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2020
Release of 1/2-inch SXGA InGaAs-Si- stacked visible and short-wavelength infrared light image sensors (Sony)

~ Discrete Semiconductor/Others ~

Light with a wavelength between 0.9μm and 2.5μm in infrared rays is called near-infrared or short-wavelength infrared (SWIR).

SWIR has properties relatively close to visible light, but is invisible to the naked eye. Because of its long wavelength, SWIR is slightly affected by scattering of fine particles, etc., and can penetrate haze, smoke, thin paper and cloth. It can also penetrate into the skin to a depth of several millimeters. It has absorption and reflection characteristics of objects different from visible light, such as absorption by water (wavelength: 1.45μm). Vegetation reflects more SWIR out of sunlight than visible light.

Utilizing this property, SWIR is widely used in night-vision and security cameras, inspection of package contents and foreign objects, measurement of sugar content of fruits, vein recognition, medical examination, and remote sensing. Face recognition using SWIR is now available in smart phones.

Photodiodes (PDs) with a lattice-matched InGaAs layer on an InP substrate as the photosensitive layer are widely used for SWIR detection, because they are superior in low dark current, high quantum efficiency, fast responsivity, and reliability. They can also be operated without cooling and have excellent productivity, although their sensitivity is limited to a wavelength of 1.7μm. InGaAs PDs were first used in the field of optical communications (1). In the latter half of the 1970s, because the propagation loss of fused silica fibers used for long-distance optical communications was found to be minimum at wavelength of 1.55μm, InGaAsP/InP lasers that emitted light at a wavelength of 1.55μm and related technologies were developed actively (2). This has led to advances in materials, crystal growth, and processing technologies of InP crystals, ternary and quaternary compound semiconductor crystals that are lattice-matched to InP. That enabled the productive manufacture of highly reliable devices.

In the 1980s, the development of linear (one dimensional) image sensors using InGaAs PDs began to start. Thomson CSF developed a linear array sensor consisting of 300 InGaAs PDs for the SPOT IV remote sensing satellite In 1987 (3). Sensor Unlimited Inc. developed an area (two-dimensional) image sensor with a monolithic integration of InGaAs/InP PDs with 16x16 pixels and JFETs as switch elements in each pixel in 1996. In 1999, Sensor Unlimited Inc. developed an area image sensor by stacking a back-illuminated InGaAs/InP PD two-dimensional array chip with a thickness as thin as 5μm on a Si substrate with a CMOS readout circuit, as shown in Figure 1 (4). The electrodes facing each other on the chip surface were connected with bumps made of Indium, a soft metal. In the 2010s, the trend toward high pixel counts continued, and SXGA (1280x1024 pixels) area image sensors were developed by a number of companies [5]. All of them adopted the method of connecting the InGaAs/InP PD chip to the CMOS readout circuit chip by bumps. Due to the limitation of bump formation processing accuracy, the minimum pixel pitch was 10-20μm, and further narrowing of the pitch has been difficult.

Sony developed a stacking technology that directly connected pixel chips and CMOS logic circuit chips with 3μm square Cu pads formed on each chip surface in 2015, which was highly productive, reliable, and suitable for fine processing and narrow pitch. The technology has been adopted for back-illuminated stacked CMOS image sensors [6]. Sony expanded the technology to more sophisticated technology of stacking InGaAs/InP PD chips on CMOS logic circuit chips in the state of wafer using Cu-Cu bonding. This led to the development and commercialization of a 1/2-inch image sensor with 1280x1024 pixels at 5μm, in which a back-illuminated InGaAs/InP PD array chip was stacked on a Si chip with a CMOS readout circuit [7,8]. Each pixel was connected to a silicon readout IC by Cu-Cu bonding. The InGaAs/InP PDs array was fabricated by epitaxial growth of an n-InGaAs layer and an n-InP layer on an n-type InP substrate, and then diffusing an array of Zn from the surface until it reached the InGaAs layer to form highly doped anodes. The InP substrate, which was the light illuminated side, was thinned by a newly developed damage-free process technology to reduce the absorption of visible light in the InP substrate. A compact image sensor was realized ,which was capable of seamless image capture over a broad range of wavelengths covering from the visible to short-wavelength infrared range (wavelength: 0.4μm to 1.7μm).

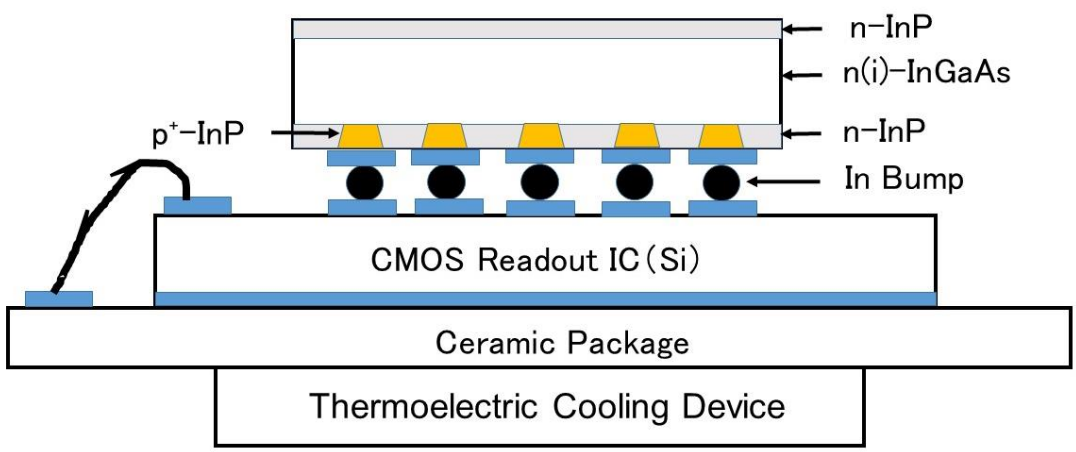
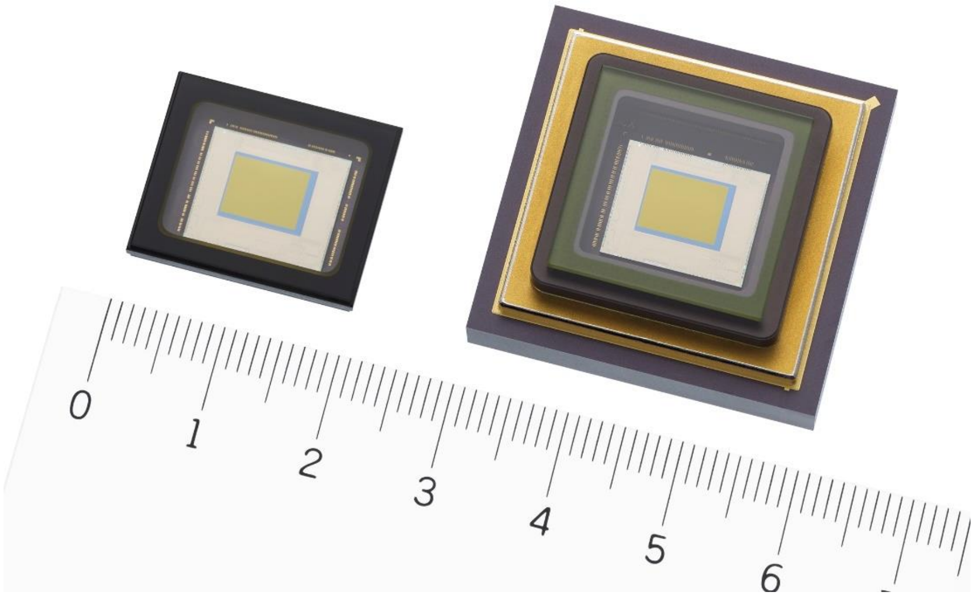


Figure 1 Schematic of the cross-sectional structure of a typical InGaAs area image sensor



Left: Ceramic LGA package　　Right: Ceramic PGA package with built-in thermoelectric cooling

Figure 2　SWIR image sensor (IMX990)
(Courtesy of Sony Semiconductor Solutions Corporation)

(Under visible light)　　(Under SWIR)

Figure 3　Example of imaging

Information of surface and under-the-skin of apples are obtained at the same time by switching the light source. It is possible to identify scratches that cannot be seen under visible light by water absorbing light with a wavelength of 1.45 ㎛.
(Courtesy of Sony Semiconductor Solutions Corporation)

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