FILTRON: Optical filters for CMOS integrated photodetectors

Samy Ahmed Heinrich Gottlob, - October 18, 2016

Optoelectronic components made of the semiconductor material silicon are sensitive to light with wavelengths ranging from the ultraviolet (UV), visible light, to near-infrared radiation (300-1100 nm). Incident light creates mobile charge carrier pairs in the semiconductor crystal through the photoelectric effect. In this way, silicon can be used as a photodetector. The measurable photoelectric current is proportional, in a first approximation, to the spectral sensitivity, the area of the detector and the intensity and spectral characteristic of the incident light. On the component side, the monolithic integration of photodetectors and amplifier circuits using CMOS technology leads to smaller product dimensions. This also facilitates greater user friendliness as the components can be controlled using digital buses and thus large dynamic ranges can be achieved as various gain levels can be selected.

The spectral sensitivity of the detector initially comes from the spectral sensitivity of silicon and the CMOS fabrication process used. The spectral sensitivity of the component can be changed by using optical filters. Such filters can be bandpass filters, for example, for ambient light sensors, adapted to the sensitivity of the human eye, or daylight filters that only allow near-infrared light to pass. The optical filters can be installed, for example, as pigments in the encapsulation material of the housing, as interference filters in front of the component or attached directly onto the silicon photodetector. Even combinations of these filters are possible. The choice is made based on the product requirements, availability of the filter material, and cost.

The patented FILTRON technology of Vishay Semiconductor GmbH uses a Fabry-Perot interference filter attached directly on the photodetector using thin-film technology. This happens at the wafer level following the CMOS fabrication process. The interference filter consists of a cavity made of two partially reflective mirror layers with a dielectric medium between them (Figure 1a). This configuration transmits light having a wavelength that satisfies the following equation to a first approximation. That is, it provides constructive interference of the two divided beams shown [1]:

\[ 2 \cdot n \cdot t = m \cdot \lambda_0 (m = 1, 2, 3 ...) \]

In this equation, \( n \) is the index of refraction and \( t \) is the layer thickness of the dielectric medium, \( m \) is an unsigned integer and \( \lambda_0 \) is the wavelength of the incident light. This corresponds to a bandpass filter and its transmission \( T(\lambda) \) is described by [1]:
The reflectivity $R$ of the mirrors determines the width of the bandpass filter and is set for thin metallic layers by means of the layer thickness. For a selected material system, for example, thin mirror layers of silver with silicon nitride as the dielectric medium, the filter transmission can be set by means of the layer thicknesses (Figure 1b). The spectral sensitivity of photodetectors with a cavity changes accordingly into a narrow bandpass filter.

The CMOS fabrication process also makes it possible to integrate a detector array made of several photodetectors onto one chip. When manufacturing the cavity, each detector gets its own bandpass filter by repeated deposition and structuring.

**Figure 1** (a) Transmission through a Fabry-Perot cavity at a mirror distance $t$ with dielectric medium having an index of refraction $n$ in between (b) Example of transmission through a cavity with silicon nitride between thin silver mirrors and the sensitivity of a silicon photodetector with and without this cavity.

**Ambient light sensor (ALS)**

Ambient light sensors provide brightness measurements, for example, to control the backlight of a display. In this way, the impression of brightness is adjusted to suite the environment, not too bright or too dark, while also reducing the energy consumption.
Brightness or darkness are human sensations perceived by the eye. The receptors in the eye are sensitive to visible light (400-700 nm), reaching a maximum in the green range. If a broadband photodetector made of silicon is used as the ambient light sensor, the measurement result will depend significantly on the spectral characteristic of the ambient light being detected. For example, a light bulb or sunlight with a large infrared (> 700 nm) component will result in more signal than a white LED (450-700 nm) with the same light intensity. FILTRON technology now makes it possible to adapt the sensor sensitivity by fabricating a bandpass filter with a sensitivity curve similar to the human eye. Deviations for different light sources are minimized in this way to ±15%.

The VEML6030 ambient light sensor, in addition to the ambient light channel, has a wideband "white" result channel (Figure 2a), which supplies additional information about the light source, resulting in a further improved accuracy. Both channels have 16-bit resolution and measurements are made in parallel. The component is addressed over an I²C bus and the integration times and gain factors can be set in this way. This allows for a high dynamic range of the sensor, functioning under full sunlight (approx. 100 klx) down to moonlight (approx. 0.01 lx) or behind designed housing elements such as darkened screens that hide the component while also attenuating the incident light.

Besides the application for controlling the backlighting of televisions, monitors or displays in mobile devices, the VEML6030 can be used to control the lighting for rooms or industrial applications.

![Figure 2a](image_url)  
(a) Spectral sensitivities of various sensor channels using FILTRON technology.  
(b) Example of the VEML6040 RGB sensor with four channels for red, green, blue and white.
A color sensor with red, green and blue channels measures the light intensity, of 3 different wavelength regions of visible light corresponding to red, green and blue. In this way, properties such as the correlated color temperature (CCT) of a light source can be determined, which contains information about the impression the light makes on the human eye.

The separate sensitivity channels of the VEML6040 are arranged as a 4×4 pixel array. (Figure 2b). The color filters of the sensor are implemented using FILTRON technology and the filter characteristics approximate the standardized sensitivity curves of CIE1931. The green channel can be used directly as an ambient light sensor. All four channels have 16-bit resolution and are measured in parallel. The dimensions of this surface-mounted device (SMD) are only 2×1.25×1 mm (L×W×H).

Using this color information, for example, for displays, the white point or the color saturation can be adjusted to match the ambient light conditions. Furthermore, color recognition of objects can be performed. As one example of this, the objects are illuminated with wideband light from a white LED and then the reflected light is analyzed using the color sensor. Via this reflected light the color of the object can be detected and passed on to the next part of an application. In the lighting market segment with pure colored RGB light sources or heterogeneous assemblies of RGB and white LEDs, the color sensor can be integrated into a control loop to compensate for temperature responses and aging phenomena [2].

UV sensor (UVA + UVB)
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Ultraviolet radiation (UV) has a shorter wavelength than visible light and reaches the surface of the earth from the sun as the natural source as UVA radiation at 380-315 nm and UVB radiation at 315-280 nm. This component of the spectrum of sunlight is relatively small at about 4.9% UVA and about 0.1% UVB. However, the short wavelengths are accompanied by higher photon energy that causes skin damage such as sunburn. With regard to the danger of sunburn, UVB radiation is considerably more hazardous than UVA.

In addition, UVB is filtered by the ozone layer while UVA reaches the surface of the earth virtually unfiltered. For this reason, the amount of UVB radiation depends on the position of the sun and local circumstances such as the ozone layer thickness. When determining the UV Index that describes the strengths of radiation of the sun relevant for sunburn, UVA and UVB are weighted differently [3]. This UV Index is an internationally standardized measured quantity with typically 12 levels that depict the strength of the sunburn-producing radiation, to help avoid a too high.

The UVA + UVB sensor VEML6075 has separate photodetectors for UVA and UVB bands (see Figure 2(a)) and additional compensation channels for determining and acting upon noise caused by visible and infrared light sources in the environment. The UV Index can be calculated using the measured results of the individual channels (see [4]) via a calculation. The sensor is used in portable electronics, the “Wearables” market segment, to warn the user in good time against too much sun or
to remind the user about appropriate protection. Another area of application is monitoring UV LED light sources, for example, for industrial curing processes.

**Demonstrators**

The patented FILTRON technology is used to implement optical bandpass filters on CMOS photodetectors. The sensors presented by VISHAY Semiconductor GmbH provide channels for light ranging from UV to near-infrared wavelengths. For all the sensors cited, there are demonstrators that can easily be operated with the Vishay USB Sensor Starter Kit [5]. Software modules are readily available and allow access to all settings for convenient testing of the components in your own application.

*Dr. Heinrich Gottlob is a senior manager of R&D automotive sensors and Samy Ahmed is a manager applications engineer for sensors at Vishay Semiconductors GmbH.*

**Reference literature**

3. CIE1987 reference spectrum and UV Index
4. Application note "Designing the VEML6075 into an Application"
5. Demonstrators, Vishay

**Also see:**

- Photosensors brighten consumer and industrial products
- CCD vs. CMOS image sensors