OmniBSI™ Technology Backgrounder

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OmniVision Technologies, Inc.

At the heart of any digital camera lies the image sensor. The image sensor is an integrated circuit, like any memory chip or microprocessor, except that it's designed to be very sensitive to visible light. Image sensor technology has undergone rapid technological improvements in recent years. OmniVision's BackSide Illumination (OmniBSI™) pixel technology truly offers a giant leap forward in the world of imaging technology.

Image Sensor Trends

Understanding the key trends in the image sensor business helps to illustrate the substantial value offered through OmniBSI technology. Specifically, the image sensor market is being driven towards lower cost devices, smaller pixels, higher resolution, thinner camera modules and better image quality.

As with all electronics, the primary trend in image sensors is lower cost and higher performance. Lower cost is achieved primarily by shrinking all features on the die. Aside from transistors, whose size reduction is driven mainly by the microprocessor and memory industries, the largest devices on an image sensor are the actual pixels themselves. It is the innovation in the pixel technology that drives higher performance.

The second trend in image sensors is better performance. 'Make them smaller and better' has been the industry's mantra for many years, from salespeople to the pixel designers. The first image sensors for mobile cameras used 5.6 µ pixels, shifting to 2.8µ, 2.2µ, 1.75µ and smaller. Current leading-edge devices use 1.4µ pixels, with 1.1 µ and 0.9µ pixels in development. For comparison, the wavelength of visible light varies from 0.65 µ (deep red) to 0.40 µ (blue). Evidently, pixels are getting close to some fundamental physical size limits. With the development of smaller pixels, engineers are asked to pack in as many pixels as possible, often sacrificing image quality.

The third most important trend in image sensors is increased resolution. While resolution, measured in megapixels, is easily the most defining specification of a digital camera, it doesn't tell the whole story. Consumers demand higher resolution coupled with other performance factors.

The fourth trend in sensors is reduction in camera module size. In the majority of consumer electronics, the camera is built as a small, self-contained module integrated into the final product. The camera module contains the image sensor, a lens, a tiny circuit board and a plastic housing to hold it all together. Like sensors, camera modules are under enormous pressure to shrink in size and cost while increasing in resolution. A primary focus in recent years has been to make modules as thin as possible, a trend emphasized by ultra-thin mobile phones.

All the while, consumers expect mobile cameras to deliver image quality and features comparable to high-end digital still cameras. And why shouldn't they, with features like auto-focus, the resolution of digital still cameras (DSC) resolutions and image processing features like red-eye reduction, image stabilization and HD video recording?

Traditional CMOS Image Sensor Design

At its core, a solid state image sensor is a two-dimensional array of light-sensitive pixels. Each pixel contains a single photodiode with supporting electronics. Photodiodes are the actual light sensing structure, and convert visible light photons into electrons. The number of electrons collected by each pixel is measured by the in-pixel electronics, and the values are transmitted to the rest of the camera's electronics for further amplifying, image processing, storage and display.

In traditional CMOS Image sensors the "front" of most integrated circuits is the top surface, which contains all photodiodes, transistors, metal wiring layers and other electronics. This front-side layer uses only the top 1 percent or so of the silicon wafer. The remaining 99 percent becomes the "backside", and serves only as mechanical support and bonding surface, as well as an electrical ground terminal.

In image sensors, the photodiode array is fabricated along with the transistors on the front-side surface. The lens projects its image onto the front surface, where the light is collected by the photodiodes and digitized into an image.

Pixel Fundamentals

To understand the advantages of OmniBSI technology, some background information on pixel performance and the limitation of current technology is useful.

Electrical circuits can't sense light directly; the light as photons must first be converted to electrons. That's the job of the photodiode which absorbs the light and converts each photon into one electron and stores those electrons as you would store rain drops in a bucket. Like a heavy rain, the brighter the image, the more photons that land on the sensor over a given period, the fuller the photodiode buckets become.

The process of converting photons to electrons is perfect; every photon that strikes the photodiode is converted into a electron by the photodiode structure. The problem is that not every photon that strikes also strikes the photosensitive area, the photosensor, because the photodiode is just a component of the sensor and so is smaller than the physical size of each pixel. The ratio of the number of photons hitting the sensor to the number actually converted to detected electrons is known as quantum efficiency (QE). QE is dependent on the wavelength (i.e. the color) of the light. The closer to 100 percent, the stronger the electrical signal, resulting in a more vivid image.

QE is an important aspect of sensitivity, which is an important metric of camera performance. In the context of sensors, sensitivity measures size of the output signal for a known number of input photons. Intuitively, more sensitivity is better noise floor also has to be considered. The noise floor is the minimum detectable signal of the photodiode. The same way it's hard to see the change in water level caused by a single drop of rain, small changes in signal are hard to accurately measure. Noise is also present in film cameras, and noisy images are usually termed "grainy". This noise floor is a critical performance parameter for image sensors, as it determines how small a signal (or how dim an image) can be before it's indistinguishable from random measurement error.

Engineers use the ratio of the measured signal to the noise floor (the signal to noise ratio, or SNR) as one of the most critical sensor performance metrics. The SNR level relates well to the overall image quality. An image with a low SNR will look grainy, and an image with a high SNR will look good.

This, however, only considers the image sensor pixel array alone. In reality, the pixels are connected to a good deal of supporting circuitry by layers of metal wiring on top of the silicon surface. Recall that light is shining downwards onto the silicon surface, and must pass though these metal routing layers first. Since metal is both opaque and reflective, it creates a huge problem in pixel design. The wires have to be kept out of the light path, or they will cast shadows or reflect the light away from the photodiode, negatively impacting image quality; i.e. lower the sensors QE and sensitivity as explained above.

Any light striking the wires is not just directed away from the right photodiode, but often reflected into another photodiode, in a phenomenon called "crosstalk" (refer to FSI pixel shown in Figure 1).

Crosstalk creates blurry images by causing the light from a small object (destined for only one or two pixels) to be spread out into neighboring pixels. Since photons aren't being collected in the right place, the resulting electrical signal at the target pixels is smaller than it could be, therefore reducing the SNR of the image. This is especially important in low-light images, where there aren't many photons to begin with. Crosstalk also reduces color quality, as the photons must pass through color filters on their way to the photodiode. Adjacent pixels possess different colored filters, and crosstalk distorts the sensor's color perception. Clearly sharp, low-noise images and good color are the desirable features in photographs, thus eliminating crosstalk is an important element.

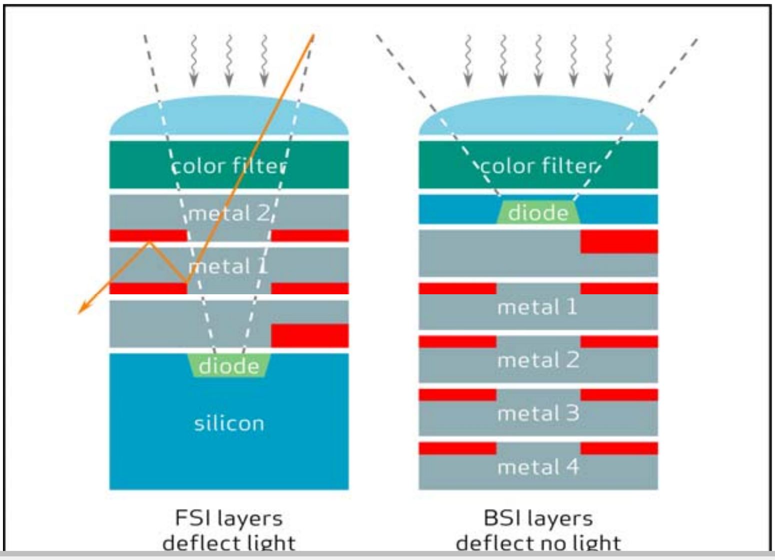

Figure 1: FSI and BSI crosstalk comparison

As Figure 1 illustrates, getting light to the pixel is quite difficult, and the trend toward shrinking pixels isn't helping. Although pixels are getting smaller, the metal layer stack-up isn't thinning as rapidly. The result is that pixels now resemble a tall glass, rather than a bucket, commonly referred to as the "pixel straw".

Since light cannot pass through the metal walls, it's very hard to get the light where you want it unless it's perfectly aimed. Pixel designers go to great lengths to achieve this, including adding tiny lenses (micro lenses) to the top of each pixel to direct light towards the photodiode and away from the metal layers. More exotic techniques include reducing the number of metal layers in the pixel array, and innovative circuit designs to minimize the number of metal wires required. But the problem remains; how do you get light past all of the metal layers while continuing to shrink pixel size?

Do tall pixels and crosstalk affect the camera design? Yes, and profoundly so, with the greatest impact being on the lens design. The best way to get light through the pixel straw is to send it straight through, which means the lens has to aim all rays of light towards each pixel at perfect right angles to the sensor surface. Doing so requires very tall lenses, which simply isn't possible in the small space allowed for mobile cameras.

Practical mobile phone lenses produce images where the rays of light form relatively flat cones. The industry term "chief ray angle" (CRA) defines the cone angles that the light passing through the center of the lens will follow. Mobile phone lenses typically have CRAs ranging from 20 to 30 degrees. Making the lens thinner (shorter) requires squishing the cone, which further increases the CRA. Twenty or thirty degrees might not seem so large, but compared to most DSC lenses where the cone angles are 5 degrees or less, it is significant. Sensor designers can compensate to some extent by adjusting the positions of the micro lenses to better align with the actual paths the light follows to the photodiode. This matching isn't perfect, since light rays destined for a particular pixel can pass though different parts of the lens and at different angles. The sensor also ends up tuned to a very specific lens design, limiting the selection of lenses a manufacturer can use, or causing problems if the lens properties change, as in the case of autofocus or zoom lenses. Mismatches between the sensor and lens can cause color shifts across the image, darkened corners and other image artifacts. The ideal sensor would not be so selective, accepting light from a range of angles and lens designs without suffering crosstalk or reductions in sensitivity.

Backside Illumination (OmniBSI) Technology

As previously described, FSI pixels have been shown to suffer many disadvantages – low QE, low sensitivity, high crosstalk and high sensitivity to CRA mismatch. So what if there was a way to get the light to the photodiode through the backside of the silicon? By avoiding the metal layers, one could avoid all the drawbacks associated with FSI pixels.

This is the essence of OmniBSI technology. As discussed, an image sensor's backside is the bottom surface of previously unused silicon. OmniVision has developed a technology for reducing the thickness of the silicon wafer without compromising the image sensor's strength or flatness.

Manufacturing CMOS Image Sensors

Image sensors are made in the same silicon fabrication process as other CMOS semiconductors as reflected in Figure 2. Devices such as transistors and photodiodes are defined and created in a pure silicon crystal wafer. Three to six layers of metal wires (aluminum or copper) are deposited on top of the silicon to connect the silicon devices together. The image sensor process involves a few more steps to create the color filters and micro lenses that enable the sensor to see color and to improve image quality.

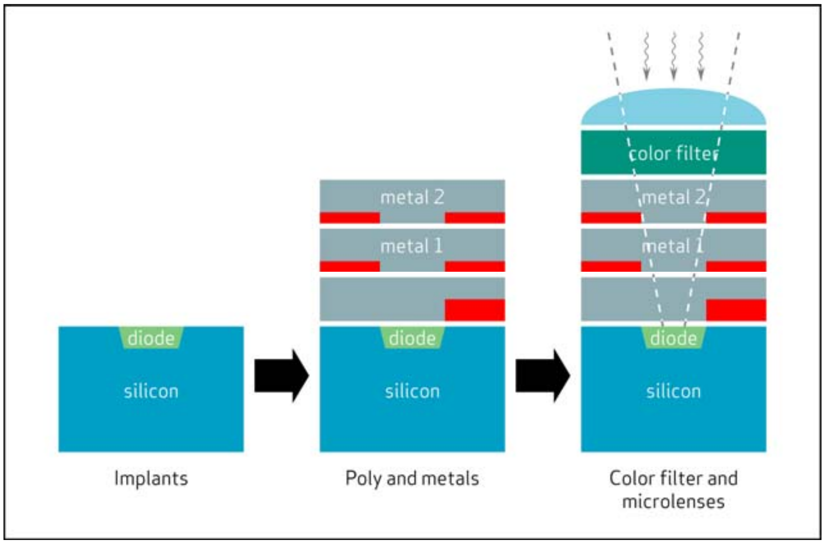

Figure 2: Manufacturing FSI pixels

Although the same initial process steps (fabricating transistors and depositing metal layers) are used for both FSI and BSI technologies, during manufacturing of OmniBSI sensors, the process takes a radical turn — literally. Once the metal layers are deposited, the silicon wafer is flipped over and ground thinner than a strand of human hair. This is a crucial step and is key to the performance of OmniBSI technology. The process of grinding a 200 mm to 300 mm diameter silicon wafer without causing it to shatter is extremely challenging. OmniVision and its manufacturing partner, TSMC, worked closely together to develop the necessary technology that allows grinding the wafer to the levels required for high-volume production.

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