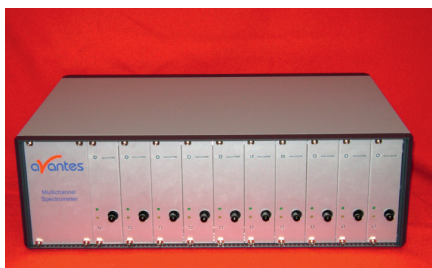


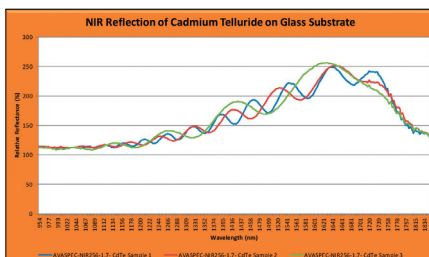
APPLICATION NOTE: SOLAR MEASUREMENTS



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

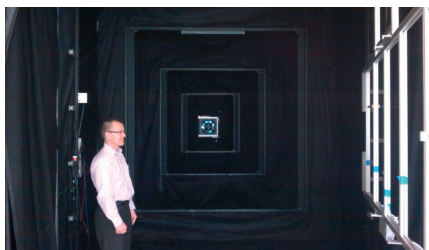


Thin Film production monitoring & quality control



Inline monitoring of thin film solar panel manufacturing is a process control function which requires high speed, 24X7 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, multichannel 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. Communication is achieved through high speed USB2 communication with the host computer and the native digital & analog input/output capabilities of Avantes AS5216 electronics

board provides for superior interface with other devices. 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-2048-USB2, AvaSpec-2048USB2 and AvaSpec-NIR256-1.7 are ideally suited to this application because of their high speed processing capabilities (900 spectra per second), 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 multi-layer coatings. The AvaSpec-2048-USB2 provides an excellent instrument for thin film metrology from 200-1100 nm and the AvaSpec-NIR256-1.7 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 be difficult as each manufacturer has different design features which 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 con-

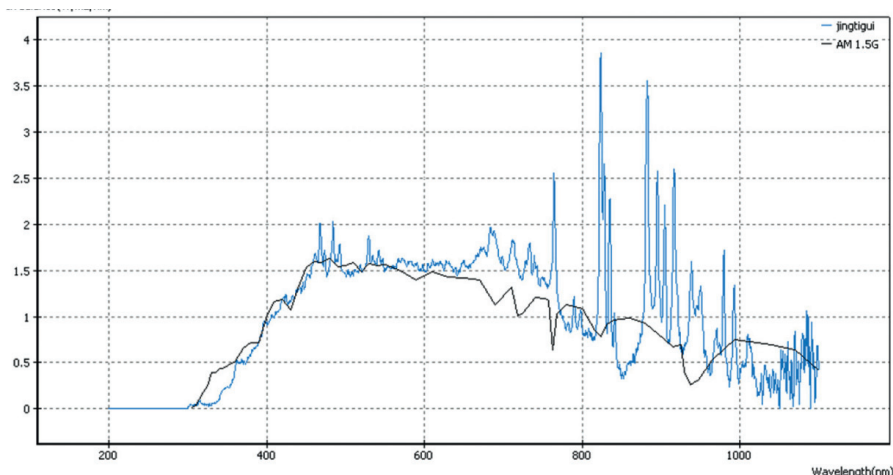
sist of a spectrometer, fiber optic and a sampling head which is typically a cosine diffuser or an integrating sphere. These components are irradiance calibrated using an NIST traceable source and delivered as a calibrated system. Avantes AvaSpec Sensline of back-thinned CCD instruments is well suited to this application due to the relatively high quantum efficiency of the detectors in the UV (250-400 nm) and NIR (>900 nm). Avantes Spectroradiometers systems are uniquely suited to this application because of high resolution afforded by our symmetrical Czerny-Turner optical bench, excellent thermal stability and the ability to send and receive analog and



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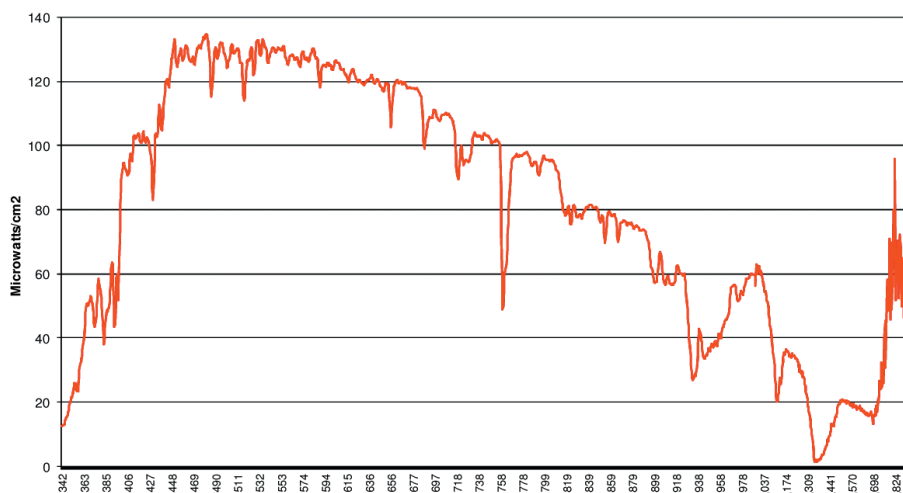
digital communication. The AvaTrigger is a device used to facilitate triggering Avantes instruments to enable measurement of pulsed solar simulators. Avantes spectrometers have the unique ability to collect and store spectra to on board RAM. This capability provides ultra-fast data collection and storage which is often required for characterizing the uniformity of pulsed solar simulators. Avantes AS5216 DLL package 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 spectro-radiometer 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-8mm) 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 optic enables placement of the sensor head at a distance several meters away from the spectrometer which is typically housed in a temperature regulated environment. Avantes AvaSoft software enables the integration of two more spectra from each spectrometer into a single combined spectrum for the range of interest.

Solar Spectrum (360-1750 nm)
AvaSpec IRRAD-EXT



Application	Inline Solar Panel Manufacturing Plasma monitoring/Thin Film	Solar Simulator Measurement	Direct Solar Monitoring
Spectrometer	AvaSpec-2048-USB2 (200-1100 nm) AvaSpec-3648-USB2 (200-1100 nm) AvaSpec-NIR256-1.7 (950-1750 nm) AvaSpec-NIR256-2.5 (1000-2500 nm)		
Resolution	200 -1100 nm - 0.7 nm and up Full Width Half Maximum (FWHM) 900-1700—6 nm (FWHM) >1700 nm (10-15 nm (FWHM)		
Accessories	Fiber optic Vacuum Feedthroughs Fiber optic Reflection Probes	AvaTrigger Integrating sphere IC-DB26 external trigger cable	Cosine function diffuser weatherproof Fiber Optic Cables