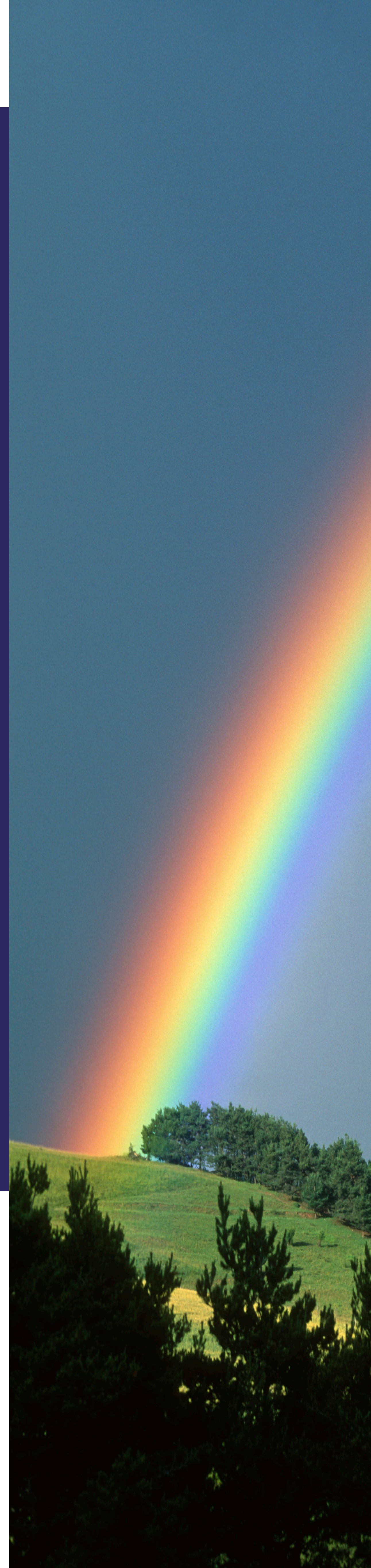
Spectroscopy Applications in the Environment



AVANTES

MEMBER OF THE NYNOMIC GROUP

Table of Contents

Overview of Environmental spectroscopy

Welcome

A key part of Avantes mission statement refers to our commitment to helping to save our planet and its finite resources for generations to come. Environmental monitoring is one way that we are able to pursue our mission directly through our technology solutions. Researchers and consumers around the world rely on Avantes instruments to perform their measurements of water, air, refuse, soil and sludge to safeguard the environment for future generations. Avantes small form factor instruments are designed to perform in harsh environments while still providing reliable and accurate measurements.

Avantes World Headquarters
Oude Apeldoornseweg 28
7333 NS Apeldoorn
The Netherlands
Telephone: +31 313 670 170
E-mail: info@avantes.com
Website: www.avantes.com

North American Branch
Avantes, Inc.
500 S. Arthur Ave., Unit 500
Louisville, CO 80027
Tel. +1-(303)-410-8668
Phone Toll free: +1 (866)-678-4248
Fax: +1-(303)-410-8669
Email: infoUSA@avantes.com
Website: www.avantesusa.com

China Regional Offices
Avantes China
Rm.1209-1210, ULO Park,
No.601 apartment of Wangjing Yuan, Chaoyang District,
Beijing, 100102 P.R. China
Phone: +86-10-84574045/84574057
Fax: +86-10-84574017
Email: info@avantes.com.cn
Website: www.avantes.cn

Air Quality

01

Spectroscopy Techniques for Measuring Air Quality

NASA's Pandora Spectrometer System

We see the application of radiometry in numerous fields of study, but possibly the most familiar uses of radiometric measurements are in climatology and astronomy.

The Pandora spectrometer system, developed at NASA's Goddard Space Flight Center, has been deployed around the world to measure atmospheric constituents such as O3, NO2, and SO2.

The Pandora system is a relatively small system that uses Avantes AvaSpec-ULS2048x64-EVO back-thinned CCD spectrometers with 50-micron slit and 1200 line/mm grating. The spectrometers are optimized for the wavelength range 280-525 nm and deliver 0.6 nm resolution with 4.5x over-sampling.

Since 2006, the Pandora system has been deployed at installations around the world, from Finland and Thessaloniki to the University of Alaska and atop the NOAA station in Boulder, CO. A specialized version of the Pandora system even allows it to operate on a ship at sea under moderate wave action while still tracking the sun continuously using software to correct for motion and keep the sun centered in Pandora's field of view.

Climate and atmospheric scientists derive important information from data about the total ozone column, other trace gas constituents, and airborne particulates.

Pandora Deployment in the Chesapeake Bay

NASA led the DISCOVER-AQ project, a four-year Earth Venture mission to improve the monitoring of air quality for public and environmental health, to study trace gas pollutants in urban estuarine ecosystems. A network of ground-based Pandora spectrometers was deployed in the Washington, D.C. / Baltimore area and throughout the Chesapeake Bay waterway in July of 2011 to provide high-resolution data on air-quality variability. Researchers used information about local pollution conditions and meteorological conditions to compare with model simulations

and space-based observations.

This campaign demonstrated the limitations in space-based pollution monitoring and temporal and spatial variability of near-surface Ozone (O3) and its precursor Nitrogen Dioxide (NO2). Near-surface, NOx is responsible for up to 70% of nitrogen loading in urban waterways and can have significant effects on terrestrial and aquatic ecosystem health.

The portability of the Pandora system allowed continuous measurements of total column O3 and NO2 and captured data on short-term and small-scale dynamics in near-surface trace gas pollution that satellite data did not detect.

Continuous Emission Monitoring

Continuous emission monitoring (CEM), also called differential optical absorption spectroscopy or (DOAS), is a technique of gas monitoring used extensively in the developing world to monitor

NOx and SOx pollutants in the atmospheric air to gauge air quality. Avantes instruments are integrated into a variety of CEMS monitoring systems around the world. Due to the high stability requirements of this technique, any of the Avantes thermo-electrically cooled spectrometers are ideal for this application, however, several of Avantes uncooled Sensline instruments have also been used successfully for CEMS.

Continuous Emission Monitoring Systems for Air Quality

From the early days of the CAA, engineers have been developing ways to purify smoke stack exhaust with technologies such as electrostatic precipitators [1, 2]. But, real-time monitoring of gaseous pollutants has historically been far more of a challenge. Fortunately, with the advances in optical sensing technologies over the past 20 years, engineers are now capable of developing a continuous emission monitoring system (CEMS), using absorption spectroscopy.

Like any other covalently-bound molecule, gases have absorption bands in both the infrared (vibrionic) and UV/vis (electronic) regions of the spectrum. There are pros and cons to operating in both of these regimes.

Standoff infrared absorption techniques both in the near-infrared (NIR) and mid-infrared (MIR), require the use of tunable laser sources such as distributed Bragg reflectors (DBRs) and quantum cascade lasers (QCLs) used in conjugation with InGaAs and HgCdTe photodetectors.

Through processes like tunable diode laser absorption spectroscopy (TLDAS) and differential absorption lidar (DIAL), NIR and MIR absorption spectroscopy can provide highly accurate quantization of molecular species. The major downside of this approach, however, is that in most cases, each species of interest will require a different excitation laser, further compounding the already expensive component cost. By contrast, using a methodology called differential optical absorption spectroscopy (DOAS), UV/vis absorption can be used to measure a wide range of molecular species with a single broadband light source. Not only does DOAS decrease the cost of multi-species detection, but it is also often far less expensive for single species detection as well. This is because of its use of inexpensive CCD spectrometers and a constant current D2 emission lamp. In many cases, DOAS can even be performed using sunlight, although this is typically not advisable for CEMS due to the inherent fluctuations of sunlight levels.

Differential Optical Absorption Spectroscopy

The earliest reported use of DOAS for atmospheric measurements was in 1973, for the monitoring of NO2 concentrations by monitoring absorption bands between 430 and 450 nm [3]. Yet, as stated above, it wasn't until the advent of modern CCD detector based spectrometers that the technique gained commercial viability.

Today, DOAS is performed by recording two absorption spectra, one being a reference scan through a column of atmosphere devoid of analyte (ideally) and one through an identical path-length containing the analyte. A detailed mathematical treatment of DOAS is beyond the scope of this application note. Still, it is essential to point out that by taking the difference of these two spectra and applying the Beer-Lambert Law, the resultant differential spectrum is now dependent solely on the absorption cross-section of the species in the analyte and the difference between the column densities of the species and reference spectrum [4].

Furthermore, since the cross-section can be represented as the sum of a slowly varying and rapidly verifying function, the differential spectrum allows for the separation of these two components. Since both Rayleigh and Mie scattering are slowly varying functions, the differential spectrum in conjunction with mathematical tools, such as a Fourier Transform filter, eliminates both attenuations and scattering from the data [5].

Figure 1 shows the absorption bands of a wide range of common atmospheric pollutants, including the SO2, NO and NO2 mentioned above. From this chart, it is clear that the vast majority of molecular species, with the notable exceptions of CO and CO2, can be detected from 200 to 460 nm. As a result, it is possible to use a single

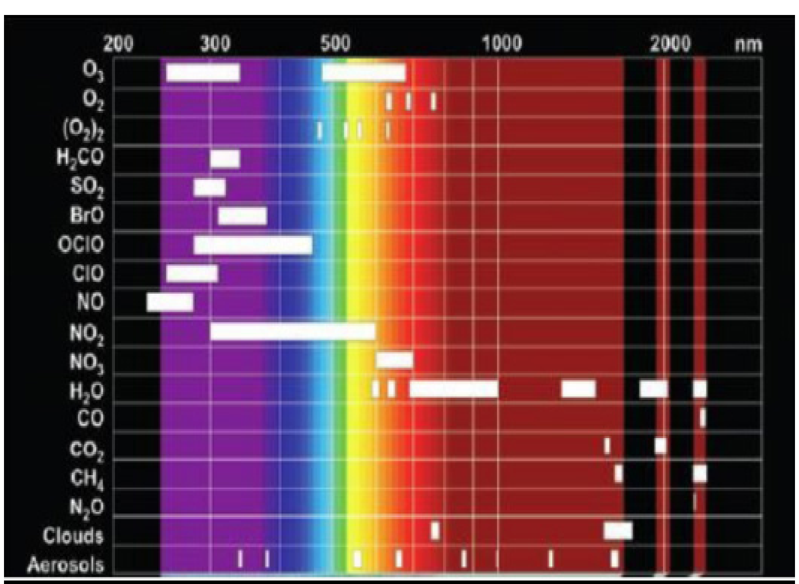


Figure 1: Absorption band of common atmospheric species

compact fixed grating spectrometer in a DOAS-based CEMS.

It is important to note that when choosing a spectrometer to measure in the UV region of the spectrum, it is critical to use an ultra-low stray light configuration to minimize stray light in the system. Cross Czerny-Turner spectrograph designs, while compact tend to have inherently higher stray light levels than transitional Czerny-Turner spectrographs. Examples of ultra-low stray light spectrometers include the AvaSpec-ULS2048XL-EVO and AvaSpec-ULS2048x64-EVO. Both of these instruments feature an ultra-low stray light design and back-thinned CCD detectors for superior UV sensitivity and signal to noise ratio.

Figure 2 shows a typical CEMS setup for DOAS where a concave mirror is used to collimate a broadband light source (typically a D2 lamp) across the monitoring path, where a second concave

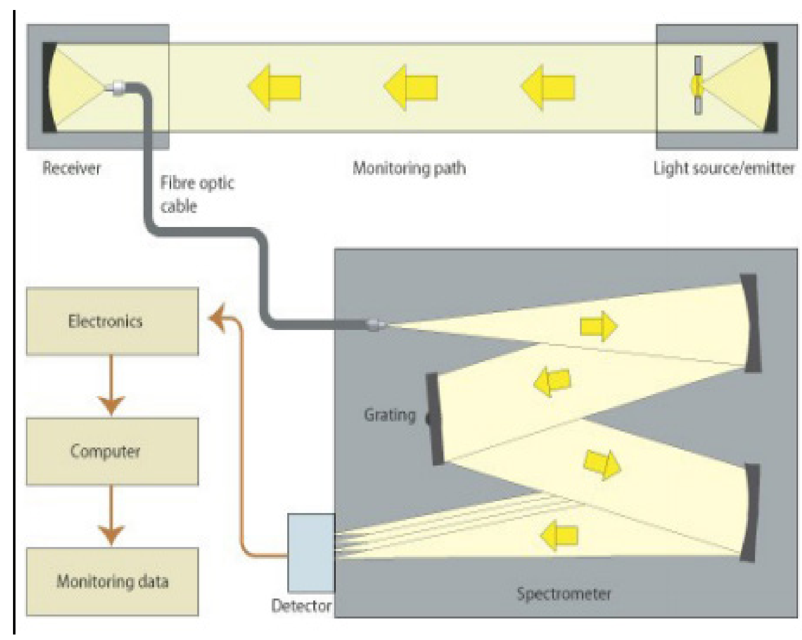


Figure 2: Typical CEMS setup using DOAS

mirror is then used to couple the transmitted light into a fiber-optic cable, which then directs it into the spectrometer.

Sunlight Based DOAS

In addition to CEMs, sunlight-based DOAS AKA "Passive" is also widely used for general environmental monitoring. For example, a team of Greek scientists presented data at the 2015 conference Advances in Atmospheric Science and Applications, where they used a mini multi-axis (MAX) DOAS system to measure tropospheric column densities of NO2, SO2 and HCHO in urban, rural and suburban locations around Thessaloniki, Greece [6]. The mini MAX DOAS system utilized an AvaSpec-ULS2048x64TEC-EVO spectrometer, configured from 300 to 450 nm. Of the three systems deployed, one used a 25 micron entrance slit with a ~0.25 nm resolution, and the other two utilized a 50 micron entrance slit with ~0.38 nm resolution.

A second group at the Max Planck Institute in Germany also used a similar mini MAX-DOAS system based upon an Avantes spectrometer to collect similar measurements in Romania and Gemany [7].

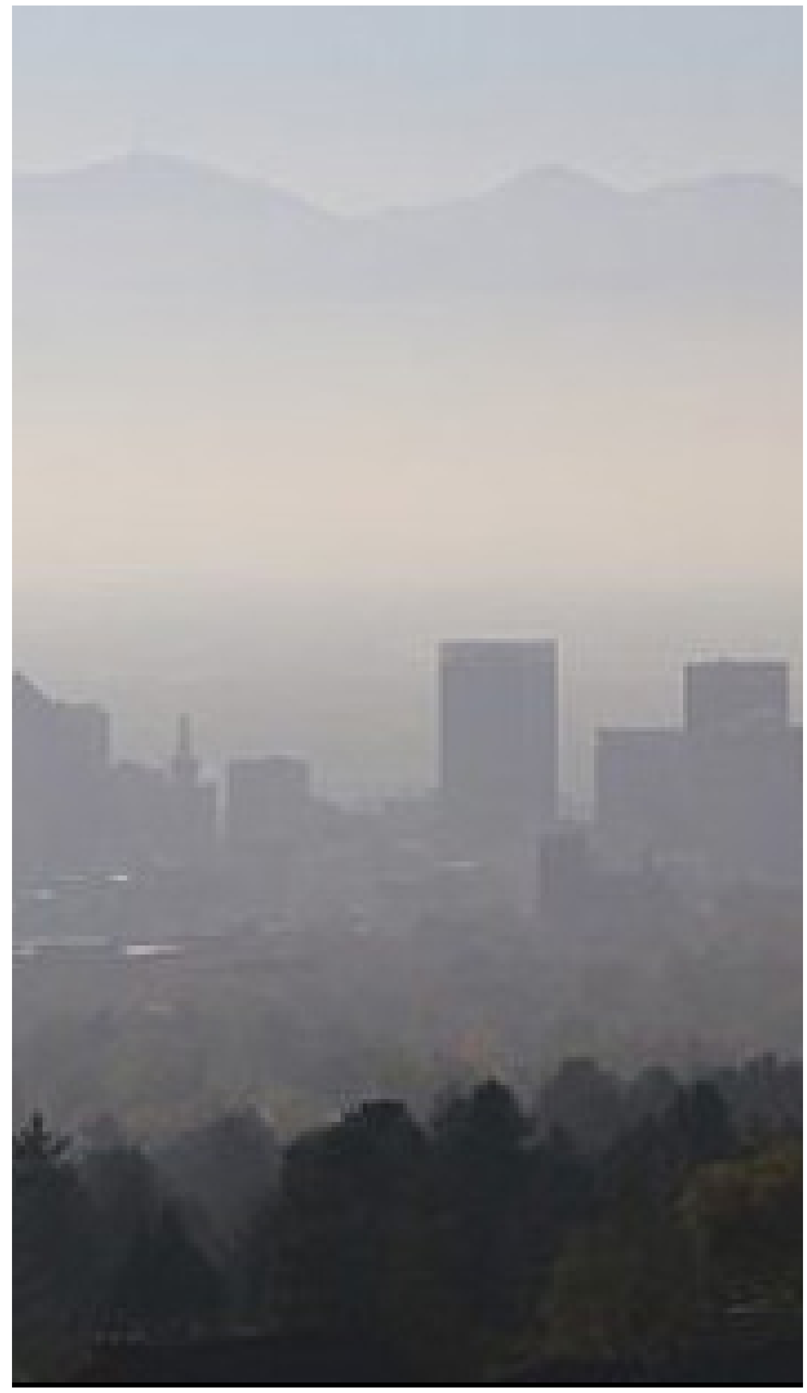
UV/VIS in the Spotlight

UV/VIS spectroscopy refers to absorption/reflection measurements performed in the ultraviolet and visible light spectrum from 200-780 nm.

The Beer-Lambert law, which relates the attenuation of light to properties of the material the light is passing through, states that the absorbency of a sample is directly proportional to the concentration of the absorbing analyte. You can frequently see this axiom at work in analytical chemistry to quantify analytes, monitor processes and reactions, and detect certain organic compounds.

Atmospheric Chemistry

Atmospheric chemistry plays a central role in our



understanding of the mechanisms of local climate conditions and factors into global radiative balance as well. Researchers study a class of compounds called Secondary Organic Aerosols (SOAs) which are the reactive products of gas-phase photo-oxidation of both naturally-occurring and man-made volatile organic compounds (VOCs). There have been many studies on the reaction mechanisms in the propagation of SOAs, Dr. Kun Li and a team of fellow researchers from the Institute of Chemistry at the Chinese Academy of Sciences and the Beijing National Laboratory for Molecular Sciences looked more closely at the optical properties of these aerosols under varying reactive conditions [8].

The scattering and absorptive properties, the direct components of the refractive index are more dependent on the composition of the aerosols than of the concentration or particle size. Understanding the link between the chemical composition of aerosol pollutants and their optical properties allows for a much more accurate estimate of the global radiative effects of localized reactive conditions.

Dr. Li's team's work tested the optical properties of SOA particles generated in a Teflon smog chamber in the lab from several different precursor compounds and under varying NOx levels. Using the AvaSpec-ULS2048L-EVO, (now replaced by the AvaSpec-ULS2048CL-EVO) the particles were shown to be nonabsorbent at wavelength 532 nm. Retrieving Refractive Indices (RI) for each sample at that wavelength yielded values ranging from 1.38-1.59 depending on which precursor compound generated the SOA and under what concentration of NOx, but independent of the concentration of SOA or of particle size. Ultimately their work suggests that many environmental models may overestimate the Refractive Index, and in turn the global radiative effects

Colloids and Nanoparticle Reactions

One area of study in Chemistry that has received a great deal of attention in recent years is Nanoparticles. These nano-scale particles are between 1 and 100 nanometers in size and are surrounded by an interfacial layer of ions, organic and inorganic compounds which can react with other substances. Nanoparticles can exist as a powder or in a solid matrix but are often found in colloidal form, dispersed in an aqueous solution or gel.

Nanoparticles are formed by either breaking down larger particles or by a controlled chemical reaction assembly process. These microscopic particles can be used for molecular tagging, DNA probes, gene therapy, and even cancer treatment. They can be found in consumer products such as sunscreens, anti-glare/non-scratch eyeglasses, anti-microbial or heat resistant coatings, and even in our food supply. The processes of chemical assembly of nanoparticles can be temperamental and the stability and reproducibility of a reaction is dependent on many factors including

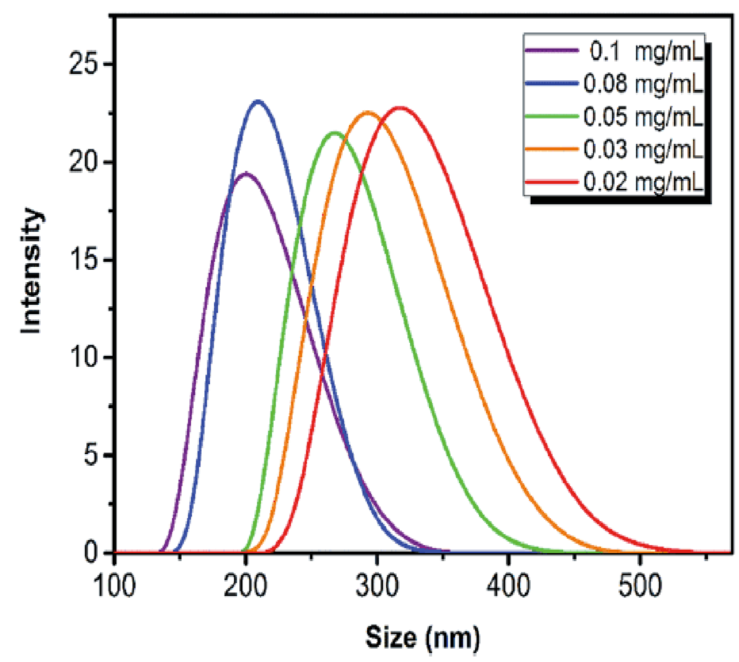


Fig. DLS distributions of NHC with different sizes while the concentration of SDS used is from 0.1 mg mL^{-1} (purple) to 0.02 mg mL^{-1} (red).

solution temperature and humidity, and the purity and concentration of the reagents. Any study of nanoparticles necessarily begins with their production and one of the most widely accepted means of reaction monitoring is UV/VIS spectroscopy.

A group of researchers Kaunas University of Technology, Department of Physics, Kaunas Lithuania analyzed colloidal silver nanoparticles created via silver salt reduction. The chemical reduction of the silver salt solution was monitored throughout the reaction process using the AvaSpec-ULS2048L, (now replaced by the AvaSpec-ULS2048CL-EVO) in the wavelength range 300-700 nm. Colloidal silver exhibits a wide absorption band from 350-550 nm with an absorption peak at 445 nm. As nanoparticles begin to form, absorption increases, then as the particles grow in size, the absorption peak shifts toward the red wavelengths. Stabilization of the absorption peak indicates that new nanoparticles have ceased forming. The data collected during the reaction process also allowed the researchers to calculate average particle size [9].

Humidity Detection

Another group of researchers from the School of Chemistry and Chemical Engineering at the Beijing Institute of Technology studying Nano-Hydrogel Colloidal (NHC) array photonic crystals for the detection of humidity, relay on UV/Vis spectroscopy during the precipitation polymerization synthesis process of developing their NHCs. The novel design of this colloidal gel humidity sensor allows the water absorbing properties of this hydrogel to swell and change volume in response to environmental stimulus. As the particles swell, the change in the size of the particle causes a shift of the absorption bands toward the red. This displays as a change in color visible to the naked eye and tunable, covering the full visible wavelength range from 400-760 nm corresponding to a 20-99.9% range in humidity. These experiments, supported and verified using the AvaSpec-ULS2048LTEC spectrometer, (now replaced by the AvaSpec-ULS2048CL-EVO) may lead to new sensor technologies which can be applied to a variety of organic and inorganic molecular detection sensors [10].

Wildfire Detection and Mitigation

The Portuguese firm NGNS is the maker of the ForrestfireFinder, a long range wildfire detection system that utilizes Avantes spectrometers to their fire monitoring system across the arid central Iberian peninsula where wildfires are a frequent danger. More researchers are using spectroscopy to evaluate damage and impacts to topsoil from wildfires, monitor vegetation recovery after a fire, or measure moisture content and assess risk.

Avantes at the Forefront of Environmental Research

Avantes spectroscopy instrumentation is trusted by environmental and climate researchers around the world for accurate, robust spectral measurements. With more than two decades experience in supporting the unique needs of diverse industries and applications, we are your trusted partner in meeting your measurement objectives. Our innovative designs and commitment to advancing the science of photonics means that Avantes spectrometers are built to handle the new and innovative uses researchers are finding for spectroscopy.

Instrument Selection for Air Quality Applications

These applications require sensitive, stable, high resolution, low stray light spectrometers; to ensure accurate and reliable DOAS measurements with low detection limits and high signal-to-noise ratios. The AvaSpec-ULS optical benches offer the highest degree of stability and smallest stray light of any miniature spectrometer on the market, and the option of either CMOS or back-thinned CCD detectors provides the flexibility to manage cost and sensitivity trade-offs. Among the most highly-recommended instruments, the AvaSpec-ULS2048X64-EVO, AvaSpec-ULS2048X64TEC-EVO, and AvaSpec-ULS2048XL-EVO are ideal for air quality applications. The AvaSpec-ULS2048XL-EVO features extra large 14×500 micron pixels that deliver exceptional efficiency in the UV range (200-400 nm) and the NIR range (950-1160 nm). The internal shutter allows in-line dark capture integration times as low as 2 microseconds. The uncooled AvaSpec-ULS2048x64-EVO is another instrument with a proven track record for DOAS applications due to its high UV response, 0.9 mm detector height and fast integration times. The thermo-electrically cooled AvaSpec-ULS2048X64-EVO has all the same performance as the uncooled X64 but with the added advantage of a hermetically sealed TE cooled detector

All of the AvaSpec-ULS series spectrometers discussed above are also available as OEM modules. They can be integrated into turn-key industrial or field-sensing devices, in addition to functioning as an add-on to existing laboratory equipment setups. These instruments can communicate via USB, Ethernet and the native digital and analog input/output capabilities of the Avantes AS-7010 electronics board, which provides for a superior interface with other devices.

Additionally, the Avantes AvaSpec DLL software development package, with sample programs in Delphi, Visual Basic, C#, C++, Labview, MatLab and other programming environments, enables users to develop code for their own applications.

References:

[1] Marks, Alvin M. "Smokestack aerosol gas purifier." U.S. Patent No.3,520,662. 14 Jul. 1970.

[2] Kirchhoff, Franz-Josef, and Joachim Brandt. "Electrostatic precipitator." U.S. Patent No. 4,097,252. 27 Jun. 1978.

[3] Brewer, A. W., C. T. McElroy, and J. B. Kerr. "Nitrogen dioxide concentrations in the atmosphere." Nature 246.5429 (1973): 129-133.

[4] U. Platt (1994), "Differential optical absorption spectroscopy (DOAS)," in Air Monitoring by Spectroscopic Techniques, M. W. Sigrist,ed.,Chemical Analysis Series, vol. 127, pp. 27–84.

[5] Haiming, Zheng. "Experiment study of continuous emissionmonitoring system based on differential optical absorption spectroscopy." 2008 International Workshop on Education Technology andTraining & 2008 International Workshop on Geoscience and RemoteSensing. Vol. 1. IEEE, 2008.

[6] Drosoglou, Theano, et al. "Retrieval of tropospheric columns fromground-based MAX-DOAS measurements performed in the greater area of Thessaloniki and comparison with satellite products."

[7] Riffel, Katharina, et al. "NOx emissions of various sources in Romania and the Rhein-Main region in Germany based onmobile MAX-DOAS measurements of NO2." EGU General AssemblyConference Abstracts. Vol. 18. 2016

[8] Li, Kun, et al. "Optical properties of secondary organic aerosols generated by photooxidation of aromatic hydrocarbons." Scientific reports 4 (2014): 4922..

[9] Riffel, Katharina, et al. "NOx emissions of various sourcesin Romania and the Rhein-Main region in Germany based on mobile MAX-DOAS measurements of NO2." EGU General Assembly Conference Abstracts. Vol. 18. 2016.

[10] Wang, Zhe, et al. "Self-assembly of a nano hydrogel colloidal array for the sensing of humidity." RSC Advances 8.18 (2018): 9963-9969.

Water and Soil Contamination, Lichen Spectra

02

Spectroscopy Solutions in Water and Soil Contamination

Introduction

As industry of all sorts advance throughout the global marketplace, both the need for ecological monitoring and the technology to implement it, advance as well. Several spectroscopic measurement techniques are proving to be effective and versatile for environmental applications.

Fluorescence measurements are a typical choice for detecting the presence of hydrocarbon pollutants, while Raman spectroscopy might be used to identify organic contaminants. Laser induced breakdown spectroscopy (LIBS) and fluorescence measurements are both used in processing nuclear material, and we see absorbance spectroscopy used in water quality monitoring of coastal waterways.

The need for environmental and ecological testing and measurement is constantly on the rise and there are a number of spectroscopy methods available. An Avantes engineer can help determine the right methods and optimized system specifications to design the right spectroradiometry solution for your measurement needs.

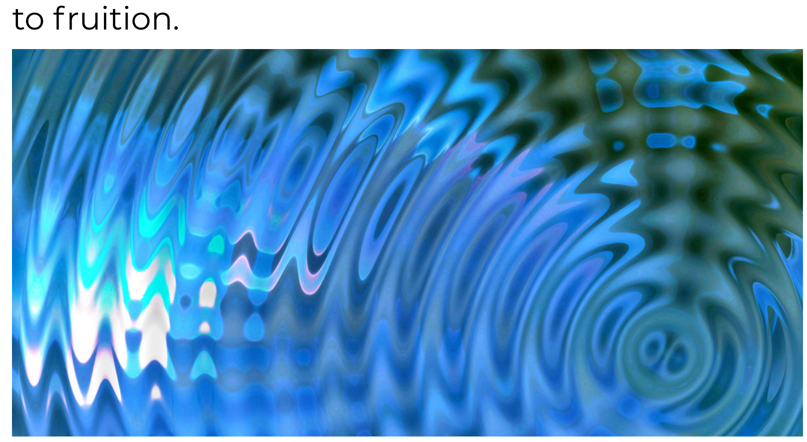
Contamination Monitoring

The monitoring of contaminants in ground water, air, soil and in products is of particular concern because of the difficulty of real-time, in-situ analysis that not only indicates the presence of, but can quickly quantitate and identify contaminants as well.

Fluorescence measurements are a typical choice for detecting the presence of hydrocarbon pollutants, while Raman spectroscopy might be used to identify organic contaminants. Laser-induced breakdown spectroscopy (LIBS) and fluorescence measurements are both used in identifying nuclear material, and we see absorbance spectroscopy used in water quality monitoring of coastal waterways.

Researchers with the Institute of Solar Energy and the Technical University of Madrid, Spain, trust the Avantes AvaSpec-2048-USB2-UA, (now replaced by the AvaSpec-ULS2048CL-EVO) in their research into the use of high-powered UV LEDs as an excitation source for continuous use fluorescence sensing. LED technology has advanced recently making these cost effective bulbs an appealing alternative. Traditional incandescent mercury bulbs produce a large amount of heat compared to LEDs, which, combined with their short life, make continuous use impossible.

The work required the mapping of detection errors to degradation of optical output power and determined a degradation limit of 30%. This means that the useful life of the bulb requires maintaining 70% of initial output power. For high-powered UV-LEDs, they estimated this was approximately 6,200 hours of continuous use or, depending on the bulb, up to 66,000 hours of cycled use (30sec on/ 30sec off) which represents a significant improvement over traditional bulbs. These scientists are working to bring real-time, continuous monitoring for hydrocarbon pollution to fruition.



Researchers from the College of Control Science and Engineering at Zhejiang University, publishing in the May 2017 Journal of Spectroscopy, are working to develop a method for rapid, on-site water quality analysis in the case of unknown contaminants. Their method employs fluorescence spectroscopy. They applied an alternating trilateral decomposition (ATLD) algorithm, after eliminating Raman scattering effects, to establish a model of a “normal” water sample. Working with an excitation wavelength of 350 nm and an emission wavelength of 397 nm, the researchers believe they were able to establish a model to detect the presence of unknown organic contaminants with fluorescent characteristics. This work on developing a profile of “normal” water (water without organic contaminants) has the potential for the development of real-time, inline water quality monitoring systems.

Water Treatment

The Avantes AvaSpec-ULS2048CL-EVO is trusted by researchers at the Solar Energy Research Center and Chemical Engineering Department of the University of Almería, Spain, in the study of LED light sources for tertiary wastewater treatment processes.

Tertiary treatment is the final stage of wastewater treatment that removes lingering inorganic compounds and other substances such as nitrogen and phosphorous. This photocatalytic process, employing UVA radiation at 365, 385 and 400nm, is the photo-Fenton Reaction in which radiation causes a rapid reaction between hydrogen peroxide and iron.

Historically the photo-Fenton reaction relied on solar radiation as the source of catalytic radiation, but weather conditions and solar cycles make artificial illumination an attractive alternative. Recently, this has been accomplished using Mercury lamps which have a limited lifespan and high cost associated with them. The Spanish researchers are testing the effectiveness of newly available LED light sources for UV radiation with positive results. LED bulbs are less expensive than traditional incandescent bulb and have a longer life.

Oceanographic Research

The health of our oceans and seas has dire consequences for humanity. The ocean produces more than half of the oxygen in our atmosphere, and roughly half the world’s population lives in a coastal zone. Protecting our oceans is vital and researchers are increasingly using spectroscopy to monitor the health of the world's seas and oceans.

Remote sensing (initially from satellites as early as the 90's, but increasingly from UAVs) has been used to monitor the health of coral reefs using pulsed laser fluorescence. Detecting symbiotic algae and the byproduct chlorophyll with fluorescence peaks at 685 and 740 nm.

Another group of researchers studying ocean and coastal waterways has been developing models to anticipate intense phytoplankton blooms using irradiance spectroscopy. These intense harmful blooming events adversely affect ecosystems and can be adverse for human health as well. Using UAVs fitted with an Avantes AvaSpec dual channel spectroradiometry solution covering 360-1000nm the team was able to derive fine-resolution spectra data and obtain timely information on bloom magnitude. While the technology is still maturing, these researchers recommended initial implementation of spectral bloom monitoring during algal bloom season.

Comparison of Water Quality with Absorbance Spectra

In March of 2019, our Avantes office in Colorado featured spectra that was the result of an experiment which compared the spectra of tap water at the Avantes, Inc. offices in Louisville, Colorado to spectra of a water sample drawn from a tributary of Coal Creek. The stream water predictably evidenced higher absorption and lower transmission values due to particulate matter and potential contaminants.

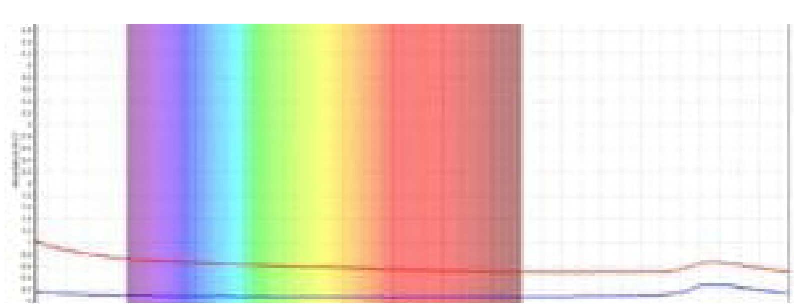
System Configuration

An absorption setup was used to analyze two different samples of water. A DHc light source was set up with a cuvette holder directly attached to the light source. An FC-UVIR600-1-BX Fiber was then attached to the cuvette holder that lead directly to the spectrometer (AvaSpec-Mini2048CL) to acquire the spectra.

Methodology

Once the system was set up, two quartz cuvettes were filled with tap water and two quartz cuvettes were filled with water from a local stream. A dark measurement was taken, with a blank cuvette taken as the reference. The cuvettes were then inserted into the cuvette holder to record the absorption and transmission of each sample. Data were collected and then analyzed in AvaSoft.

Comparison of Absorbance Spectra



Comparison of Transmission Spectra

Soil Management

Soil is a compound mixture of organic matter, minerals, gases, liquids, and even living organisms. In addition to supporting the plant life we need for crops, soil also functions as a means of storing, transporting, and purifying water; it helps to modify the atmosphere we all depend on, and even serves as habitat for organisms large and small. Sustainable soil management is as critical for future food production as it is for life on Earth.

Soil Contamination Applications

The use of laser-induced breakdown spectroscopy is widely used for soil contamination detection. Researchers from the Department of Environmental Sciences of the Government College University, Faisalabad, Pakistan are studying Chromium VI and other heavy metal contamination from industrial waste produced by the economically important leather tanning industry. The Avantes AvaSpec-3648 dual-channel , (now replaced by the AvaSpec-ULS4096CL-EVO) spectrometer system working in the 300-750 nm wavelength range provided researchers with quantitative and qualitative analytical data with a very low detection limit.

Mineral, Rock, Sediment, and Soil Analysis

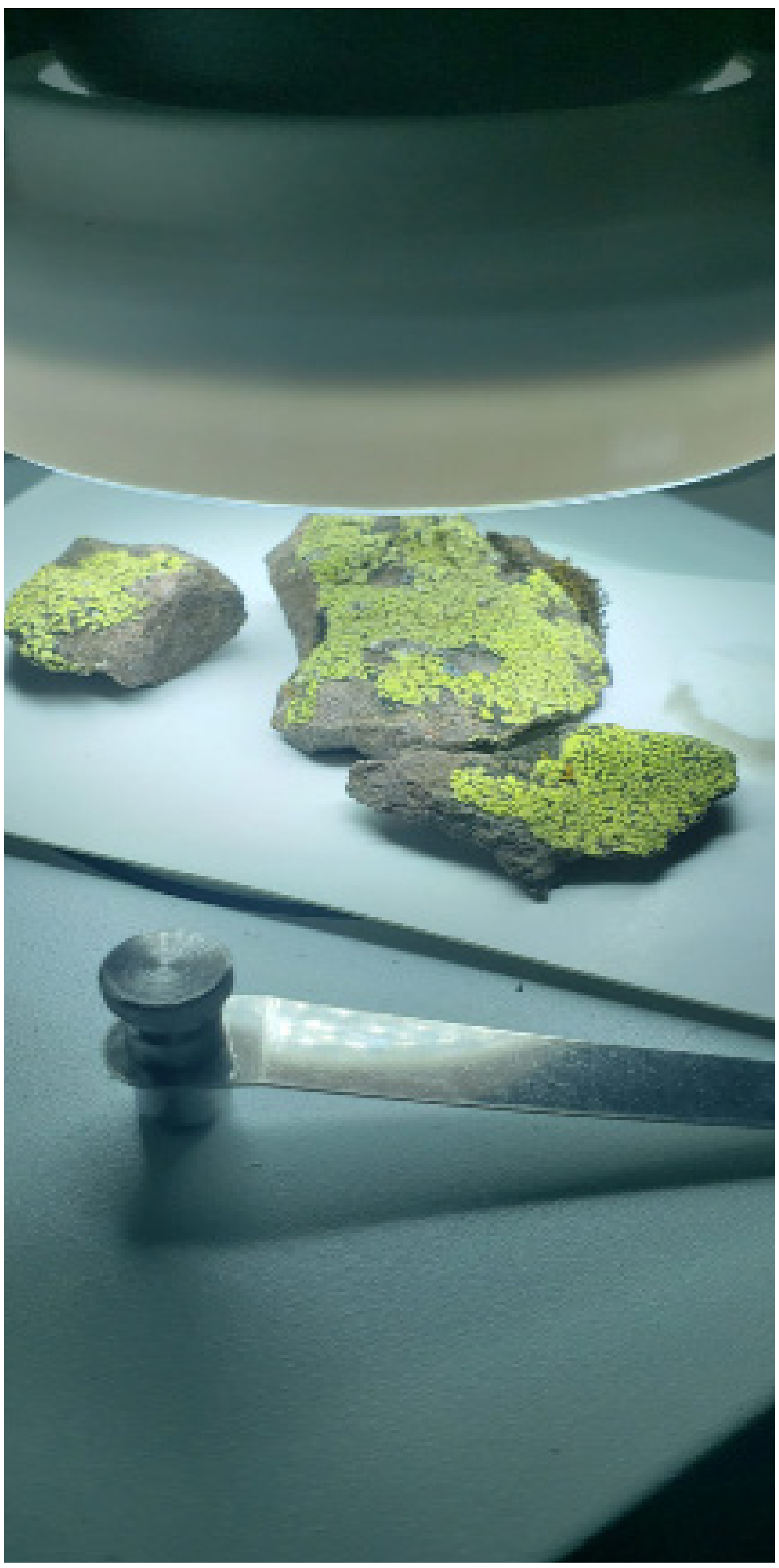
Minerals are the fundamental building blocks of most rocks and soils with more than 4,000 identified minerals on Earth. Knowledge about chemical composition is essential to understanding the formation and characteristics of any rock or soil body. The field capabilities and prep-less sampling of LIBS measurements explains why this spectroscopic technique is commonly used across many different areas of the geosciences.

LIBS spectroscopy was employed in the characterization of stalagmites for Magnesium and Strontium in the Caves of Nerja near Malaga,

Spain. Researchers isolated deposits of manganese (Mn), magnesium (Mg), strontium (Sr), calcium (Ca) and iron (Fe) in speleothems taken from the the caves.

03

Absorption and Reflection Spectra of Lichen

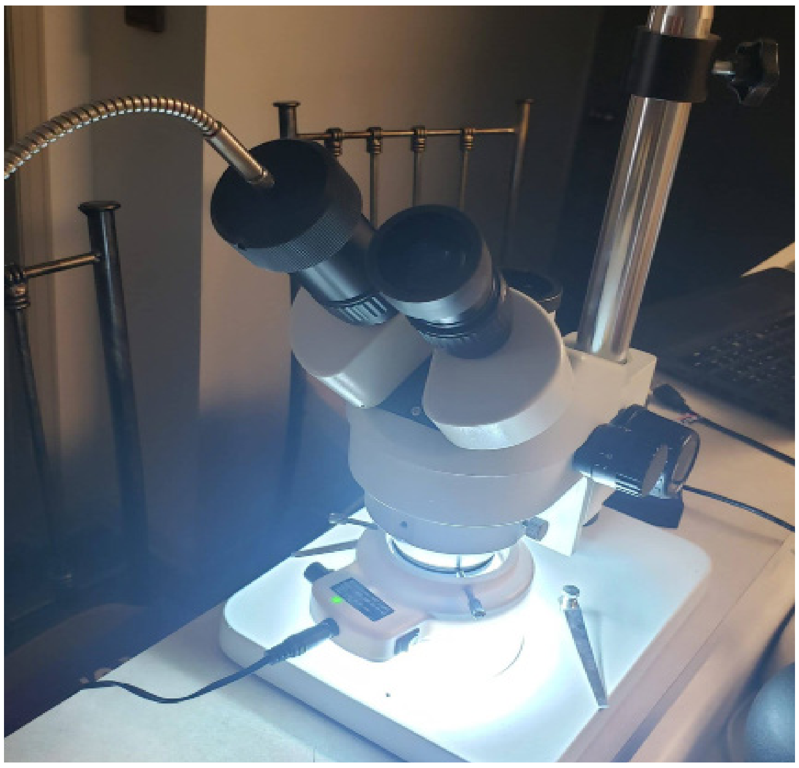


Introduction

Absorption and reflection spectra can reveal the unique properties of many different types of materials and samples. This includes biological samples and plant life. This can range from leaf's, flower petals, grass and lichen. The optical properties of lichens have been traditionally explored in the context of geological mapping where the encrustation of lichens on rocks may influence the detection of minerals of interest. As of today, several studies have looked into the potential of using the optical properties of lichens to classify them, such as reflection and absorption of light. Avantes equipment is well suited for these types of applications

Description of System

A white LED light source is ideal for absorption and reflection measurements because of its power and good output in the VIS range, which is the wavelength range many researchers use to characterize reflection, absorption and fluorescence in the visible range. The white LED light source used in this testing is a ring light for the stereoscope that was used to obtain the close-up views of the lichen samples. The ring light is mounted to the base of the stereoscope to illuminate the samples. From there, the scope is adjusted to optimal magnification to view the lichen up close. A fiber bundle is connected to one of the ports of the stereoscope, which feeds the light directly to the spectrometer.



For this experiment, the AvaSpec-Mini2048CL was used. The AvaSpec-Mini-CL series can be equipped with a 2048-pixel CMOS detector or our first-to-the-market 4096-pixel array. Enjoy the speed and enhanced native UV/NIR response of CMOS with an incredible resolution of up to 0.09 nm unavailable anywhere else. The low stray light design allows stray light levels from as low as 0.2% and the fast response time boasts data transfer speeds as fast as 4.6 ms/scan and integration times ranging from 30 µs to 50 s. The configuration used in this testing is optimal for absorbance and fluorescence measurements as it is fitted with a 200-um slit. In addition to the large slit, this Mini is configured with an OSC-UA and OSF-305.

Description of Methodology

For this experiment, we used the absorbance and reflection modes in AvaSoft. These modes are built to capture the absorbance of samples in absorbance units and the reflectance of samples in percent, respectfully.

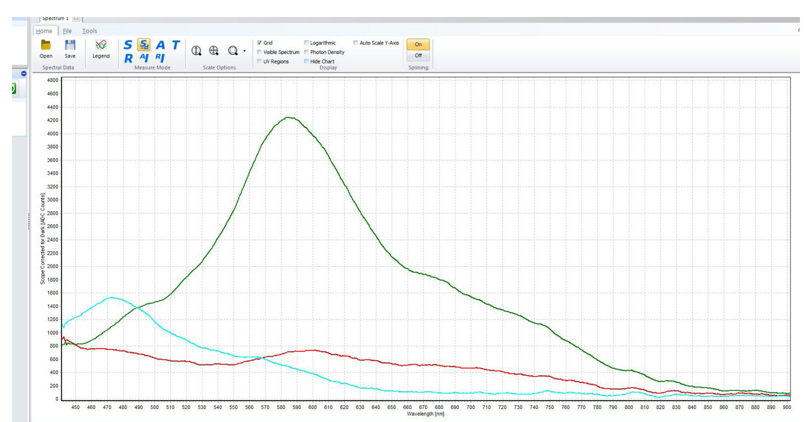
Our setup will be used to measure the absorbance and reflection spectrum of three different types of lichen. Lichens occur in one of four basic growth forms:

- Crustose – crust-like, growing tight against the substrate.
- Squamulose – tightly clustered and slightly flattened pebble-like units.
- Foliose – leaf-like, with flat sheets of tissue not tightly bound.
- Fruticose – free-standing branching tubes.

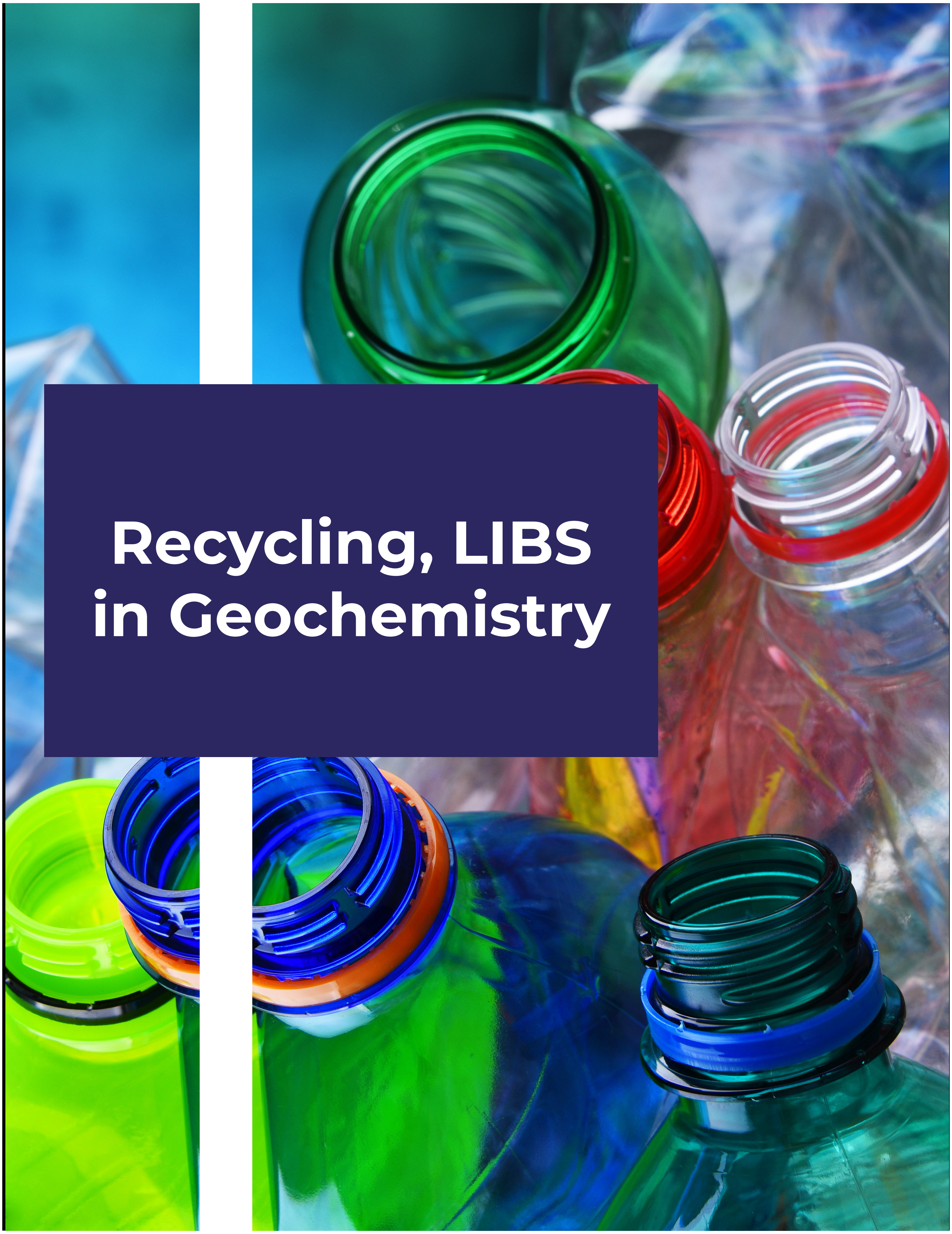
For this experiment, we were able to obtain lichen in three of is basic growth forms: crustose, squamulose and foliose.

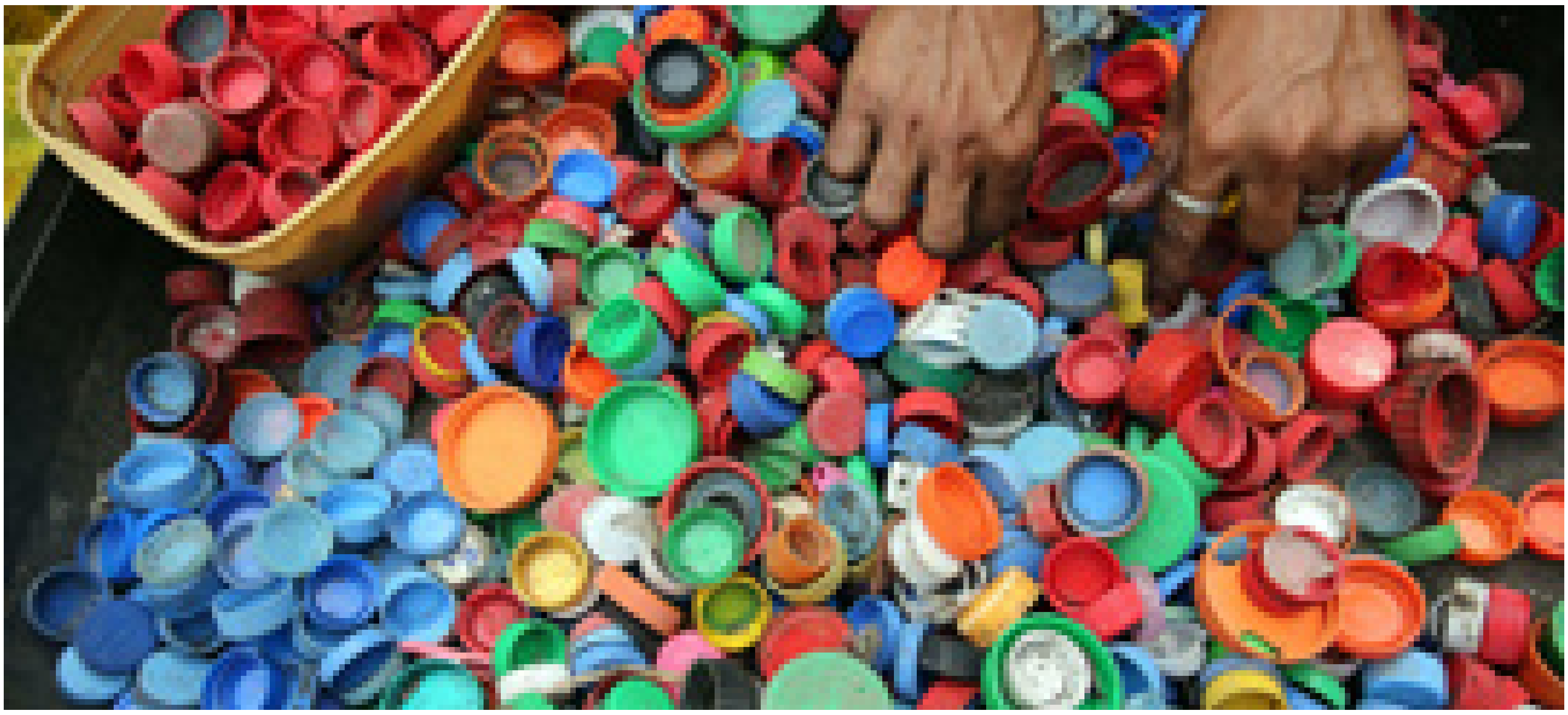
A WS-2 reflection tile will be used as our reference. With the tile, we will use this to optimize the integration time and averaging for the spectrometer in the VIS wavelength range.

Test Data and Results:



Recycling, LIBS in Geochemistry





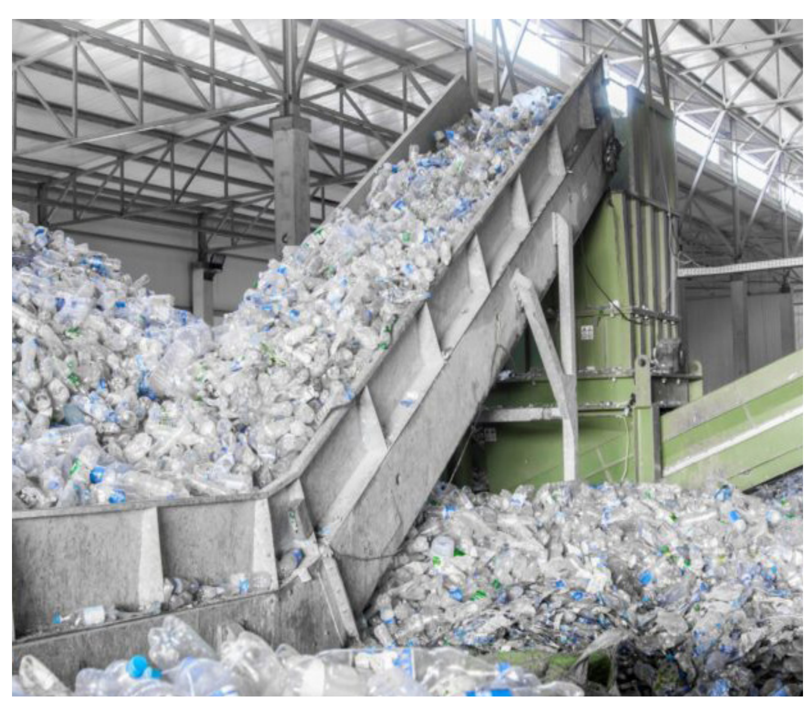
04

Recycling Applications with NIR Spectroscopy

Introduction

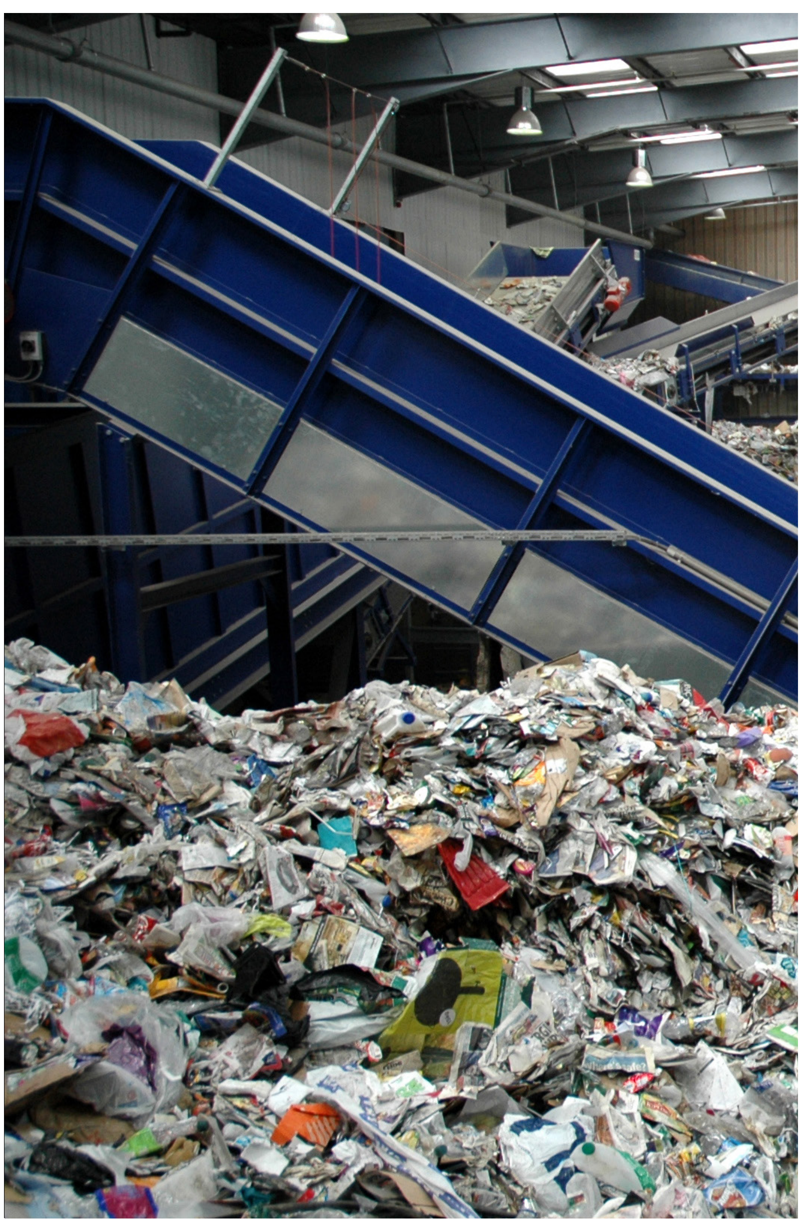
Recycling has become an important subject in today's society due to the impact of waste on our environment and the loss of valuable recources. In the past, sorting of recyclable materials (e.g. paper, plastics and textiles) was mainly done by hand. Nowadays, the use of near-infrared (NIR) spectroscopy has become a standard in the recycling industry.

One of the most difficult materials to classify in a recycling waste stream is plastic. Reflection measurements employing near-infrared spectroscopy enable the classification of many of the most common polymers present in recycling waste streams.



Modern large-scale recycling sorting systems are using NIR spectroscopy to rapidly and automatically identify different plastics and eliminate contaminants. The AvaSpec-Mini-NIR is well suited for this environmental application because of its versatility in the 900-1750 nm range. Due to its small form factor, this miniature spectrometer can easily be integrated into different recycling systems.for farms of all sizes. Anything from erosion to contamination, loss of biodiversity, soil compaction, and everything in between, can be detrimental to crop production and the viability of the farm itself.

Experiment Using NIR Reflection of Plastic for Recycling Applications



The importance of NIR reflection spectra has proven to be a reliable method of identifying unique characteristics and properties of various materials, including types of plastics. Different types of plastics may look similar to one another at an initial glance with the naked eye, but evaluating the NIR reflection properties of plastics can reveal just how unique each sample is.

Description of NIR Reflection System

A 100W halogen light source is used to illuminate the plastic samples we have acquired. These samples will be placed on the base of the stand holding the spectrometer, approximately 2 inches away from the slit of the spectrometer. Attached to the SMA connector on the slit of the spectrometer is a direct attach collimating lens to collect as much light as possible from this free space measurement.

For this experiment, the brand new AvaSpec-Mini-NIR will be utilized. The AvaSpec-Mini-NIR is a compact near-infrared spectrometer, based on a combination of our popular AvaSpec-NIR256-1.7 and Mini-series. This NIR spectrometer might not be as sensitive as our bigger NIR spectrometers, but this loss in sensitivity is greatly compensated by its size and robustness. Like our other CompactLine spectrometers, this device is only the size of a deck of cards and USB powered, which makes it easy to integrate into other devices, including but not limited to OEM handheld applications. This versatile miniature NIR spectrometer is well suited for various applications, including food analysis and the recycling industry. Some application examples include fertilizer analysis, dairy industry, recycling, wheat and grain analysis, and moisutre content measurement.

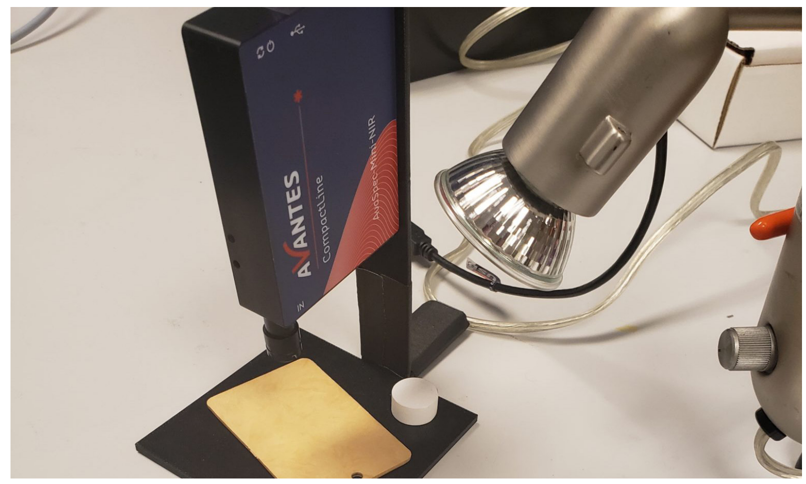
Description of Methodology

For this experiment, we used the reflection mode in AvaSoft. This mode is built to capture the NIR reflectance of samples in percent.

Our setup will be used to measure the reflection spectrum of six different types of plastics. The types of plastics we will be looking at are:

- HYDLAR Z – HYDLAR possesses a combination of physical properties that cannot be found in any other commercially available engineered plastic. HYDLAR Z is a family of resistant thermoplastics using aramid fiber reinforced polymer. This technology makes possible for aramid fiber reinforced plastic to be used in combination with a nylon base resin.
- Tecafine LDPE – Polyethylene (PE) polymers are semi crystalline thermoplastics with a high degree of toughness and very good chemical resistance. When compared to other plastics, polyethylene plastic tends to exhibit lower mechanical strength and temperature resistance. This polyethylene is a low-density version (LDPE).
- Tecaform – POM plastic (chemically known as Polyoxymethylene) is a semi crystalline thermoplastic with high mechanical strength and rigidity. Acetal polymer has good sliding characteristics and excellent wear resistance, as well as low moisture absorption. The good dimensional stability and particularly good fatigue strength, as well as excellent machining ability, makes POM polymer a highly versatile engineering material, even for complex components.
- Tecamid 6/6 MDS – The most common extruded nylon is a polyamide 66, which offers a balanced combination of performance and cost that provides users with a unique engineering plastic polymer.
- Tecapeek – PEEK polymer is a high-performance plastic material with an excellent balance of physical properties. It has one of the highest levels of heat resistance and mechanical strength available among plastics. It is also one of the best choices when looking for good chemical resistance, as well as radiation resistance. Click on the list below for detailed PEEK characteristics.
- Ultem – Polyetherimide or PEI material is an amorphous thermoplastic with high mechanical strength and rigidity.

A WS-2 reflection tile will be used as our reference. With the tile, we will use this to optimize the integration time and averaging for the spectrometer in the NIR wavelength range.



Analysis

Upon analysis of the various samples, it becomes clear that each plastic sample, while similar in visible appearance and texture, has its own unique spectrum in the NIR region. A chemometric model would be a fascinating next step that would demonstrate the uniqueness of each plastic sample and provides a reliable method of identifying plastics. This model could then be incorporated into a handheld instrument to allow rapid sample identification..

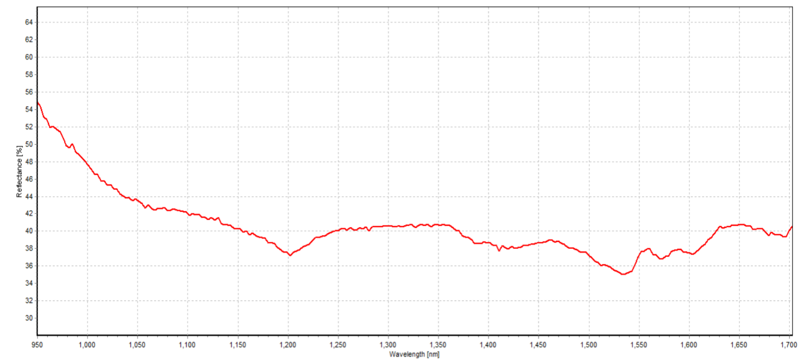
Conclusion

The new AvaSpec-Mini-NIR from Avantes is an excellent tool that has proven itself useful for not only identifying plastics but also revealing the unique traits of all types of samples in the NIR spectrum. Combining the reliability of the AvaSpec-Mini-NIR with its compact size, this portable spectrometer is an excellent option for handheld applications and fieldwork.

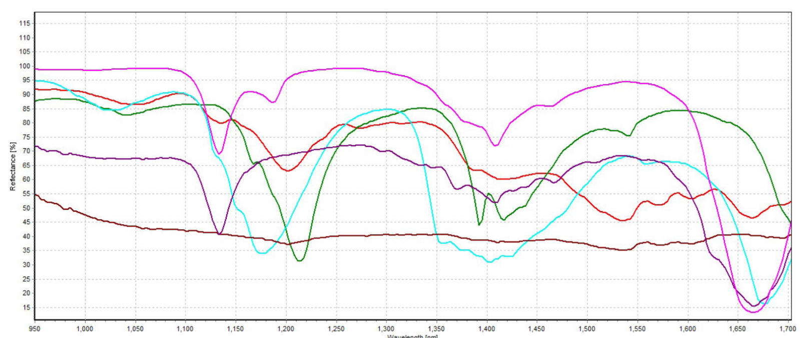
NIR Reflection Test Data and Results:

Displayed below is the NIR reflection spectrum collected from the six plastic samples.

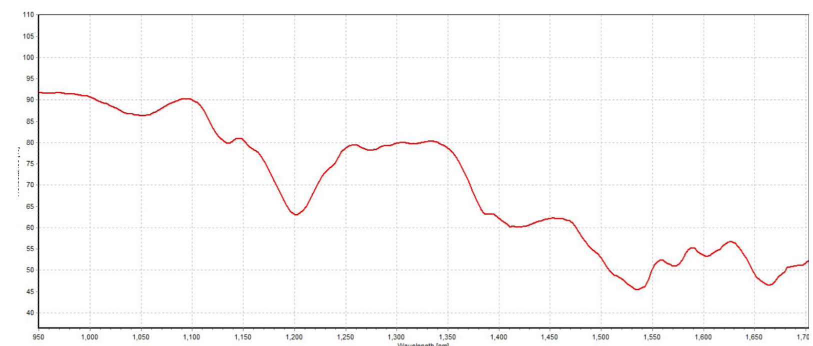
Integration time: 35 ms; Averaging: 15



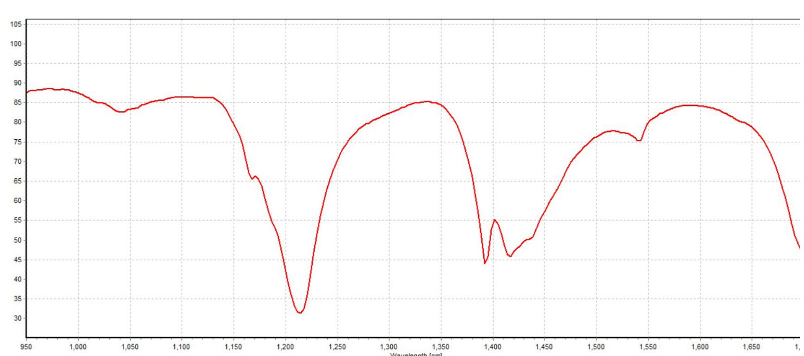
Tecamid 6_6 Reflection Spectrum



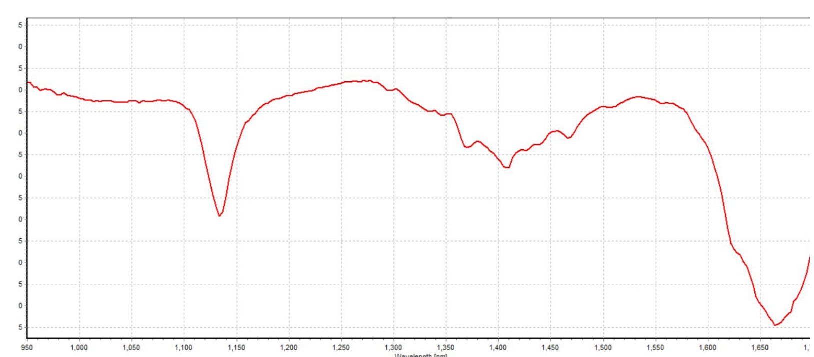
NIR Reflection Composite graph



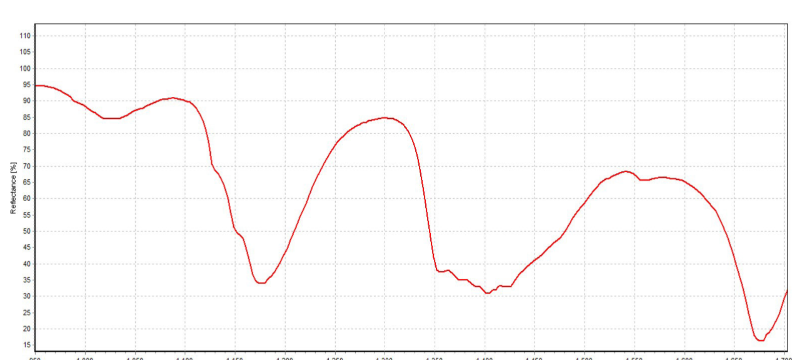
NIR Reflection of HYDLAR Z



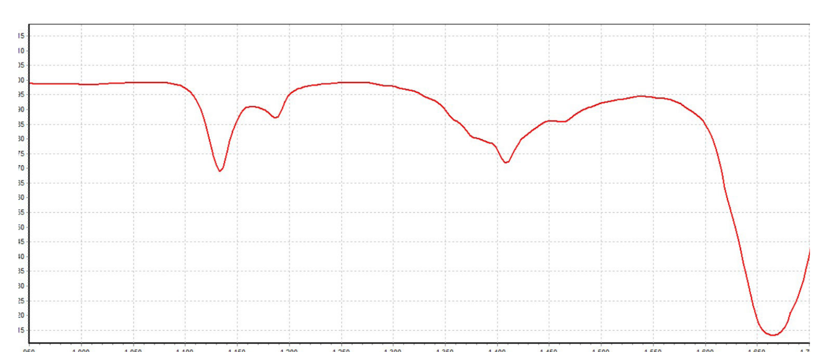
NIR Reflection of Tecafine LDPE



NIR Reflection of Tecapeek



NIR Reflection of Tecaform



NIR Reflection of Ultem

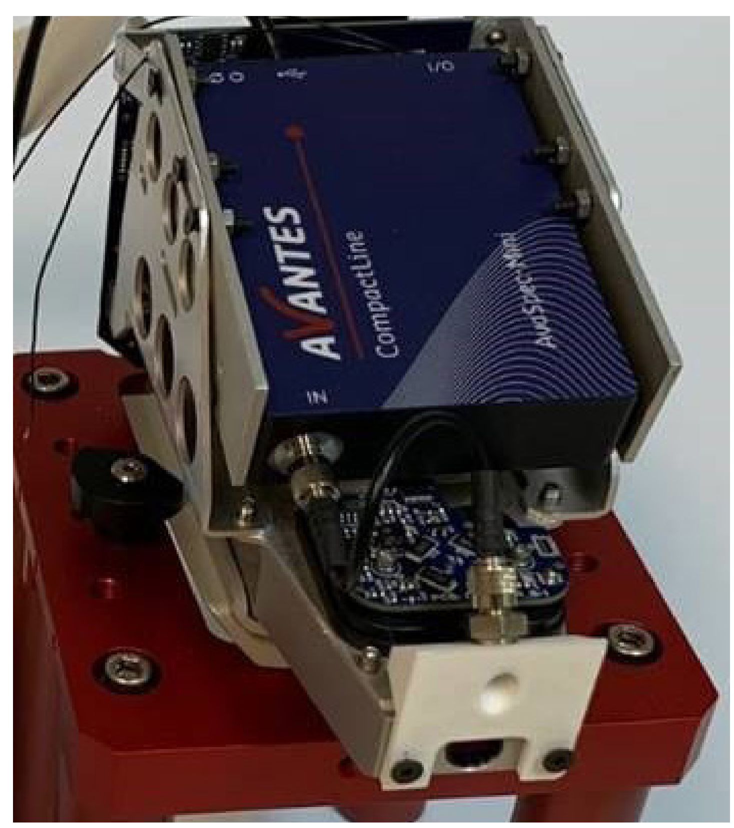
05

LIBS in Geochemistry & Ore/Mineral Extraction

Introduction

Laser-induced breakdown spectroscopy (LIBS) techniques have been researched since nearly the invention of the laser itself. Only recent developments, however, have finally made LIBS a suitable measurement technique for industrial applications. Recent developments in miniaturization and industrial hardening of key system components have had a positive impact on LIBS industrial adoption.

Laser-induced breakdown spectroscopy has both advantages and disadvantages. LIBS offers rapid measurements of multiple atomic elements simultaneously in a single scan. It requires less



- *Portable Libs Test Kit; includes Falcon Laser, courtesy of Lumibird and the Avantes AvaSpec-Mini spectrometer into a single, compact package* sample preparation than other methods and with the use of fiber optics, can be deployed from a distance or used to sample on a very small scale. Even with its benefits, there have been obstacles to wider LIBS adoption.

First, the advantage of being able to perform measurements at a distance is especially useful for measurements in hostile environments, but those same environments offer ambient conditions that are less than ideal. Airborne particulates, condensation, and temperature fluctuations can impede a LIBS system's ability to capture spectral data and distinguish it from background noise.

Hardening instruments to ambient conditions is crucial in LIBS measurements where, for example, low-light conditions would be adversely affected by thermal instability. Adjusting focal length, selecting ideal wavelength regions, and processing out matrix effects are variables that can drastically change measurement parameters. LIBS generally requires a robust set of matrix-matched samples to develop a calibration model which can support qualitative and quantitative measurements. These standards may or may not exist and require validation using more traditional methods of testing such as ICP MS.

In spite of these challenges, however, LIBS is beginning to make steady progress in select industries.

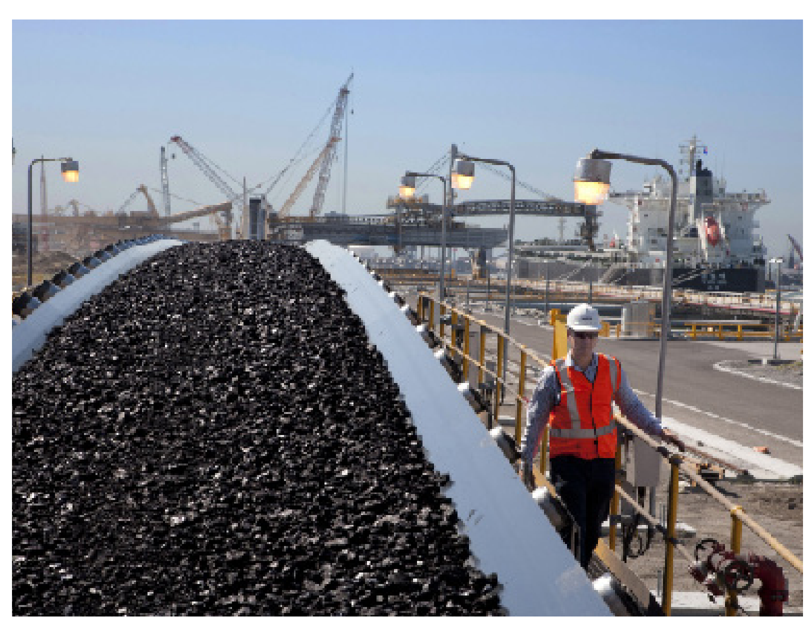
Energy Generation

LIBS can also be deployed in energy production. Coal-fired power generation requires precisely calibrated fuel mixtures to run most efficiently. Coal is monitored for ash content and other constituents before entering the plant combustion zone. Adjusting the fuel mix helps plants prevent slagging and reduces greenhouse gas emissions.

While the phrase "clean coal" might be a misnomer, controlling greenhouse gas emissions from existing coal-fired power plants is valuable to reducing the carbon impact of our existing infrastructure. Researchers at Shanxi University, Taiyuan, China, developed a system designed for inline quality analysis of pulverized coal. The plasma spectra were captured by a three channel spectrometer system based on the AvaSpec-ULS2048CL-EVO with one 3600 g/mm grating and two 1200 g/mm gratings, and numerical apertures of 0.22. The wavelength range for the system of 227-816 nm with resolution of 0.3 nm measured C, Ca, Mg, Ti, Si, H, Al, and Fe as well as Ash, Free Carbon, and Moisture Content of samples. The elemental LIBS system passed proof of capability testing with measurement errors within 10% and was deemed capable of providing rapid, efficient inline analysis of coal quality for plant operators

Geochemistry & Ore/Mineral Extraction

Laser-induced breakdown spectroscopy is gaining a foothold in mining, mineral extraction, and metallurgy with a large body of research supporting the development of reference calibration data, and in turn leading to increased adoption for industrial applications.



LIBS can be applied throughout the ore extraction and processing industries. Monitoring metallurgical processes involves the measurement of plasma created at the surface of molten metals, inline systems that monitor raw ore composition in preprocessing, and quality management testing the composition of alloys in finished ingots.

Green Tech

Laser-induced breakdown spectroscopy is at work in the recycling industry, too. Plastics and metals can be more easily separated using the rapid material identification capabilities of a LIBS system. In aluminum recycling, LIBS allows faster and more accurate sorting of scrap metal, because it can differentiate alloys in the same family. The recycling relies heavily on handheld LIBS instruments.

Sponsored by SHREDDERSORT, the European project to improve recycling rates of non-ferrous metal automotive waste, researchers in Italy are using artificial neural networks to process LIBS spectra of primarily aluminum alloys. Conventional sorting methodologies, such as X-ray Transmission (XRT) are not adequate for determining specific alloys. Paired with the artificial neural network was a dual channel spectrometer system featuring AvaSpec-ULS4096CL-EVO instruments.

This system collected spectra simultaneously between 200-430 nm at 0.1 nm resolution and 415-900 nm at 0.3 nm resolution. Multiple spectra per sample were fed into the ANN, this method was shown to improve classification of the non-ferrous metallic automotive scrap to better than 75% in conditions simulating an industrial environment.

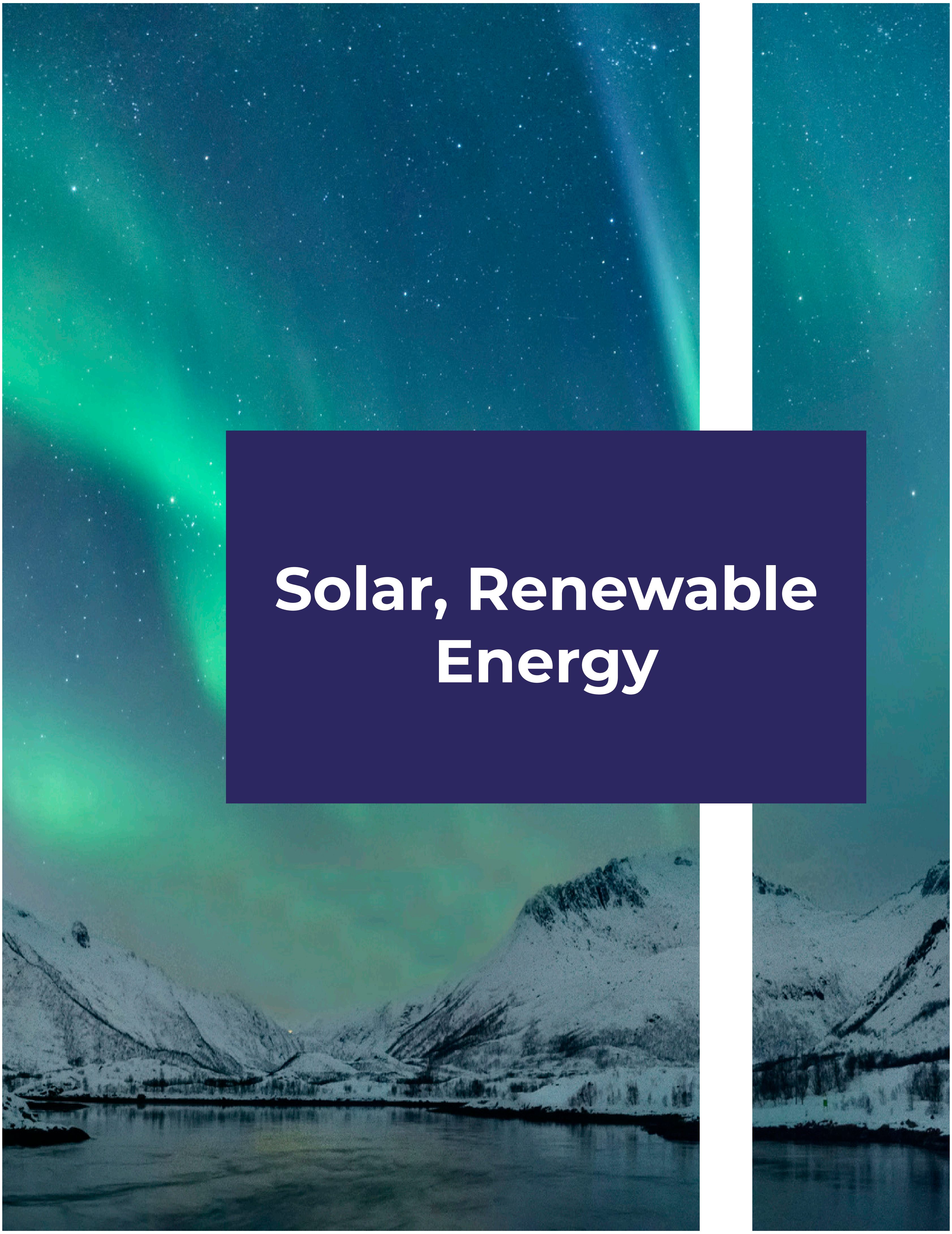
Resources

Campanella, B., et al. "Classification of wrought aluminum alloys by ANN evaluation of LIBS spectra from aluminum scrap samples." Spectrochimica Acta Part B: Atomic Spectroscopy(2017). https://www.avantes.com/images/Whitepapers/3._Classification_of_wrought_aluminum_alloys_by_ANN_evaluation_of_LIBS_spectra_from_aluminum_scrap_samples.pdf

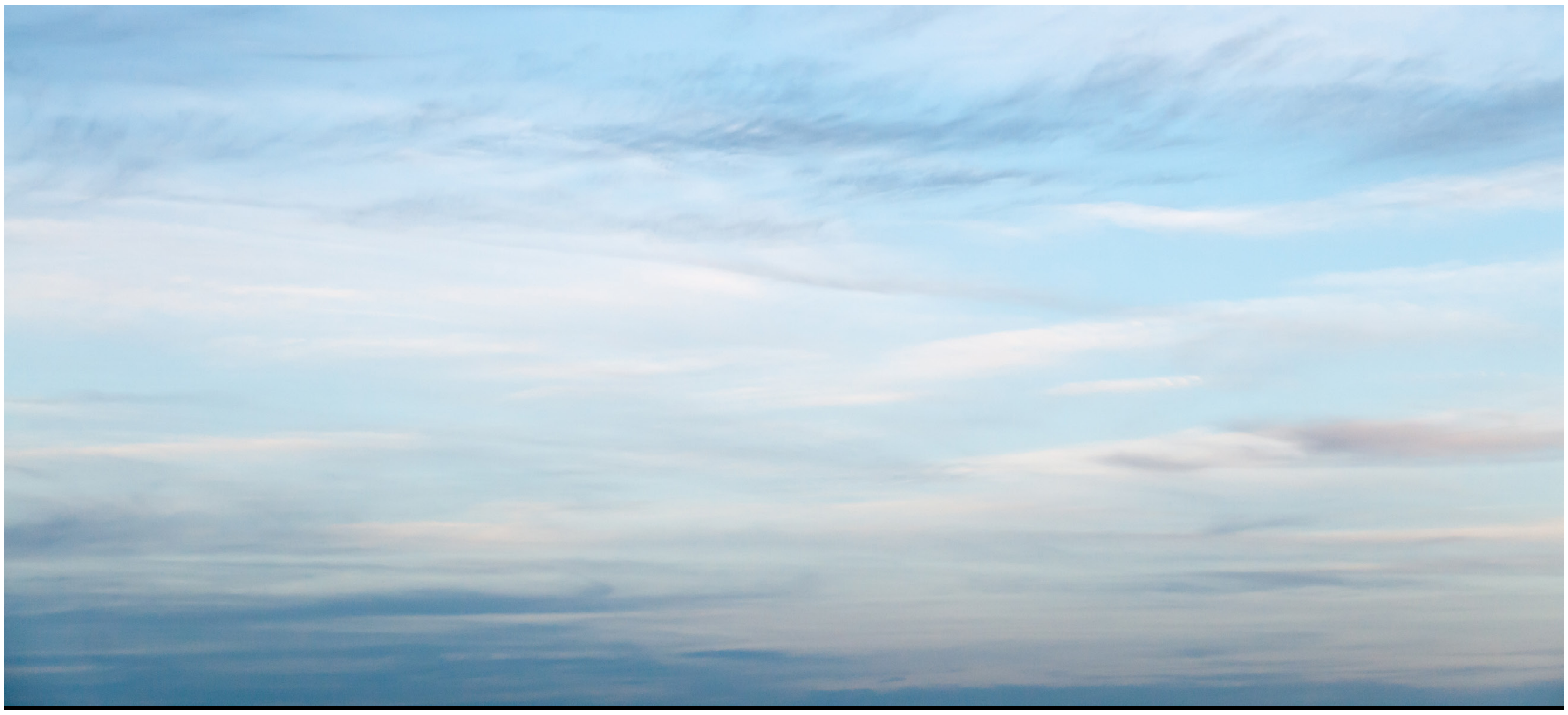
Li, Jie, et al. "Effects of experimental parameters on elemental analysis of coal by laser-induced breakdown spectroscopy." Optics & Laser Technology 41.8 (2009): 907-913. https://orbi.ulg.ac.be/bitstream/2268/145058/1/Effects%20of%20experimental%20parameters%20on%20elemental%20analysis%20of%20coal%20by%20laser-induced%20breakdown%20spectroscopy.pdf

Mirzaee, Fateme Hadavand, et al. "Laser induced fluorescence and breakdown spectroscopy and acoustic response, to discriminate malignant and normal tissues." European Conference on Biomedical Optics. Optical Society of America, 2013. https://www.researchgate.net/publication/256093830_Laser_induced_fluorescence_and_breakdown_spectroscopy_and_acoustic_response_to_discriminate_malignant_and_normal_tissues

Xia, H., and M. C. M. Bakker. "Online sensor system based on laser-induced breakdown spectroscopy in quality inspection of demolition concrete." 27th International Conference on Solid Waste Techand Mngt, Philadelphia, USA 11-14 maart 2012. International Society for Industrial Ecology, 2012. https://repository.tudelft.nl/islandora/object/uuid:73f5290f-1563-45b3-9dd2-023cd7598947/datastream/OBJ



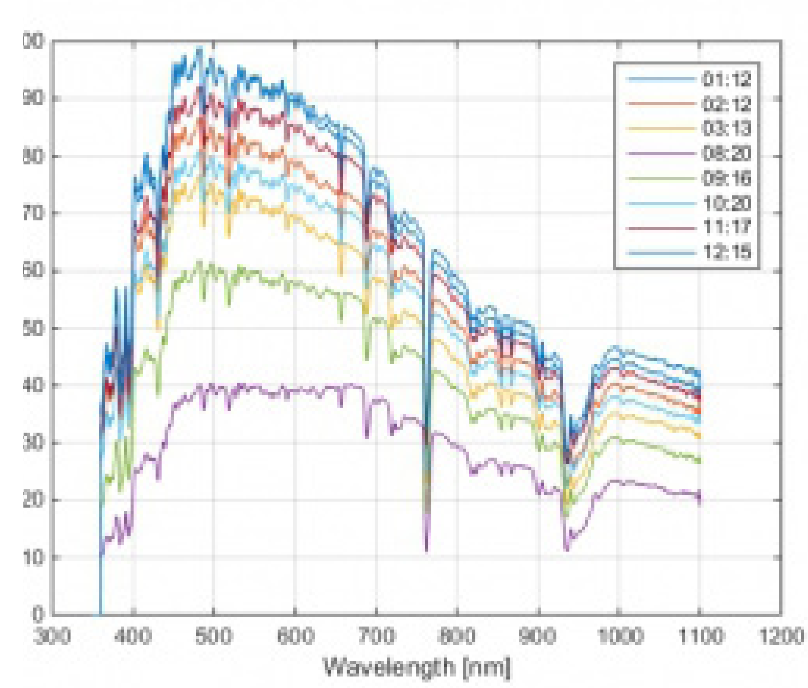
Solar, Renewable Energy



06

Solar Irradiance and Solar UV Field Measurements

The Sun is the primary source of energy on Earth. Radiation from the sun strikes the Earth's atmosphere and begins to be absorbed by air particles and gases, while the remaining energy reaches the Earth's surface. Earth absorbs much of this radiation, and reflects and emits radiation as well. Even small changes to the equilibrium of this energy system is believed capable of causing intense changes to Earth's climate.



Solar Irradiance data is a critical component of climate and environmental study, but solar radiation can affect many other areas of life on Earth, from agriculture and health to technology and manufacturing. Researchers and scientists from academia and industry need access to reliable, repeatable solar characterization data. For solar spectra collection and solar characterization systems, trust Avantes, the world leader in the manufacture and design of optical spectroscopy equipment.

Defining Solar Irradiance

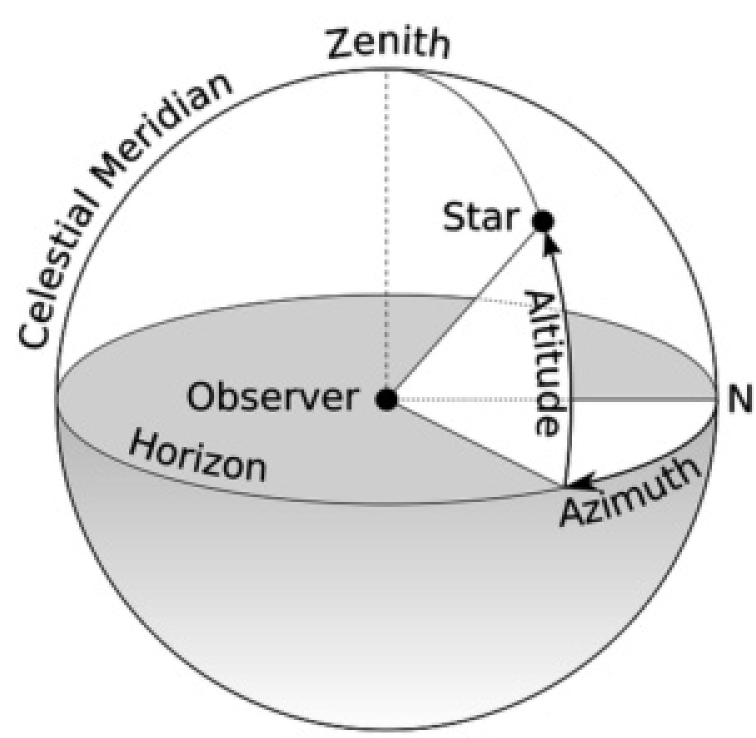
Total solar irradiance is defined as the sum of solar energy, over all wavelengths, per meter squared at the point of incidence upon the Earth's outer atmosphere. This total solar irradiance is approximately 1,360.8 Watts per meter squared, But we know that the Sun's energy is not a homogenous constant. Rather the sun's energy fluctuates slightly as it emits radiation across the entire electromagnetic spectrum. This spectrum includes what we characterize as visible light as well as ultraviolet and infrared radiation.

A solar spectra measurement differs from the total solar irradiance in that it gives an intensity measurement for each wavelength. The characterization of the full spectrum of sunlight provides important data points for researchers. As the sun's energy passes through the layers of Earth's atmosphere, a portion of that energy is reflected, scattered or absorbed by gases, water vapor, or airborne particulates. This scattering is what gives the sky its blue appearance. The shorter wavelengths, like those in the blue range, are scattered more than longer wavelengths. We know that every element in the periodic table absorbs light at a particular wavelength. Each element has a unique spectral signature like a fingerprint allowing scientists to identify materials with spectral analysis. Measuring the spectral irradiance of the Sun's light tells us about the chemical makeup of Earth's atmosphere and aids in predicting how the climate will respond to changes in Earth's energy system.

Measurement Parameters

There are many factors that affect the behavior and characteristics of light from the sun as observed on Earth. The sun's energy does fluctuate, and solar storms and other phenomena can affect solar output. Air pollution, water vapor, and cloud coverage can also affect the quality of light reaching the Earth due to absorption and light scattering.

Also, solar position is a dominant factor in solar irradiance measurements. Parameters such as season, time of day, and the observer's geographic location affect solar measurements. The Sun's radiation is strongest near the equator during summer when the Earth's tilt brings the observer's hemisphere closest to the sun, and at noon when the sun is closest to its zenith. At this point the energy from the sun has the least distance to travel through atmosphere. At sea level, this is referred to as 1 atmosphere (1 atm). When measurements are taken at other latitudes, or other times of day, the angle of the sun will affect solar irradiance. The amount of atmosphere that energy must travel through before reaching the



point of observation is called the air mass index. This is expressed in ratio to the constant 1 atm so that for most latitudes of North American the Air Mass index is considered to be approximately 1.5 atm.

Capturing Solar Spectra

The state of Colorado in the U.S. Rocky Mountains boasts a healthy solar research community because the mile-high altitude is an advantage for solar measurement applications. Avantes engineers at the U.S. offices near Boulder, CO took advantage of the location at 1,626 m above sea level to perform some solar irradiance tests recently. The higher altitude gives the Boulder, Colorado region a noon-time air mass index slightly lower than the majority of the United States. Colorado also averages nearly 300 days of sunshine per year.

Over a series of days, Avantes engineers gathered broadband spectra of global horizontal irradiance

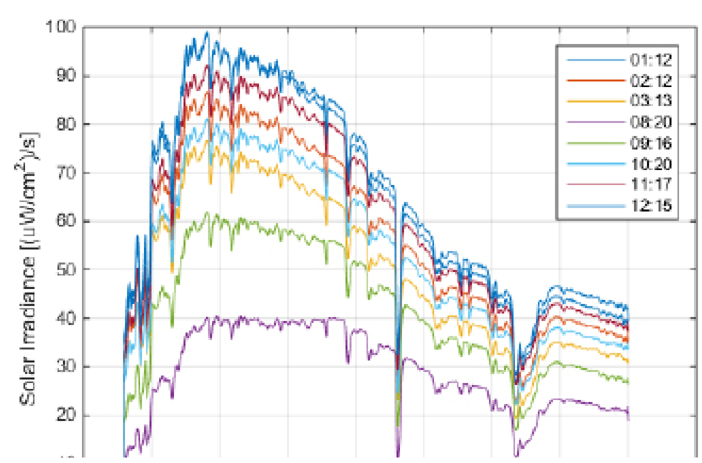
using the Avantes cosine corrector (CC-UV/VIS) to compensate for solar zenith angle and any other inherent sampling geometry. The cosine corrector was coupled to the Avantes AvaSpec-ULS2048CL-EVO spectrometer using a solarization resistant FC/PC 400µm core UV fiber.

The AvaSpec-ULS2048CL-EVO was calibrated for irradiance using a NIST traceable source over the range from 300-1100 nm. After such calibration, the spectrometer was used to collect solar spectra using a laptop running AvaSoft in Absolute Irradiance mode.

Avantes engineers set up the monitoring station in the same geographic location for each series of solar irradiance spectra measurements. In the first series, measurements were taken at roughly the same time of day over the course of several days. Additional atmospheric data was collected for reference.

Solar Spectra Data

In the second series of measurements, spectra data was collected hourly throughout the course of the workday. The same geographic location was used throughout sampling process. Hourly atmospheric data was also collected for reference.



date	time	Spectral Integer	humidity %	visibility mi	pressure in	Zenith angle°	air mass index	GHI record
3/29/17	12:08	49,475.88	66	25	30.09	35.69	1.23	1050.8
3/30/17	12:15	37,307.73	30	50	29.76	35.38	1.23	1051.2
3/31/17	8:35	1,151.90	93	0.1	29.78	58.37	1.9	927.6
4/3/17	12:20	43,968.43	19	50	29.78	34.19	1.21	1052.1
4/4/17	12:01	42,496.18	81	7	29.97	33.60	1.2	1053.2
4/6/17	12:21	46,645.97	29	50	30.19	33.12	1.19	1053.2
4/7/17	12:02	37,169.57	23	50	29.96	32.47	1.18	1054.3
4/10/17	12:15	45,702.08	24	50	30.18	31.52	1.17	1054.9
4/11/17	12:16	45,542.88	17	35	30.16	31.19	1.17	1055.1

time	date	temp °F	dew point °F	humidity %	pressure in	Zenith angle°
7:51 AM	4/11/17	39.2	17.6	49%	30.2	15.15
8:50 AM	4/11/17	44.6	21.2	34%	30.21	26.36
9:50 AM	4/11/17	50	19.4	30%	30.21	37.32
10:50 AM	4/11/17	55.4	19.4	25%	30.2	47.22
11:49 AM	4/11/17	59	14	17%	30.16	54.79
12:50 PM	4/11/17	62.6	10.4	13%	30.18	58.55
1:47 PM	4/11/17	64.4	10.4	12%	30.14	56.98
2:50 PM	4/11/17	66.2	12.2	12%	30.1	50.30

07

Spectroscopy in the Production of Solar Panels

The measurement needs of the solar industry are quite diverse, ranging from process control applications in the manufacturing of thin film photovoltaic panels through direct solar measurements and solar simulator characterization. Avantes has worked closely together with a number of industrial and research customers in the solar industry to design spectroscopy and spectroradiometry systems that meet the demands of this fast-growing industry.

Thin Film Production Monitoring and Quality Control

In-line monitoring of thin film solar panel manufacturing is a process control function which requires high speed, 24/7 spectral data acquisition over long duration production runs. Typical applications involve real-time plasma emission monitoring or reflection measurements in the range from 200-1700 nm during the deposition process of CIGS, CdTe and other materials on substrate materials. Multi-point monitoring in various stages of the process and at regular intervals across a web of material is often desirable. Avantes industrial, multi-channel AvaSpec spectrometers are ideally suited to inline spectroscopic measurements.

Capable of supporting up to 10 simultaneously spectrometer channels, the rackmount platform can accommodate a number of detector options from low cost, front-illuminated CCDs to high sensitivity back-thinned CCDs and InGaAs detectors for the NIR range. Fiber optics enable porting of the measured signals from the detection point to a control modules nearby or up to hundreds of meters away. The AvaSpec-ULS2048CL-EVO and AvaSpec-NIR256-1.7-EVO are ideally suited to this application because of their high speed processing capabilities, high resolution and excellent throughput in the wavelengths of interest.

Quality control inspection of thin film solar panels can also be achieved with Avantes spectrometers. This process may include a quantitative thin film reflection measurement to measure single or multilayer coatings. The AvaSpec-ULS2048CL-EVO provides an excellent instrument for thin film metrology from 200-1100 nm and the AvaSpec-NIR256-1.7-EVO extends the range out to 1750 nm. Avantes OEM modules are an affordable alternative for high volume manufacturers that prefer to integrate spectrometers into their manufacturing control systems. All of Avantes instruments are available as lab instruments or OEM modules.

Solar Simulator Characterization

Solar simulators are a critical tool for test and measurement of photo-voltaic arrays, but their characterization can difficult as each manufacturer has different design features to meet the needs of the many photo-voltaic panel manufacturers.

ASTM E927 – 10 Standard Specification for Solar Simulation for Terrestrial Photovoltaic Testing and IEC 60904 Photovoltaic Devices are standards which provide testing procedures for measuring pulsed and continuous wave solar simulators. The class of solar simulator is defined by the similarity of the measured spectrum to the Air Mass 1.5 Global (AM1.5G) reference spectrum. Avantes spectroradiometer solutions consist of a spectrometer, fiber-optic cable and a sampling head which is typically a cosine diffuser or an integrating sphere. These components are irradiance calibrated using an NIST traceable source and delivered as a calibrated system. Avantes' SensLine series of back-thinned CCD instruments is well suited to this application due to the relatively high quantum efficiency of the detectors in the UV (250-400 nm) and NIR (>900 nm) range.

The AvaTrigger is a device used to facilitate triggering Avantes instruments to enable measurement of pulsed solar simulators. Avantes spectrometers have the unique ability to collect and store spectra to on-board RAM. This capability provides ultra-fast data collection and storage which is often required for characterizing the uniformity of pulsed solar simulators. The DLL package we offer enables our customers to develop their own code for demonstrating adherence to the various photovoltaic standards. The DLL package comes with samples programs in Delphi, Visual Basic, C#, C++, LabView and many other programming environments.

Direct Solar Measurements

Measurement of direct solar radiation is necessary for both research and industrial applications. Government labs and many university researchers use Avantes spectroradiometer systems to measure solar radiation for research on climate change. Industrial customers may use Avantes

systems to quantify solar concentrators, monitoring heliostats or as a alternative technology for a spectro-heliometer.

Avantes solutions for direct solar measurements typically consist of a dual-channel spectrometer covering 250-1700 nm or 250-2500 nm depending upon the needs of the customer. A specialized bifurcated fiber-optic cable is used to couple the spectrometer to the sensor head which is normally a cosine function diffuser (CC-UV/VIS/NIR or CC-UV/VIS/NIR-8 mm) with a 180 degree field of view or a 5 degree cosine function diffuser (CC-UV/VIS/NIR-5.0) for solar tracking. The flexibility of fiber optics enable placement of the sensor head at a distance several meters away from the spectrometer which is typically housed in a temperature regulated environment. Our AvaSoft software enables the integration of two more spectra from each spectrometer into a single combined spectrum for the range of interests.

08

Solar Irradiance CubeSat Using Avantes Spectrometer for Test Flight

The University of Colorado, Boulder project for Research at high-Altitude on Distributed Irradiance Aboard an iNexpensive CubeSat Experiment (RADIANCE), sponsored by the University Corporation for Atmospheric Research (UCAR) is preparing for a two-week test flight aboard the Arctic HiWind Gondola.samples, such as grains, fruits, and plastics.

RADIANCE Project

The CU Bachelor's program in Aerospace Engineering offers senior students the opportunity to work on projects for real world customers. The RADIANCE project was proposed by the High-Altitude Observatory (HAO), part of the National Center for Atmospheric Research (NCAR). The , lead by Engineering Fellow, Jenny Kampmeier was selected from among the aerospace engineering student applicants.

The purpose of the RADIANCE project is to develop a 3U CubeSat prototype made entirely of commercial off-the-shelf (COTS) components. The ultimate goal is to develop the means to provide climate scientists with reliable continuous solar irradiance data using CubeSats that are inexpensive and easy to mass produce and calibrate.

Maintaining a continuous record of solar irradiance data is important to climate scientists studying the effects of solar radiation on Earth's climate. The available historical record of irradiance data dates to November 1978 with the launch of the Nimbus-7 spacecraft, but funding and development delays, launch schedules, and even instrument failure have led to gaps in the record.

Additionally, current methods for measuring solar irradiance using active cavity electrical substitution radiometry and involve massively funded space missions such as the TIM instrument aboard the NASA SORCE spacecraft. Each previous irradiance instrument is unique and developed by different agencies, thus calibration can vary widely. For this reason, even available data is inconsistent.

Design Challenge

The 3U CubeSat program gives scientists and researchers the means to deploy a standardized payload on a space flight mission. The 3U payload, where one "U" represents 1000cm3, measures 10cm x 10cm x 30cm and must house the full complement of sensors, power supply, data handling, and command processor for deployment on the HiWind Gondola flight.

In addition to strict weight and size limitations, this project also required the use of commercially available off the shelf parts within an equally strict budget. Other constraints notwithstanding, operational requirements would still need to be met.

The environmental conditions aboard the HiWind Gondola require the team to include thermal systems to maintain operational conditions during ascent, descent and during the flight itself. In addition to irradiance measurements, and still solar images, the RADIANCE CubeSat will also collect other environmental data, like temperature and humidity, and record attitude by measuring the off-sun angle.

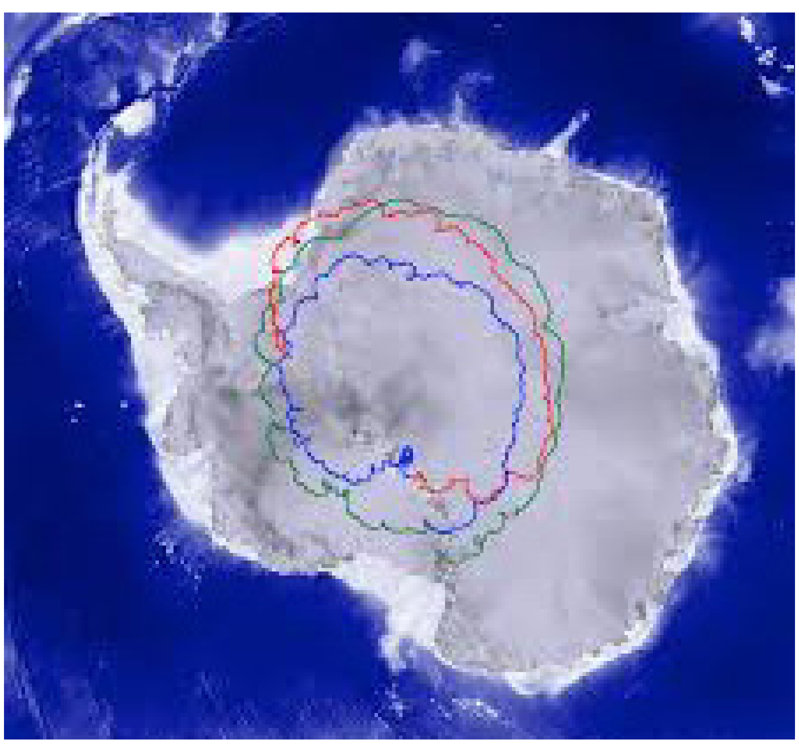
Spectrometer Selection

Through peer recommendation and research, the RADIANCE team discovered Avantes spectrometers. Working closely with Damon Lenski, General Manager of Avantes, Inc., the RADIANCE team selected the AvaSpec-MINI which has a back-thinned CCD linear array 2048 pixel detector and provides resolution up to 0.1 nm. The team was initially drawn to the Mini because of the price. "We had a budget of $5000 to complete the entire project." Project Member, Jeremy Muesing says, "Other companies that produce spectrometers small enough to fit inside our form factor quoted prices outside our budget."

While it may have been price considerations that initially led the team to select the Avantes' AvaSpec-MINI spectrometer, the team has been more than pleased with the performance of the instrument. The project scope required irradiance spectra measurements in the 250-1000nm range, but the MINI delivers the full range of UV/VIS spectra of 200-1100nm. “We are getting a slightly larger range, and our customer is always happy whenever we can provide more scientific data,” Muesing says.

The Mini weighs just 174g and is roughly the size of a deck of cards (94.5x67x19.5mm), making this ultra-low stray light device easily integratable. The RADIANCE team also took advantage of Avantes’ demo program for code development and worked closely with Avantes engineers to perfect calibration and integration of the AvaSpec-Mini.

Arctic HiWind Gondola Mission



The 3U CubeSat RADIANCE project passed design review and has a prototype now in testing. The final phase of this project will be to deploy this 3U payload during a 2-week circumpolar high-altitude balloon flight aboard the HiWind Gondola, circling the Antarctic continent at an altitude of 40 km.

To meet projectrequirements, the payload is expected to tolerate and operate in adverse environmental conditions during ascent, flight, and descent, survive landing, and operate on power independent of the HiWind Gondola. It shall record solar irradiance data at greater than the required 1 nm resolution (AvaSpec-MINI achieves resolution of 0.1nm), and exceeding the 250-1000nm spectrum target. The RADIANCE CubeSat will also store all collected spectra and ambient environmental data on a durable data storage device for easy retrieval.

This highly anticipated maiden flight for the RADIANCE CubeSat is scheduled to take place Winter of 2017-2018 and will mark the completion of this phase of the RADIANCE project.

Radiance Path to Space

The HiWind RADIANCE deployment appears on track to exceed expectations. Encouraged by the apparent progress of the CU design team in developing mass-producible Irradiance CubeSats using commercially available components, HAO and NCAR already have plans to continue development for space-readiness.

The path to space will not be without its own challenges, however. The thermal system for a space ready RADIANCE CubeSat will need to be reconfigured to cool the instrument, and direct heat away from the payload rather than heat the instrument during ascent. A space payload would additionally need to incorporate at least three reaction wheels to control attitude, an adjustment controlled by the HiWind during high altitude testing.

Nonetheless, the sponsors of the RADIANCE project seem likely to have favorable results in the next phase of development of a lost cost solar irradiance measurement standard and toward a future in which solar irradiance data will be complete and accessible for future climate research.

Resources

https://www2.ucar.edu/about-us

https://www2.ucar.edu/about-us/history

http://www.colorado.edu/aerospace/current-students/undergraduates/senior-design-projects/past-senior-projects/2016-2017/radiance

http://lasp.colorado.edu/home/missions-projects/quick-facts-sorce/

http://nanoracks.com/products/smallsat-deployment/

https://www.nasa.gov/mission_pages/station/research/news/cubesat_deployment

https://sites.google.com/site/cuengineeringfellows/members

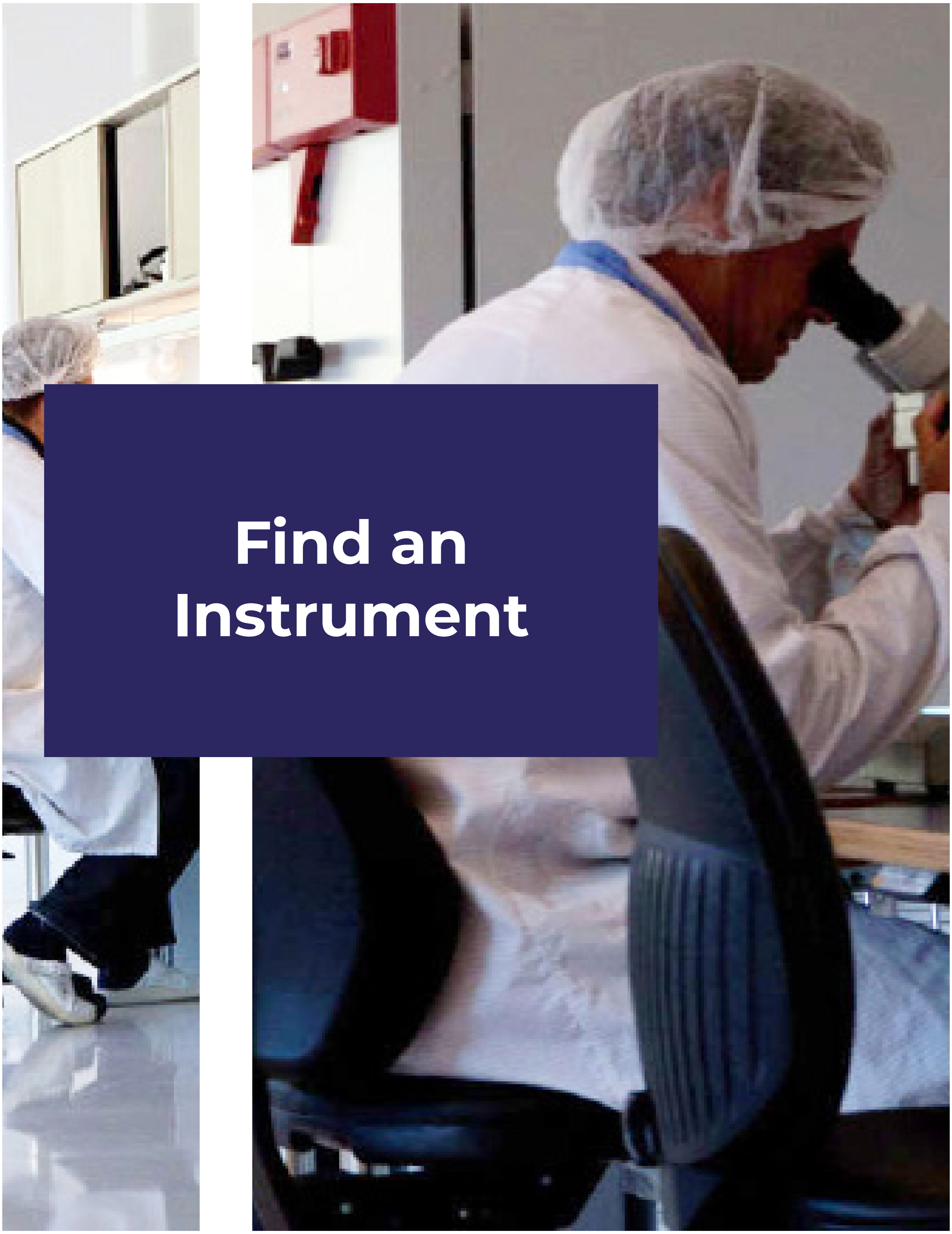
https://avantes.com/products/spectrometers/compactline/item/723-avaspec-mini

http://www.jeremymuesing.com/

https://avantes.com/company/about-us/item/1011-damon-lenski

https://www.nasa.gov/centers/armstrong/features/lower_cost_solar_research.html

http://stratocat.com.ar/fichas-e/2011/KRN-20110613.htm



Find an Instrument

SensLine 200-1160 nm

AvaSpec-ULS2048XL-EVO

- Ultra-low stray light (ULS) symmetrical Czerny-Turner, 75 mm focal length optical bench
- Back-thinned CCD, 2048 pixel detector
- Wavelength range: 200-1160 nm
- Resoloution of 0.09-20 nm, depending on configuration
- Sensitivity of 460,000 counts/μW per ms integration time
- Integration time of 2 μs-20 sec
- USB 3.0 high speed, 5 Gbps, Gigabit Ethernet 1 Gbps interface
- 2.44 ms/scan sample speed with store to RAM

Click here for complete specifications

AvaSpec-ULS2048x64-EVO

- Ultra-low stray light (ULS) symmetrical Czerny-Turner, 75 mm focal length optical bench
- Back-thinned CCD detector with 2048×64 pixels (height: 0.89 nm)
- Wavelength range: 200-1160 nm
- Resoloution of 0.09-20 nm, depending on configuration
- Sensitivity of 650,000 counts/μW per ms integration time
- Integration time of 2.4 ms-25 sec
- USB 3.0 high speed, 5 Gbps, Gigabit Ethernet 1 Gbps interface
- 2.44 ms/scan sample speed with store to RAM

Click here for complete specifications

SensLine 200-1160 nm

AvaSpec-ULS2048x64-EVO

- Thermo-electrically cooled, Ultra-low stray light (ULS) symmetrical Czerny-Turner, 75 mm focal length optical bench
- Back-thinned CCD detector with 2048×64 pixels (height: 0.89 nm)
- Wavelength range: 200-1160 nm
- Resolution of 0.09-20 nm, depending on configuration
- Sensitivity of 300,000 counts/µW per ms integration time
- Integration time of 9.7 ms-120 sec
- USB 3.0 high speed, 5 Gbps, Gigabit Ethernet 1 Gbps interface
- 9.7 ms/scan sample speed with store to RAM

Click here for complete specifications

Starline 200-1100 nm

AvaSpec-ULS2048CL-EVO

- Ultra-low stray light (ULS) symmetrical Czerny-Turner, 75 mm focal length
- Wavelength range: 200-1100 nm
- Resolution: of 0.06-20 nm, depending on configuration
- Stray light is 0.19-1.0%, depending on grating
- Sensitivity in counts/µW per ms integration time is 375,000
- Signal to noise is 300:1
- 9 µs-59 sec seconds integration time
- Sample speed of 0.13 ms/scan with store to RAM
- HD-26 connector, 2 Analog in, 2 Analog out, 13 Digital bidirectional, trigger, sync., strobe, laser
- Data Transfer speed: 0.38 ms/scan (USB3), 1.0 ms (ETH)
- Interface: USB 3.0 high speed, 5 Gbps, Gigabit Ethernet 1 Gbps
- Dimensions and weight: 177 x 127 x 44.5 mm, 1135 g

Click here for complete instrument specifications

NIRLine up to 2500 nm

AvaSpec-NIR256-2.5-HSC-EVO

- TE-cooled symmetrical Czerny-Turner, 100 mm focal length optical bench
- InGaAs linear array detector with 2 stage TE-cooling, 256 pixels
- Wavelength range: 1000 – 2500 nm
- 4.4-85.0 nm resolution, grating and slit dependent
- Dual gain mode, switch between high sensitivity (HS) and low noise (LN) settings
- LN Sensitivity of 55,000 counts/µW per ms integration time
- HS Sensitivity of 990,000 counts/µW per ms integration time
- 10 µs – 5 ms integration time
- Sample speed of 0.54 ms/scan with onboard averaging

Avaspec-NIR256-1.7-HSC-EVO

- TE-cooled symmetrical Czerny-Turner, 100 mm focal length optical bench
- InGaAs linear array detector with 2 stage TE-cooling, 256 pixels
- Wavelength range: 1000 – 1700 nm
- 0.88-85.0 nm resolution (grating and slit dependent)
- Dual gain mode, switch between high sensitivity (HS) and low noise (LN) settings
- LN Sensitivity of 160,000 counts/µW per ms integration time
- HS Sensitivity of 4,800,000 counts/µW per ms integration time
- 20 µs – 20 s integration time
- Sample speed of 0.54 ms/scan with onboard averaging

Click here for complete instrument specifications

CompactLine 200-1750 nm

AvaSpec-Mini-NIR

- Symmetrical Czerny-Turner, 75 mm focal length
- 256 pixel InGaAs array detector
- Wavelength rage: 900-1750 nm
- Dual gain mode, switch between high sensitivity (HS) and low noise (LN) settings
- LN Sensitivity of 38,000 (integral 1000-1750 nm) counts/µW per ms integration time
- HS Sensitivity of 665,000 (integral 1000-1750 nm) counts/µW per ms integration time
- 10 µs-5 sec integration time
- Sample speed of 0.53 ms/scan with store to RAM
- Drop-in OEM ready

Click here for complete instrument specifications

AvaSpec-Mini2048CL

- Symmetrical Czerny-Turner, 75 mm focal length
- Wavelength range of 200-1100 nm
- HAM S11639, CMOS linear array, 2048 pixels (14 x 200 µm)
- Sensitivity of 337,500 counts/µW per ms integration time
- 30 µs-40 sec integration time
- Interface: USB 2.0 (480 Mbps), pigtailed (40 cm) USB-A
- Data transfer speed is: 4.6 ms/scan

Click for Lightsources

Click for Fiber

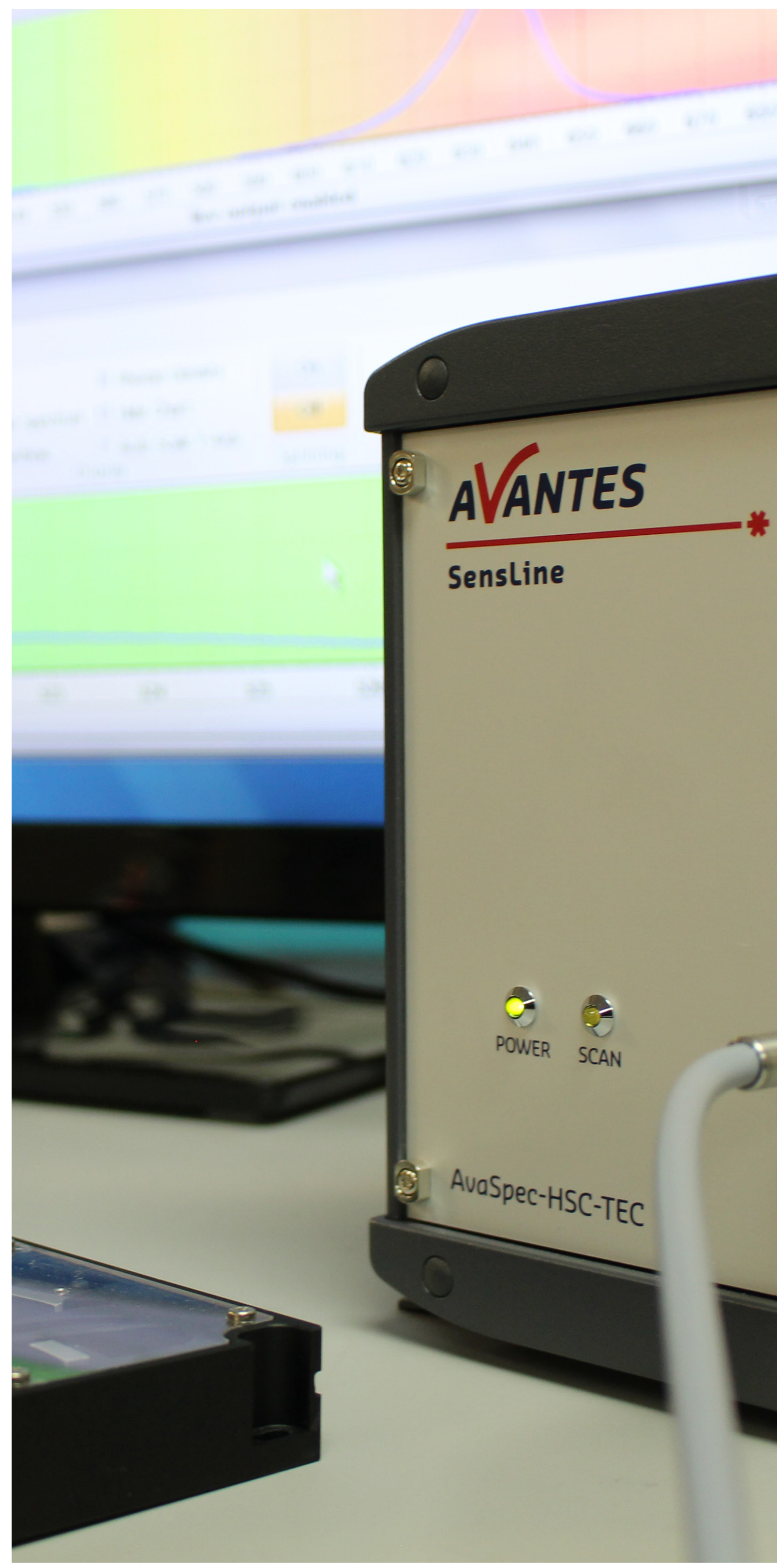
Click for Accessories

Click for full line of OEM instruments

Test Drive an Instrument Today with our Demo Program

Try Before you Buy

We understand the importance of getting it right when making an instrument purchase decision. Sometimes applications have special needs that are not known in advance. The Avantes demo program allows you to test an Avantes spectrometer, light source, and even some accessories in your experiment or operation to validate functionality and fine tune specifications. Vetting our instruments in your applications ensures you will be successful after you make a purchase. In the rare event we don't meet or exceed your measurement demands, we eliminate the need for costly returns and reworks.



Compare with an Existing Instrument

Often our customers have experienced a competitive or different class of instrument and would like to have a comparison to see if their measurements can be improved or cost optimized. Demanding applications such as fluorescence and Raman are often performed with high cost instrumentation which may be overkill for the needs of the applications. Avantes instruments raise the bar of performance such that our more affordable technology can replace higher cost, slower systems.

Fine Tune Software Integration and Control

The Avantes demo program allows you to familiarize yourself with our software or take a closer look at our software development kit (SDK) and sample programs. Avantes instruments can be controlled using our proprietary software AvaSoft or via your own software written in Labview, Matlab, C#, C++, Visual Studio, Python or any of a variety of Linux environments.

Request a Demo

Thank you

The Advantage of Avantes

- *3 year limited warranty*
- *ISO 9001:2016 certified*
- *Comprehensive line of spectrometers, light sources and sample accessories*
- *Uniform software development kit/application for all instruments*
- *Multi-channel instrument configurations*
- *Free software upgrades for Universities/Academic institutions*
- *Full line of OEM ready spectrometer modules*
- *100% subcomponent traceability for all instruments*
- *8 hour thermal cycle burn in testing on all manufactured instruments*
- *Wide selections of gratings, detectors and optical designs*

World Headquarters
Oude Apeldoornseweg 28
7333 NS Apeldoorn
The Netherlands
Telephone: +31 313 670 170
E-mail: info@avantes.com
Website: www.avantes.com

Us Regional Offices
500 S. Arthur Ave., Unit 500
Louisville, CO 80027
Tel. +1-(303)-410-8668
Phone Toll free: +1 (866)-678-4248
Fax: +1-(303)-410-8669
Email: infoUSA@avantes.com
Website: www.avantesusa.com

China Regional Offices
Rm.1209-1210, ULO Park,
No.601 apartment of Wangjing Yuan, Chaoyang District,
Beijing, 100102 P.R. China
Phone: +86-10-84574045/84574057
Fax: +86-10-84574017
Email: info@avantes.com.cn
Website: www.avantes.cn