The "Light- in-Flight" Imaging with a Silicon Image Sensor Operating at 10 ns

Kindai Univ.[1], Ritsumeikan Univ.[2], ○ T. G. Etoh[1,2], Hitoshi Nakano[1], K. Takehara[1], K. Shimonomura[2]

E-mail: yb6t-etu@asahi-net.or.jp

PURPOSE A silicon image sensor operating at the frame interval of 10 ns (the equivalent frame rate: 100 Mfps) was developed. The pixel and the frame counts are respectively 576 x 512 pixels and 10 frames. The sensor was applied to "The Light-in-Flight imaging". The frame rate is highest among those of the image sensors capturing consecutively more than several frames. The theoretical highest frame rate of the silicon image sensor is about 10 ps[1)]. The frame interval of 100 ps is achievable with the existing technologoies[2)]. The sub-nano-second image sensors will innovate advanced measurement technologies, such as LIDAR, FLIM and Imaging TOF MS.

The imaging of the flying light has been achieved on the laboratory tables[3), 4)]. On the other hand, the imaging by the test camera requires a large experimental setup for the light flying 30 m during 10 ns x 10 frames. It's still worth giving it a try as explained below.

In 1991, Kindai University developed a digital high-speed video camera of 4,500 fps. The frame rate of 100 Mfps is 22,222 times higher. The increase of the frame rate in the 27 years has been supported by several innovations. It took several years for the practical importance and the technical feasibility of each innovative technology to be understood and accepted. However, once the camera with the technology was developed and the example images were released, the technical field immediately developed. The success of the light-in-flight imaging of the test camera of 10 ns will encourage further development of the sub-nano-second image sensors, and proceed the innovation of the advanced measurement technologies requiring the ultra-high-speed image sensors.

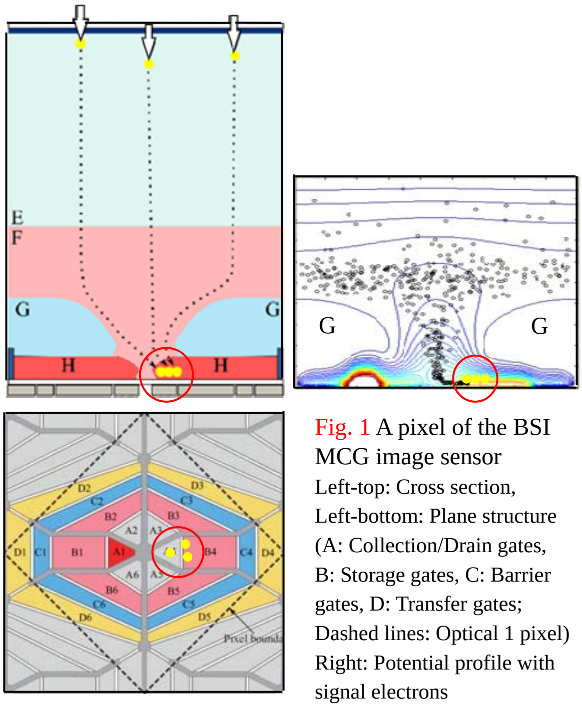

Fig. 1 A pixel of the BSI MCG image sensor
Left-top: Cross section,
Left-bottom: Plane structure
(A: Collection/Drain gates,
B: Storage gates, C: Barrier gates, D: Transfer gates;
Dashed lines: Optical 1 pixel)
Right: Potential profile with signal electrons

STRUCTURE Fig. 1 shows one pixel of the backside-illuminated multi-collection-gate (BSI MCG) image sensor: the cross section, the electrodes on the front side, and the potential distribution with the signal electron distribution at a certain time after the instantaneous illumination. The generated electrons move around the p-well (G in Fig. 1) to the center, fall down through the center hole of the p-well, and are collected by one of the five collection gates placed at the center to which a higher voltage VH is applied. One gate is the drain gate. The VH is applied to the collection gates in turn at a very short time interval to collect five signal charge packet. Originally, the frame count is about 600 kpixels (=576 x512 x2). The interlace operation doubles the frame count to 10, sacrificing the pixel count to the half, 300 kpixels. The fill factor is 100 %.

Fig. 2 A single frame with the laser beam extracted from images taken with a consumer video camera

LIGHT-in-FLIGHT IMAGING A pair of mirrors are erected with the distance of 7.43 m, between which the pulsed laser beam of the width of 5 ns are reflected and propagates. Fig. 2 shows one frame extracted from the images taken with a consumer video camera, in which the laser beam was captured. Fig. 3 shows three consecutive frames among ten frames captured by the test camera. The motion picture is more attractive[5)].

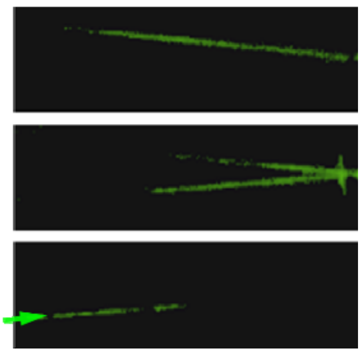

Fig. 3 Reflecting light
3 frames from 10 consecutive frames captured at 10 ns

References 1) Etoh, et al., The theoretical highest frame rate of silicon image sensors, Sensors, 17(3), 2017. 2) A. Q. Nguyen, et al., Toward the ultimate-high-speed image sensor: from 10 ns to 50 ps, MTA, ITE, submitted, 2018. 3) T. Kubota, Y. Awatsuji, Observation of light propagation by holography with a pico-second pulsed laser, Opt. Lett. 27, 815-817, 2002. 4) L. Gao, et al., Single-shot compressed ultra-fast photography at one-hundred billion frames per second, Nature, 516, 74-77, 2014. 5) YOUTUBE: https://youtu.be/GYrvkcoou54