Smartphone Photography

Anatomy of the Active Pixel Sensor Photodiode

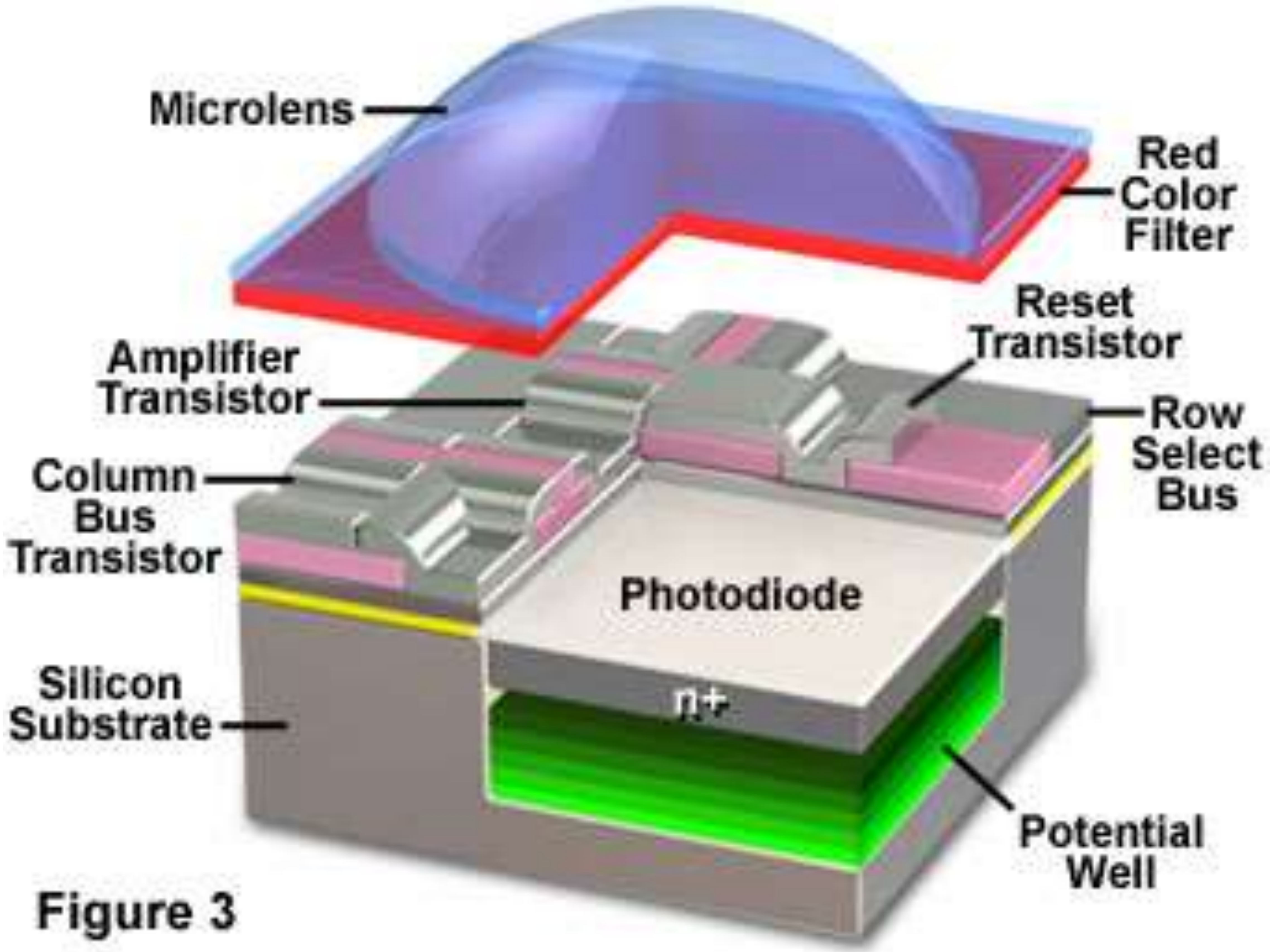


Figure 3

CMOS Image Sensor Integrated Circuit Architecture

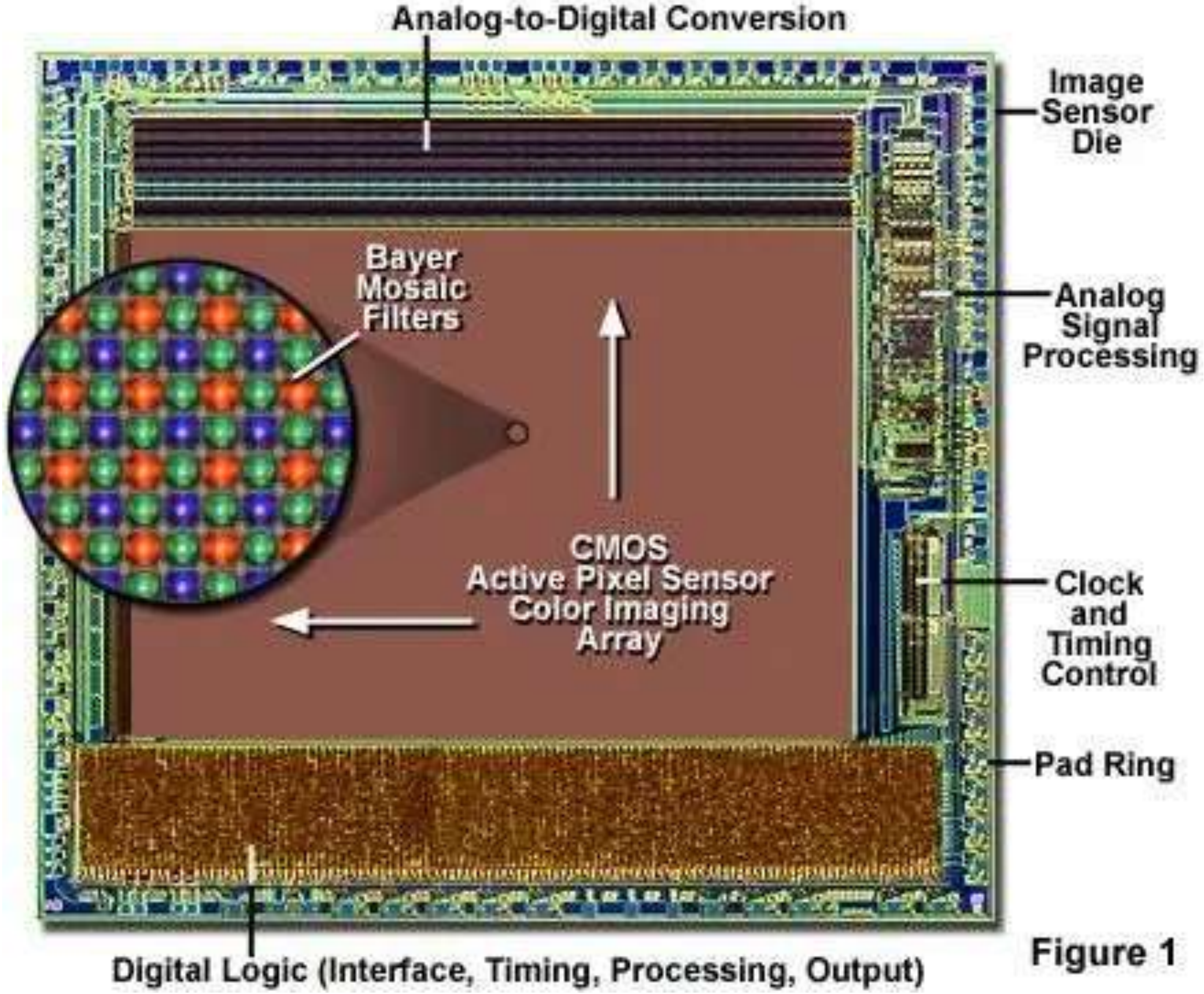
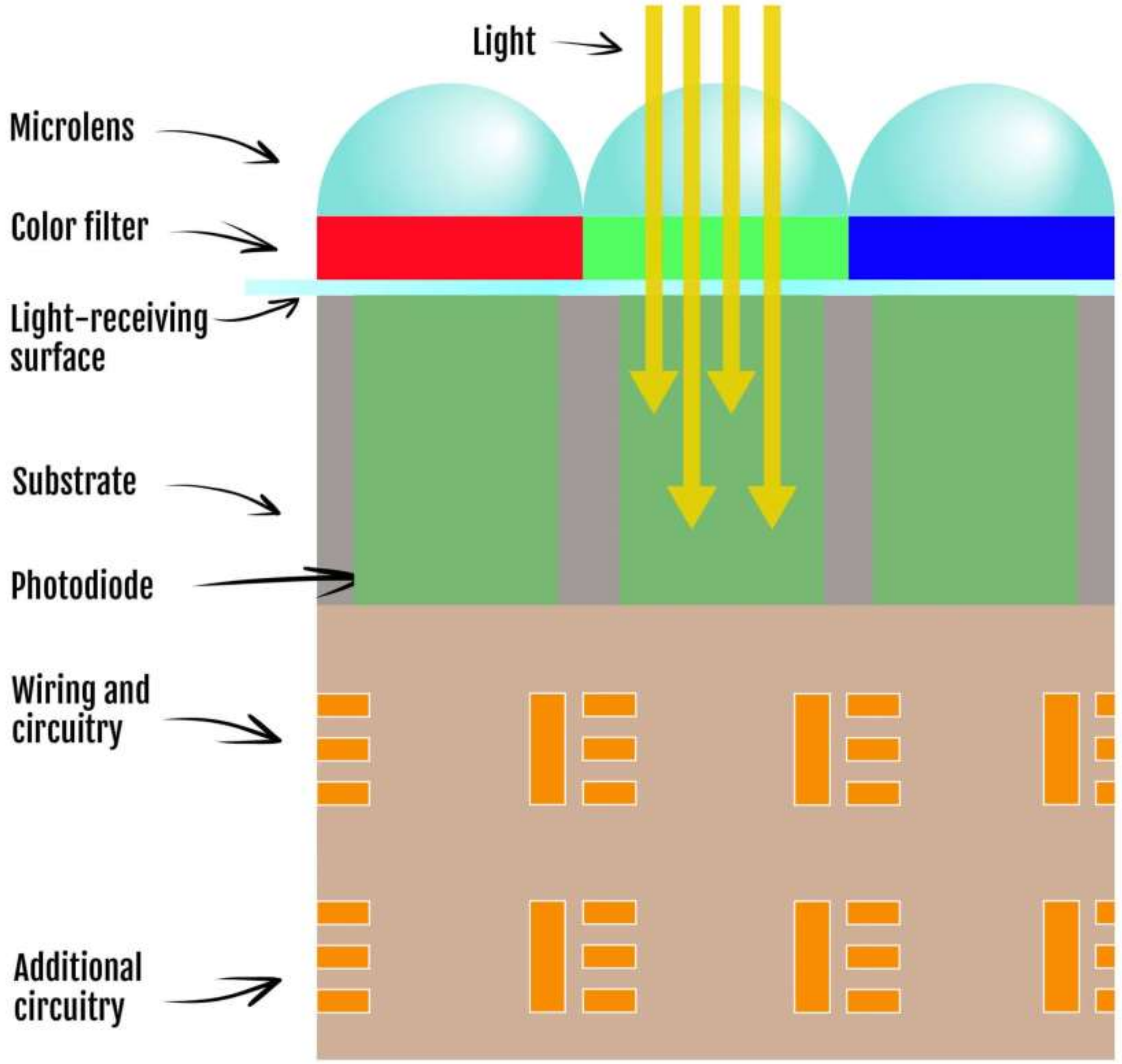


Figure 1

Stacked Sensor

Figure 6: Cross section of a stacked CMOS sensor. For illustrative purposes only.



While the BSI sensor design increases quality, the stacked sensor is all about increasing speed.

Until the introduction of the stacked sensor, CMOS sensors operated on a single layer. This meant the signal readouts from each pixel had to travel along strips of wiring all the way to the outside of the sensor before they were processed.

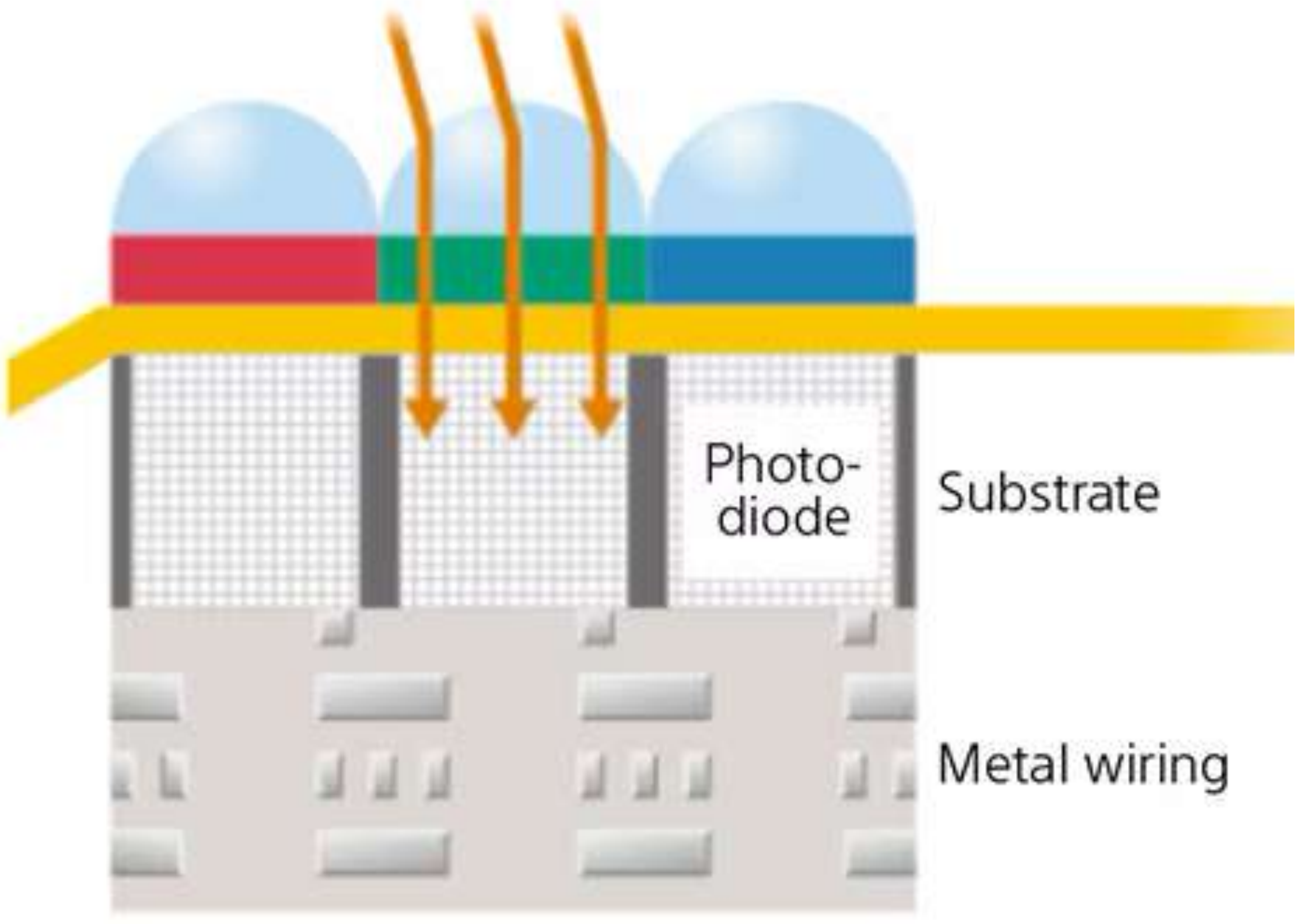
With stacked sensors, these processing chips have been added to the back of the sensor, essentially creating a 'stack' of chips sandwiched together.

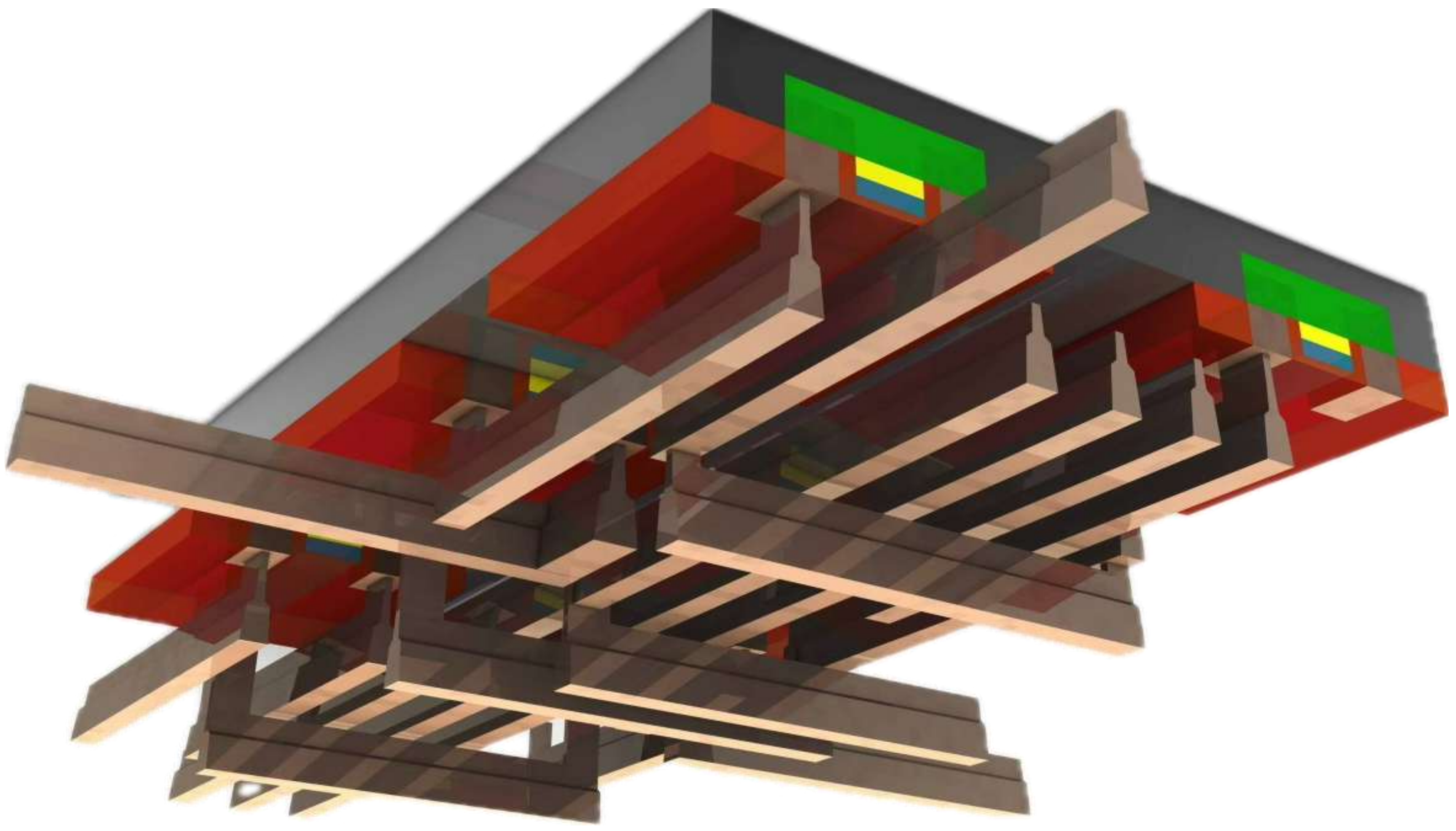
By stacking them in this way, the distance the pixel values have to travel is drastically reduced, resulting in much faster processing speeds.

For example, the X-Trans CMOS 5 HS stacked sensor found in **FUJIFILM X-H2S** enjoys four times the reading speed of its predecessor and 33 times the reading speed of the original X-Trans CMOS sensor featured in X-Pro1.

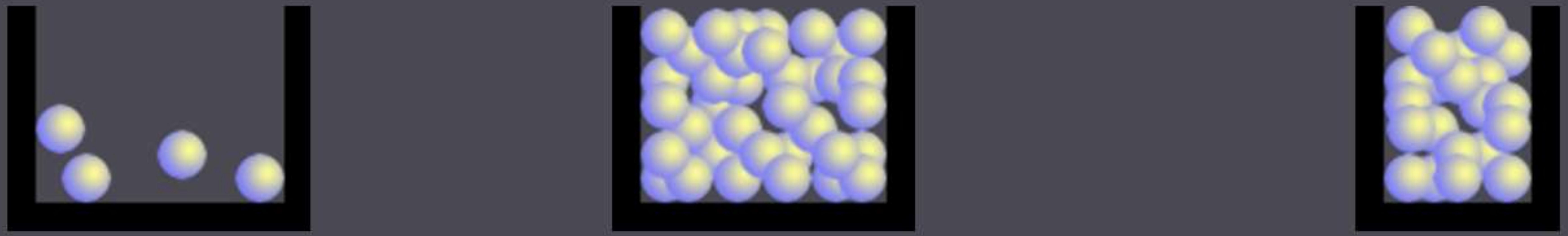
What's more, without the problem of obstructing light entering the sensor, it's possible to keep stacking additional chips, offering huge potential for future developments.

- Smartphone sensors because of dense packaging have severe design problems
- Thermal management , heat dissipation.
- Electrical noise, siganal degradation and cross talk.
- Dynamic range





Although the meaning of dynamic range for a real-world scene is simply the ratio between lightest and darkest regions (contrast ratio), its definition becomes more complicated when describing measurement devices such as digital cameras and scanners. Recall from the tutorial on digital camera sensors that light is measured at each pixel in a cavity or well (photosite). Each photosite's size, in addition to how its contents are measured, determine a digital camera's dynamic range.



Black Level
(Limited by Noise)

White Level
(Saturated Photosite)

Darker White Level
(Low Capacity Photosite)

Photosites can be thought of as buckets which hold photons as if they were water. Therefore, if the bucket becomes too full, it will overflow. A photosite which overflows is said to have become saturated, and is therefore unable to discern between additional incoming photons — thereby defining the camera's white level. For an ideal camera, its contrast ratio would therefore be just the number of photons it could contain within each photosite, divided by the darkest measurable light intensity (one photon). If each held 1000 photons, then the contrast ratio would be 1000:1. Since larger photosites can contain a greater range of photons, **dynamic range is generally higher for digital SLR cameras compared to compact cameras** (due to larger pixel sizes).

Full Frame 36mm x 24mm 864mm2

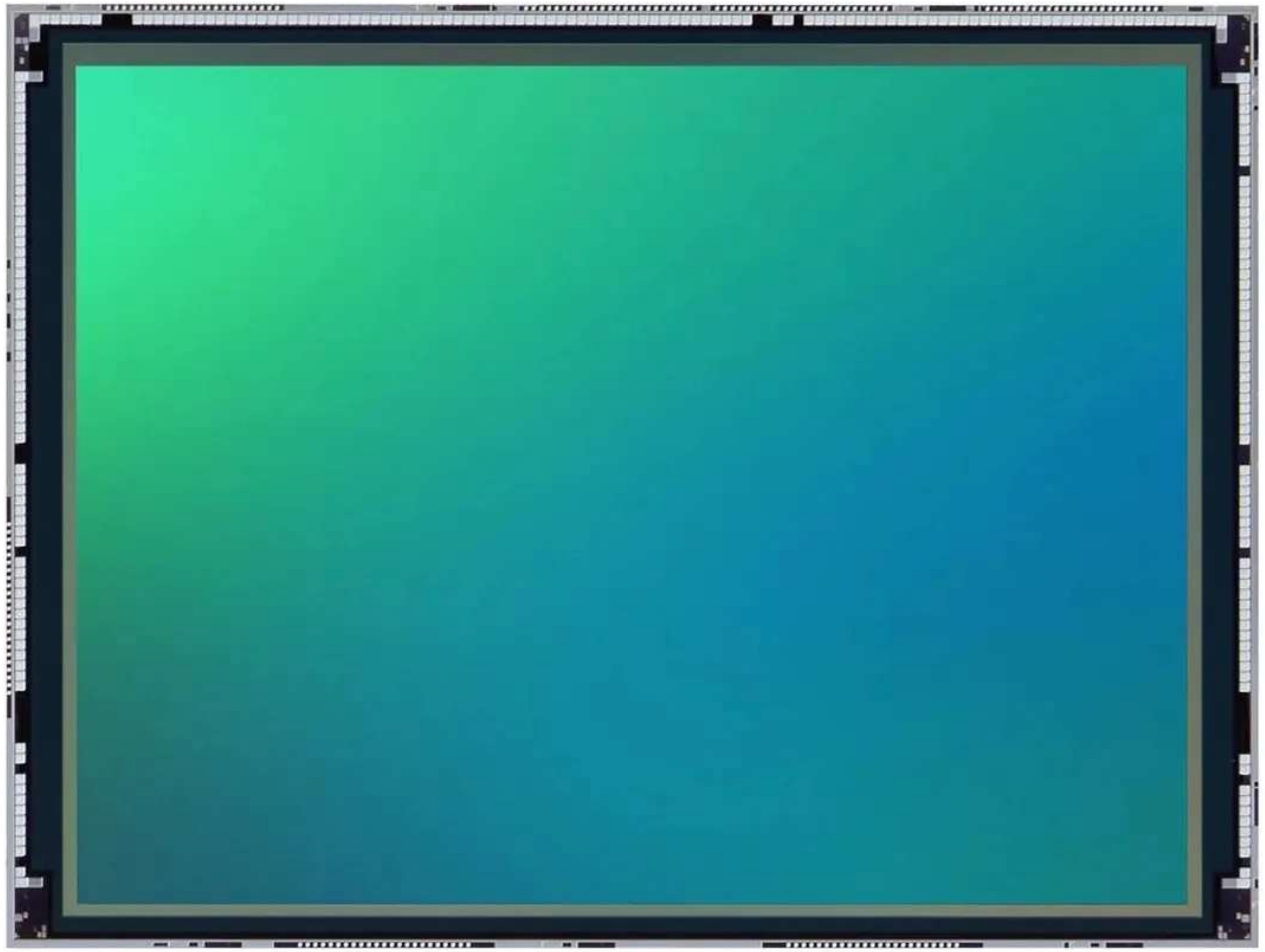
18mm Diameter 254 mm2

200 megapixel?
9mm x 11.5mm 103 mm2

Sony's LYT-901 is its first 200MP camera sensor

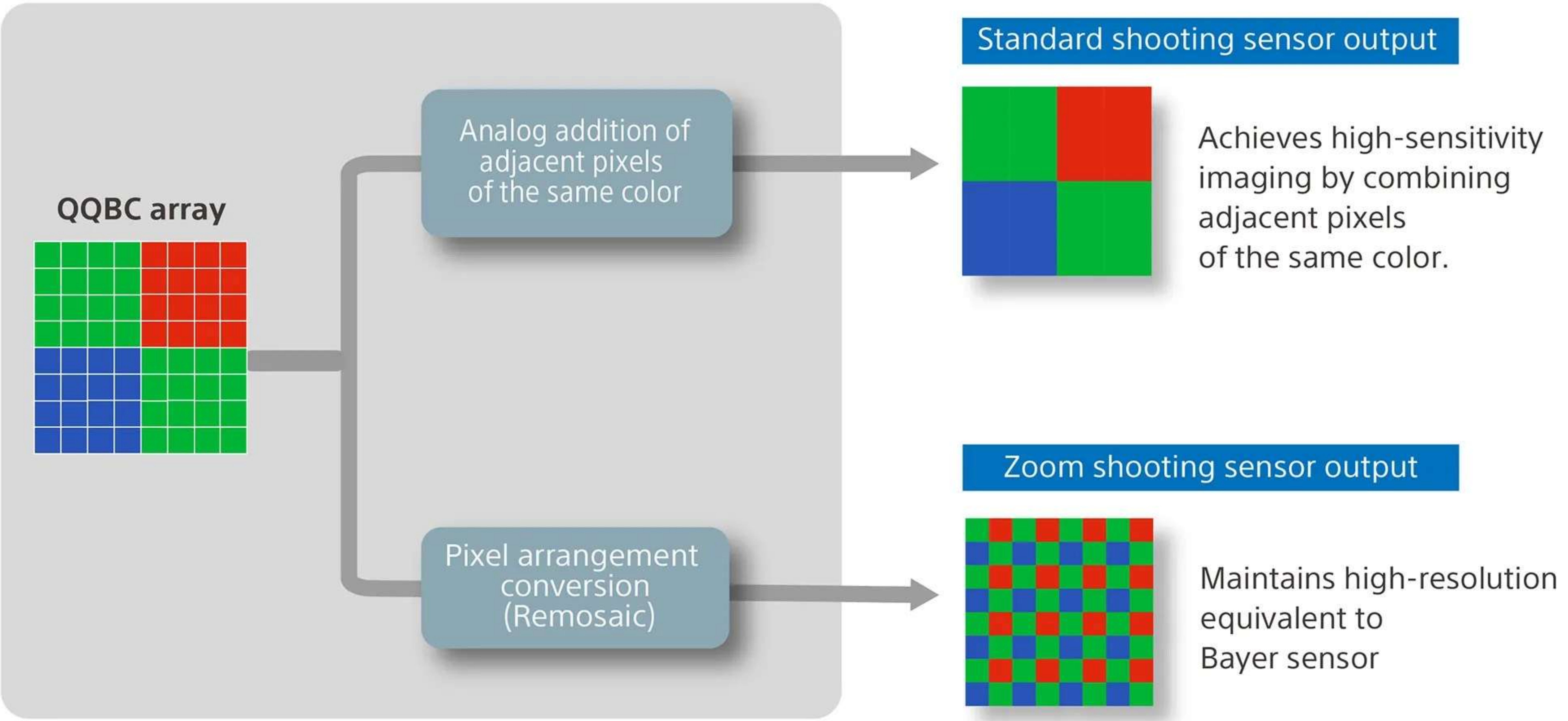
Sony Semiconductor has launched the [LYTIA LYT-901 camera sensor] for mobile devices. It is a 1/1.12-inch sensor with 200MP resolution and 0.7-micron pixels. This means it is slightly bigger than Samsung's biggest 200MP camera sensor, the ISOCELL HP1, which is a 1/1.22-inch sensor with 0.64-micron pixels. Its bigger pixels should theoretically allow it to capture images with relatively less noise in low-light and mixed lighting conditions.

Sony's new sensor offers all-pixel autofocus, likely referring to dual-pixel phase-detection autofocus. It can also capture images and videos with 4x in-sensor zoom, offering optical zoom-like quality, and 16-in-1 pixel binning for capturing 12.5MP images with improved quality in low-light conditions.



■Approximately 200-effective megapixels and Quad-Quad Bayer Coding (QQBC) array deliver both high resolution and high sensitivity

- **The new sensor uses a pixel pitch of 0.7 μm for an approximately 200-effective megapixel resolution on a 1/1.12 large-format sensor. Advances in pixel structure and color filter design increase the saturation signal level, contributing to improved dynamic range.**
- **To leverage the high resolution of approximately 200-effective megapixels, the new product employs a Quad-Quad Bayer Coding (QQBC) array in which 16 (4×4) adjacent pixels are clustered with filters of the same color. During normal shooting, the signals of the 16 clustered pixels are processed as a single pixel unit, allowing the camera to maintain high sensitivity even at night and in dim indoor shooting conditions. On the other hand, during zoom shooting, a form of array conversion processing known as remosaicing reverts the clustered pixels to a normal pixel array, to deliver high-resolution imaging.**



Array conversion processing (remosaicing), which reverts the QQBC array to a normal pixel array, requires extremely advanced calculation processes. For this product, Sony has developed a new AI learning-based remosaicing for the QQBC array and mounted the processing circuit inside the sensor, for another Sony industry-first.

This new technology makes it possible to process high-frequency component signals, which are generally difficult to reproduce, offering superior reproduction of details such as fine patterns and letters. Furthermore,incorporating AI learning-based remosaicing directly in the sensor enables high-speed processing and up to 30 fps high- quality video capture when shooting with up to 4x zoom in 4K resolution.

Demosaicing

As covered above, a single pixel can only record a single value. But if you zoom into a digital image, each individual pixel can contain a mixture of colors, rather than just the red, green, or blue allowed by the color filter array.

So, how are the other colors added? And how does the camera know the correct amount to use?

The answer is a process called demosaicing, in which a demosaicing algorithm predicts the missing color values for an individual pixel based on the strength of the color recorded by the pixels that surround it.

This is done automatically by the camera's built-in processor, which then turns it into a viewable image file format such as JPEG or HEIF.

In many cases, such as photographing on a smartphone, that is the end of the process. However, most mirrorless cameras have the ability to save images in RAW format, providing photographers with more options.

As the name suggests, a RAW file contains the raw image data before any demosaicing has taken place. This allows photographers to demosaic images using external software such as **Capture One**.

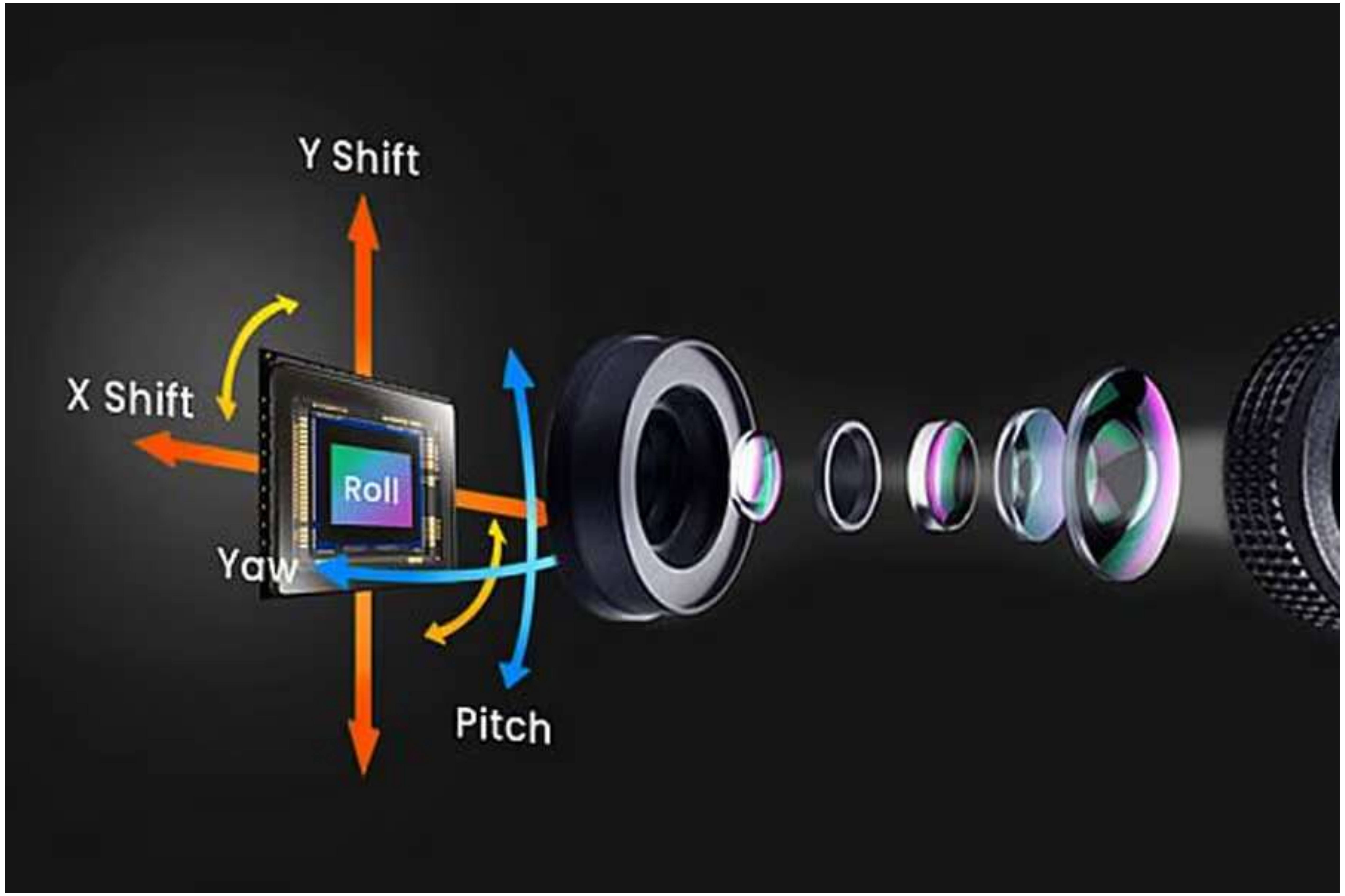
Different types of software use distinct demosaicing algorithms, each offering unique aesthetics. An obvious advantage of this is that photographers can choose their personal preference, but the benefits of creating in RAW format extend much further.

Advantages of RAW Files

File types such as JPEG and HEIF are designed to make image files easily portable, so significant compression takes place to achieve the smallest possible file sizes.

During the compression process, a large amount of tonal and color information read by the sensor is lost. Less information means lower quality and, in turn, restricted freedom to edit.

As a result, RAW files contain a wider dynamic range and broader color spectrum, which allows for more effective exposure correction and color adjustments.



Optical Image Stabilization (OIS)

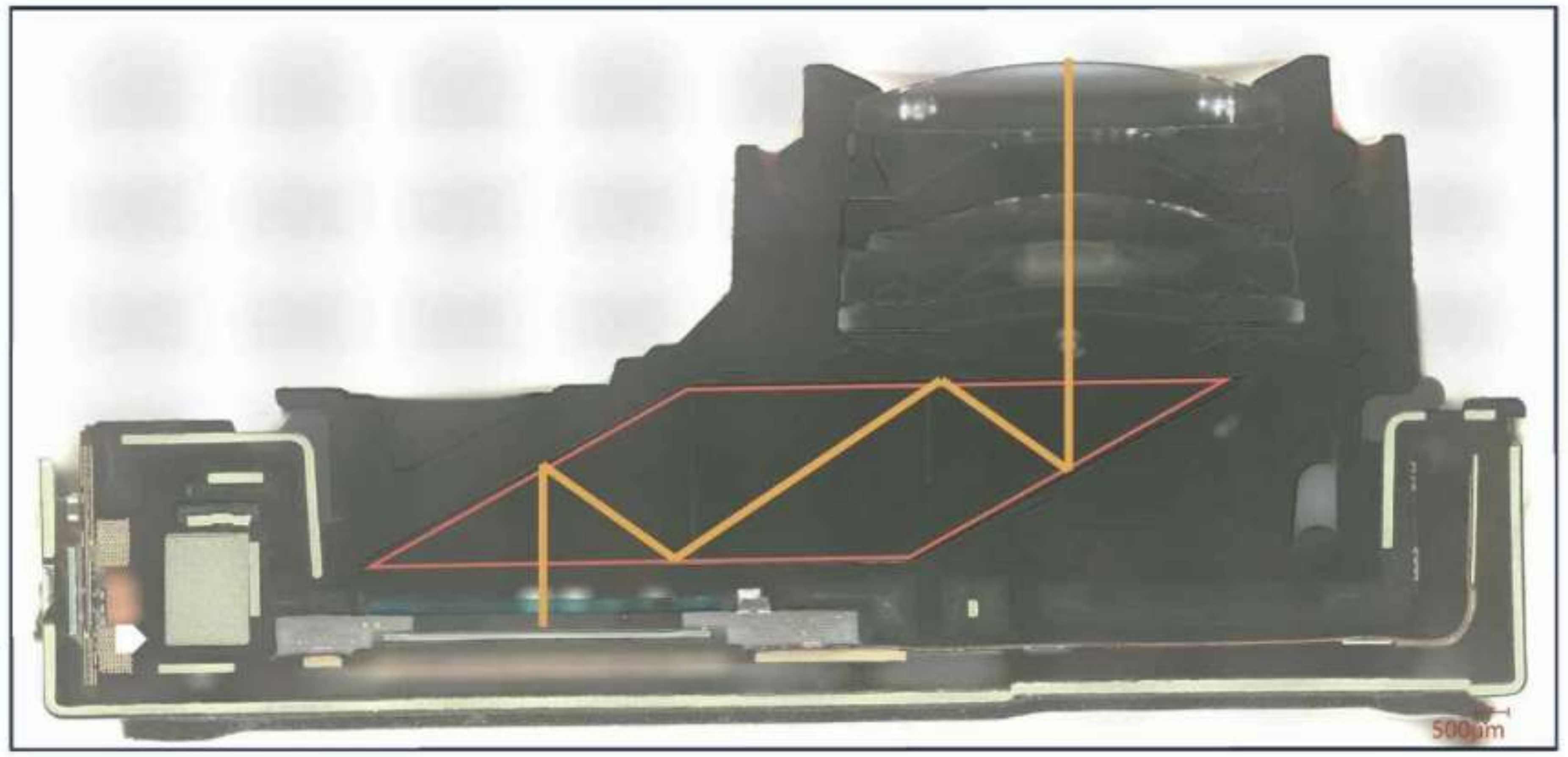
Here's the breakdown: **Detection**: OIS uses tiny gyroscopic sensors to detect any tilting or wobbling of your smartphone. These sensors work together with moving lens parts and a gyroscope to stay on top of your phone's movements. **Compensation**: When you snap a photo or start recording, OIS jumps into action. It notices any hand shakiness and quickly moves the lens or camera sensor to balance things out. For instance, if your hand tilts left, OIS shifts the camera a bit to the right. **Result**: This superhero feature is fantastic, especially in low-light situations or when you're shooting videos. It makes your photos and videos much clearer and sharper compared to if you didn't have stabilization, especially when using your phone without a tripod. OIS ensures that your memories come out looking top-notch!

Optical Image Stabilization (OIS)

Olympus released their first IBIS system in the E-510 DSLR in 2007. They ran with the technology, delivering the world’s first 5-axis IBIS system in the OM-D E-M5 camera in 2012. They also repurposed the accurate control of the image sensor to implement a *pixel shift high resolution* multi-shot in 2015. They move the sensor by 1/2 and 1 pixel increments to deliver two interstitially overlapping images delivering full R, G, and B samples per pixel for every pixel cell. Olympus did a great deal of work on voice coil motors and improved gyro sensors in order to keep improving their IBIS system over the years.

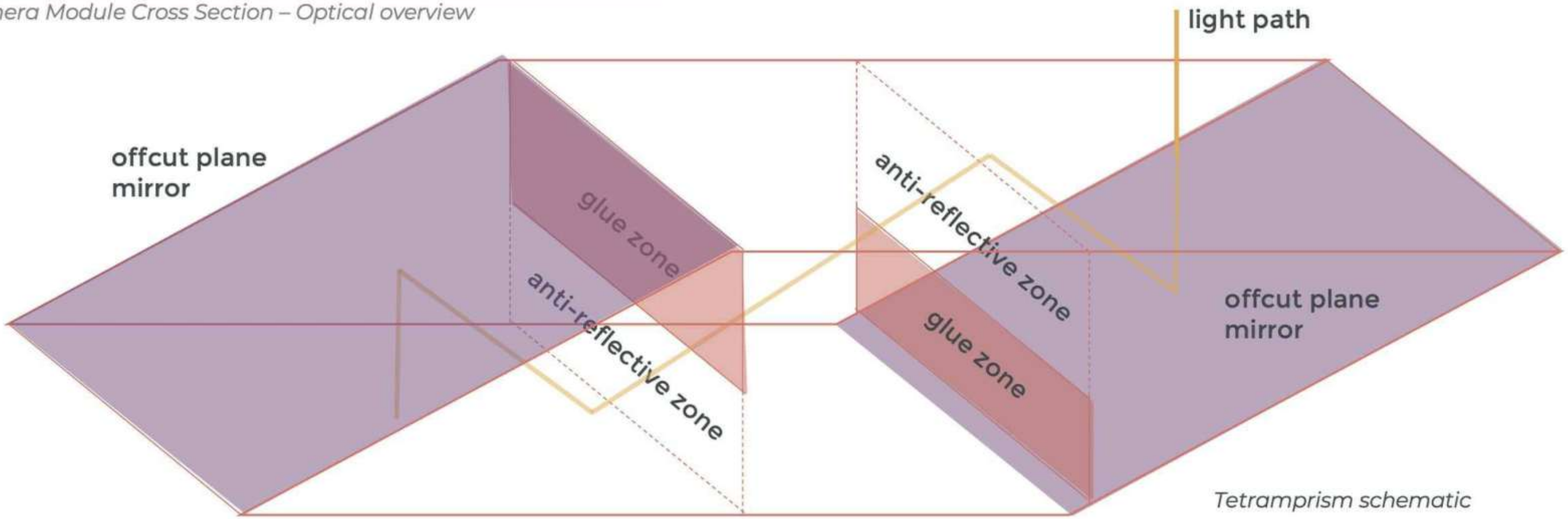
IPHONE 15 PRO MAX
– REAR PERISCOPE CAMERA MODULE: TETRAPRISM FOCUS

Source: Smartphone Camera Module & CIS Comparison 2024, Vol. 1:
iPhone technology, process, and cost comparison report, Yole SystemPlus, 2024



Camera Module Cross Section – Optical overview

- The tetraprism is a parallelepiped made by fusing 3 pieces of glass
- At each interface between glass pieces, there are 2 zones: a glue zone to hold the pieces together and an anti-reflective zone to increase transmission of light.
- The offcut planes are coated with metal to create mirrors
- Top and bottom planes are not coated, instead relying on total internal reflection.



Tetramprism schematic

What is a Ring Buffer

- Ring buffer - The camera records frames in a “ring”, with each frame filling a new spot on the ring. When the ring is full, the next frame overwrites the first frame in the buffer. Each subsequent frame is also overwritten. This means you can start recording whenever you want, and the camera will only save the buffer when you press the trigger. By default, when you press the trigger it immediately stops recording.

Figure 3 - 7 frames of video recorded into an 8-frame ring buffer.

Figure 4 - 8 frames of video recorded into an 8-frame ring buffer.

Figure 5 - 9 frames of video recorded. The 9th frame has replaced the 1st frame.