica fotoacustica, Filiera agroalimentare, Sicurezza alimentare

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1. Introduction

The food safety testing market is expected to grow at a compound annual growth rate of 7.2% (2016-2021) [1] and is projected to reach 18.54 billion $ by 2022 [2]. A preceding report [3] tried to outline the main features of the global problem of food safety, whose importance explains why The Consumer Goods Forum [4] - organization that gathers consumer goods retailers and manufacturers - launched the Global Food Safety Initiative [5] that brings together key actors of the food industry to collaboratively drive continuous improvement in food safety management systems around the world.

The Diagnostics and Metrology Laboratory (FSN-TECFIS-DIM) [6] of the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) applied for years laser photoacoustic spectroscopy (LPAS) [7] to food safety. Up to now, CO_2 lasers were used, as in the prototype developed in the framework of the SAL@CQO Project [8]. These sources are good candidates for this research because they are discretely tunable from 9 to 11 μm, inside the fingerprint region.

In recent years, QCLs[1] [9] tunable in the fingerprint region have become commercially available. Although their power is still lower than CO_2 lasers, they are significantly smaller and their tunability is continuous and broader, thus allowing to record spectra that provide more information on the sample.

Having in mind that control authorities that routinely verify food quality will greatly benefit from a portable and user-friendly system, we decided to develop a QCL based photoacoustic spectrometer fully managed by a dedicated software. In our mind, this prototype is an intermediate step toward a field instrument.

[1] QCL is the acronym of quantum cascade laser.

2. Instruments and methods

A block diagram of the QCL based photoacoustic spectrometer is given in Figure 1. The continuous wave (cw) emitted by the QCL is chopped at an audio frequency and irradiates a food sample inside the photoacoustic (PA) cell. The radiation is absorbed by the sample, with the consequent temperature increase, adiabatic expansion and pressure wave generation. Acoustic resonance amplifies the signal that is detected by the microphone coupled with the lock-in amplifier. A small part of the laser beam is sent to the power meter by the beam splitter. A personal computer (PC) controls the experiment.

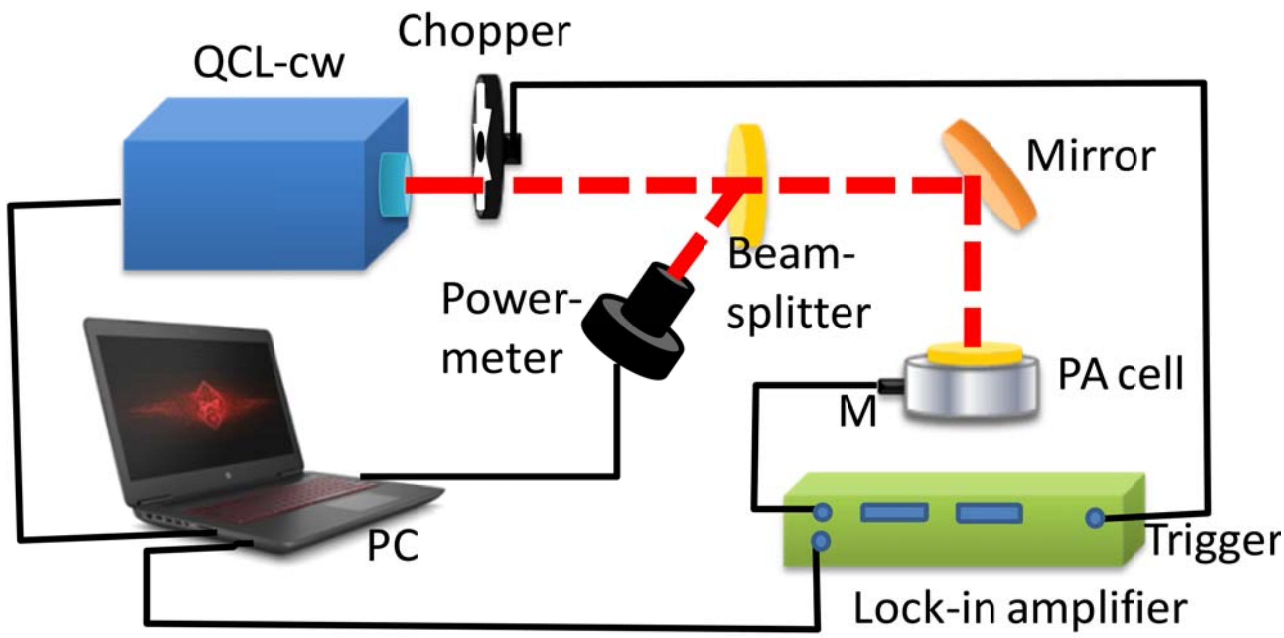

Figure 1. Block diagram of the instrument (cw: continuous wave. M: microphone. PA: photoacoustic. PC: personal computer).

A dedicated software fully manages the spectra acquisition. The user has to input on the interface:

- minimum wavelength, maximum wavelength and wavelength step,
- number of measurements at a given wavelength (each measurement lasts 1 s),

and simply start the instrument from the PC that records microphone signal and laser power per each measurement. Usually, each point of the LPAS spectrum (photoacoustic signal) is given by the ratio of the average of microphone signals and the average of laser powers.

2.1 QCL emission profile

The QCL emission profile has been characterized from 8.3 to 11.1 μm (Figure 2). Maximum power (38.4 mW) was achieved at 10.1 μm without chopping: if the chopper is activated, only half of the power is delivered. Although a step of 0.1 μm has been used in this characterization, the source can be tuned at any wavelength between 8.3 to 11.1 μm.

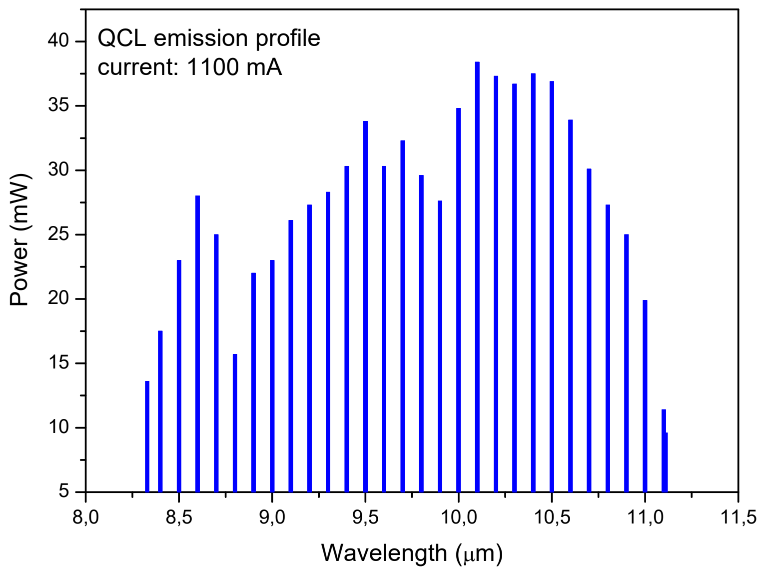

Figure 2. QCL emission profile.

2.2 Cell frequency response

The cell frequency response has been determined measuring photoacoustic signal *vs* chopping frequency. A sample of charcoal powder[2] has been irradiated at 10.1 μm (Figure 3). A 10× amplifier has been interposed between microphone and lock-in amplifier. Each point represents the average of 10 measurements. Each measurement lasts 1 s. A clear resonance at about 100-900 Hz can be observed. The maximum is at 215 Hz and the full width at half maximum (FWHM) is 800 Hz.

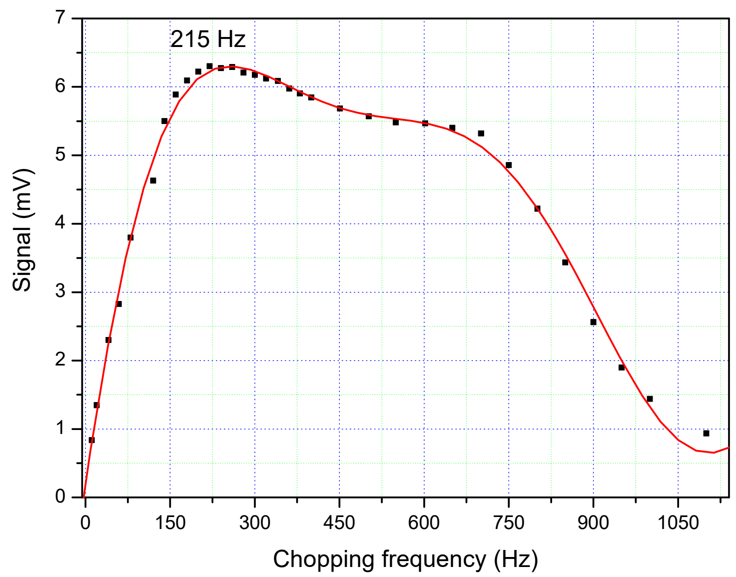

Figure 3. Microphone signal for a sample of charcoal powder *vs* chopping frequency.

[2] The charcoal powder has been obtained by grinding for some minutes charcoal activated granules (Carlo Erba, Batch Number Q1D099281F).

2.2 Signal linearity test

The linearity between the microphone signal and the laser power has been tested at 10.1 μm irradiating a sample of charcoal powder (Figure 4). Each point represents the average of 10 measurements. Each measurement lasts 1 s. The microphone signal is proportional to the laser power with zero intercept and good correlation coefficient (R=0.991).

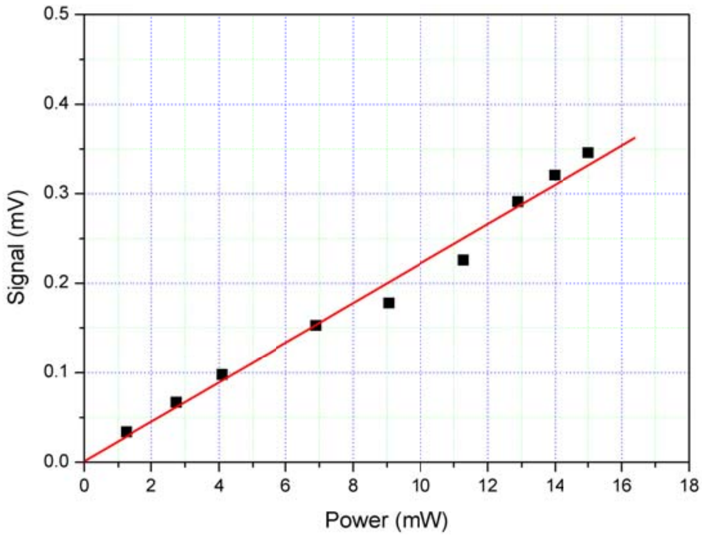

Figure4. Microphone signal for a sample of charcoal powder *vs* laser power. R: correlation coefficient.

3. Results and discussion

In the framework of the project Metrofood [10], some types of rice flour were analyzed. The measurement procedure was as follows:

- Sample preparation: grains were grinded for some minutes and pressed (12-15 tons) in a pellet of 2 mm thickness and 20 mm diameter (about 1 g).
- The pellet was put on the sample holder.
- The LPAS spectrum of each sample was acquired from 8.5 to 11 μm with a step of 0.1 μm, corresponding to 26 measurements (1 s per each measurement).
- 10 spectra were averaged.

Care has been taken to:

1. Center the laser footprint in the sample holder.
2. Fill the sample holder.
3. Check that the grain size of the flour was smaller than the laser footprint.

The task assigned to our lab was to discriminate between different types of rice. It was impossible to achieve easily this goal simply looking at the LPAS spectra (even if it they were normalized to their maximum) but, fortunately, principal component analysis (PCA) [11] could easily perform this assignment (Figure 5).

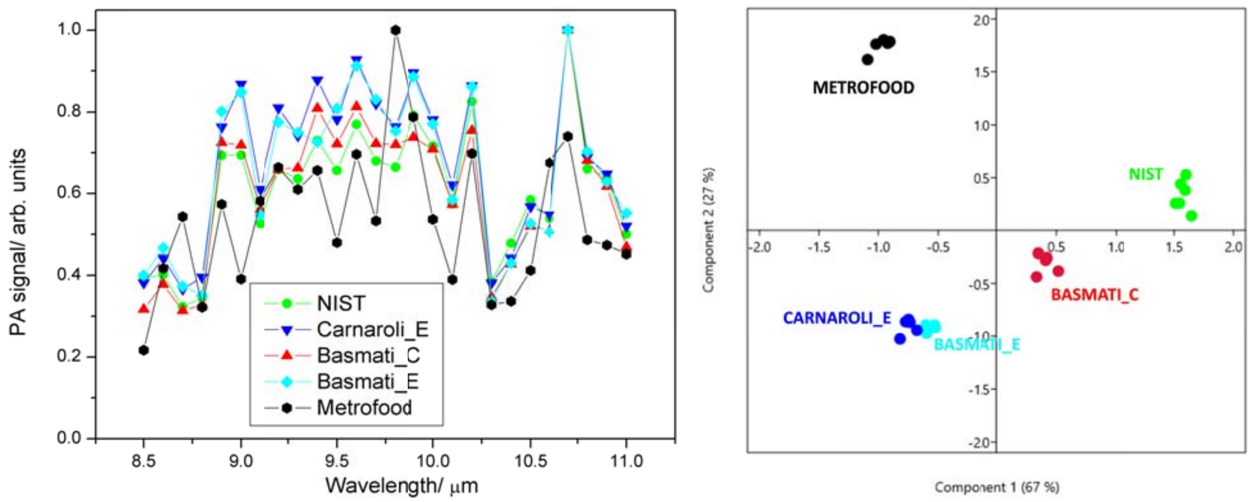

Figure 5. LPAS spectrum (left) and PCA (right) of different rice flours.

The following types of rice flour have been examined:

1. Basmati sold by Eurospin,
2. Basmati sold by Coop,
3. Carnaroli sold by Eurospin,
4. Metrofood,
5. NIST.

Six samples of each type of rice were prepared and measured. Each LPAS spectrum (Figure 5 left) is the average of the six measurements, while each PCA point (Figure 5 right) corresponds to one sample.

4. Conclusions

A QCL based photoacoustic spectrometer has been developed at the Diagnostics and Metrology Laboratory (FSN-TECFIS-DIM) of the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA).

At first, the LPAS instrument has been carefully examined: QCL emission, frequency response and signal linearity have been characterized. The conditions for optimum operation have been determined.

Then, some food samples have been measured and the photoacoustic spectrometer demonstrated its discrimination capability in the case of different types of rice flour.

This new system is an intermediate step toward the realization of a portable and user-friendly tool that would help control authorities to quickly verify food safety.

Acknowledgements

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Appendix - Characteristics of the instrument components

Pulsed and cw tunable mid-IR external cavity laser, model MIRcat™

Operating Parameters	Pulsed Laser	CW Laser
Operation Mode	Pulsed only	CW or Pulsed
Current Range	Factory-set	Factory-set
Laser Temperature	Factory-set	Factory-set
Relative Temperature Range	Up to ± 5.0 °C	Up to ± 5.0 °C
Cooling Requirements	None	Must use water cooler in CW mode
Beam Properties		
Pointing Stability	< 1 mrad	< 1 mrad
Height Above Base	1.5" (38 mm) without pedestals	1.5" (38 mm) without pedestals
Profile	Elliptical Gaussian, non-astigmatic	Elliptical Gaussian, non-astigmatic
Minimum Spot Size	< 2.5 mm	< 2.5 mm
Beam Waist	approximately 30 to 50 cm from laser	approximately 30 to 50 cm from laser
Divergence	< 5 mrad	< 5 mrad
Pulsed Parameters		
Pulse to Pulse Power Variation	< 5%	< 5%
Long Term (1 hr) Power Variation	< 2%	< 2%
Pulse Repetition Range	100 Hz - 100 kHz user selectable in 0.1kHz increments	100 Hz - 100 kHz user selectable in 0.1kHz increments
Pulse Width Minimum	40 nsec	40 nsec
Pulse Width Maximum	500 nsec	500 nsec
Minimum Step Size	20 nsec	20 nsec
Duty Cycle	0.4 - 5%	0.4 - 5%
Tuning Parameters		
Tuning Range	Factory-set	Factory-set
Center Wavelength	Factory-set	Factory-set
Maximum Tuning Rate	Full Range < 1 sec	Full Range < 1 sec
Set and Read Resolution	0.1 cm^{-1}	0.1 cm^{-1}
Absolute Accuracy	± 0.5 cm^{-1}	± 0.5 cm^{-1}
Output Power (for max. operating current)		
Peak Pulse Power	Up to 350 mW	Up to 350 mW
Average Power Min.	1 mW	1 mW
Average Power Max.	Up to 50mW	Up to 50mW (check with Daylight Solutions for your MIRcat configuration)
Line width		
Line width	Pulsed : < 1 cm^{-1}	Pulsed : < 1 cm^{-1} CW : < 0.003 cm^{-1}
Polarization		
Linear	> 100:1, vertically polarized, perpendicular to laser base	> 100:1, vertically polarized, perpendicular to laser base

QCLs are a type of semiconductor laser which utilizes epitaxially grown quantum wells that contain electrons in lasing states. In a QCL the lasing transition occurs between states within a given quantum well.

One advantage of this construction is that the electron responsible for the emission of the photon tunnels into the next quantum well and as a result, multiple photons can be generated by a single electron, thereby making them extremely efficient. The tunneling from one well to the next is where the term "quantum cascade" comes from. Furthermore, the well depths can be engineered by controlling layer depths during the fabrication process and hence the wavelength of the lasing transition is dependent on the physical structure of the device.

The gain profile of a quantum cascade laser can be quite broad (> 500 cm^{-1} in some cases). By providing monochromatic feedback - either through the use of distributed feed back or by constructing an external cavity (ECqcL™) - the free-running linewidth of the emission can be practicably narrowed to as little as 0.00002 cm^{-1} (~0.5 MHz). The ECqcL™ configuration employed at Daylight Solutions is shown in Figure A.1.

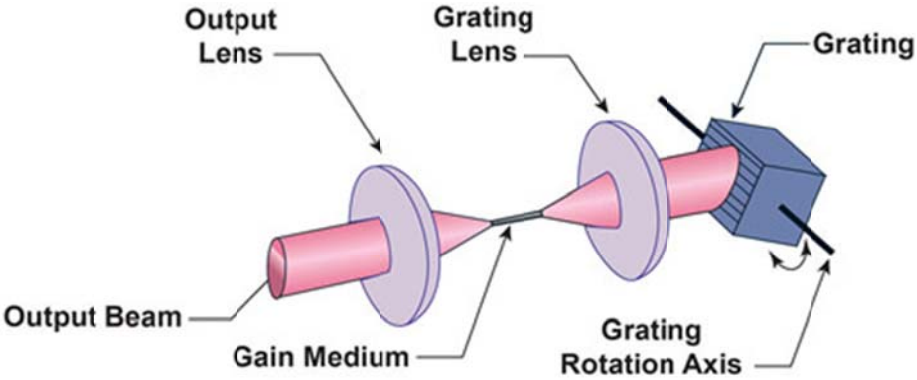


Figure A.1. External cavity quantum cascade laser design.

A number of applications have been well served by mid-IR quantum cascade lasers. This region of the spectrum is interesting because of a combination of two facts. The atmosphere is (at least somewhat) transparent at these wavelengths and many species of interest have strong fundamental absorptions that make it possible to detect and identify them. Figure A.2 is a depiction of the transmission of the atmosphere in the visible through the mid-infrared portion of the electromagnetic spectrum. Significant regions of high transmission exist in the mid-IR and can be exploited to transmit powers at these wavelengths for various applications. Free-space communication, infrared countermeasures, remote imaging, beaconing, and illumination are all enabled by QCLs at an appropriate wavelength. Figure A.3 is a graph of the mid-infrared portion of the spectrum with a number of species placed where their strong absorptions occur. The mid-IR is rich in information for those wishing to probe, detect, image, or quantify these and many other species including explosives, nerve agents, and toxins. Detection limits in the parts per trillion range and/or discrimination between similar species are possible.

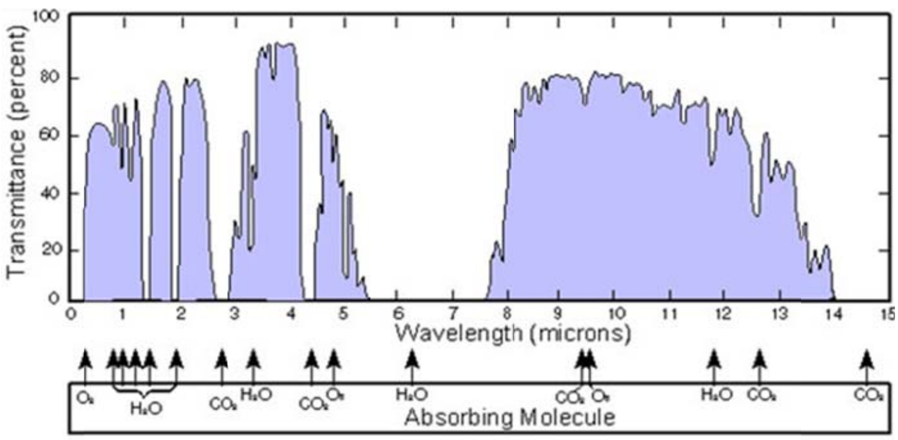


Figure A.2. Transmission of light through the atmosphere from the visible to the mid-IR. The sources of the major absorptions are also indicated.

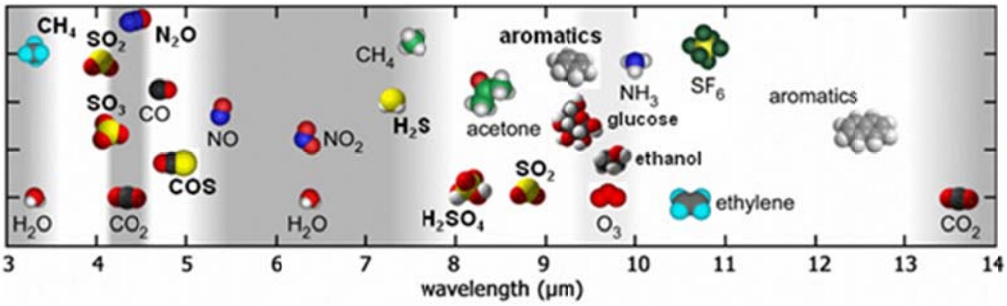


Figure A.3. Graphical representation of the location of strong absorptions of molecules of interest.

[https://www.daylightsolutions.com/]

Thermoelectric chiller, model THERMOCUBE 200/300/400

Operating Range (Set Point)	5°C to 50°C standard (down to -5°C with low temp option - LT) (up to 65°C with high temp option – HT, 60°C for centrifugal pumps)
Ambient Temperature Range	0°C to 40°C non-condensing
Stability / Repeatability	±0.05°C with constant load (even near ambient)
Cooling Capacity (typical[1])	200, 300 or 400 Watts @ 20°C in 20°C ambient air [1] Cooling capacity will vary with configuration.
Heating Capacity (typical)	400, 600 or 800 Watts @ 20°C in 20°C ambient air
Noise Level (at 1 meter)	< 63 dBA (down to 49 dBA with "-VS" variable speed fan option)
Coolant / Process Fluid	Koolance (27% propylene glycol / water mix) or 27-50% ethylene glycol / water mix Options available for PAO, Fluorinert / Galden or HFE (contact SSCS for advice on other fluids)
Process Fluid Fittings	1/4" John Guest standard (see options section for other fitting types)
Pumps	Diaphragm, Centrifugal or gear pumps available
Tank Volume	300 ml with level sensor
Wetted Materials	Aluminum, stainless steel and polymers or Copper, stainless steel and polymers ("-CU" option)
Dimensions (L x W x H)	13" x 11" x 13" (32cm x 28cm x 32cm)
Weight	28 lbs (12.7 kg) – standard model
Power Input	Universal: 115-230 VAC, 50/60 Hz, 7-5 amps max.
Controls	Digital PID controller for heating and cooling
Communications	Keypad or optional RS232 interface
Alarms	Temperature, fluid level, system or component failure (display and RS232 option)
Standards	TUV listed to UL, CAN/CSA and EN 61010-1, CE 61010-1

[www.sscooling.com]

Optical chopper, model SR540

Chop frequency	4 Hz - 400 Hz (5/6 slot blade) 400 Hz - 3.7 kHz (25/30 slot blade)
Frequency stability	250 ppm/°C (typ.)
Frequency drift	< 2 %, 100 Hz < f < 3700 Hz
Phase jitter (rms)	0.2° (50 Hz - 400 Hz) 0.5° (400 Hz - 3.7 kHz)
Frequency display	4-digit, 1 Hz resolution and accuracy
Frequency control	10-turn pot with 3 ranges: 4 Hz - 40 Hz 40 Hz - 400 Hz 400 Hz - 3.7 kHz
Input control voltage	0 - 10 VDC for 0 - 100 % of full scale Control voltage overrides frequency dial
Reference modes	f_{inner}, f_{outer}, $5 \times f_{outer}$, $f_{inner} + f_{outer}$, $f_{outer} - f_{inner}$
Dimensions	Controller: 7.7" × 1.8" × 5.1" (WHD) Head: 2.8" × 2.1" × 1.0" (WHD)
Blade diameter	4.04" ± 0.002"
Cable length	6 ft.
Power	12 W, 100/120/220/240 VAC, 50/60 Hz

[www.thinkSRS.com]

High sensitivity thermal sensor, model 3A (10µW - 3W)

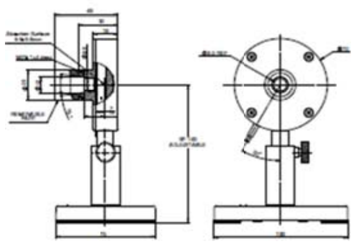
Absorber Type	Broad band
Spectral Range (µm)	0.19 - 20
Aperture (mm)	Ø 9.5
Maximum Beam Divergence	NA
Power Mode	
Power Range(*)	10µW - 3W
Power Scales	3W to 300µW
Power Noise Level	1µW
Thermal Drift (30min)(*)	5 - 20µW
Maximum Average Power Density (kW/cm²)	1
Response Time with Meter (0-95%) typ. s	1.8
Power Accuracy +/-%(**)	3
Linearity with Power +/-%	1
Energy Mode	
Energy Range	20µJ - 2J
Energy Scales	2J to 200µJ
Minimum Energy	20µJ
Maximum Energy Density (J/cm²)	
<100ns	0.3
0.5ms	1
2ms	2
10ms	4
Cooling	convection
Weight (kg)	0.2
Fiber Adapters	ST, FC, SMA, SC
Part number: Standard Sensor	7Z02621

Note (*): Depending on room airflow and temperature variations. Lowest measurable powers are achieved by thermally quiet room conditions, using removable snout averaging and offset subtraction.

Note (**): The sensor has a relatively large spectral variation in absorption and has a calibrated spectral curve at all wavelengths in its spectral range to the above specified accuracy. Nova, Orion and LaserStar meters do not support this feature and when used with those meters, the accuracy will be ±3% as above for 532nm, 905nm, 1064nm and 10.6µm but there will be an additional error of up to 3% at other wavelengths in the spectral range 190 - 3000nm.

Absorber Type	**Max Energy Density J/cm² Pulse Length**		
	10ns	**1µs**	**300µs**
P	10	10	10
HE/HE1	5	10	100
BB	0.3	0.5	5
EX	0.5	0.6	4
PE, Metallic	0.1	0.2	0.2
PE, BB	0.3	0.3	0.3
PE-DIF	1.5	3	3
PE BB-DIF	3	3	3

3A



[www.ophiropt.com/photonics]

Display system, model Laserstar

Input Specifications - Thermal, Photodiode	
Input Ranges	15nA - 1.5mA full scale in 16 ranges
A to D sampling rate	15Hz
A to D resolution	17 bits plus sign. (0.0009% resolution)
Electrical accuracy	±0.25% ± 20pA new; ±0.5% ±50pA after 1 year
Electrical input noise level	500nV or 1.5pA + 0.0015% of input range @3Hz.
Dynamic range	9 decades (1:109)
Input Specifications - Pyroelectric Heads	
Input Ranges	23mV - 6V full scale in 9 ranges
A to D Sampling rate	40KHz maximum
A to D resolution	12 bits no sign, 11 with sign (0.02-0.05% resolution)
Electrical accuracy	+/-2mV new, +/-4mV after 1 year
Electrical input noise level	2mV
Dynamic range)	3.5 decades (1:4000)
General Specifications	
Detector Compatibility	Thermopile, photodiode and pyroelectric
Analog output	0-1 Volt with 3mV (0.03%) resolution. 100 ohms impedance
Analog output accuracy	±0.2% ±2mV relative to display
Dimensions (mm)	228W x 195D x 54H
Mass	1.45 Kg.
Display	240 x 64 pixel super twist LCD
Display digit height	17mm
Backlight	EL: Operates from charger or battery
Bargraph segments	240
Battery	3 x D size. 4.0A-h NiCd battery built in.
Charger input	DC: 12 - 25V, 5W; AC: 9 - 18V RMS, 5W Charge time 10 - 14Hr, 15 - 20Hr if operating
Operation between charges	18 Hrs, thermal and photodiode, 14 Hrs, pyroelectric heads.
Data Logging and Com.	
RS232 output	Max real time data logging rate* >30Hz Onboard data logging rate* >200Hz Data transfer from instrument to PC ~500 points/s Max points stored onboard 59,400 * The above refers to the rate for logging every single point. Above that rate the instrument will sample points but not log every single point.
IEEE 488.1 GPIB	Compliance: IEEE488.1 Max real time data logging rate* >1500Hz Onboard data logging rate* 1500Hz Data transfer from instrument to PC >1500 points/s * The above refers to the rate for logging every single point. Above that rate the instrument will sample points but not log every single point.
General	Maximum communication rate 38400 baud
	Can store up to 10 files for a total of 54,000 points (Max points stored onboard per power file is 5400). Data is not lost when instrument is turned off.

[www.ophiropt.com/photonics]

Lock-in amplifier, model SR830 DSP

SIGNAL CHANNEL	
Voltage Inputs	Single-ended (A) or differential (A-B).
Current Input	106 or 108 Volts/Amp.
Full Scale Sensitivity	2 nV to 1 V in a 1-2-5-10 sequence (expand off).
Input Impedance	Voltage: 10 MW+25 pF, AC or DC coupled. Current: 1 kW to virtual ground.
Gain Accuracy	±1% from 20°C to 30°C (notch filters off), ±0.2 % Typical.
Input Noise	6 nV/ÖHz at 1 kHz (typical).
Signal Filters	60 (50) Hz and 120(100) Hz notch filters (Q=4).
CMRR	100 dB to10 kHz (DC Coupled), decreasing by 6db/octave
Dynamic Reserve	Greater than 100 dB (with no signal filters).
Harmonic Distortion	-80 dB.
REFERENCE CHANNEL	
Frequency Range	1 mHz to 102 kHz
Reference Input	TTL (rising or falling edge) or Sine. Sine input is1 MW, AC coupled (>1 Hz). 400 mV pk-pk minimum
Phase Resolution	0.01°
Absolute Phase Error	<1°
Relative Phase Error	<0.01°
Orthogonality	90° ± 0.001°
Phase Noise	External synthesized reference: 0.005° rms at 1 kHz, 100 ms, 12 dB/oct. Internal reference: crystal synthesized, <0.0001° rms at 1
Phase Drift	<0.01°/°C below 10 kHz. <0.1°/°C to 100 kHz
Harmonic Detect	Detect at Nxf where N<19999 and Nxf<102 kHz.
Acquisition Time	(2 cycles + 5 ms) or 40 ms, whichever is greater.
DEMODULATOR	
Zero Stability	Digital displays have no zero drift on all dynamic reserves. Analog outputs: <5 ppm/°C for all dynamic reserves.
Time Constants	10 µs to 30 s (reference > 200 Hz). 6, 12, 18, 24 dB/oct rolloff. Up to 30000 s (reference < 200 Hz). 6, 12, 18, 24 dB/oct rolloff. Synchronous filtering available below 200 Hz.
Harmonic Rejection	80 dB
INTERNAL OSCILLATOR	
Frequency	1 mHz to 102 kHz.
Frequency Accuracy	25 ppm + 30 µHz
Frequency Resolution	4 1/2 digits or 0.1 mHz, whichever is greater.
Distortion	f<10 kHz, below -80 dBc. f>10 kHz, below -70 dBc.1 Vrms
Output Impedance	50 W
Amplitude	4 mVrms to 5 Vrms (into a high impedance load) with 2 mV resolution. (2 mVrms to 2.5 Vrms into 50W load).
Amplitude Accuracy	1%
Amplitude Stability	50 ppm/°C
Outputs	Sine output on front panel. TTL sync output on rear panel. When using an external reference, both outputs are phase locked to the external reference.
DISPLAYS	
Channel 1	4 1/2 digit LED display with 40 segment LED bar graph. X, R, X Noise, Aux Input 1 or 2. The display can also be any of these quantities divided by Aux Input 1 or 2.
Channel 2	1/2 digit LED display with 40 segment LED bar graph. Y, q, Y Noise, Aux Input 3 or 4. The display can also be any of these quantities divided by Aux Input 3 or 4.
Offset	X, Y and R may be offset up to ±105% of full scale.
Expand	X, Y and R may be expanded by 10 or 100.
Reference	4 1/2 digit LED display. Display and modify reference frequency or phase, sine output amplitude, harmonic detect, offset percentage (X, Y or R), or Aux Outputs 1-4.
Data Buffer	16k points from both Channel 1 and Channel 2 display may be stored internally. The internal data sample rate ranges from 512 Hz down to 1 point every 16 seconds. Samples can also be externally triggered. The data buffer is accessible only over the computer interface.
INPUTS AND OUTPUTS	
Channel 1 Output	Output proportional to Channel 1 display, or X. Output Voltage: ±10 V full scale. 10 mA max output current.
Channel 2 Output	Output proportional to Channel 2 display, or Y. Output Voltage: ±10 V full scale. 10 mA max output current.
X and Y Outputs	Rear panel outputs of cosine (X) and sine (Y) components. Output Voltage: ±10 V full scale. 10 mA max output current.
Aux. Outputs	4 BNC Digital to Analog outputs. ±10.5 V full scale, 1 mV resolution. 10 mA max output current.
Aux. Inputs	4 BNC Analog to Digital inputs. Differential inputs with1 MW input impedance on both shield and center conductor. ±10.5 V full scale, 1 mV resolution.
Trigger Input	TTL trigger input triggers stored data samples
Monitor Output	Analog output of signal amplifiers (before the demodulator).
GENERAL	
Interfaces	IEEE-488 and RS232 interfaces standard. All instrument functions can be controlled through the IEEE-488 and RS232 interfaces.
Preamp Power	Power connector for SR550 and SR552 preamplifiers.
Power	40 Watts, 100/120/220/240 VAC, 50/60 Hz.
Dimensions	17"W x 5.25"H x 19.5"D
Weight	30 lbs.

[www.thinkSRS.com]

Microphone, model EK-23024-000.

Dimensions	5.56mm x 3.98mm x 2.21mm (.219in x .157in x .087in)
Sensitivity (1 kHz)	-53
Port location	12S
Response	Std
Directional	Omni-directional
Peak Frequency	3500-5500
Dc supply	1.3 V
Amplifier current Drain in	50 µA max.
Output impedance (Ohm)	Min. 2800, Nor. 4400, Max. 6800

[http://www.knowles.com/eng/Products/Microphones/Subminiature-performance/EK-EY-series]

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