White Paper
By Kevin Jensen

Chip-scale spectral sensing: understanding the new uses for ultra-precise sensors from UV, VIS to NIR

How manufacturers can use the spectral information which image or color sensors cannot see to create new consumer and industrial applications and better performing products

am OSRAM

Introduction

Spectrometry is an important technique deployed in advanced scientific laboratories to analyze materials and detect chemical characteristics.

In the lab, scientists use large and expensive benchtop instrumentation to take spectral measurements. But the development of a new type of optical semiconductor device, the spectral sensor, brings the power of spectrometry within reach of the manufacturers of affordable, handheld industrial and consumer devices.

A spectral sensor or ‘spectrometer-on-chip’ such as the AS7343 from ams OSRAM provides accurate measurements of spectral power distribution in both emissive and reflective measurement applications. A small surface-mount chip, the AS7343 can be integrated into products as small as a smoke alarm or a handheld colorimeter.

Product manufacturers can now explore the opportunity to develop completely new applications for low-cost, convenient spectral sensing, or to dramatically improve the capability or performance of existing applications. In agriculture, a handheld device based on a spectral sensor can accurately measure the ripeness of fruit, or assess whether the light in an indoor farm is optimized for plant growth and crop yields.

Chip-scale spectral sensing also offers remarkable value in the industrial and consumer worlds. A spectral sensor in a smoke alarm can distinguish between sources of smoke to give a more precise indication of the type of fire, improving safety and saving lives; or it can identify fabric types in better, energy-saving washing machines.

These and other applications depend on the detection of the distinctive spectral signature of light sources (in emissive measurement applications) or materials and substances (in reflective measurement applications): in the semiconductor world, this capability is unique to spectral sensors such as the AS7343.

In this white paper, ams OSRAM describes the complex spectral characteristics of natural and artificial light, explains how a spectral sensor is different from other types of color sensor, and describes exciting applications for a spectrometer-on-chip.

Understanding the impact of light & color on human visual perception

Everyone is familiar with the effect which distorting light sources have on our perception of color. For instance, incandescent sodium streetlights emit a strongly orange-hued light under which it is almost impossible to distinguish most colors. Under sodium light, a scene becomes flattened, and the viewer is deprived of huge amounts of visual information that is available in daylight. Similarly indoors, fluorescent lighting and low-cost LED light sources distort color and wash out the rich palette perceived under natural sunlight.

This concept of distortion implies that there is a 'perfect' light source, or that some light sources are more 'true' than others.

In fact, every light source has its own distinct signature. Daylight itself is infinitely variable. The sun's light is more warm-white in the morning and cool-white around noon, and becomes progressively more golden towards dusk. The nature of sunlight varies not only with time but with place: the color content of sunlight is affected by its path through the Earth's atmosphere. This helps to explain why painters have prized the special quality of the light in places such as the Mediterranean coast of France. This is not some artistic oddity – the light really is different in different places.

And since we see the color of an object when light from an external source is reflected from the object to our eyes, if the characteristics of the light source change, the object's color will also appear to change.

There is, then, no such thing as a single perfect light source under which the true color of any object will be rendered. Nevertheless, humans instinctively know that a light source such as a fluorescent lamp does not render color truly. In fact, evolution has conditioned the human visual perception system to operate optimally in normal daylight. And this has led industry to define daylight-like reference light sources, the spectral characteristics of which are intended to exactly match those of 'average' daylight. These reference sources are specified at various color temperature points. The D65 reference (the D stands for Daylight), for instance, is a representation of daylight with a correlated color temperature (CCT) of 6500K – a typical value on a bright sunny day at noon.

Viewed under D65 light, colors will be rendered in a way that the average human will generally perceive as 'true'.

The spectral characterization of light

In fact, the human eye is a relatively crude device for visual perception. Like an RGB or XYZ sensor, the eye has three sensing elements, or 'cones', sensitive to the red, green and blue portions of the spectrum. The eye also contains rods which are fairly sensitive to relative brightness, but not in a linear fashion – for instance, when the optical power output of a typical articificial light source is reduced by 50% from maximum brightness, the human eye typically perceives the drop in brightness as just 25%.

In most conditions, the eye's three-channel method for sensing color works well enough. But in fact a source of visible light such as sunlight is a complex physical phenomenon which has a spectral power distribution over the spectrum of visible wavelengths (approximately 400nm-700nm).

A representation of the spectral power distributions of various light sources is shown in Figure 1. All of these light sources are nominally 'white light': fluorescent lamp, ultra-white LED, halogen bulb, white LED, incandescent bulb, and daytime sunlight.

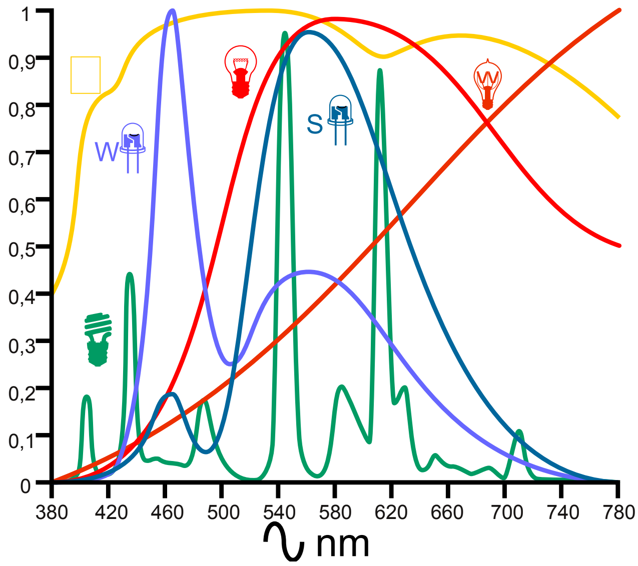


Fig. 1: the spectral power distributions of various white light sources.

(Image credit: A7N8X under Creative Commons 4.0 license.)

What is striking about the graph is that each light source's curve has a distinctive shape, and concentrates its radiant power in different parts of the spectrum. This explains why each source has different perceived color effects.

But now look at Figure 2, showing the spectral characteristics of the eye's sensitivity to light:

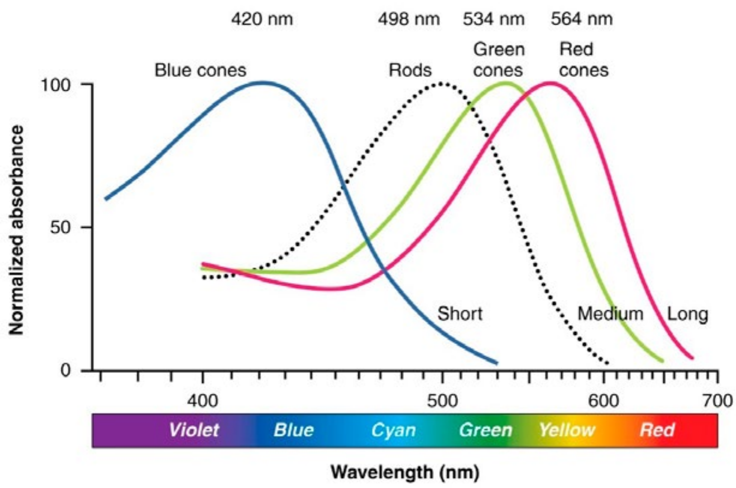


Fig. 2: average human eye sensitivity to color and brightness.

(Image credit: OpenStax College under Creative Commons 3.0 license.)

The human brain can fuse the inputs from the eye's blue, green and red cones to produce a color sense output, but it cannot distinguish the complex pattern of color peaks and troughs which distinguish a white LED from a fluorescent lamp, when both have average peak output at around 540-580nm, perceived as a blue-green white.

This is the capability enabled at chip scale by a new generation of spectral sensors developed by ams OSRAM. The AS7343 spectral sensor is supplied in a compact 3.1mm x 2mm x 1mm package suitable for mounting on the PCB of a smartphone, or of an industrial or consumer device. It is a 14-channel sensor which includes 11 channels in the visible light spectrum, as well as Clear, Near Infrared and Flicker

Detection channels. Because the sensor can slice the spectral power distribution of visible light into narrow bands (see Figure 4), it is able to detect the distinctive spectral signature of the light sources shown in Figure 1, and of any other sources or combination of sources of visible light.

This capability is valuable in many applications for color sensing – but why is a spectral sensor the right type of device to use? To answer this question, it is helpful to understand the differences in the operation of a multi-channel spectral sensor, an XYZ color sensor and an RGB color sensor.

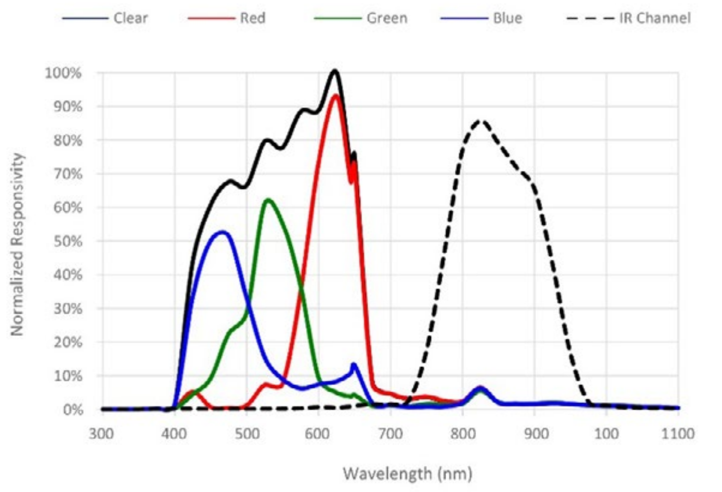
RGB color sensors

An RGB sensor commonly consists of three band-pass filters in the visible light spectrum. The peaks of the spectral graphs are not set uniformly in relation to particular wavelengths, but are defined during the design process in response to the specification of the measurement task and cost.

This kind of color measurement is not aligned to any standard or model of the human eye's perception of color. An RGB sensor can, nevertheless, be used in colorimetric tasks depending on the required accuracy. But even with the application of complex calibration methods, the accuracy of an RGB sensor's color measurement is limited by the device's three-channel configuration.

Fig. 3: typical spectral characteristics of an RGB sensor.

(Image credit: ams OSRAM)



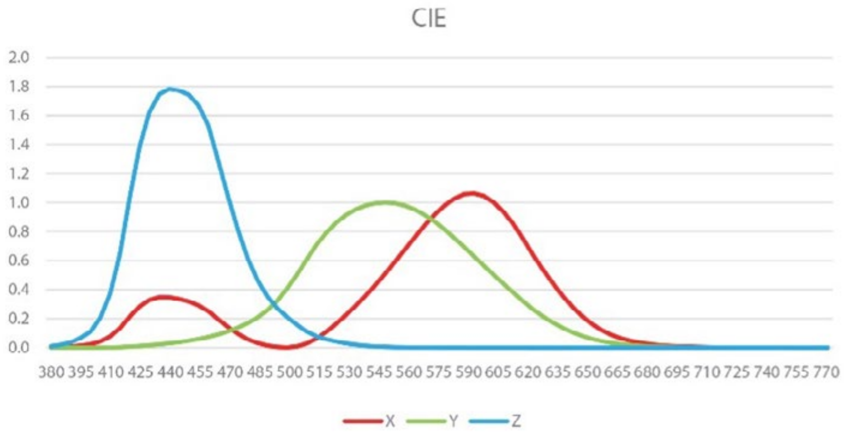
XYZ True Color sensors

XYZ sensors, also known as True Color sensors, may be used for absolute-value color measurements. They use interference filters, which provide a sound technological basis for the measurement of color to industry-standard definitions. These sensor ICs measure values as accurately as the human eye sees them. The spectral sensitivity diagram in Figure 4 reveals a close match to the human eye's sensitivity as shown in Figure 2.

The interference filters allocate specific sensitivity values to each wavelength in each of three color channels. When calibrated, it is possible to render the measured color values as XYZ values (chromaticity co-ordinates), which are used as base values for conversion into other color spaces. XYZ coordinates are based on the CIE 1931 'Standard Observer' characteristics of the average human eye. The use of a True Color sensor IC therefore makes it possible to describe in number values the color of an object such as a swatch of fabric, or a printed block of color, as the human eye sees it.

Fig. 4: typical spectral characteristics of True Color sensors, which incorporate interference filters.

(Image credit: ams OSRAM)

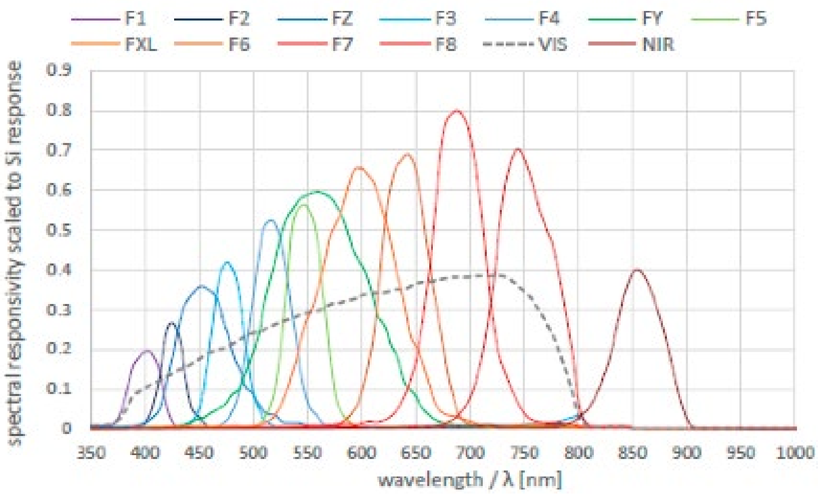


Multi-channel spectral sensors

Multi-channel spectral sensors such as the AS7343 are next-generation sensors which use multiple channels to provide a rich color information output at a low price point (see Figure 5). When color coordinates are not enough, the spectral composition of objects is measured.

The spectral sensing principle can compensate for metamerism (false color matching). A multi-spectral sensor provides the answer to the question whether an orange color sample is a mix of red and yellow, or a pure orange. A spectral sensor can also measure spectral light values such as the color rendering index (CRI), as well as commonly measured values such as brightness and CCT.

Fig. 5: the spectral sensitivity of the AS7343 multi-channel spectral sensor



Multi-spectral sensors separate the chosen spectrum into spectral channels. As Figure 5 shows, the AS7343's filters produce eight narrow bands which cover the entire visible spectrum, overlaid by three XYZ channels which closely match the CIE 1931 Standard Observer model. This enables backwards compatibility towards exising XYZ based applications, as well as future proofing towards full spectral measurements.

In the visible range, a multi-spectral sensor's measurement takes place at the radiometric level rather than the colorimetric level. This means the sensor measures the spectral power distribution of the sample, and calculates the color point from these spectral values.

Near Infrared Range

In the Near Infrared (NIR) range, the measured spectrum can also be used to look at specific wavelengths at which the user may identify substances such as moisture, fats or proteins. An one does not have to be a data scientist to turn a measured NIR spectrum into a meaningful value. Simple teaching methodologies enable new applications. For example moisturing a sponge at 3 different levels. 0% moisture = dry, 50% moisture = damp, and 100% moisture means wet. The concept of teaching allows to implement new applications very easily.

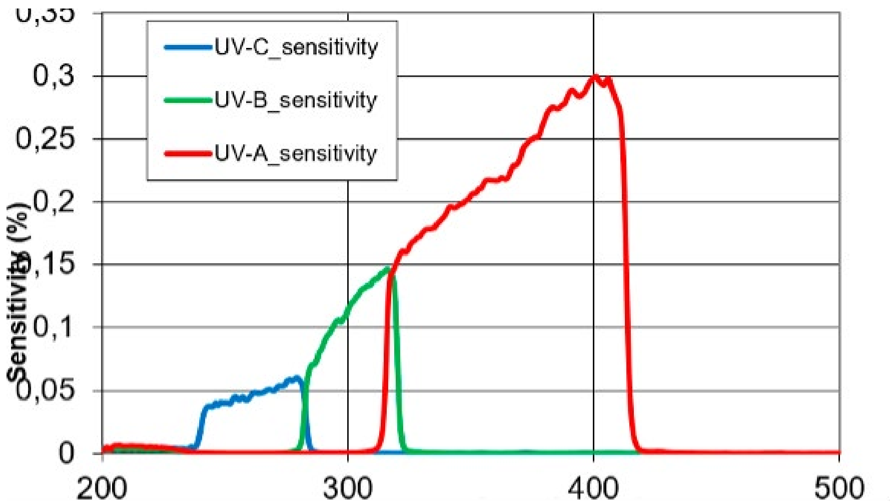
UV Range

The UV range consist of a variety of useful applications from consumer to industrial grade. Most commonly known is the principle of UV-C treatment. Water, air or surfaces are irradiated by UV-C radiation to destroy the DNA of viruses and bacteria, and create healthy environments. The downside? Material often decays faster when exposed by too much UV-C emmisions. Here sensors can help to monitor the right dosage and optimize maintenace cycles, that both a best possible disinfection occurs, but at the same side the materials are not harmed more than needed.

Together with UV-C LED solutions from ams OSRAM optimized system designs are now possible for consumer applications like sanitizing surfaces to industrial applications like upper air treatment in public spaces. The OSLON® UV portfolio meets the needs of UV-C treatment solutions for a clean and purified environment.

The common UV-Range is split into three main values A, B, and C what also determine the intensity of the specific radiation level.

Figure 6: The typical response curves of a UV-A/B/C multi-spectral sensor



New home, industrial and commercial use cases for spectral analysis

A multi-channel spectral sensor supports the most accurate possible white-point balancing across the widest range of lighting conditions. Spectral sensors help smartphones to produce the superior camera performance that consumers care about. The spectral sensing capability results in more true rendition of color even in scenes which defeat RGB or XYZ sensors.

The multi-channel measurement capabilities of spectral sensors in the ams OSRAM portfolio also have potential uses in many types of consumer and industrial equipment.

Saving lives and property: a smoke alarm which detects types of smoke more accurately

The simple two-channel optical sensor in today’s smoke alarms is sensitive only to blue light in the visible spectrum. The second optical channel detects infrared light, to respond to the heat generated by a fire. Unfortunately, this simple sensor responds to smoke in the chamber in a similar way as it does to vapor, and so tends to generate false alarms when the atmosphere becomes steamy, for instance when a nearby bathroom is in use. It is also slow to respond to smoke that is not blue.

Technology developed by ams OSRAM operates on the same principle as conventional smoke alarms – but much better. For the sensing element, it uses an AS7343 spectral sensor complemented by an SYNIOS® P 2720 LED emitter which emits light across the visible spectrum, matching the spectral range of the AS7343.

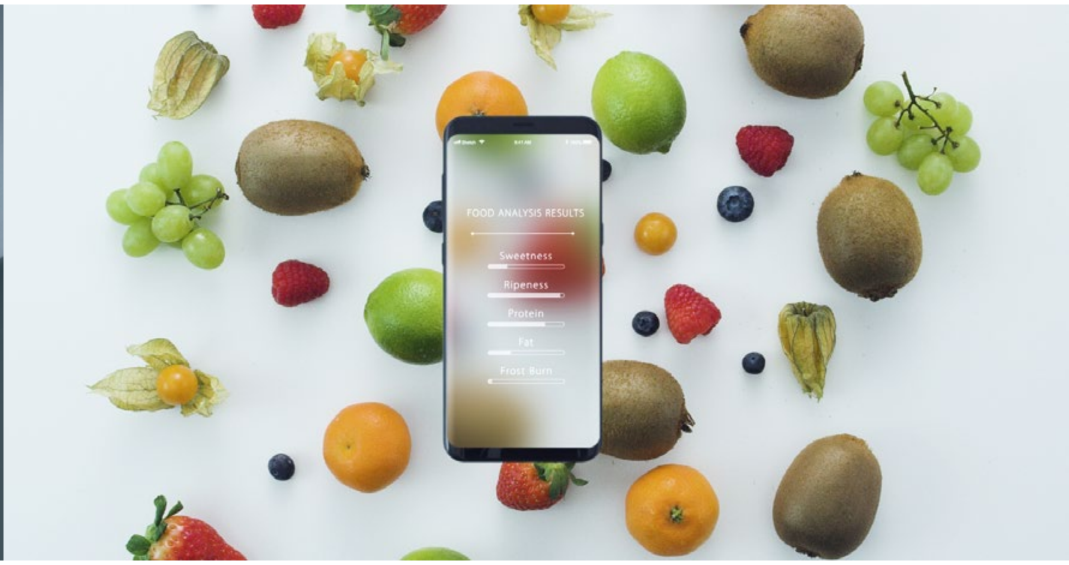
When these two chips are mounted inside a smoke detection chamber, the characteristic spectral signatures of smoke can be distinguished. This allows smoke detector manufacturers to create better performing products:

- By distinguishing different types of fires, a smoke alarm based on the ams OSRAM technology can inform emergency services about the type of fire they are responding to before they arrive at the scene. This means that fire departments can be well prepared with the correct equipment to hand when they arrive at the scene of a fire emergency.

  When used in a smoke alarm, the superior capability of the AS7343 can detect fire types more quickly and enable a faster response from emergency services, helping to save lives and protect property from damage.

- The ability to distinguish cigarette smoke from the emissions from vaporizors (vapes) enables the development of new value-added capabilities for a smoke detector deployed for instance in hotel accommodation or in the cabin of a car.

Low-cost, handheld device for measuring the ripeness of fruit



One of the toughest problems in agriculture is timing the harvesting of fruit to ensure that it reaches the supermarket ripe after shipment across oceans and continents.

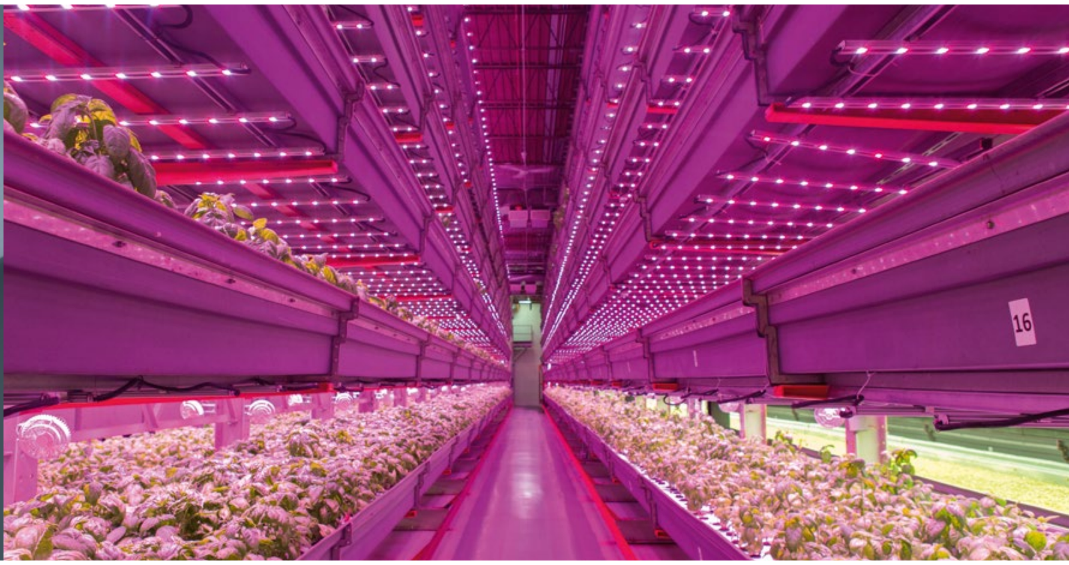
Today, growers test ripeness with specialist test instruments which are bulky, heavy, and often cost thousands of dollars. The market could benefit from a smaller, cheaper solution which is affordable by small as well as large growers, and which can be used easily in the field or orchard.

Now ams OSRAM has developed a demonstration design for a superior Near Infrared (NIR) spectrometer for fruit testing that is small, light and portable. When the technology is built into a commercial fruit tester product, manufacturers will be able to sell at prices that everyday users can afford.

This innovative design offers a dramatic cost reduction, while maintaining performance at a level comparable to that of trusted NIR spectrometers on the market today. In the demonstration system, the sensor's spectral measurements are post-processed by dedicated chemical analysis models to produce values for BRIX (sugar content) and dry matter content (DMC). Tests show that the ams OSRAM demonstration system produces measurement results comparable to those of a reference instrument costing thousands of dollars.

The development of a handheld fruit ripeness tester will enable growers and retailers to reduce waste, while increasing the value of their products.

Horticultural lighting: tuning light & color to maximize crop yield



New intensive models of indoor agriculture, such as vertical farms located in cities close to consumers, use specialist agricultural lighting to provide the energy for crops' photosynthesis. Different plants' leaves are stimulated to grow by different lighting recipes. By adjusting the spectral content of a horticultural light source to match the plant's requirement, the grower can maximize crop yield while minimizing energy use.

Conventional laboratory-grade spectrometers are bulky and expensive. An AS7343 spectrometer-on-chip enables the production of a portable device which provides accurate and detailed characterizations of tunable light sources at a competitive cost such as the OSLON® Square Horticulture portfolio of LEDs. With the expansion of LED lighting into horticulture, the real test of expertise and know-how lies within offering consistent growth practices and responsible use of energy whilst ensuring the cultivation of high quality crops for growers and end users. Reducing fixture size, reducing shadowing and ultimately lowering the fixture BOM cost all become possible.

Quantum meters, or so called PAR detectors are a simple way of defining what the right amount of light is needed for a plant to grow ideally. The AS7343 can easily map out PAR values and on top knows what levels of light need to be added at the plant, to optimize. Since it can see more than just the PAR value itself, it also observes the missing spectrum of light, that needs to be added to improve the measured values.

So imagine a sensor that monitors the light that hits the plants, it detects a deficentcy in PAR value, due to clouds, dirty glass of the greenhouse or other environmental conditions, and the LED lighing system then knows what level of illumination and spectral composition to change to meet optimized growing conditions.

On-top of traditional daylight harvesting that is controls the illumation output based on existing natural light from the sun. This can help save energy, reduce heat production and drives sustainable growth in horticulture applications.

UV-C treatment: how to clean clothes without washing

A washing machine's operation entails both environmental and financial costs. A load of washing consumes many liters of water. Electricity is required to heat the water, as well as to dry clothes in a tumble dryer. The user has to pay the cost of water and electricity with every load of clothing they wash.

Now innovators are developing a new approach to the cleaning of clothing which is not heavily soiled, based on the use of UV-C treatment.

In a new high-tech washing machines, an NIR spectral sensor, under development in 2023, and infrared emitter will detect the type of fabric in each garment through the application of NIR spectroscopy.

The machine will then deliver an appropriate dose of UV-C radiation to disinfect and freshen the clothing, without using a single drop of water. A new UV-C sensor from ams OSRAM will measure the UV-C radiation delivered to the clothing to ensure effective disinfection with the smallest possible dose of UV light.

In combination, the NIR spectral sensor and emitter for identifying fabrics and the UV-C sensor for measuring disinfection enable a new water-free mode of washing, reducing the consumption of water and energy and reducing the cost to the user of freshening clothing.

Material detection and surface monitoring

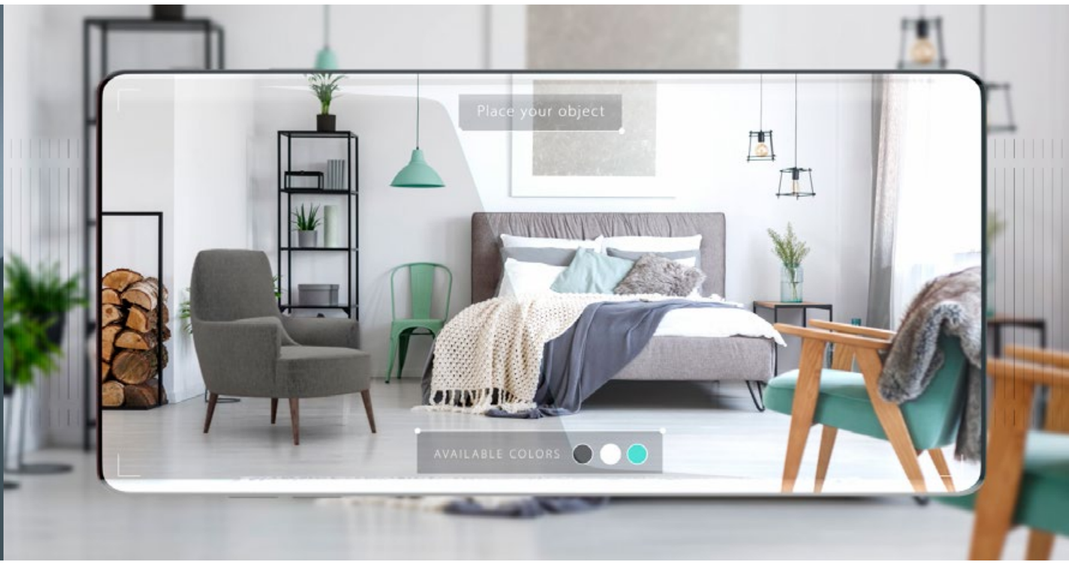
The mini-spectrometer demonstrator enables to measure 64 wavelengths from 750-1050nm. This allows to perform a spectral sweep of fabrics, surfaces, floors and other material and look at specific spectral footprints.

Via simple teaching methods these materials or surfaces can be categorized in a lookup table. So for example in home sweeping robots a device would be able to not only detect that the floor type is wooden, tile or carpet, but also use the bandpasses around 960nm to detect the moisture level of these floor types. Making fully automated cleaning even easier and more efficient.

But also fabrics and plastics have their specific spectral footprint, enableing to authenticate fakes from real brands or looking at specific methodologies to optimize recycling principles and improve sunstaniblity. It can be also used in quality procedures to check specific parameters of shipped goods. For example in how far is the printing material of a 3D printer varing from ship-ment to shipment. Can I use it to achieve similar quality results, or a variations expected?

There are many applications automated systems or robots can tackle better, when the device have more awareness of the materials they are working with.

Environment awareness in wearable devices



Virtual Reality (VR) and Augmented Reality (AR) devices are in their infancy, but almost all manufacturers of VR/AR devices are competing to render the virtual world as realistically as possible. Accurate color rendition is a crucial visual signifier of realism. When a VR/AR device's image sensor is backed by a multi-channel spectral sensor, it can apply accurate color compensation in any lighting conditions, and with any background color, to render truly the color and brightness of real-world objects.

Environment awareness also has another use, to support healthy living regimes. Wearable devices such as fitness monitoring wristbands or smart frames (glasses) have traditionally been used to monitor body functions such as motion or heart rate. But external factors also affect health: an example is exposure to light. A multi-channel spectral sensor can identify the light sources in which the wearer spends time, and inform an app which will analyze the proportion of time spent under light sources which the user might classify as 'unhealthy', and show the time the wearer has been exposed to the potentially harmful elements of sunlight, like UV radiation.

Healthy lighting for homes and offices

A similar use case shows the value of embedding a multi-channel spectral sensor in indoor lighting fixtures or lighting controllers. The science of 'human-centric lighting' is a fast-developing field, and the health impacts of types of artificial light, or of specific wavelengths, are not yet proven.

Nevertheless, some users harbor concerns, for instance, about exposure to specific wavelengths of blue light in sources such as white LEDs. There is evidence that the potential for harm arises from the relative intensity of benign and harmful wavelengths, rather than the absolute intensity of a specific wavelength.

The detailed analysis this calls for is only possible with a spectral sensor – and a device such as the AS7343 is small enough to be embedded into any type of lighting fixture.

In tunable white lighting fixtures, the spectral information provided by the AS7343 also allows for the dynamic configuration of light output in combination with ambient light to provide a user-specified spectral power distribution.

Taking these effects into consideration to provide a holistic and application oriented approach to light for humans, Human Centric Lighting can balance visual, emotional and biological needs of humans in lighting applications. The OSCONIQ® E 2835 line of mid-power LEDs offers key features where color, that is to say specific wavelengths matter.

Conclusion

Accurate rendition of color in imaging and lighting systems has long been a characteristic valued by consumers and professional buyers. New developments in color sensing have seen the introduction of a new generation of multi-channel spectral sensors which for the first time provide for chip-scale spectral analysis of incident light – a more detailed type of information than the color-point measurements provided by the XYZ color sensors pioneered by ams.

Spectral sensors from ams OSRAM provide accurate measurements in the visible range, the NIR-range and soon UV-range. This offers value in a wide range of applications for spectral sensing, from measuring the ripeness of fruit to managing the spectral power distribution of horticultural lighting, disinfection monitoring, material detection, or in smoke alarms to detect the optical signature of different kinds of smoke.

The combination of sensors and emitters by ams OSRAM allows customer to develop optimized optical solutions for a wide range of applications.

Biography

Kevin Jensen, Senior Marketing Manager at ams OSRAM, is a sensor and lighting expert. He is a bilingual German-American dual citizen with international experience in management, sensors, electronic engineering, expansion strategies, internationalization and marketing. His background is in spectral analysis, optical sensors, signal analysis, system solutions and software concepts. He graduated with a General Management Masters and a Bachelor background in Engineering and Software Development.

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