Spark Spectral Sensor Offers Advantages

Spark is a small spectral sensor from Ocean Optics that bridges the spectral measurement gap between filter-based devices such as RGB color sensors and CCD-array instruments such as miniature spectrometers. As this whitepaper explores, Spark reflects recent trends in spectroscopy design – instruments that have become smaller, more affordable and simpler to integrate – but at a scale that makes it accessible to a wider range of potential applications than similar devices.

Background

For more than two decades, Ocean Optics has been an innovator of miniature, high performance spectrometers, covering spectral ranges from the deep ultraviolet to the near infrared spectral region. The focus has been on producing compact, cost effective spectrometers that help meet the needs of applications across multiple markets.

This approach has been very effective, helping to create a market for flexible, affordable spectrometers and inspiring thousands of new applications for miniature UV-Vis and NIR spectroscopy. Along the way, Ocean Optics and its imitators helped to shatter the perception that miniature spectrometers are too small and inexpensive to perform as well as larger, more expensive spectrometers.

Inevitably, as the miniature spectroscopy market has matured, demand for smaller, faster and less expensive technology has emerged. Much of this demand is led by customers with high-volume measurement needs, where even subtle improvements in product quality and savings in measurement costs can have a significant impact on the bottom line.

The market has responded with a variety of microspectrometers and RGB filter-like devices, each with its advantages and limitations. For example, the Ocean Optics STS microspectrometer provides full spectral analysis in a very small footprint, but even at modest pricing by spectrometer standards, may be too costly for some large-volume customers. Also, although less expensive and even simpler to integrate, RGB filter diodes are limited to measuring just a few wavelengths.

The Spark spectral sensor introduces another class of product, a device to fill the price-performance niche between diode filter-based devices and spectrometers. Spark is a visible sensor that adds a new dimension both in size – which is about the same as a small microcontroller -- and in cost reduction, but with the ability to perform full spectral analysis from 380-700 nm.

About the Spark Spectral Sensor

The limiting factor for most traditional spectrometers is that a finite volume is required to fold and split the incident beam of light from the sample or the environment where the measurement is being made. Spark uses a form of solid-state optical sensing to reduce the light from the sample into its component wavelengths. Effectively, the Spark is a detector chip that functions as a spectrometer.

Spark produces a digitized spectrum from a 1024 pixel array and can be used for all types of spectral measurements including absorbance, emission and fluorescence. It can be embedded into handheld OEM devices for biomedical, environmental and QC applications; integrated onto process lines; or used as a benchtop instrument in the lab.

Spark comprises a family of spectral sensor products and is available in three formats – a core spectral sensor product and two embeddable, OEM-friendly versions – with the level of integration up to the customer. The Spark-DET-VIS, the smallest version, is at the heart of the plug-and-play core device, and is the smallest spectral device on the market (Figure 1).

With this format flexibility, the Spark allows for many new applications to be considered that otherwise would be physically difficult or too expensive to implement, providing a valuable complement to the standard Ocean Optics spectrometer product line. The Spark truly creates a new category in the spectral sensing market.

Figure 1: The Spark spectral sensor is available in stand-alone (at right) and embeddable versions.

			
Item:	**Spark-VIS**	**Spark-OEM-VIS**	**Spark-DET-VIS**
Description:	Core spectral sensor; plug-and-play with micro-USB	OEM product requires driver and communication electronics; ribbon cable connector with raw analog output	Detector only, for high volume applications; requires custom electronics and complete integration
Dimensions:	53.3 x 36.4 x 19.9 mm	38.4 x 22.6 x 10.2 mm	18.42 x 9.65 x 0.375 mm
Weight:	15 g	3.8 g	<1 g
Accessories:	Optional accessories including clip-on diffusers and cuvette holders	Optional accessories including clip-on diffusers and cuvette holders	NA
Best for:	R&D; simple integration	OEM integration	High volume integration
Applications:	Education; application development	Medical diagnostics; process monitoring	Handheld instruments; embedded devices

With the Spark-VIS option and other inexpensive development tools, users have tremendous flexibility in testing and evaluation processes. Spark-VIS is compatible with the Ocean Optics Raspberry Pi development kit for applications engineering and can be used with our standard OceanView spectroscopy operating software or with SeaBreeze, an open-source C/C++ device driver that lets users control essential command-and-control functions for basic spectral measurements.

Figure 2: A magnetically mounted diffusing optic helps to provide even illumination of the Spark aperture.

Spark Design and Operating Principles

All spectral devices have inherent design trade-offs. For example, most miniature spectrometers use fiber optic coupling for optical interfacing between the light source, the sample and the spectrometer. This makes it much easier to control the light, but adds significant volume to the measurement system and makes it difficult for such systems to be unobtrusively integrated into an embedded system.

Figure 3: An SMA 905 coupler is available for connecting Spark to fiber optic accessories.

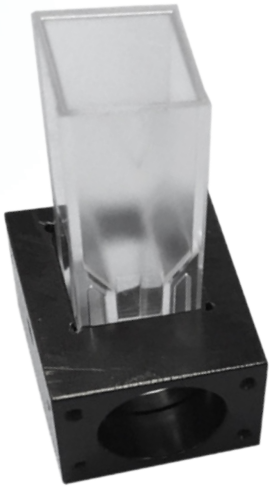


Figure 4: Spark is available with sampling accessories such as a 10 mm pathlength cuvette holder.

Unlike grating-based spectrometers, Spark uses a solid-state optical sensor to capture the spectrum. Although this design feature does eliminate some trade-offs associated with traditional spectrometers, it does require the user to manage the light path carefully.

The following must be considered when taking any measurement. The entire 1 mm x 8 mm aperture on the front of the Spark must be illuminated; this ensures that each detector pixel receives light and gives out a reading. This is straightforward when coupling to an optical fiber as the SMA 905 adapter accessory projects light from the fiber across the entire aperture. For free space measurements, however, the user must take more care to:

- fix the Spark in place such that a diffuse light source fills the aperture from a normal angle of incidence (perpendicular to the slit); or
- in situations where this is not possible – such as when using light sources casting an uneven intensity of illumination across the aperture, or illuminating the aperture from an angle – use the diffuser accessory (Figure 2).

Although Spark does not have to rely on optical fibers for sample interfacing, as most spectral devices do, an SMA 905 fiber optic coupler (Figure 3) is available for coupling Spark to existing Ocean Optics sampling accessories and light sources. Other Spark-specific accessories include the clip-on diffuser; also, a cuvette holder for 10 mm cuvettes (Figure 4) and microfluidic flow cells are in development. These are magnetically attached enabling users to switch between setups and experiments quickly and easily – ideal for application testing and for the educational market.

Spark Example Applications

The Spark spectral sensor is ideal for simple absorbance, fluorescence and emissive color measurements, across a range of visible applications. Here are some examples:

Absorbance

With its full visible spectral output, the Spark not only measures color-based analytes for specific chemical responses, but can also monitor multi-analyte systems. Mixtures can be analyzed for medical and environmental applications, providing multiple diagnostic testing from a single measurement. When used for such testing the Spark can provide performance and flexibility comparable to a laboratory-based system, but in a simple handheld sensor.

Spark performs well for most absorbance applications. As the food dye absorbance results in Figure 5 suggest, Spark provides linear response well above 1AU and has the potential to provide maximum absorbance up to 2AU. This is ideal for concentration analysis in the food and beverage industries, for water purity analysis and for biomedical research.

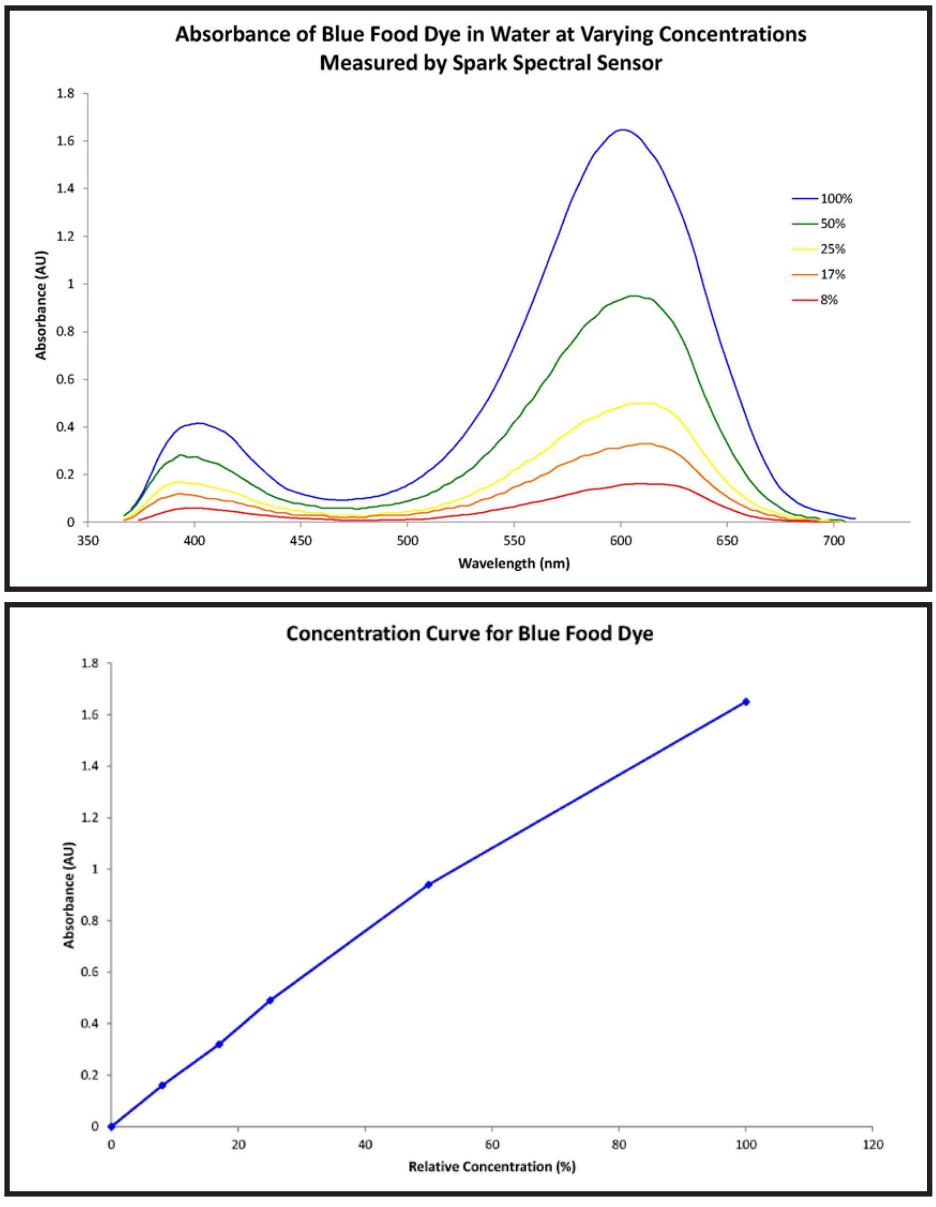


Figure 5: Absorbance of food dyes measured with Spark (top graph) shows a linear quantitative response >1AU.

Emission

The Spark provides a standard spectral output from the 1024 pixel array within a defined spectral range. Spark can be used successfully for characterizing lamps (Figure 6) and illuminants in the visible range, including LEDs and other sources (Figure 8). Indeed, Spark makes an ideal testing tool for LED production and for the implementation of LEDs in specialized lighting applications, where it can be used as a handheld spectral light meter for photographic and theatrical lighting measurements.

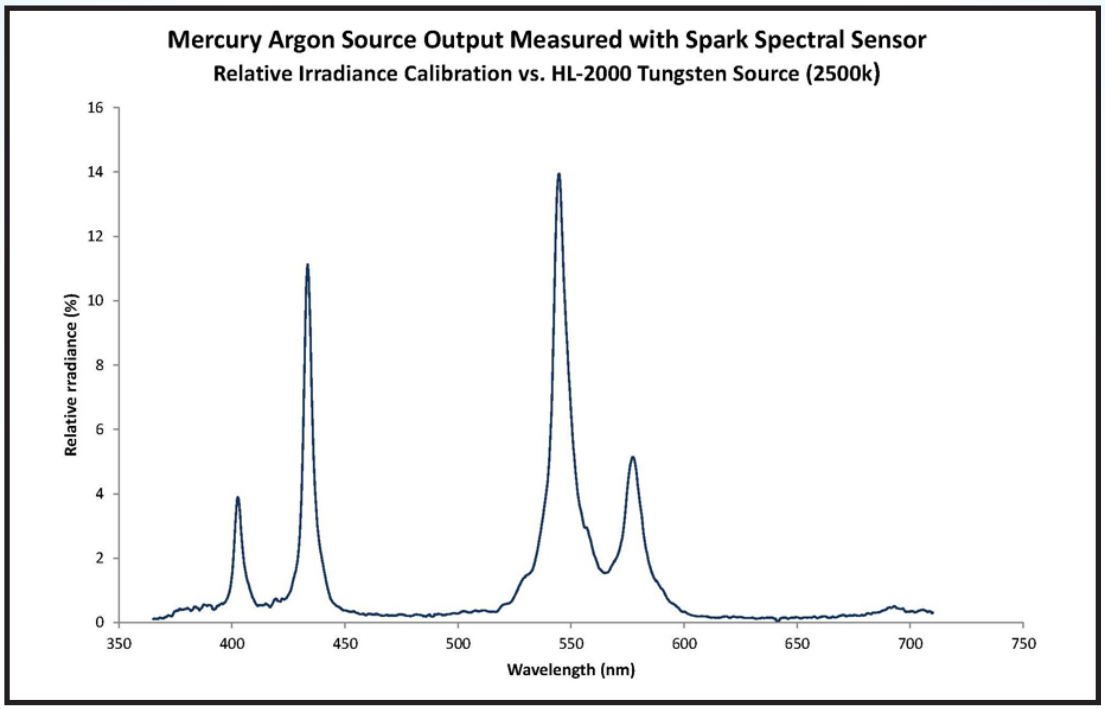


Figure 6: Emission spectrum output for a mercury argon lamp

As mentioned earlier, even intensity of illumination across the Spark aperture is recommended. For relative measurements, this is not necessary, as any variation in intensity across the aperture may be referenced out. For absolute measurements, it is essential that the lighting and geometry of the setup is **exactly the same** when calibrating the device as when taking a measurement. Any variation from the calibration setup (moving of fibers, light source or device, or altering the background lighting) will nullify the calibration. This includes the intensity of illumination.

Fluorescence

Fluorescence typically requires high sensitivity for measurements at low levels. The full aperture, full flood illumination of the Spark makes it ideal for fluorescence measurements, as the increased throughput from the large aperture allows low levels of light to get through to the detector.

The Spark's high dynamic range and Signal to Noise Ratio (SNR) enables it to detect both high and low sample concentrations, as highlighted in Figure 7.

Figure 7 shows the fluorescence spectra for aqueous (di)sodium fluorescein, measured with a Spark spectral sensor in a 90° excitation setup using a 470 nm LED light source (Ocean Optics LLS-470). Fluorescein has a maximum absorption peak at 494 nm and a maximum emission peak at 521 nm. Spectral data were recorded in a simple experimental setup using standard plastic, disposable 10 mm cuvettes, with no optical filters or mirrors to enhance the signal.

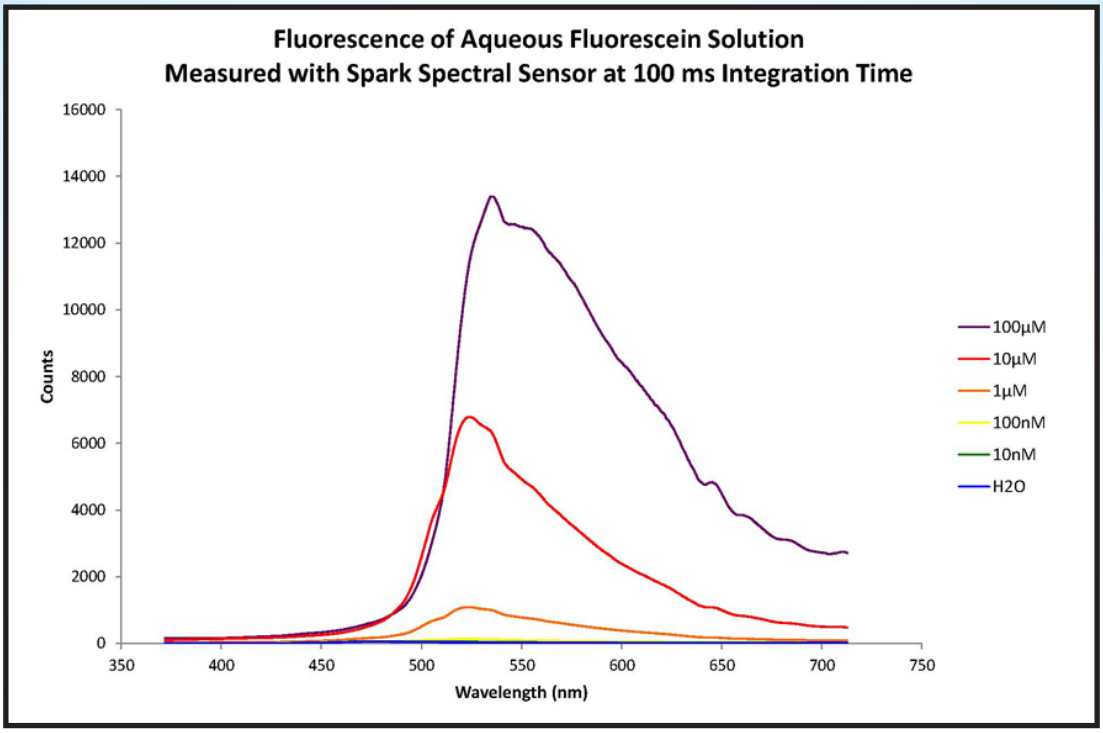
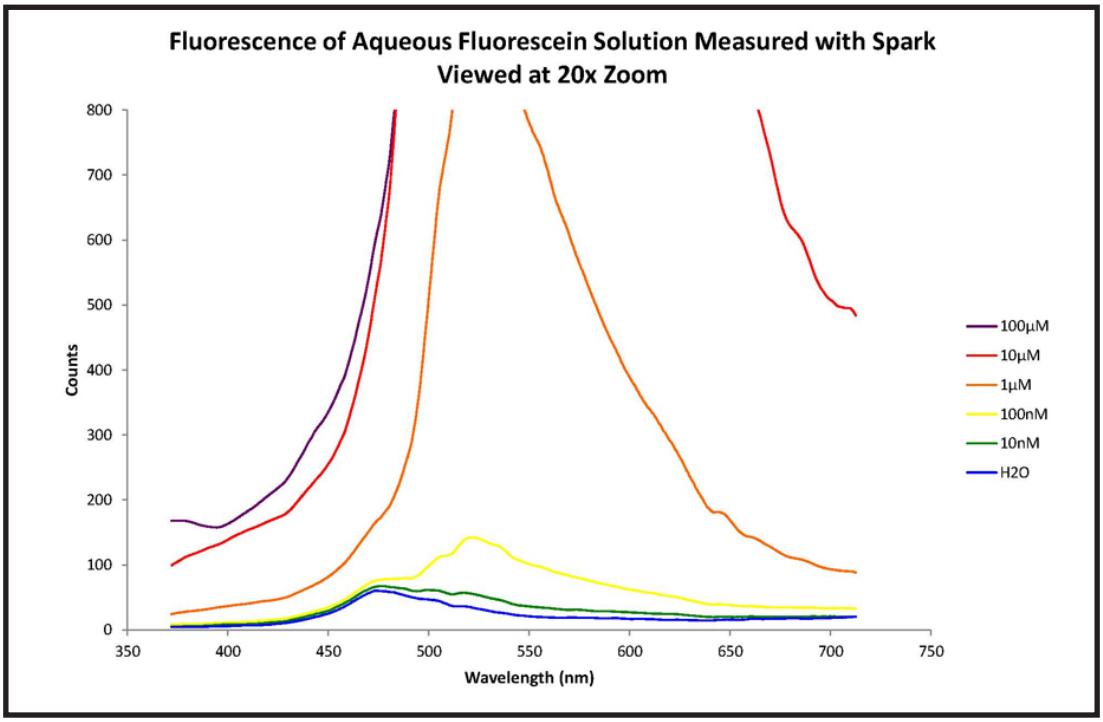


Figure 7: The example shows fluorescence response with fluorescein in the concentration ranges of 10^{-4} to 10^{-8} Molar, measured at 100 ms integration. When zoomed in at 20x (see below), the fluorescein spectra reveal additional features.



The Spark gave a clear peak at 100 nM fluorescein, a shoulder peak at 10 nM and a tail at 1 nM (not shown). This suggests that under optimal fluorescence conditions (using filters, quartz cuvettes and a strong excitation source), the Spark-VIS can be used for analysis to approximately 10 nM fluorescein solutions, and possibly even lower with a suitable calibration curve. This makes the Spark ideal for a range of diagnostics, both medical and environmental, yielding high sensitivity measurements.

Fluorescence, either native or induced from special reagents, is a useful measurement technique for medical diagnostics, trace materials analysis and bacterial assay measurements for water quality testing. Many biological applications also use fluorescent molecules as markers for other non-fluorescing compounds. With an inexpensive fluorescence sensor like the Spark, users can reduce measurement costs, incorporate the sensor more easily into applications and effectively combine Spark with other devices and techniques such as flow injection analysis and liquid chromatography.

Color Measurement

Spark measures a complete spectrum within the range 380-700 nm for the price of a RGB filter-diode device, offering a rich dataset from which detailed color variables may be calculated. The Spark is ideal for emissive color measurements of LEDs and other sources (Figure 8), as well as reflectance measurements of manufactured goods on process lines.

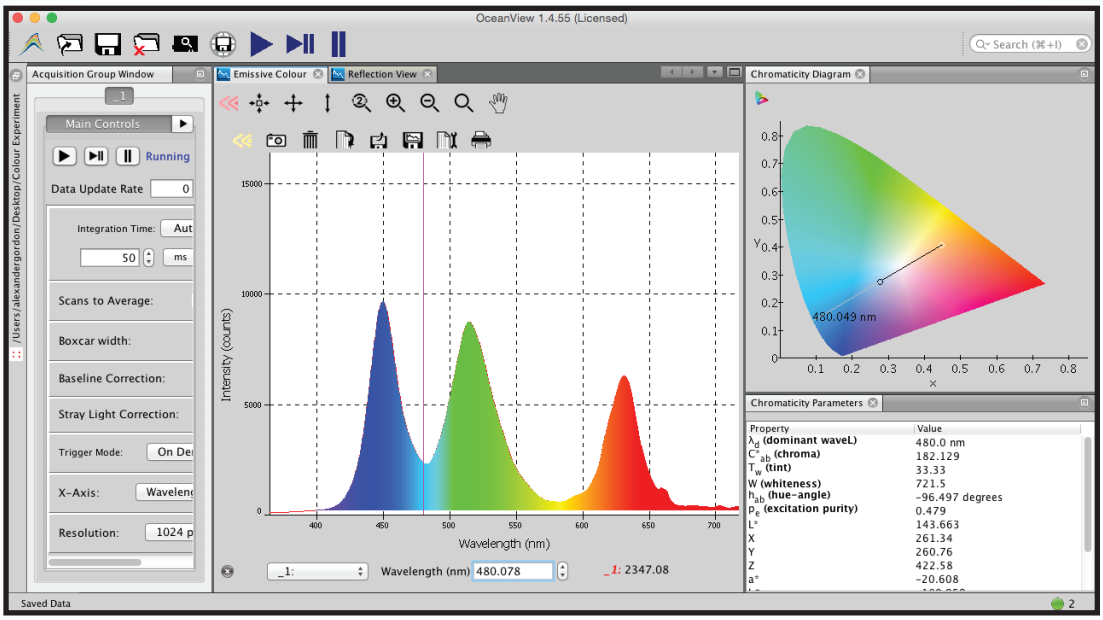


Figure 8: Spark is a useful tool for emissive color measurements of LEDs.

Color is an especially versatile application. There is a significant market for handheld colorimetric systems for measuring color and color-based responses in chemical testing. Such testing for clinical applications, food quality determination and environmental monitoring is often based on simple RGB-diode measurements, both in solution and via indicators immobilized on solid surfaces such as paper strips and membranes. As such, the level of sophistication for the measurement is low, capturing data at only a handful of wavelengths (and, of course, missing it at all the others!). With the Spark, the user enjoys the power of a laboratory-based spectrometer in a compact, affordable package that can be integrated almost anywhere.

Spark Performance – and Possibilities

Whether alone or embedded into a measurement system, Spark is ideal for absorbance, color, fluorescence and other applications requiring a low-cost, small-footprint visible spectral sensor. Both qualitative and quantitative measurements are possible.

The primary strength of the Spark is its size. The OEM and the detector formats of the Spark weigh 3.8 g and under 1 g, respectively, and can easily be integrated into any number of systems and environments. In fact, the largest Spark format – the stand-alone Spark-VIS, which contains all necessary driver electronics -- is still only 15 g.

The Spark is also thermally rugged, with an operating temperature range of -10 °C to +60 °C, and has a very high optical throughput due to its large aperture. These additional features make it ideal for extreme environments and low-signal experiments. For a list of Spark features and specifications, see Appendix I.

The Spark differs in response when compared with traditional instruments. As noted, Spark does not require sophisticated optics when integrated into a system. However, users must take care with the method of illumination, remembering that there is a spatial sensitivity in regard to the need to provide even light distribution over the entrance slit. The Spark's unique aperture design requires even illumination with a collimated or a diffuse light source. With attention to how the device is implemented and with guidance from the Ocean Optics team, optimizing the light is straightforward.

Spark introduces a new class of spectral device, and is the first Ocean Optics device to replace traditional diffraction gratings with a solid-state optical sensor. Thanks to that advance and other novel design elements, Spark provides users with the size and cost advantages typical of less robust RGB filter diode devices, but with the benefits of full spectral measurements. Ultimately, this will make possible a wider range of spectral applications than once thought possible, from OEM applications where Spark is embedded into other devices to educational settings where Spark's ease of use and graceful simplicity make it an ideal tool for inspiring the next generation of innovators.

Appendix I: Spark Features and Specifications

Feature	Specification	Good for…
Wavelength range:	380 – 700 nm	Color, PAR, fluorescence and absorbance measurements
Highly compact:	15 g including electronics, 3.8 g without electronics, <1.0 g for detector	Integration into handheld and portable devices or onto process lines
Thermal range:	-10 to 60 °C operating range	Analysis in harsh environments
Good optical resolution:	4.5 – 9.0 nm (FWHM)	>80 element color measurements
SNR:	1500:1	Absorbance and fluorescence applications
Integration time:	10 µs – 10 s	Wide range of applications
Stray light:	~0.5 – 1% from 380-700 nm	Absorbance, color and other measurements
Good value:	Our lowest cost spectrometer	Accessibility for bulk orders and budget-limited labs
Ease of use:	Plug and play with microUSB connectivity	Education environments, remote control on UAVs and new applications