White Paper: Deep-cooled CCD & InGaAs Detectors/Cameras

"TE Cooled CCD and InGaAs Detectors for Ultra Sensitive and High Dynamic Range Spectroscopic Applications"

Instrumentation professionals have long recognized great potential for NIR/Raman spectroscopic analyzers in many application areas ranging from lab analysis to portable field monitors. Until now, however, NIR and Raman process analytical instrumentation were too big, too expensive, too fragile, and so sophisticated they required highly trained operators for "real-world" application use. One of the main drawbacks preventing the full potential realization of these spectroscopic applications owes itself to the photodetectors requiring deep cooling to achieve high sensitivity and high dynamic range. A key component for the resolving many of the practical problems associated with measurement and diagnostics is related to the availability of ruggedized, sensitive, high dynamic range, yet low cost photodetectors that can operate at various environmental conditions and without the use of liquid nitrogen (LN2) cooling.

High volume optical telecom device manufacturing has driven recent advances in the hermetic sealing process, thus, presenting a disruptive new picture today.

Figure 1: Small footprint *Nunavut*™ Detector

The Deep Cooling Choice

In the research labs, detector cooling used to be achieved by liquid nitrogen (LN2). The use of LN2 as the coolant is understandably cumbersome and almost impossible for applications in remote areas or out of lab environments. Advancements in semiconductor technology over the last 30 years has increased the availability of thermal electrical cooler chips, created improvements in hermetical sealing and long life vacuum generating processes, and allowed for the development and use of TE cooled detectors.

Photodetector cooling reduces the dark noise of the detector. The dark noise arises from statistical variation in the number of electrons thermally generated within the semiconductor structures, such as silicon in the case of CCDs (200-1100 nm) and InGaAs (900-2500 nm). The dark noise is directly dependent on the semiconductor temperature. The generation rate of thermal electrons at a given CCD temperature is referred to as dark current. Cooling the CCD reduces the dark current dramatically. The dark noise typically drops to half when the temperature of the CCD detector chip drops every 10°C (Refer to Fig. 2).

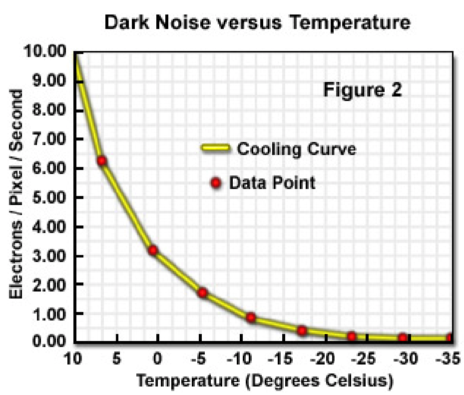

Figure 2: *Nunavut*™ CCD Detector Dark Noise vs. Temperature response curve

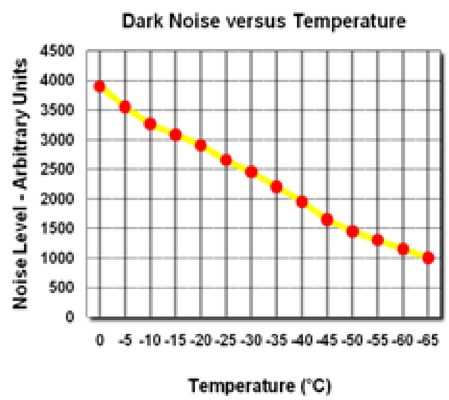

Figure 3: *Nunavut*™ InGaAs Detector Dark Noise vs. Temperature response curve

The dark noise for InGaAs arrays are also reduced to half at every 7~8°C reduction in sensor temperature (Fig. 3). In practice, high-performance detectors and cameras are usually cooled to a temperature at which dark current is negligible over a typical exposure time.

Description of the BaySpec Cooling Technology

In order to keep the photodetector temperature low and stable, the detector must be thermally isolated from the surrounding environment, leaving only one pathway for heat dissipation. This is accomplished via pumping the heat outside the Dewar through multi-stage TE coolers, as indicated by the schematic of Figure 4 below.

The most optimal way to achieve this insulation of heat transfer is by vacuum. This is obtained by some evacuating and sealing processes that are carefully designed and meticulously carried out. BaySpec's proprietary evacuating methods and its hermetic sealing process involves metal

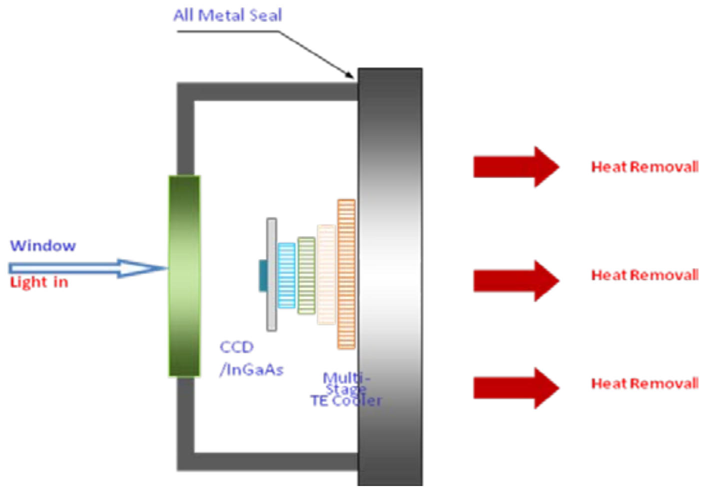

Figure 4: Schematic of the BaySpec proprietary Hermetically-sealed micro Dewar

to metal as well as metal to glass seals. Our manufacturing process ensures vacuum integrity and stability for five plus years of vacuum life time allowing continuous adequate cooling of the photo detector at -60°C Min.. Figure 5 presents 8000 hours of continuous sensor temperature testing for the *Nunavut*™ 512-pixel and 256-pixel detectors to show the three-stage TEC working stability and vacuum integrity. Operating in a sealed vacuum environment, the *Nunavut*™ series cameras use significantly less power to cool and maintain detector temperature. Utilization of the optimized cooling allows for extremely low dark current levels resulting in longer exposure times and significantly enhanced sensitivity.

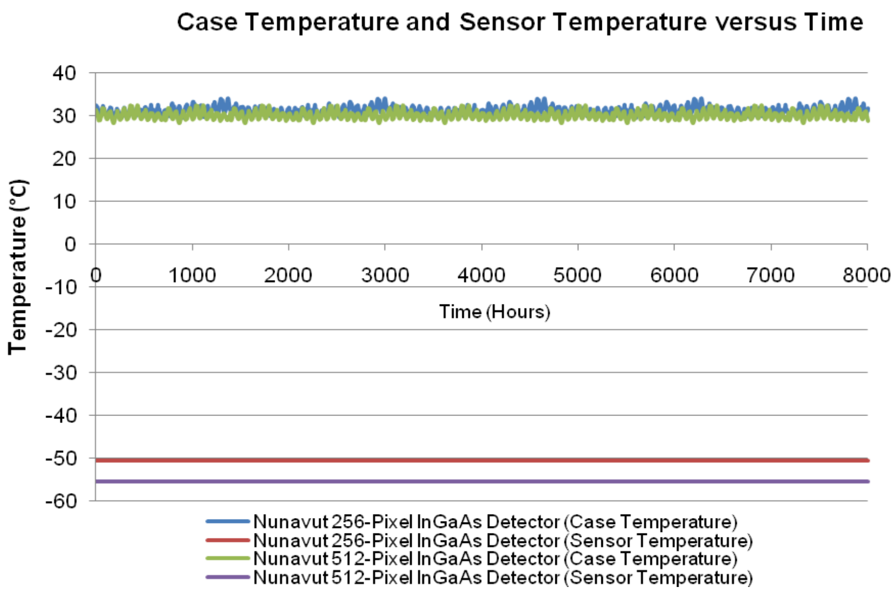

Figure 5: 8000 hour Sensor Stability Test

Profile and Key Optoelectronic Attributes

The *Nunavut*™ Series detectors employ the latest in opto-electrical components to bring you the very best capability at a very affordable price. Each Detector/Camera is designed to meet real-world challenges for best-in-class performance, long-term reliability, compact size and low power consumption. When matched to the *Nunavut*™ Raman spectrograph or photoluminescence spectrograph you will have a high performance, light weight, cost effective instrument. Each camera is calibrated in the factory after extensive thermal cycling. The control electronics read out the processed digital signal to extract required information. Both the raw data and the processed data are available to the host.

Key Features:

- Real-time spectral data acquisition
- Small footprint profile
- Design for ultra-low power consumption and improved reliability
- Hermetic-sealing ensures reliable operation in harsh environments
- Air Deep-Cooling to -60°C min
- Water cooling optional to -90°C
- CCD Detector wavelength ranges from 200-1100 nm
- CCD-Deep Depletion Detector wavelength ranges from 400-1100 nm
- InGaAs wavelength ranges: 900-1700, 1100-2200, or 1250-2500 nm

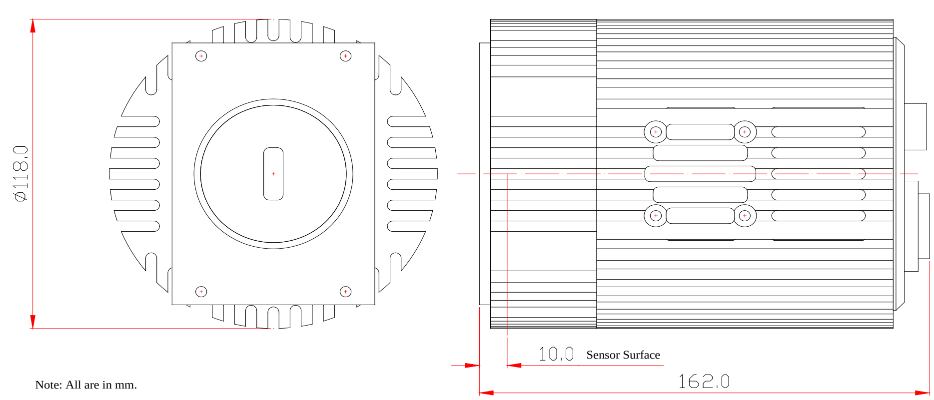

Figure 6: Profile (outline) drawing with outside dimensions of a typical camera

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For traditional spectroscopy applications, integration times can range from a few seconds to hundreds of seconds. During these experiments, adjustment in scan rates may be utilized to optimize system noise and detection limit since readout times are less significant compared to the sensitivity resulting from increased exposure times. BaySpec's *Nunavut*™ cameras offer a range of scan rates designed to meet the needs of both low light level and high brightness applications. For time resolution applications with moderate to high brightness levels, it is possible to obtain up to 1000 continuous scans per second. Table 1 presents some of the key technical specifications for our standard *Nunavut*™ line of cameras/detectors.

Parameter	**Specification**		
	InGaAs	**CCD**	**CCD-Deep Depletion**
PERFORMANCE			
Wavelength Range	900-1700, 1100-2200, or 1250-2500 nm (Custom Design Available)	200-1100 nm (Custom Design Available)	400-1100 nm (Custom Design Available)
Integration time	1 ms to 300 seconds	10 µs to 300 seconds	10 µs to 300 seconds
Dimensions (mm)	118 x 118 x 162	118 x 118 x 162	118 x 118 x 162
DETECTOR SPECS			
Detector array	256 x 50µ or 512 x 25µ	1024 x 64 or 2048 x 64 - 14µ	1024 x 256 - 26 x 14µ
Quantum Efficiency @ ʎ pk Min.	60% to 70%	75%	94%
Readout noise	180 µVrms typical, 300 µVrms Max.	6 e-rms typical, 15 e- rms Max.	2 e- /count (@ 33Khz, Typ.)
Stray light	0.05%	0.05%	0.05%
Detector	3 stage TE Deep-cooled InGaAs	3 stage TEC Deep-cooled CCD	3 stage TEC Deep-cooled CCD-DD
A/D converter	16 bit	16 bit	16 bit
Power	3.0A@+12VDC	3.0A@+12VDC	3.0A@+12VDC
Data ports	USB 2.0 Standard/ RS-232 Optional	USB 2.0	USB 2.0
Software	BaySpec "Spec 20/20" software	BaySpec "Spec 20/20" software	BaySpec "Spec 20/20" software

Table 1: Key Specifications for *Nunavut*™
Deep-cooled InGaAs and CCD Detectors

Applications Using Deep Cooling

A. Raman Spectroscopy Applications

As mentioned previously, deep cooling is generally used for low light level applications where the additional sensitivity and detector stability is necessary for sample measurement. Recognizing the need for additional sensitivity in Raman applications, BaySpec has developed the *Xantus*™-2 and the *RamSpec*™-1.

The *Xantus*™-2, to the best of our knowledge, is the only battery operated, portable, dispersive Raman spectrometer with a 1064 nm laser excitation on the market today. This spectrometer is customized to cover the 250 – 2000 cm^{-1} range which is the most chemically informative spectral region, thus leaving no pixels wasted. The detector is a 512 element InGaAs array thermoelectrically cooled to a user settable low temperature, such as –55°C min., which drastically reduces dark currents and delivers superior signal to noise ratios.

Figure 6: *Xantus*™-2 Portable Raman Analyzer

The *RamSpec*™-1 Raman analyzer, being the most compact instrument in its class, can easily be transported from one location to another, yet it is equipped with a high performance Raman spectral engine. Aided by a 512 element InGaAs array thermoelectrically cooled to –60°C min, the RamSpec™-1 delivers full spectral coverage (300 to 3200 cm^{-1}) with 5 cm^{-1} resolution.

In addition to the standard 1064 nm excitation laser wavelength, the *RamSpec*™-1 can also be integrated with a 532 nm or 785 nm excitation source, thus offering unprecedented flexibility and versatility in a laboratory instrument.

Figure 7: *RamSpec*™-1 Raman Analyzer

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B. NIR Spectroscopy Applications:

1) Transflectance: 800 to 1100 nm. This section is most suited to transflectance through a thick sample, such as, seeds, slurries, liquids and pastes. The absorption bands are due to 3rd overtones of the fundamental stretch bonds in the Mid IR region.

2) Transmission: 1100 to 1800 nm. This section can be used for transmission through liquids and films, as well as diffuse reflectance measurements off samples with high water contents. The absorption bands are due to the 1st and 2nd overtones of the fundamental stretch bonds in the Mid IR region.

3) Reflectance: 1800 to 2500 nm. This section is predominantly used for making diffuse reflectance measurements off ground or solid materials. The absorption bands are due to combination bands, i.e., C-H stretch and bend combination bands.

4) Reflectance: 1800 to 2500 nm. This section is predominantly used for making diffuse reflectance measurements off ground or solid materials. The absorption bands are due to combination bands, i.e., C-H stretch and bend combination bands.

5) Photoluminescence: 400 to 1100 nm, 900 to 2500 nm. This section is predominantly used for making fluorescence or phosphorescence measurements where detector stability and sensitivity are required for low photon emitting applications.

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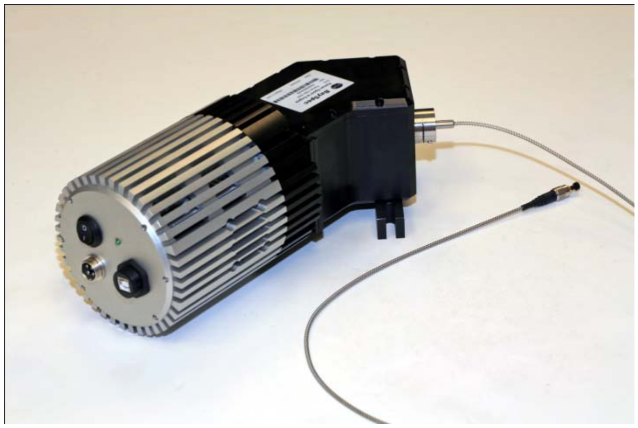

Figure 8: *Nunavut*™ Deep Cooled Detector coupled
to a typical BaySpec NIR spectrograph

Conclusion:

BaySpec's innovative engineering approach to designing new instrumentation around recent advancements in telecom and semi-conductor technology has led to low cost, reliable systems that meet the needs of most any application. The *Nunavut*™ line of high performance CCD and InGaAs detectors is no exception. These detectors incorporate the most recent advances in vaccum sealing technology which provide ultra low dark current levels and enable low light level applications. Utilizing the latest in opto-electronic components, *Nunavut*™ detectors offer excellent quantum efficiency, high dynamic range, very low readout noise, and integration times designed to work for both high brightness and low light level applications.

For more information contact: **BaySpec, Inc.**, Fremont, California, U.S.A. (www.bayspec.com).

Reference:

CCD noise sources and Singal-to-noise ratio, review article by Thomas J. Fellers and Michael W. Davidson - National High Magnetic Field Laboratory, 1800 East Paul Dirac Dr., The Florida State University, Tallahassee, Florida, 32310. http://learn.hamamatsu.com/articles/ccdsnr.html