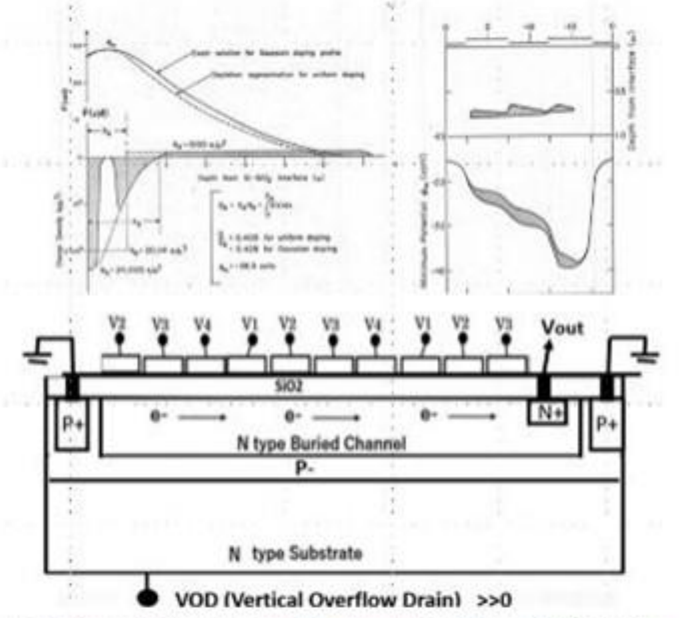

Fig. 3 Simple MOS capacitor type Four-Phase Buried Channel CCD delay line with the substrate type VOD, widely applied in frame transfer (FT) CCD image sensors in early 1970s and the results of its numerical computations reported at the ISSCC1974 conference as PhD student paper by Hagiwara [5-6] in Feb 1974.

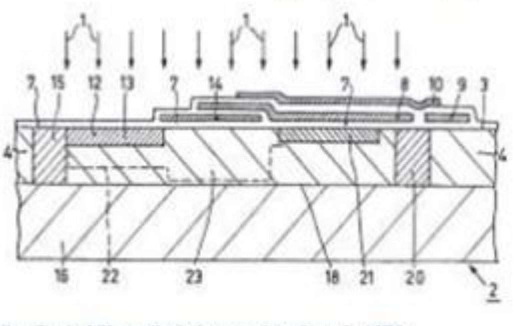

Fig. 4 Philips Buried Photodiode invented on June 9, 1975

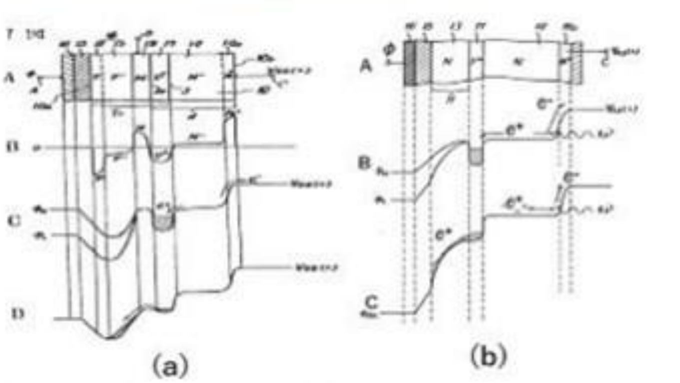

Fig. 5 Sony Pinned Buried Photodiode invented on October 23, 1975

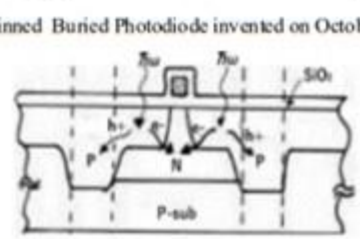

Fig. 6 PNP junction Pinned Phtodiode used by Sony in FTCCD imager in 1978.

In the 2023 January issue of IEEE EDS Newsletter, the author focused on works done by teams from Sony, including double junction-, triple junction-type PPDs, FT PPDs, ILT PPDs, HADs, to name a few. The main author's message is that (i) the short-wave blue light sensitivity is the most important advantage of the double- and multi-junction Pinned Buried Photodiodes, and (ii) Pinned Buried Photodiodes enabled implementation of the electronic shutter in the image sensors and realize the completely mechanical-parts free and light-sensitive video cameras in the HD digital TV era.

Furthermore, in this paper it is added that (iii) Pinned Buried Photodiode is a important semiconductor device element widely used in real-time robot vision future systems including AIPS and VAR and that (iv) the excellent short-wave blue-light sensitive PNP double junction type Pinned Buried Photodiode has another potential future application to realize a high quantum efficiency (QM) solar cells to solve the problem of our future energy crisis.

In this paper, more technical sides of inventions, research and development efforts made by NEC, Kodak, Hitachi and Toshiba are focused and explained. The difference between floating-surface photodiodes and pinned-surface type photodiodes is discussed. And the difference of the floating-surface type and the pinned-surface type Buried Photodiodes are also discussed.

II. Difference of Surace-floating Buried Photodiode and Pinned-surface Pinned Buried Phtodiode

The first charge coupled device (CCD) was invented in 1969, but it was a surface channel type CCD. It had only the 99.9 % or less charge transfer efficiency, which was useless for image sensor and also for DRAM applications because of its power issue. Then, Buried Channel type CCD was invented, which had the 99.999% charge transfer efficiency.

Fig.3 shows a typical Buried Channel Frame Transfer (FT) type CCD image sensor with the back light illumination and the substrate anti-blooming vertical overflow drain (VOD) scheme. By applying a strong substrate voltage, the excess photo charge in high light is drained to the substate VOD.

The complete charge transfer flow of Buried Channel CCD was studied [5] and the results obtained by the computer t-x-y three dimensional numerical calculation were reported at the ISSCC1974 conference in February 1974 in the form of a computer graphics (CG) moving picture by Hagiwara as a PhD student paper [6]. See Fig.3.

Philips invented on June 9 1975 for the first time in the world a double junction type Buried Photodiode [7] and explained the complete charge transfer capability and the no image lag feature by showing an empty potential profile in the charge collecting region in the patent figure. However, the surface layer of Philips Buried Photodiode is connected to the high resistivity substrate and this photosensor may have a serious RC delay time constant problem. Being exposed to the surface oxide, a good light sensitivity is expected. See Fig. 4

Fig. 5 shows the triple and double junction type Pinned Buried Photodiodes invented by Sony on October 23 1975 for the first time in the world [8-10]. Fig. 6 shows the PNP double junction type Pinned Buried Photodiode Sony developed [11-13].