

The invention of Modern Photodiode by Hagiwara at SONY in 1975

- (1) Historically we had P+N junction type photodiode which suffered the serious image lag problem.
- (2) When CCD was invented, we obtained image lag free fast action picture quality. However, the CCD type MOS capacitor structure had serious blue light sensitivity problem and surface dark current.
- (3) Hagiwara at SONY invented in 1975 the P+NPNsub junction type photodiode with the heavily doped P+ surface hole accumulation layer and the built-in vertical overflow drain (VOD) function with complete charge transfer operation mode with no image lag. See the Japanese Patent 1975-134985.
- (4) Hagiwara at Sony in 1975 also invented the back light illumination type Pinned Photodiode and with the MOS Capacitor type Buffer memory for the built-in Global Shutter Scheme in his Japanese Patent 1975-127649, which is useful specially for the modern CMOS image sensor applications.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

There are basically four kinds of Photodiode.

- (1) The classical N+P junction type photodiode
- (2) The Buried Photodiode named by NEC in IEDM1982
- (3) which is also Depletion Photodiode with no image lag.
- (4) The Pinned Photodiode named by KODAK in IEDM 1983, which has low surface dark current.

SONY developed the complete production quality of Hole Accumulation Diode Sensor with VOD function in 1984. Everyone thought that the invention of SONY HAD was after the NEC IEDM1982 and the KODAK 1983 IEDM papers. But that is not true. Hagiwara at SONY invented in 1975 the Buried Photodiode, Depletion Photodiode and Pinned Photodiode with the vertical overflow drain (VOD) Function and the in-pixel MOS capacitor type Buffer memory for the built-in Global Shutter operation and the Back Light Illumination Scheme.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

Please look carefully at the original NEC patent 1980-123259 on the Buried Photodiode filed by Shirai-san and Teranishi-san at NEC.

This patent describes about the Buried Photodiode and the Depletion Photodiode which were already Invented by Hagiwara at SONY in 1975. But this patent does not describe about Pinned Photodiode.

This is NOT Pinned Photodiode Patent !
Teranishi-san did not invent Pinned Photodiode !

The Toshiba 1978 VOD Patent and the NEC 1980 Buried Photodiode Patent are both invalid. They are copies of Hagiwara 1975 P+NP/Sub Pinned Photodiode with built-in VOD function.

Yamada 1978 at Toshiba
Japanese Patent 1978-1971
NPN Junction Photodiode

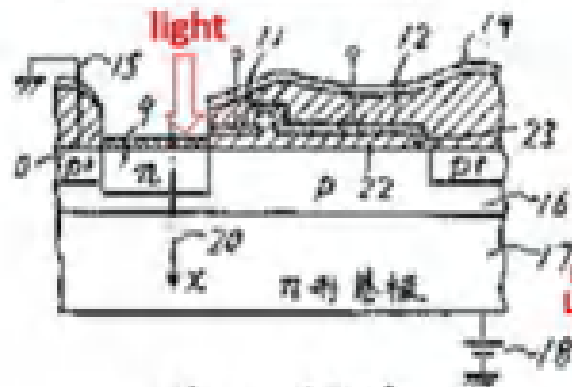
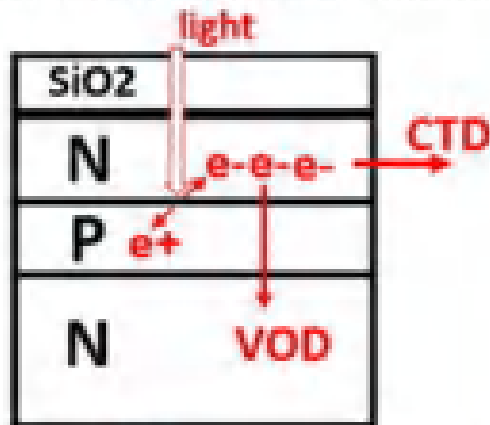


Figure 2C of
Toshiba Yamada 1978
Vertical OFD (VOD)
Japanese Patent
1978-1971

Shiraki&Teranishi 1980 at NEC
Japanese Patent 1980- 123259
PNP Buried Photodiode

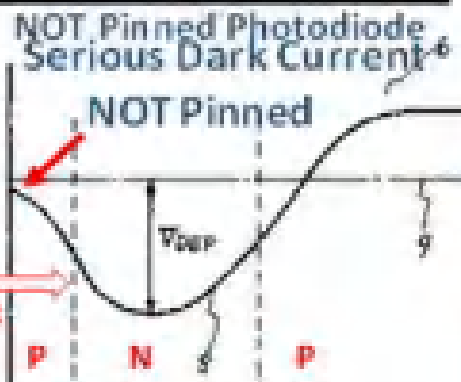
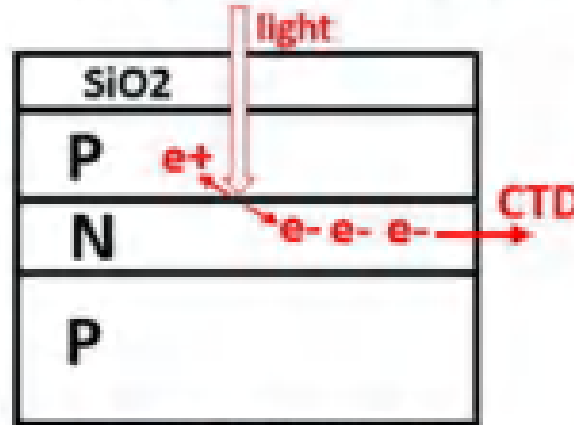


Figure 2 of
NEC Teranishi 1980
Buried Photodiode
Japanese Patent
1980-123259

Hagiwara 1975 at Sony
Japanese Patent 1975-134985
P+NP/Sub Pinned Photodiode

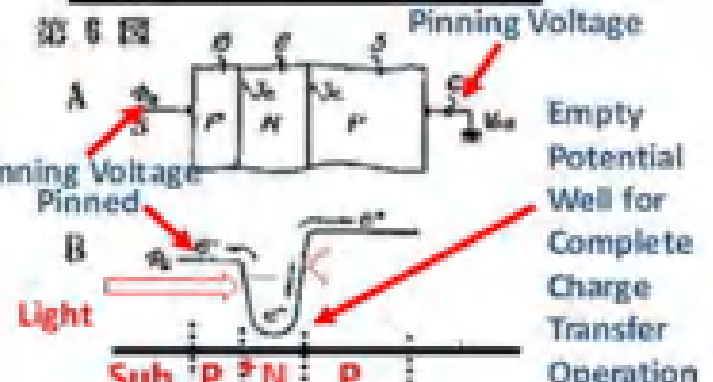
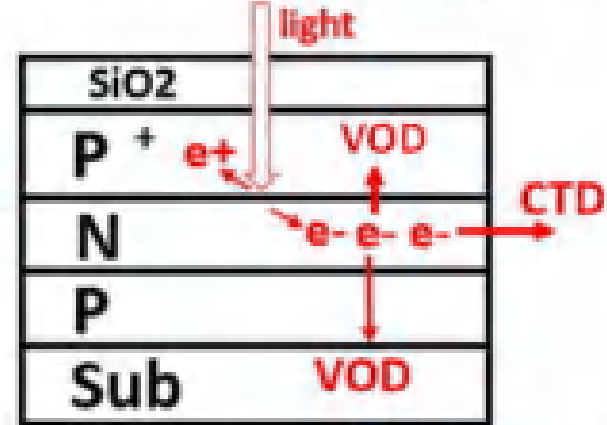
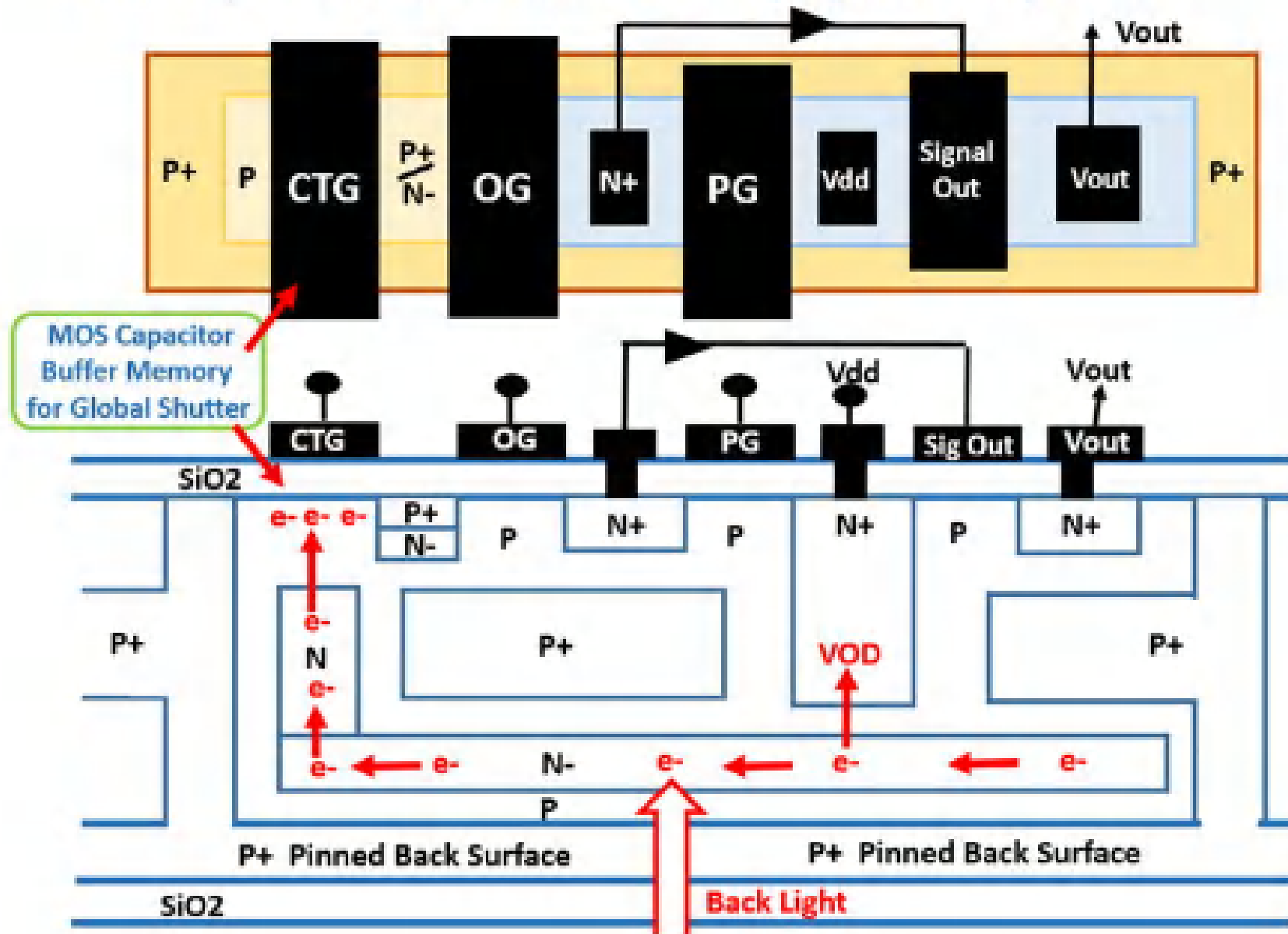


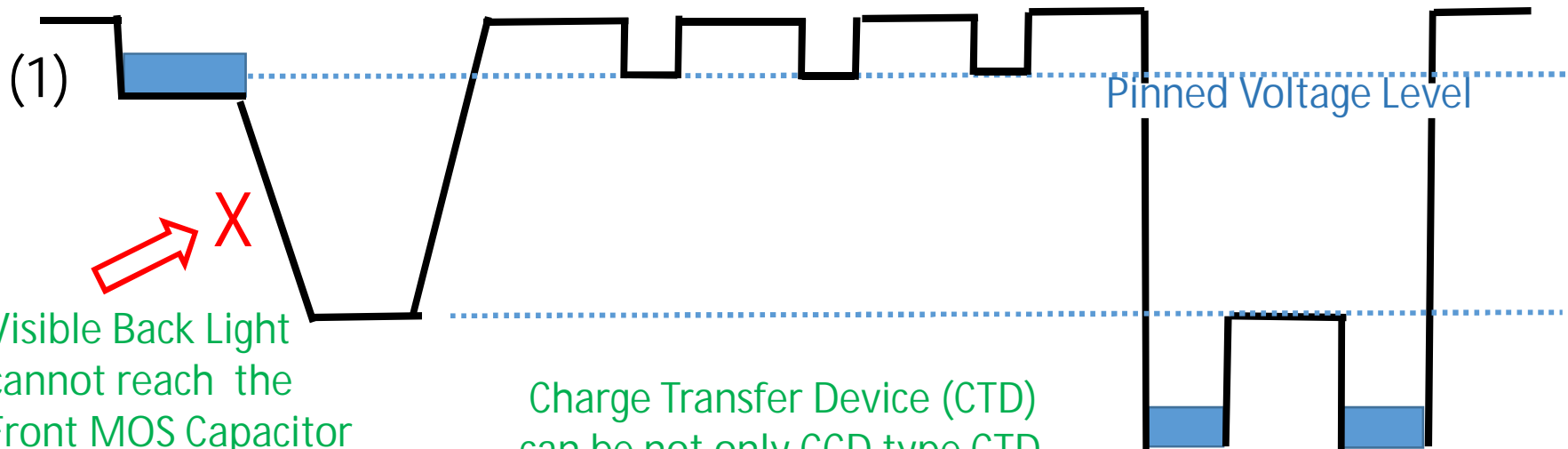
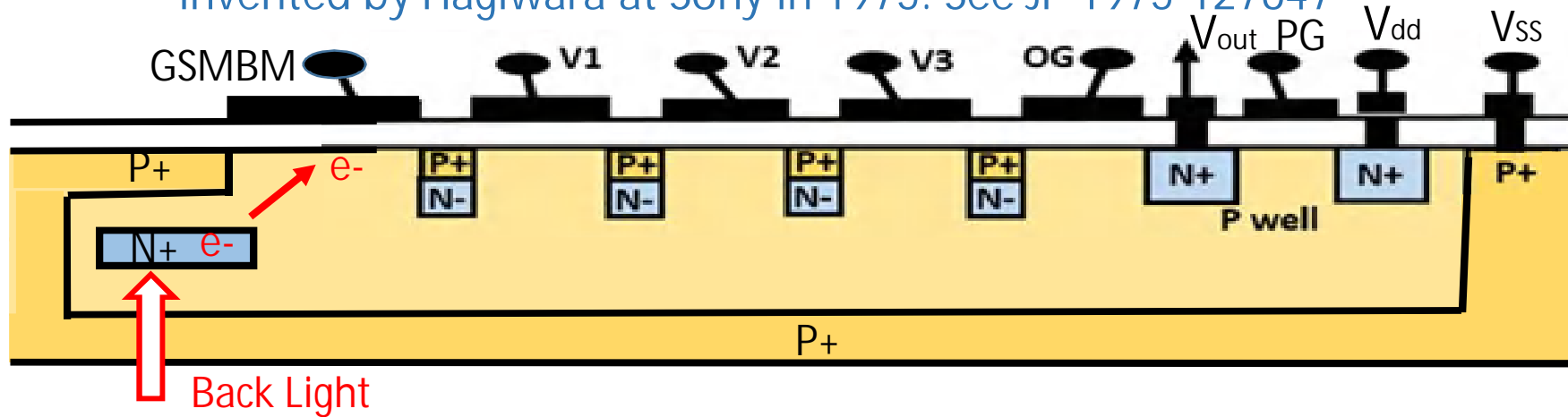
Figure 6 of
SONY hagiwara 1975
Pinned Photodiode with VOD
Japanese Patent
1975-134985

P+NP junction type Pinned Photodiode with Back Light Illumination and VOD function.
 See the Japanese Patent 1975-127647 invented by Hagiwara at Sony in 1975



Pinned Photodiode (PPD) with Back Light Illumination Scheme and with Global Shutter MOS Buffer Memory (GSMBM)

invented by Hagiwara at Sony in 1975. See JP 1975-127647



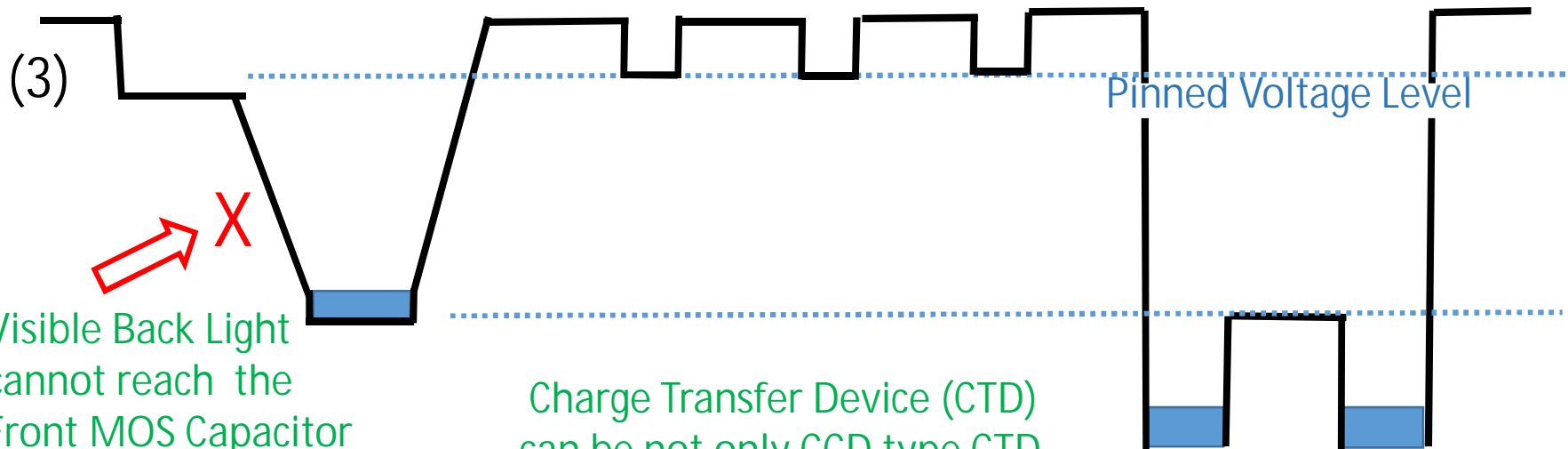
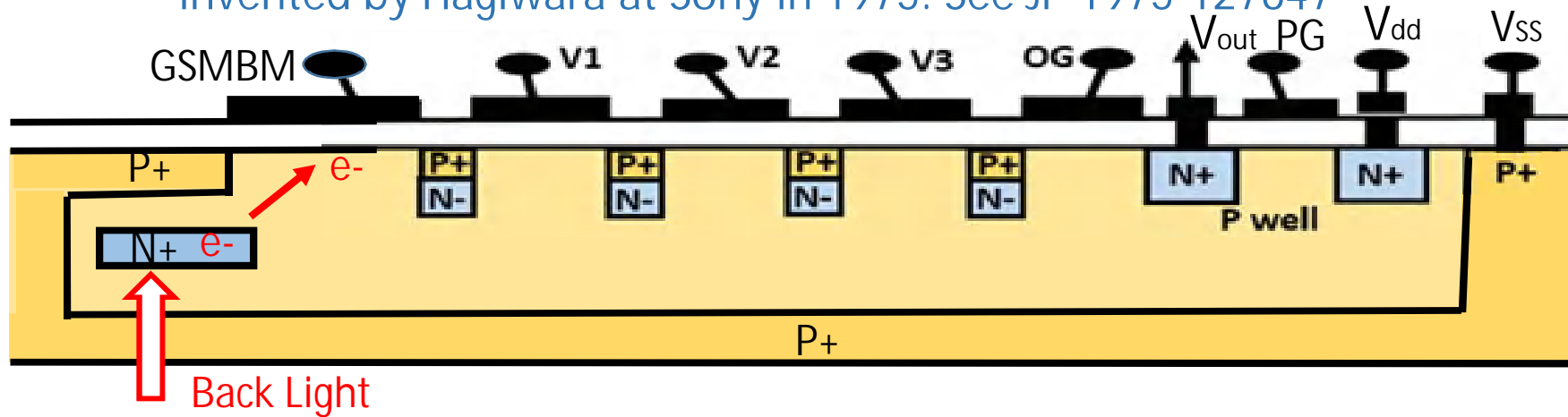
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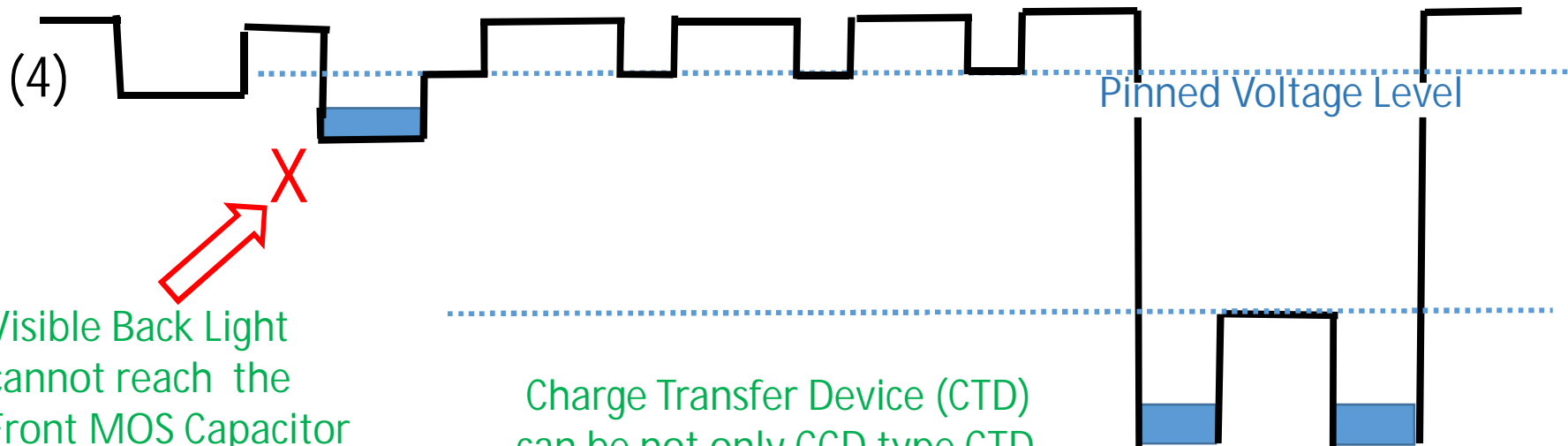
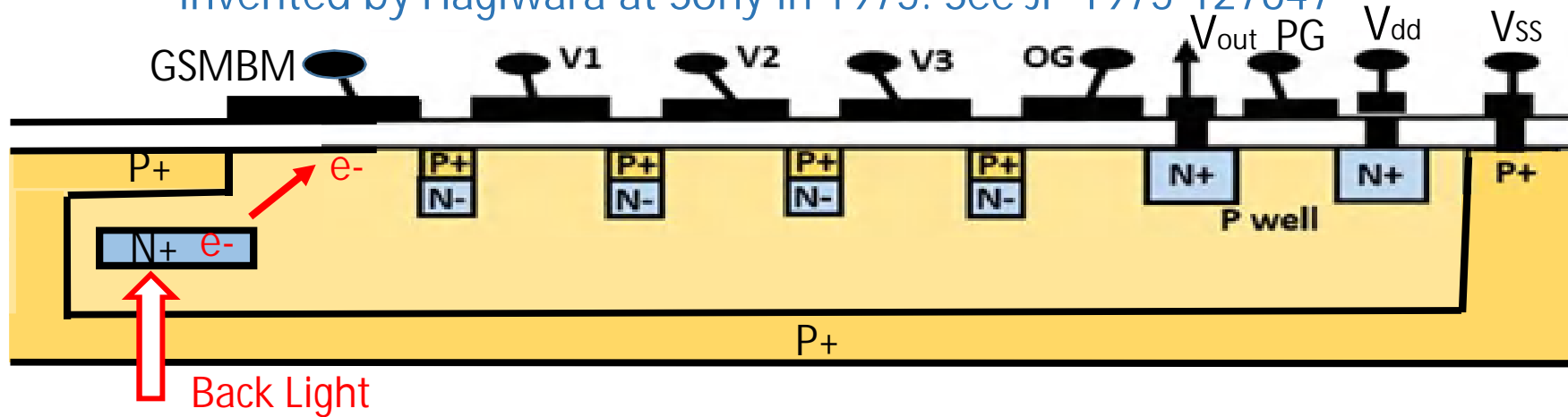


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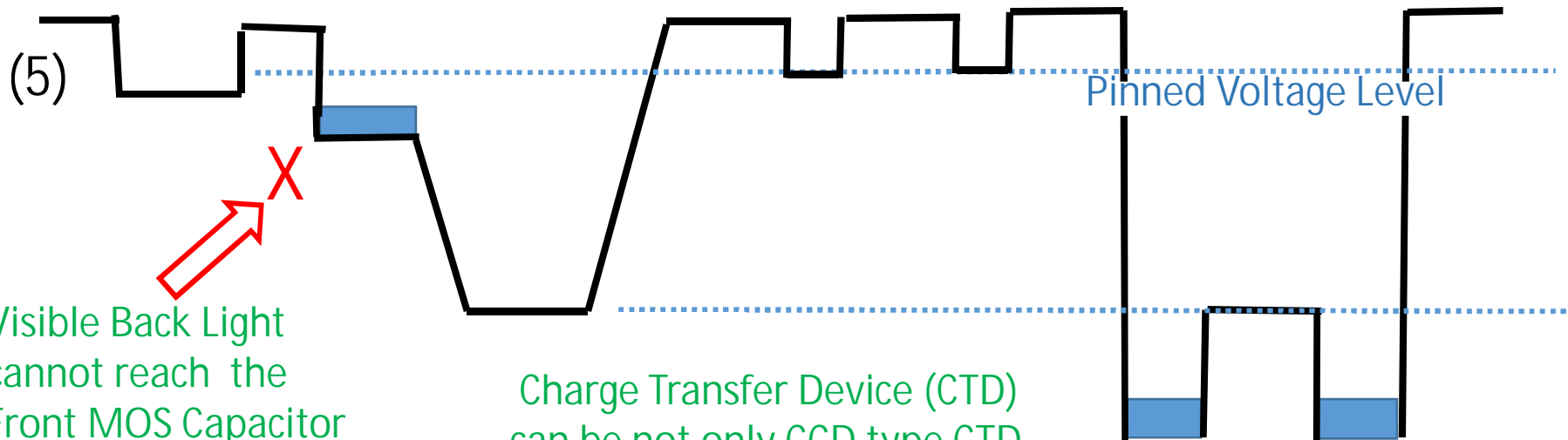
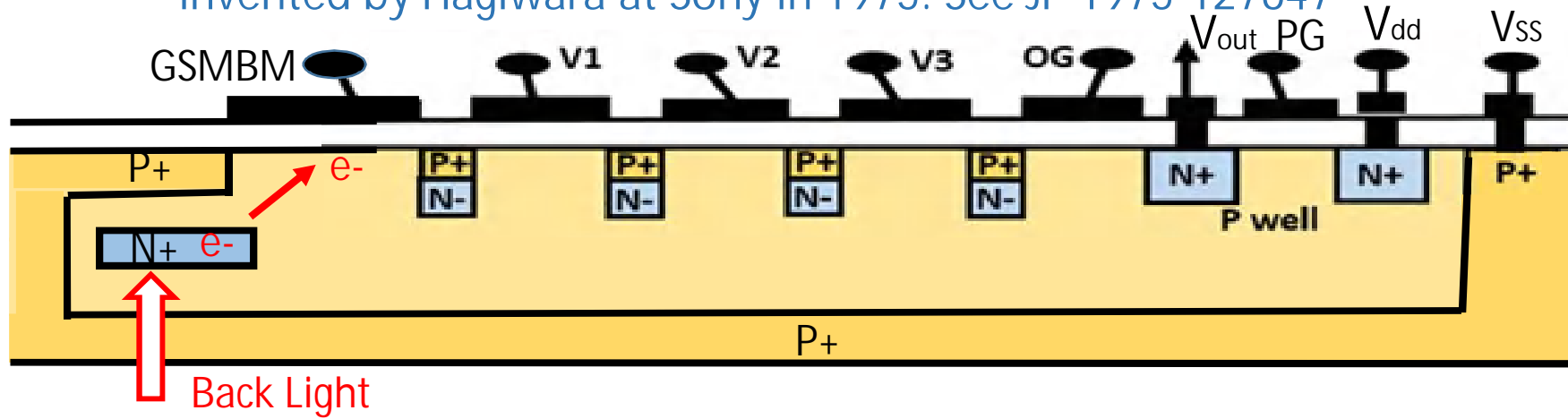
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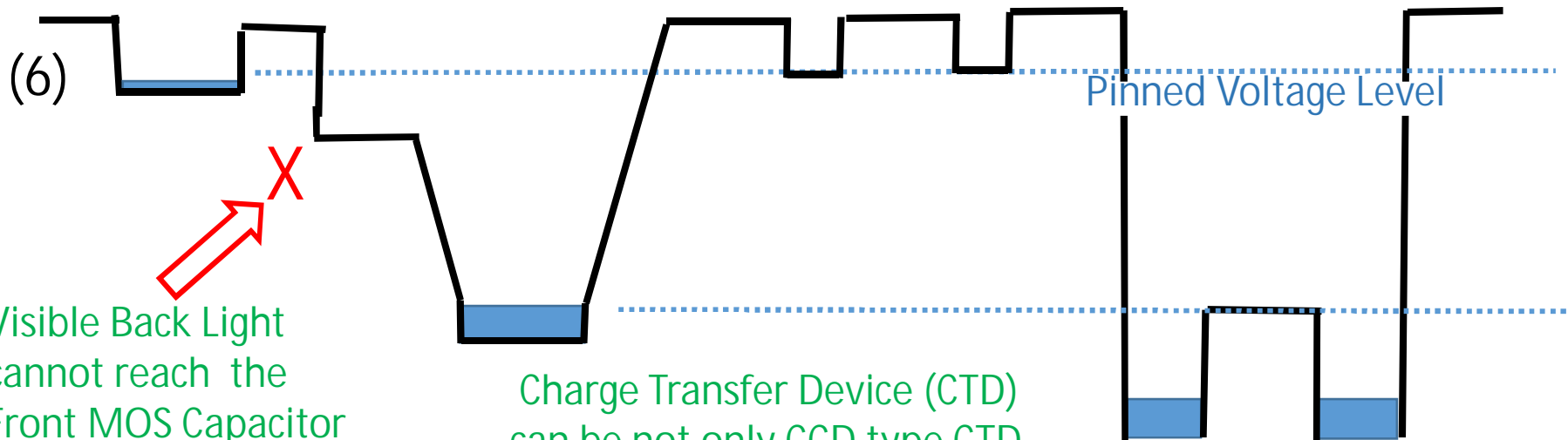
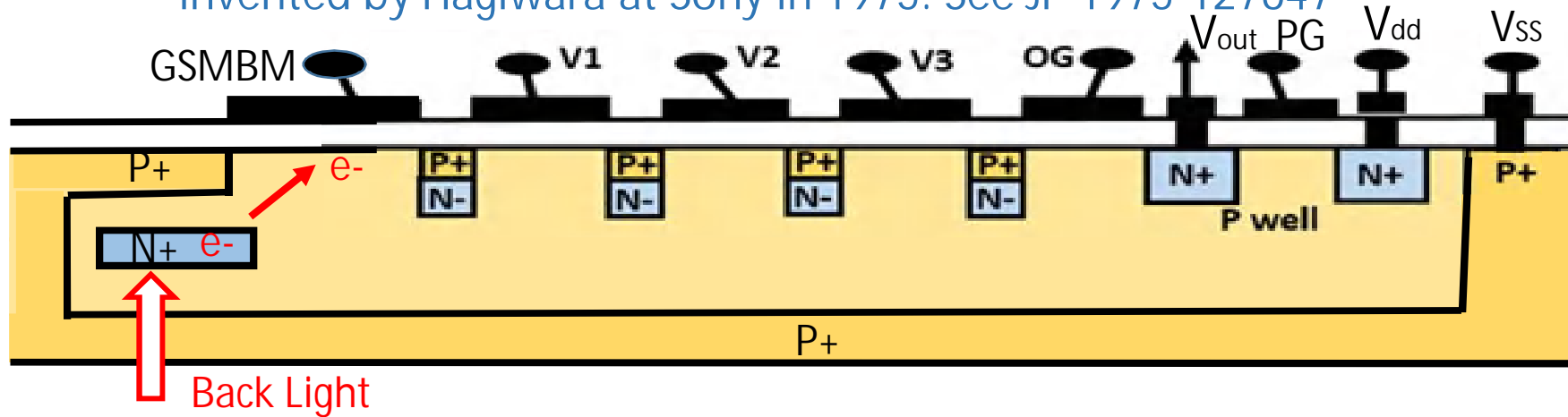
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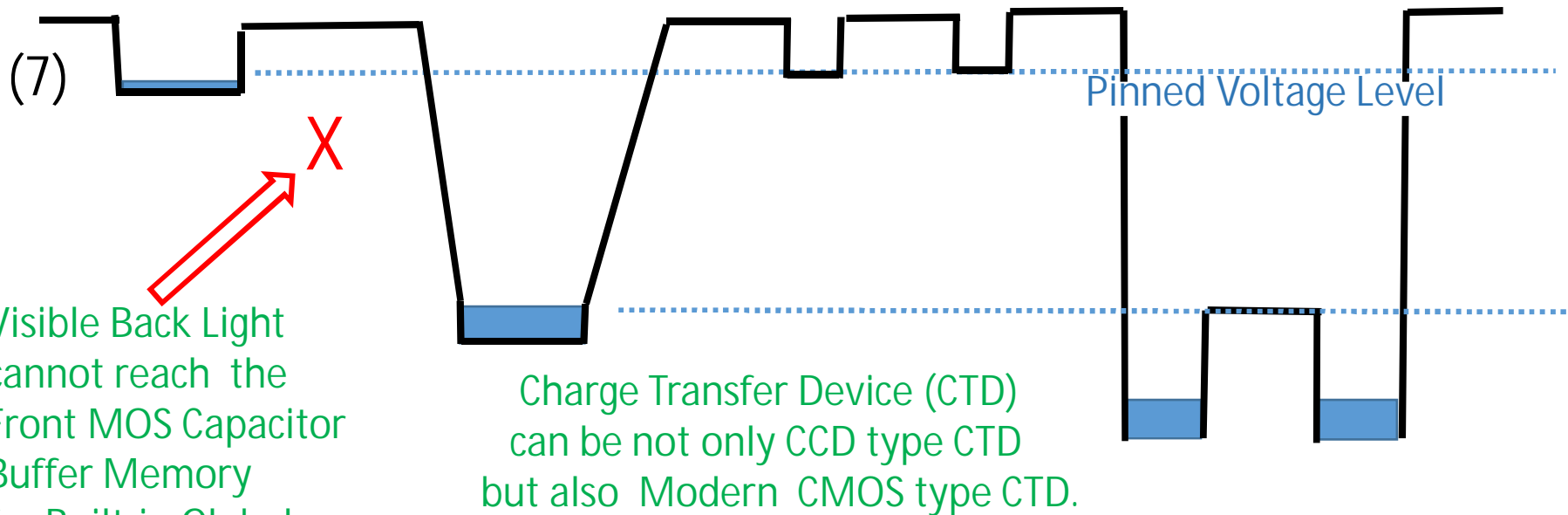
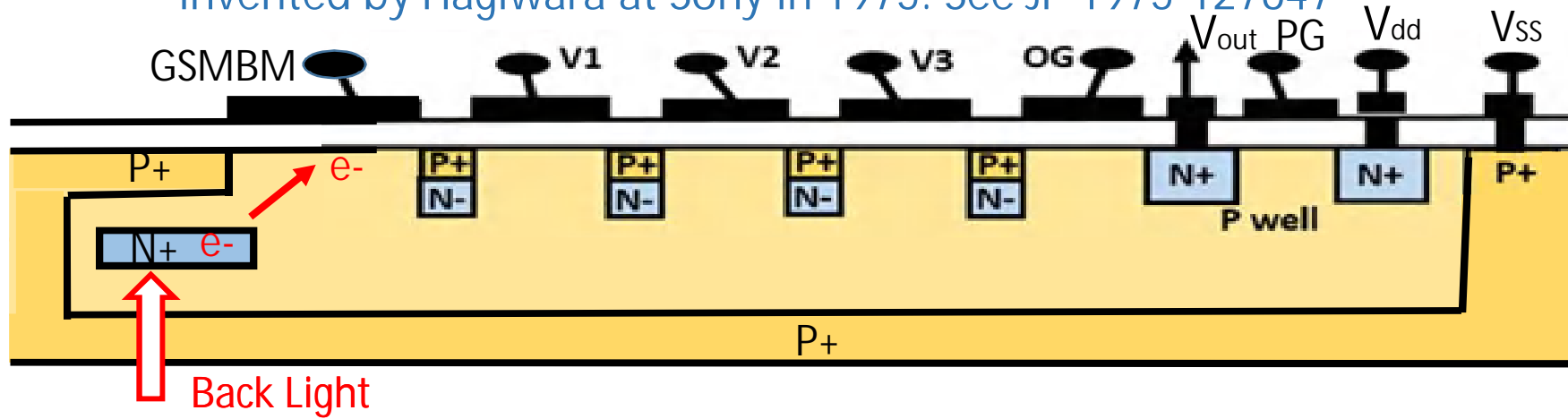
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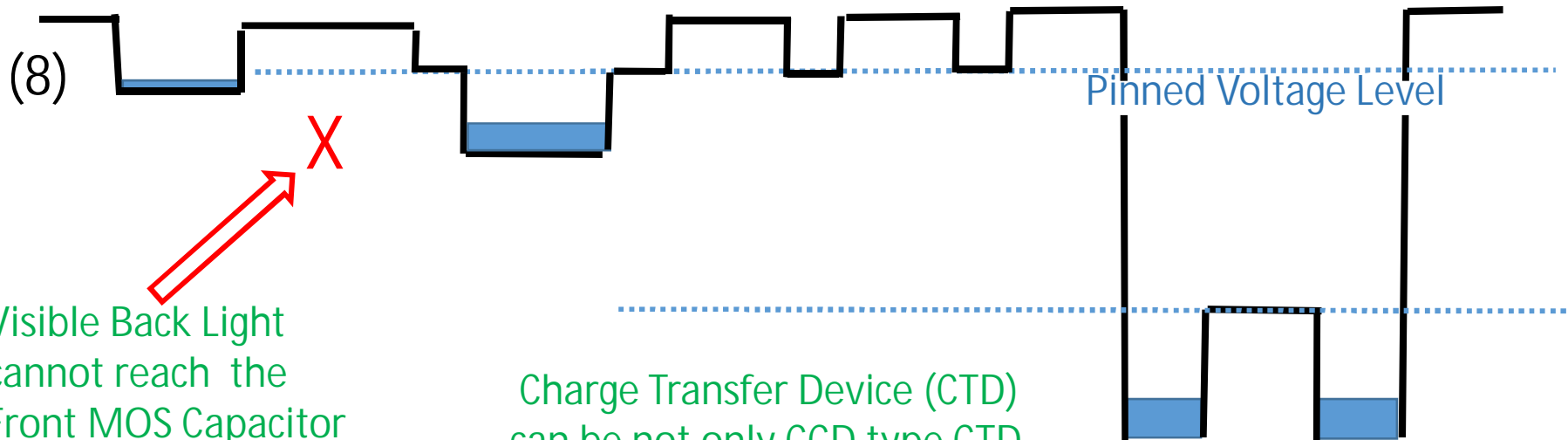
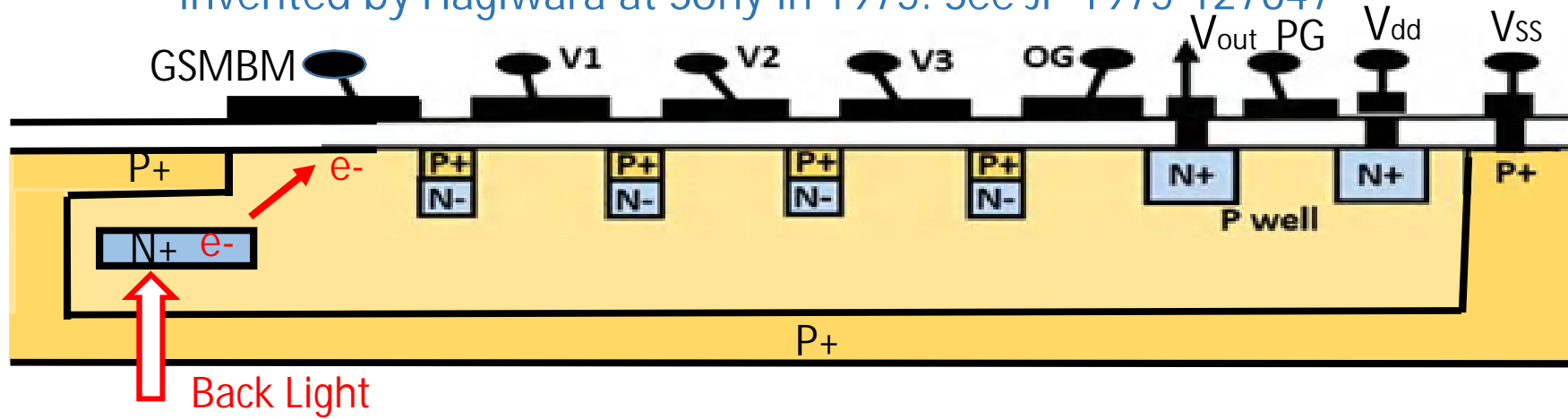
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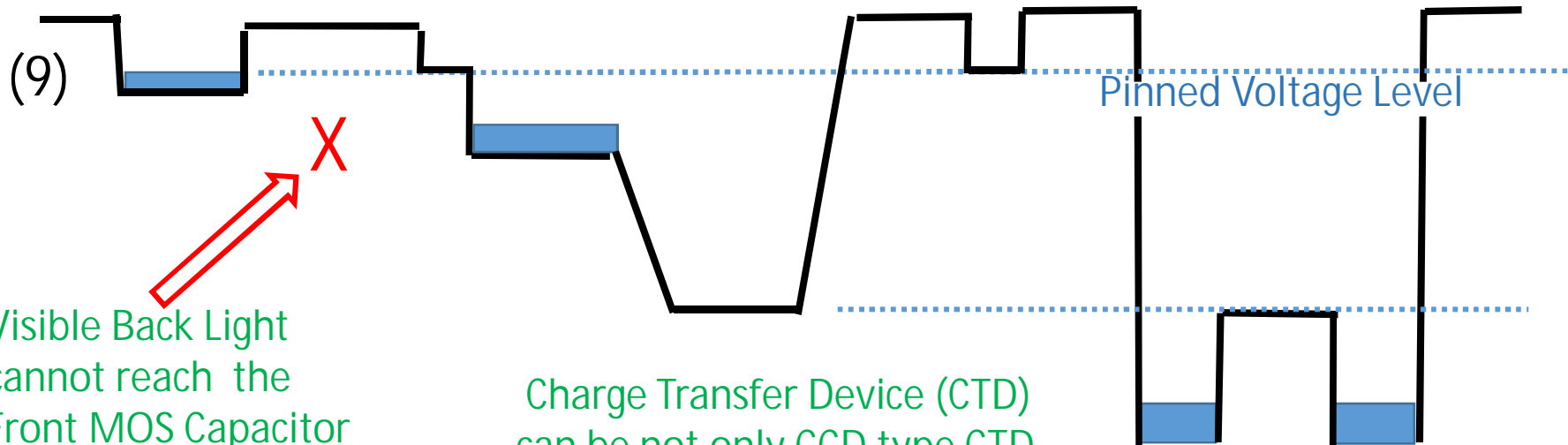
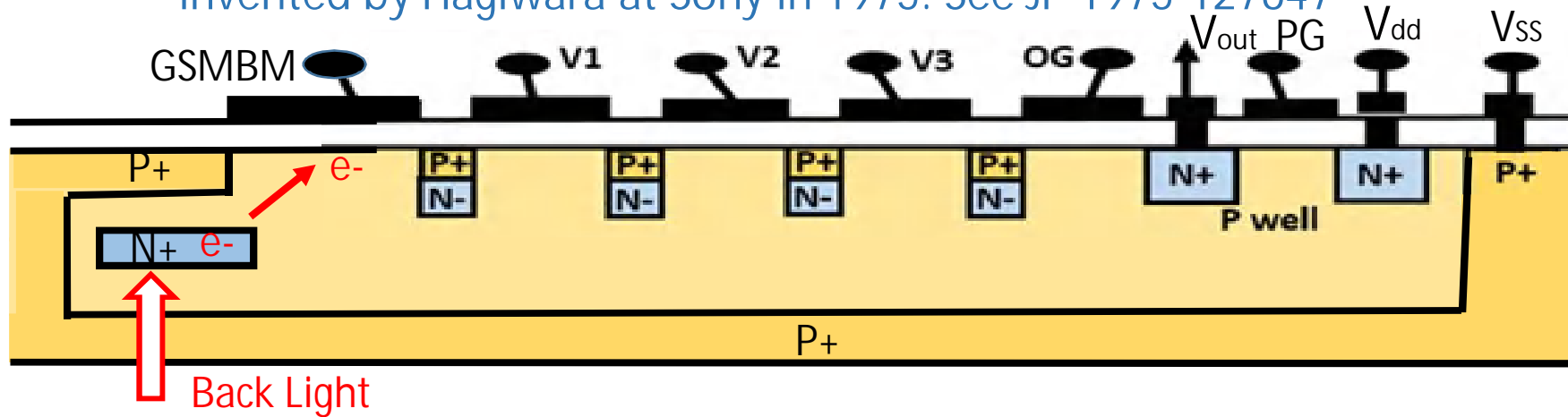
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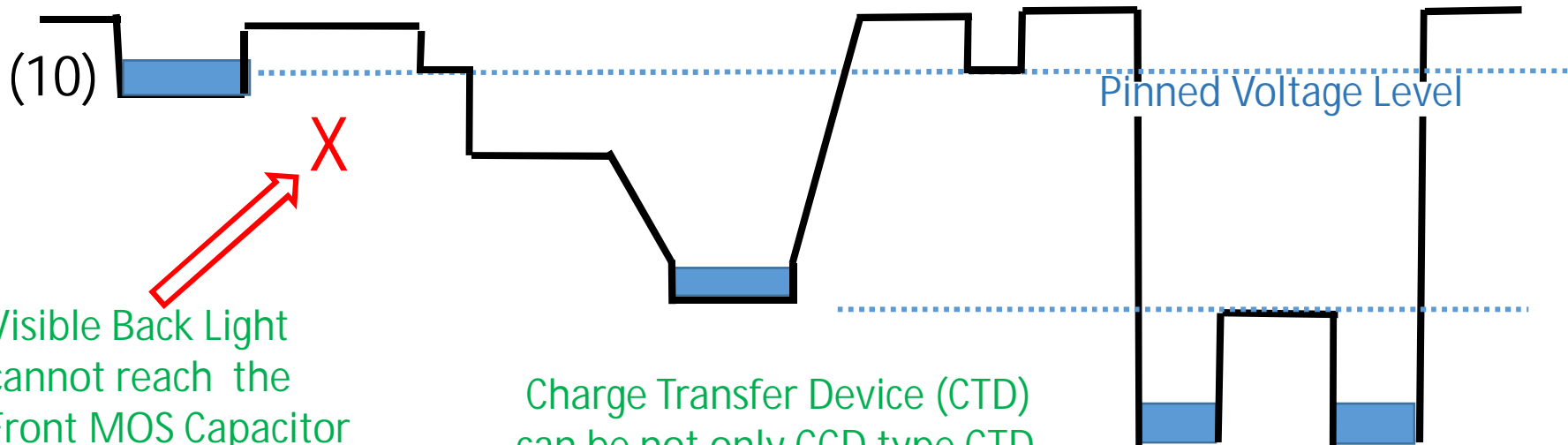
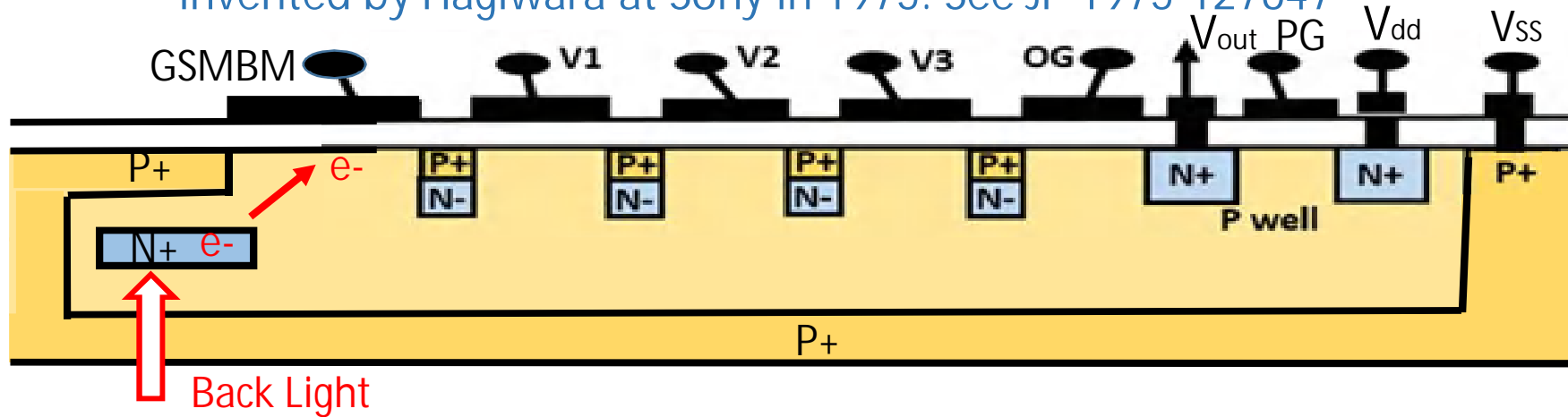
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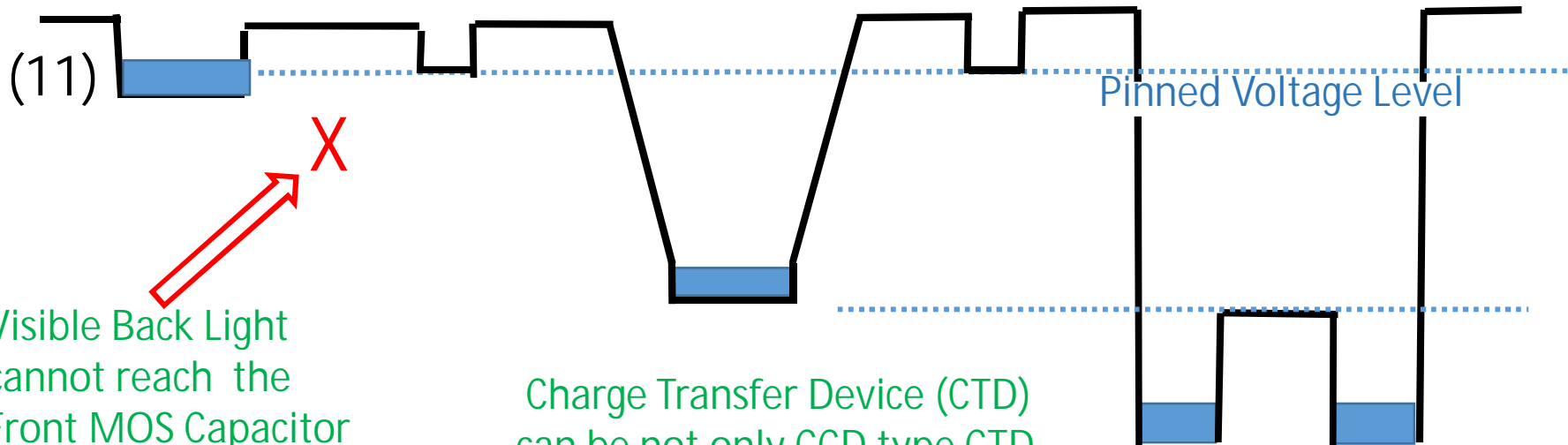
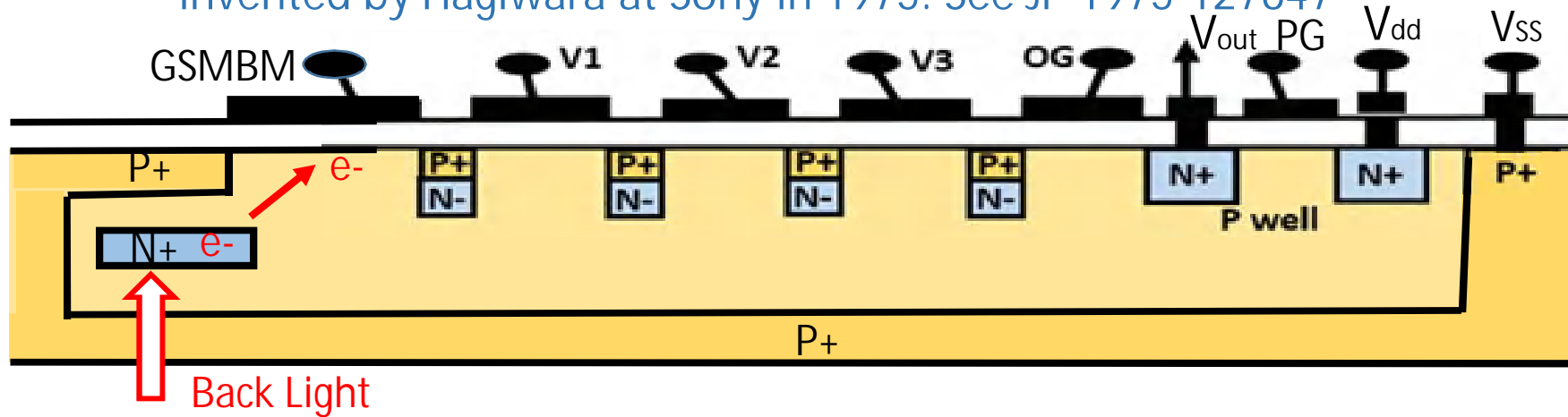
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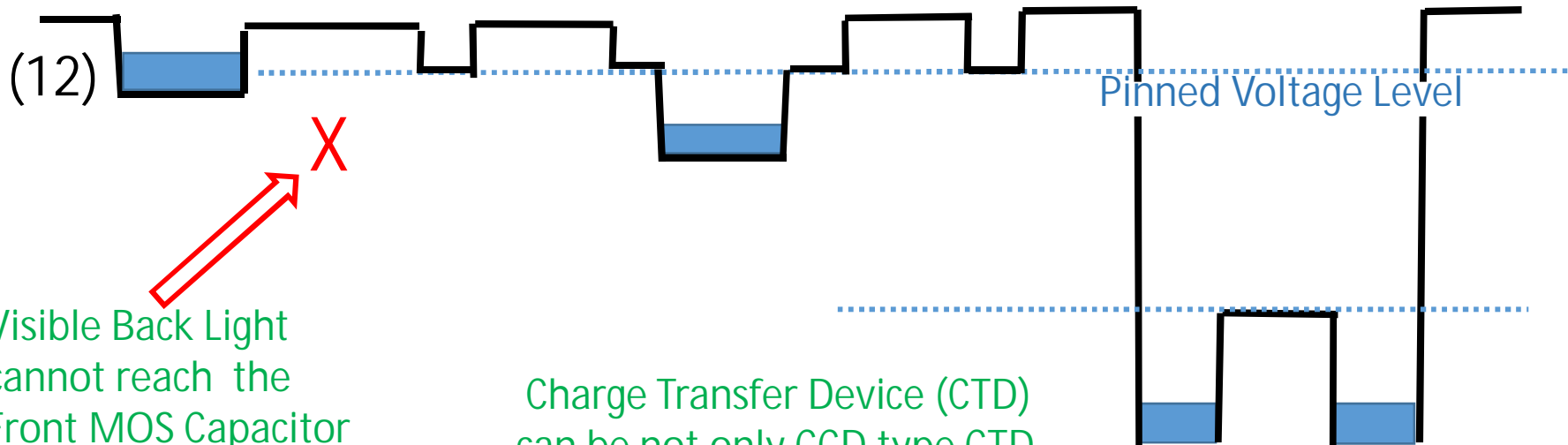
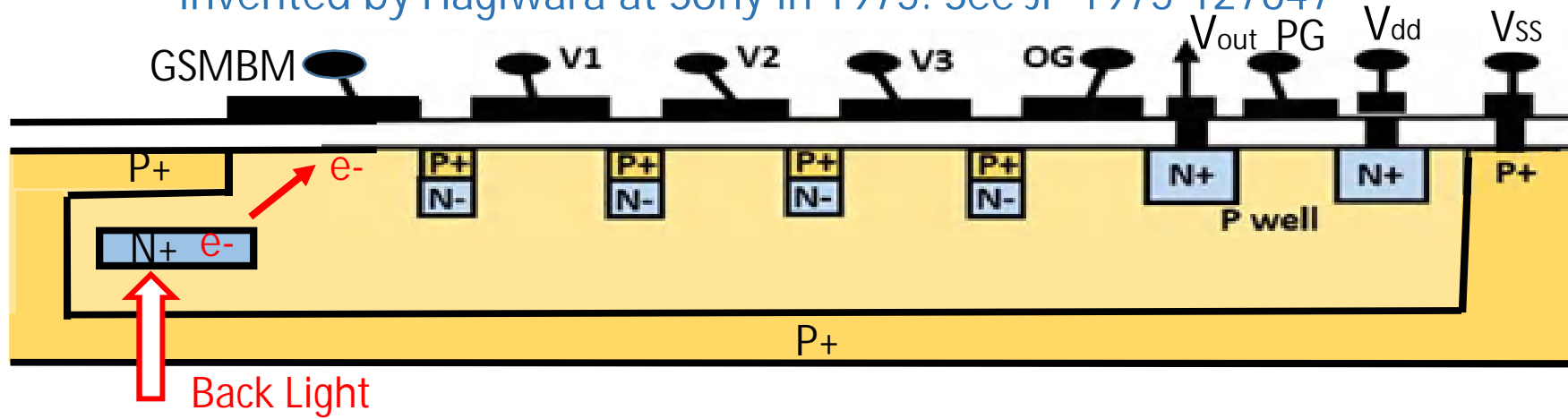
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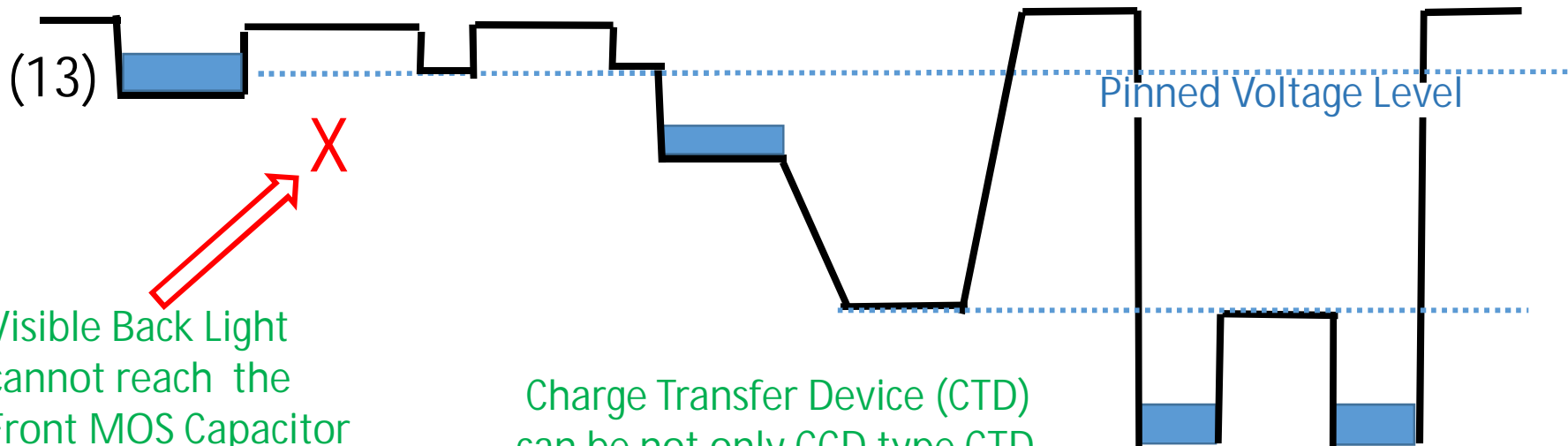
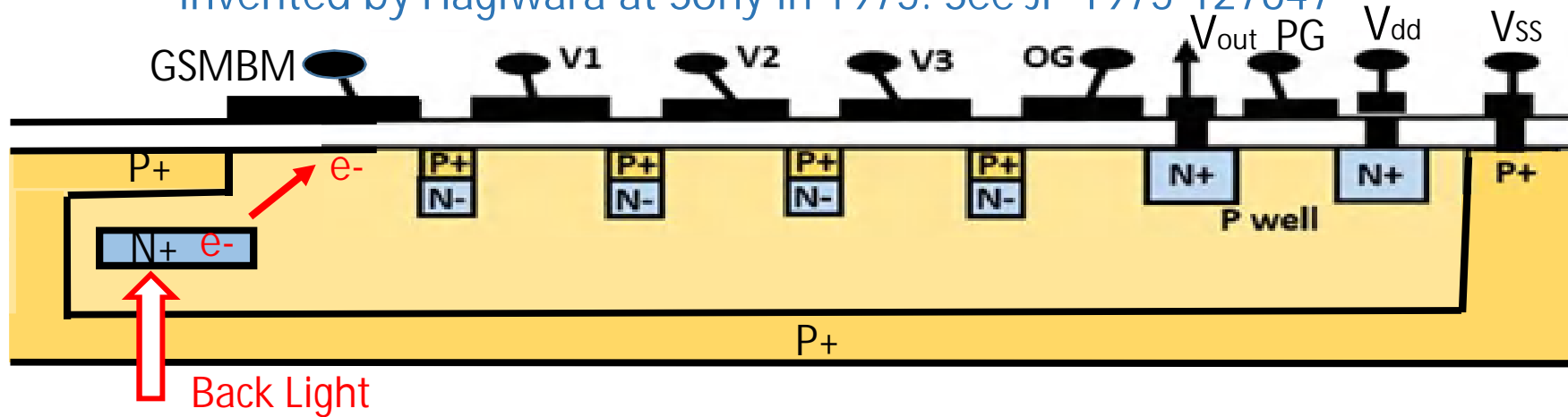
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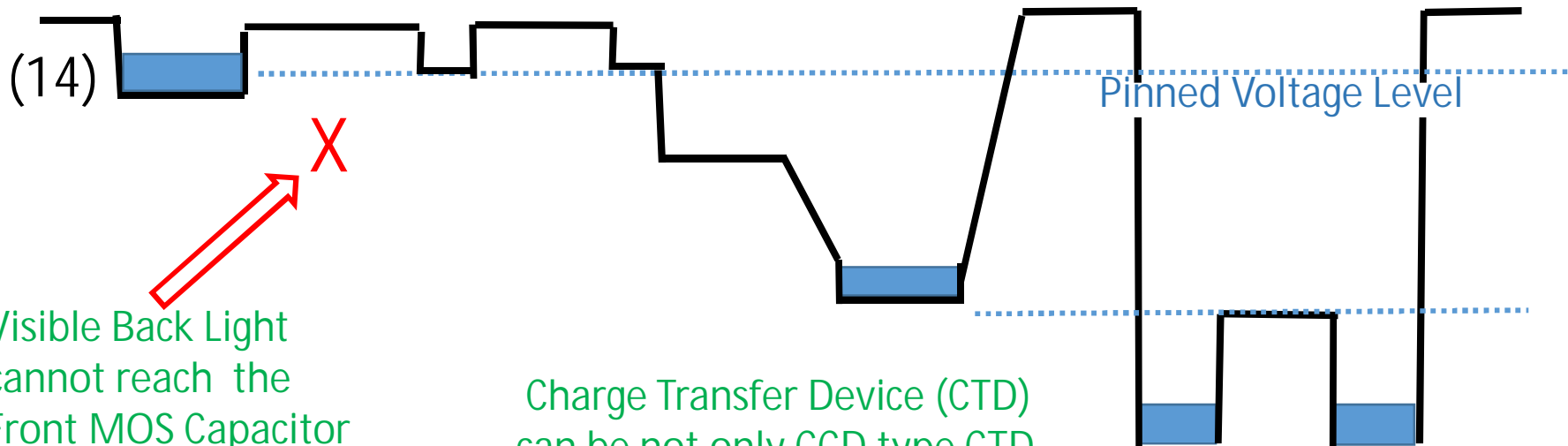
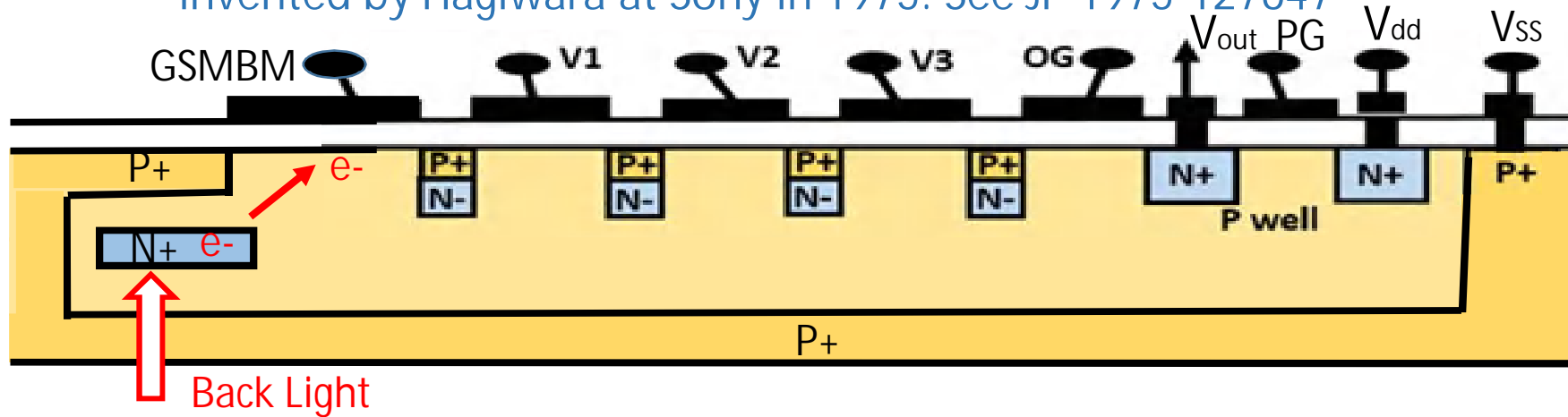
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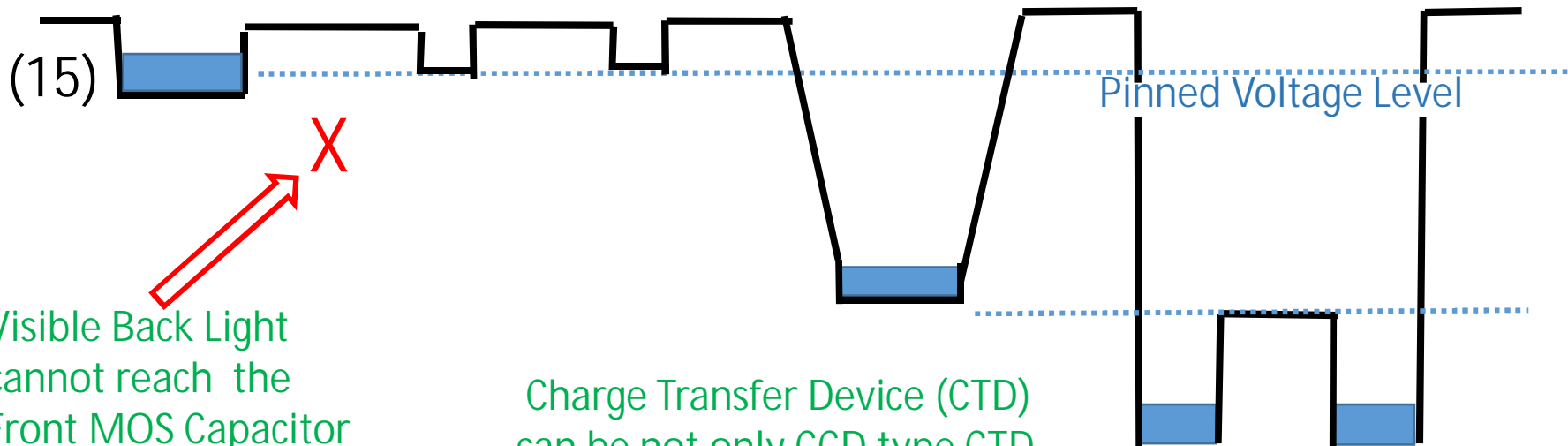
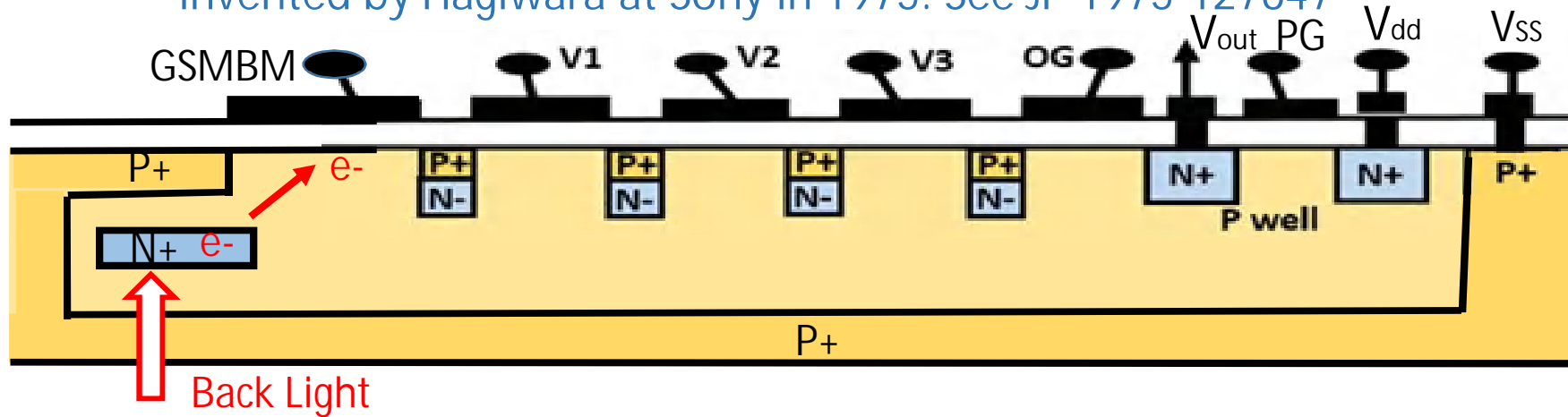
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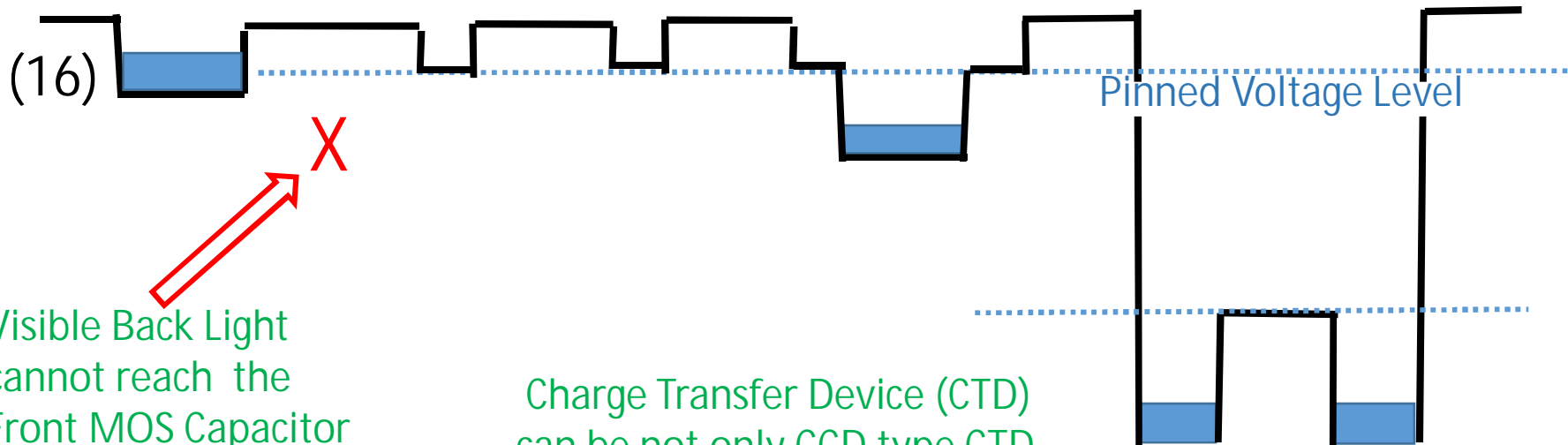
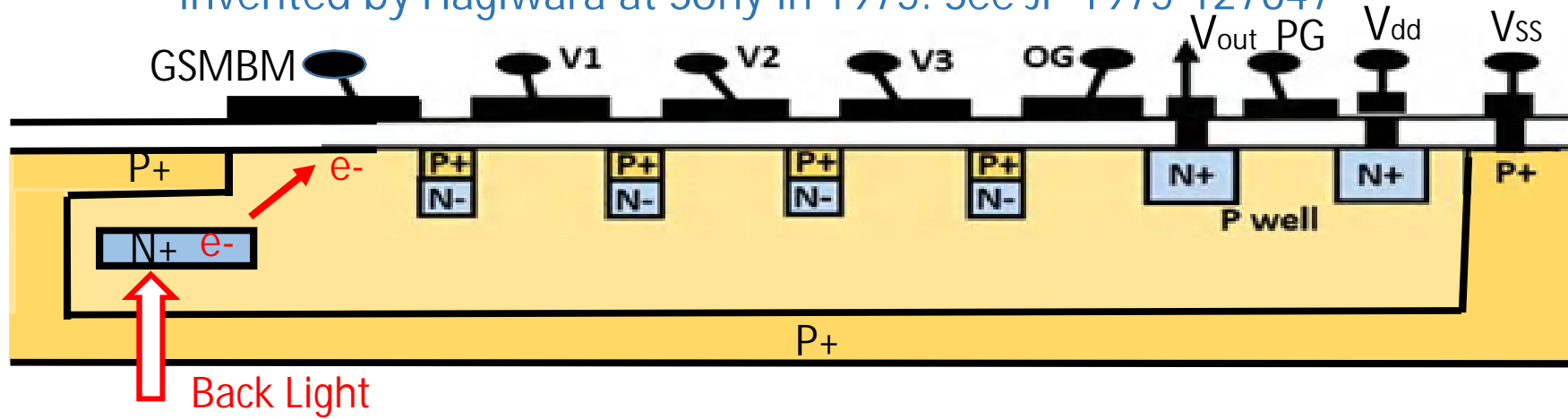
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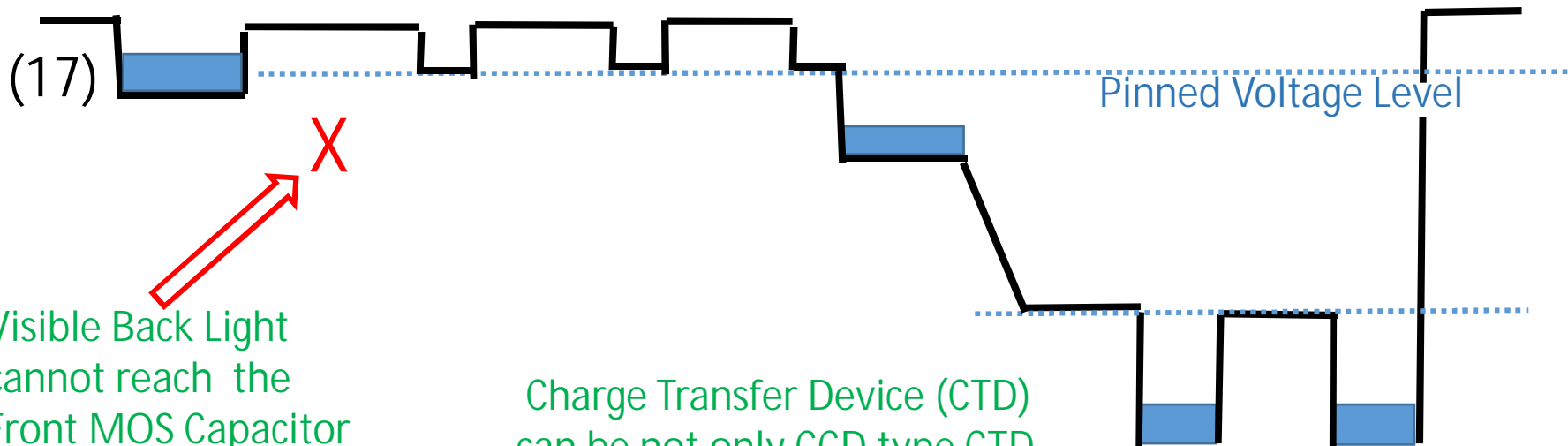
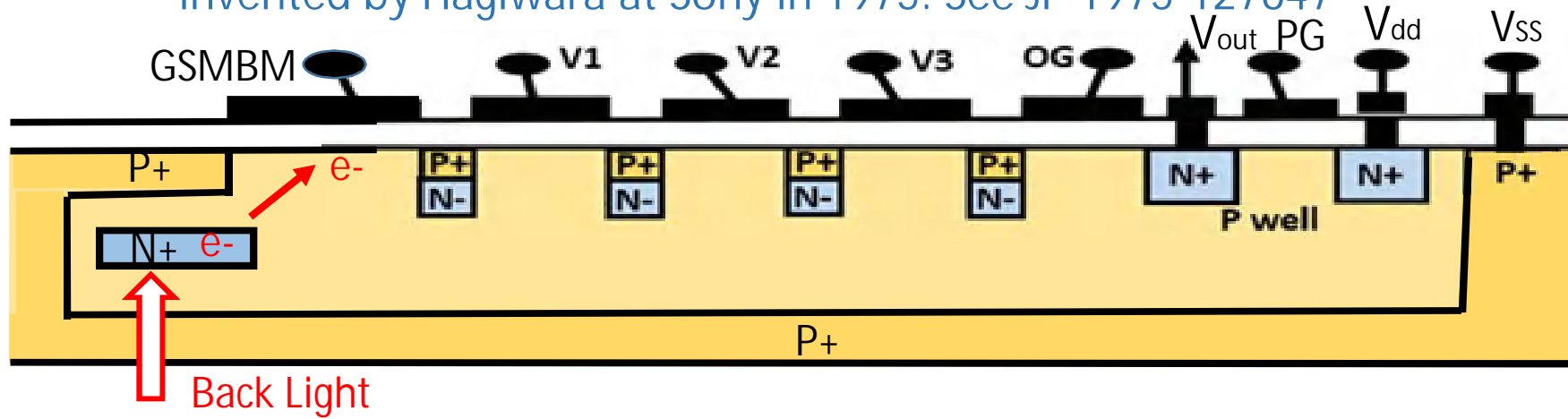
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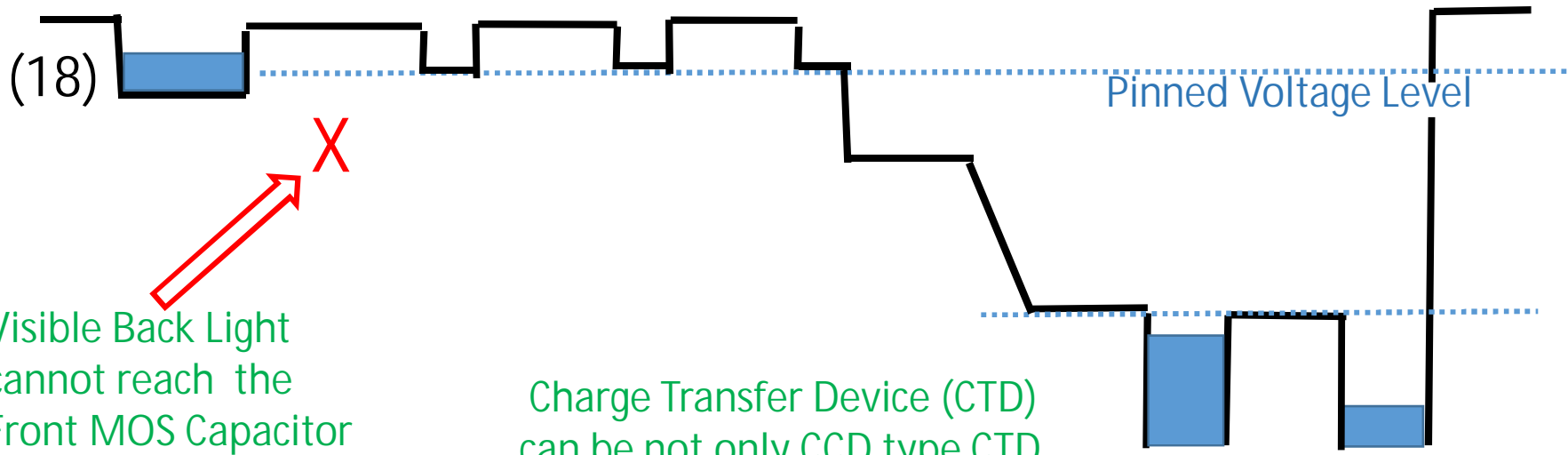
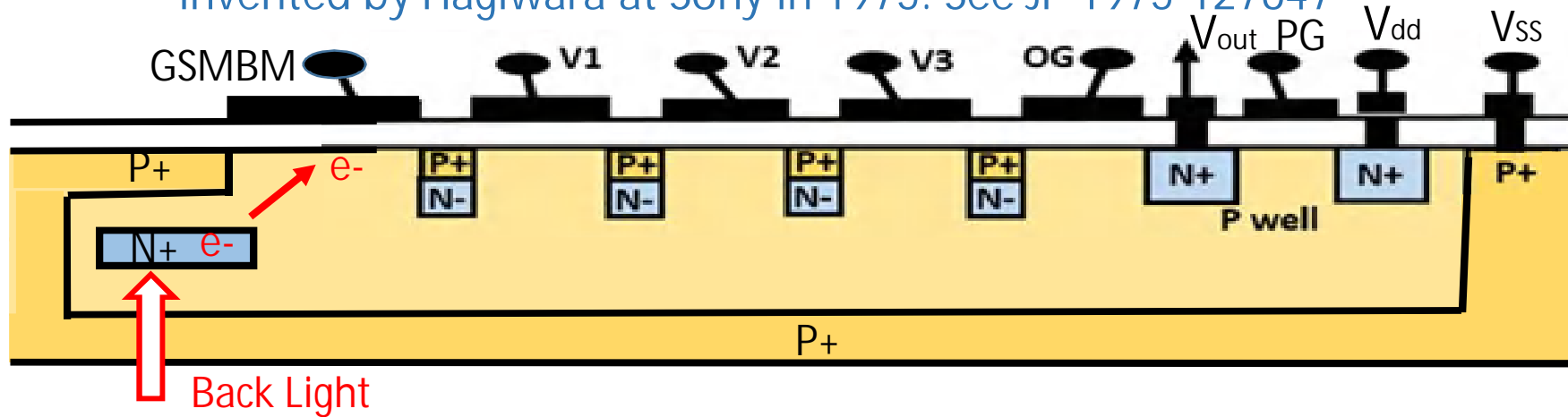
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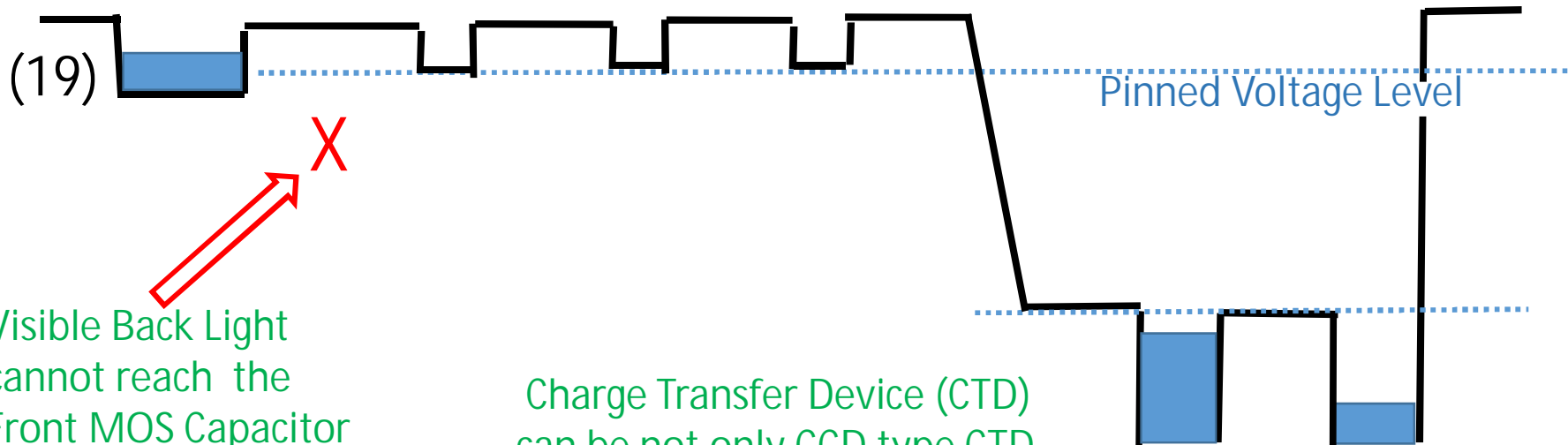
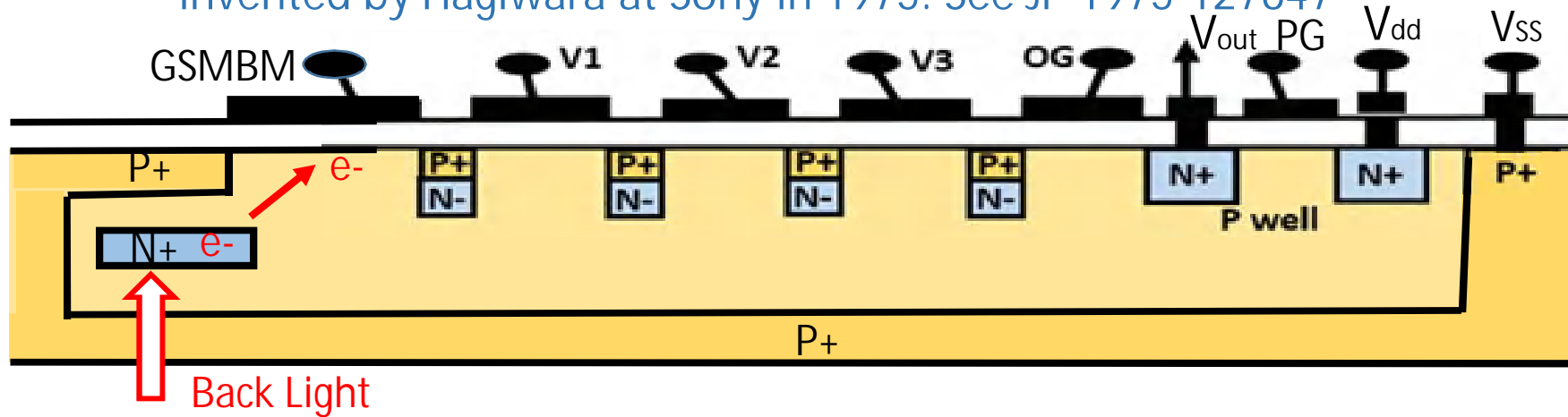
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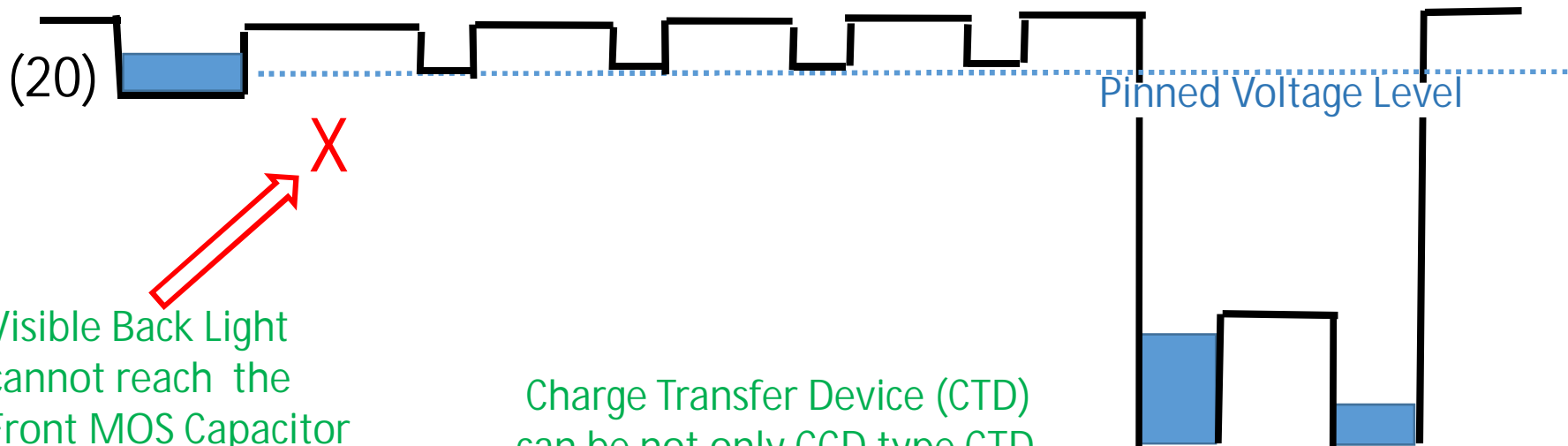
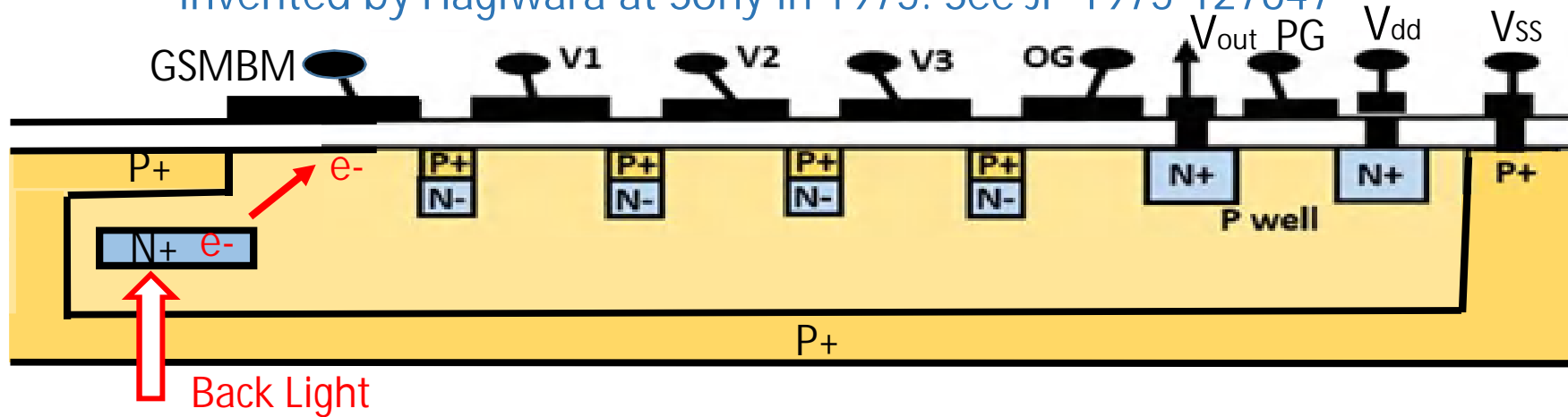
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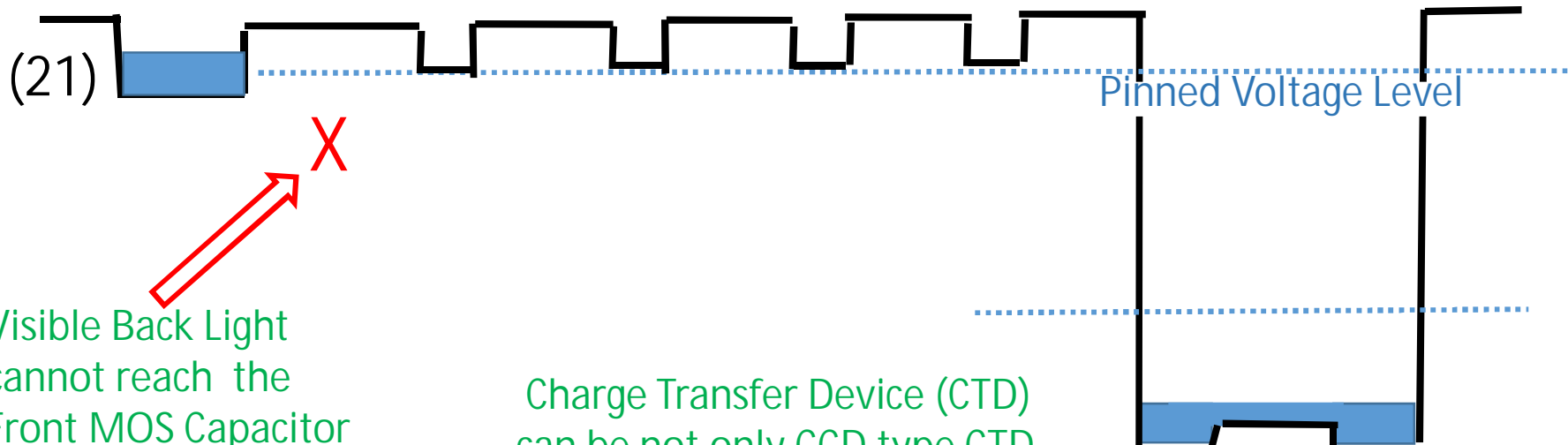
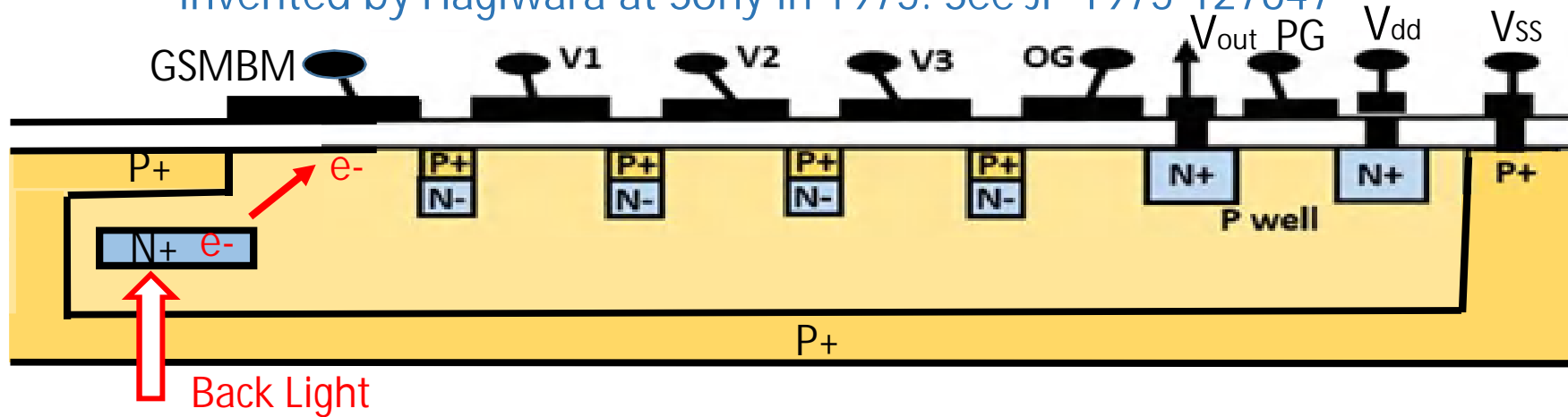
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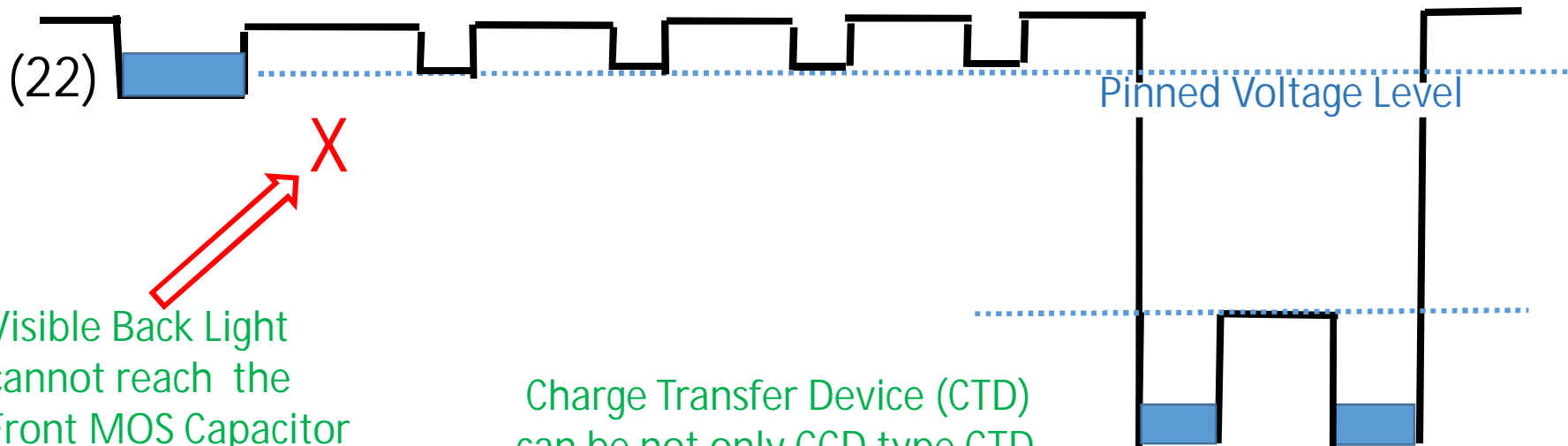
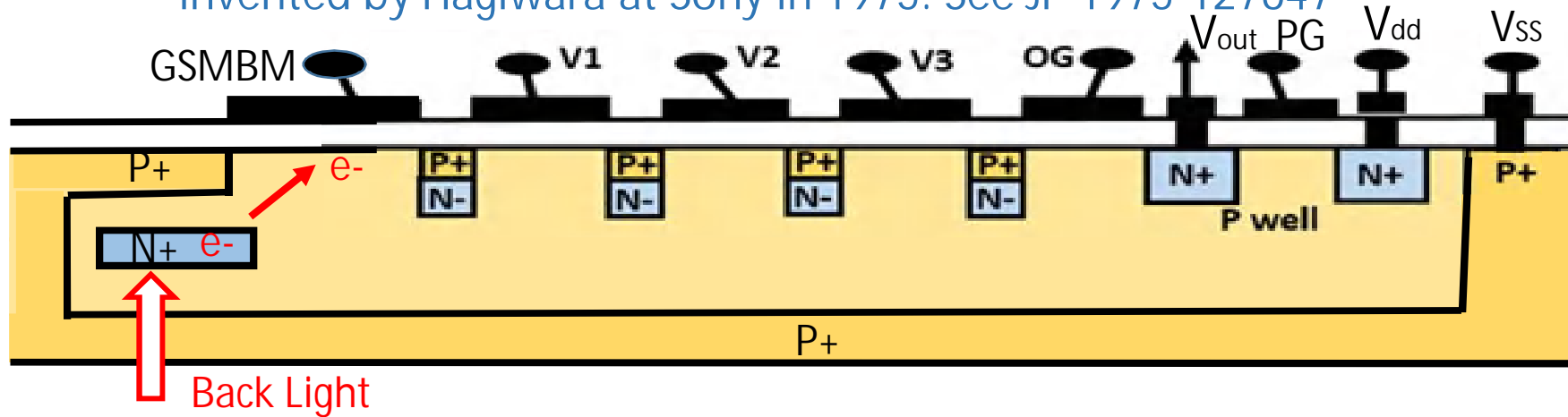
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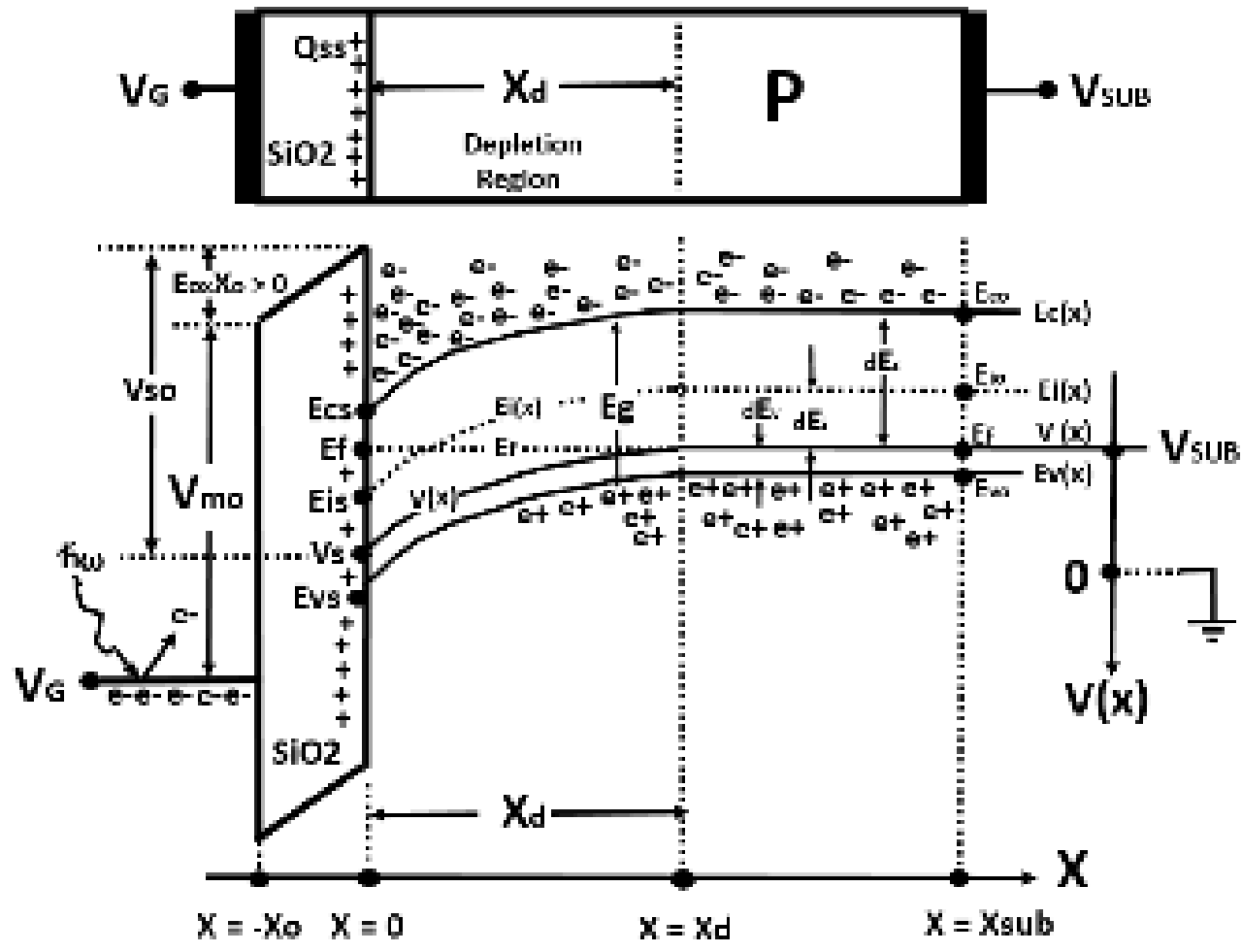


Figure 1

The band diagram of one Dimension MOS structure of P-type silicon wafer with a positive gate voltage

The invention of Modern Photodiode by Hagiwara at SONY in 1975

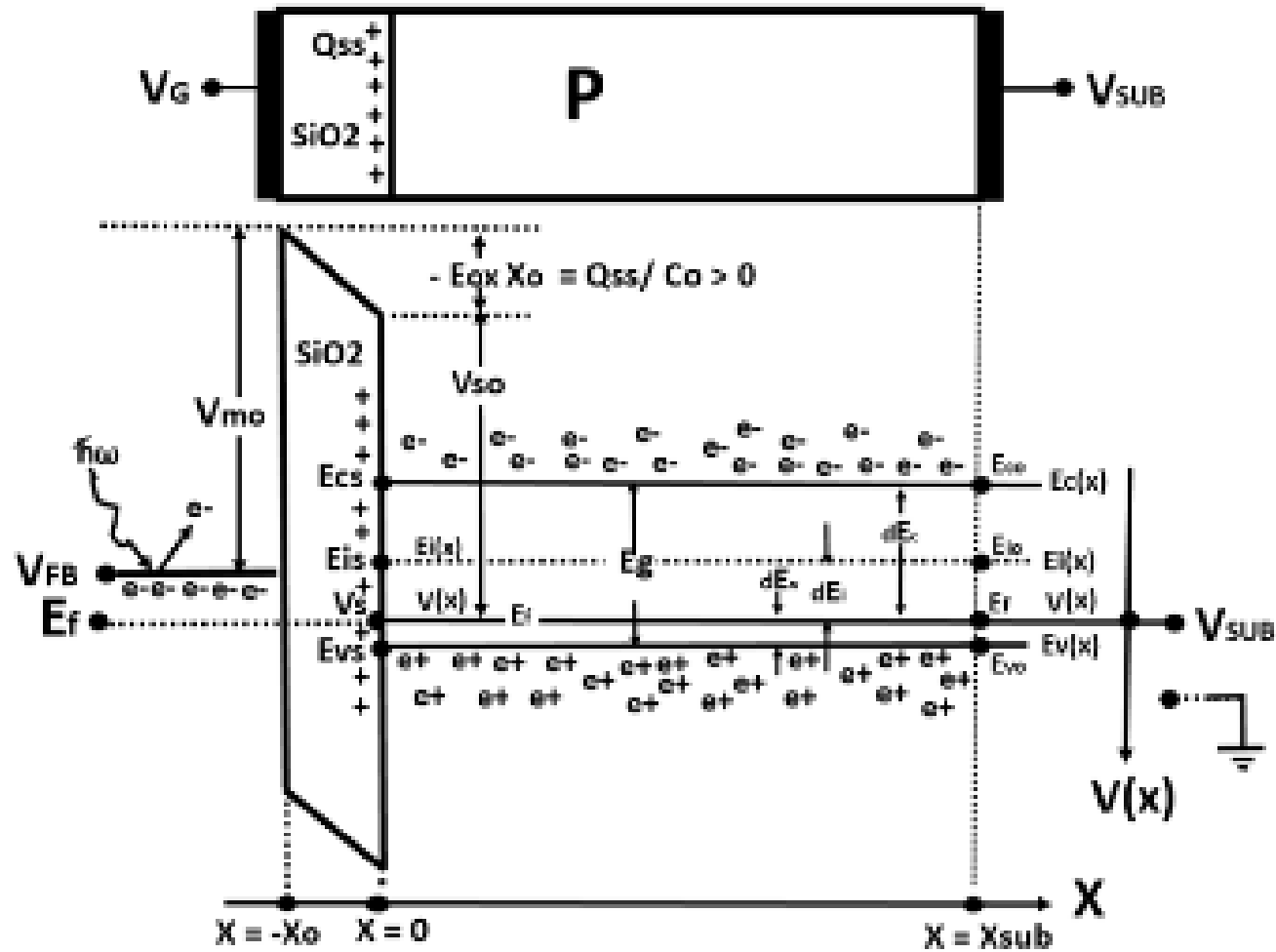


Figure 2

The band diagram of one Dimension MOS structure of P-type silicon wafer at the flat band gate voltage.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

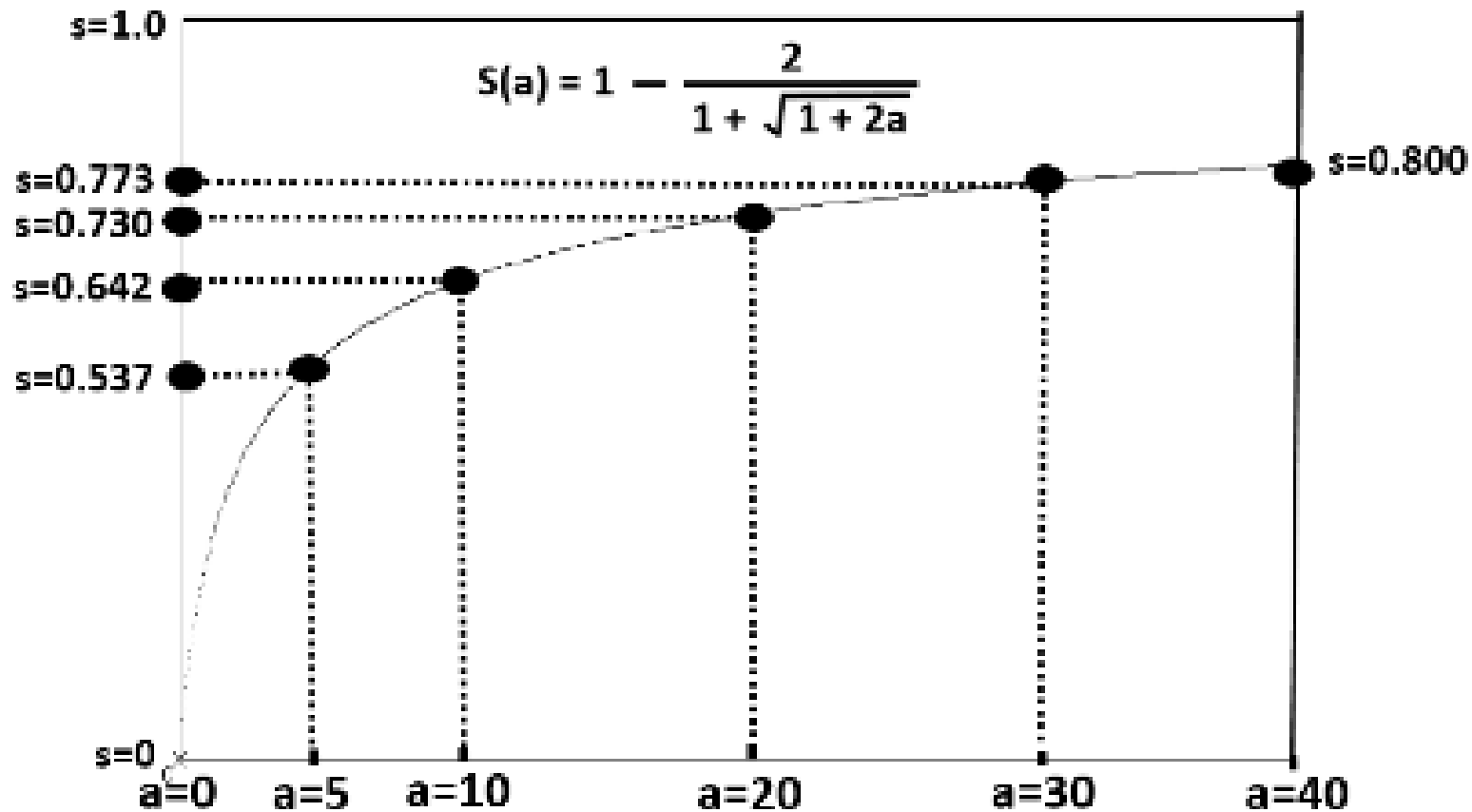


Figure 3

The values of the function $S = S(a)$ plotted against the input physical parameter $a = VGG/VA$.

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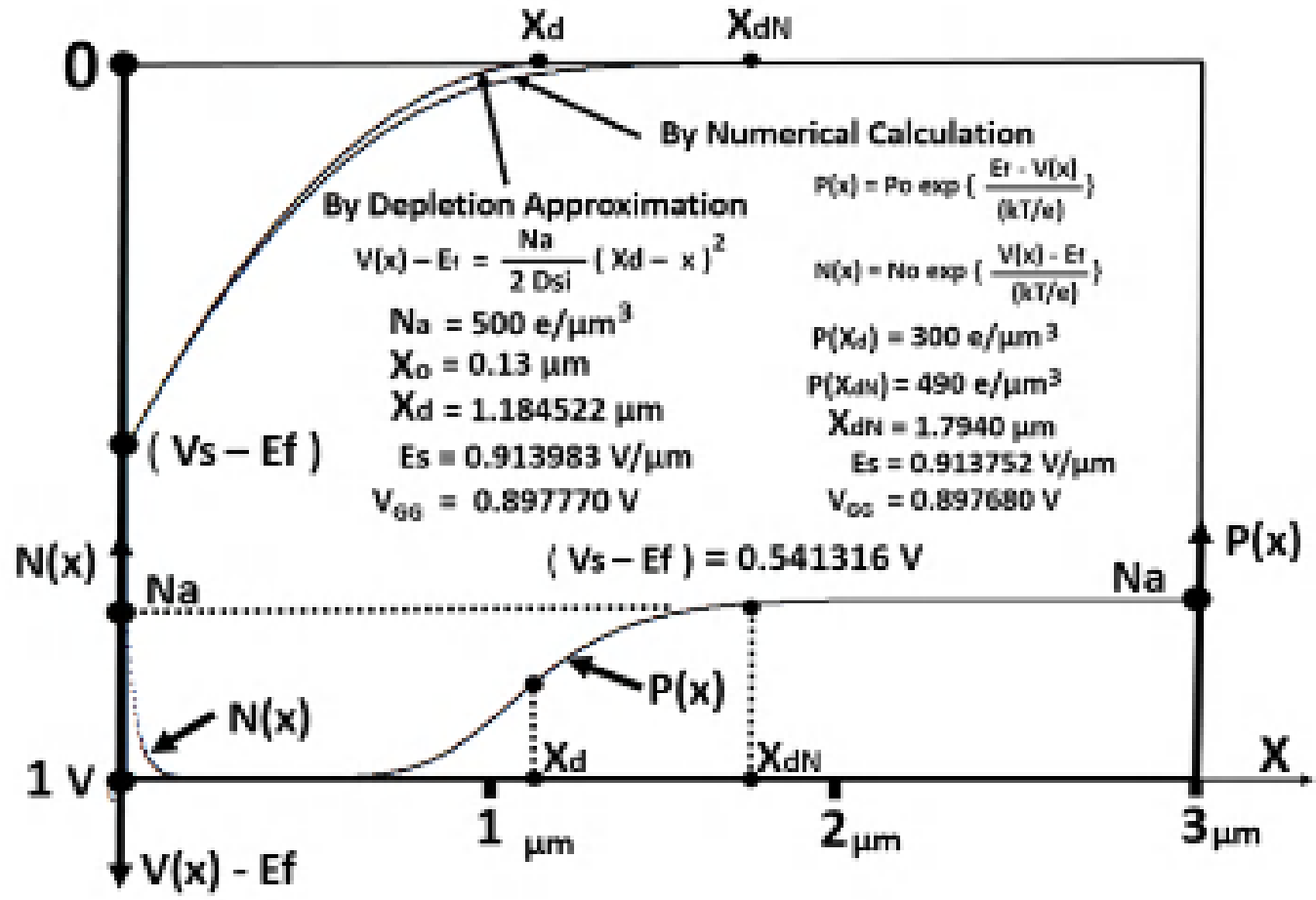


Figure 4

The internal potential $V(x)$ and the mobile electron and hole densities $P(x)$ and $N(x)$ at the onset of the strong inversion condition.

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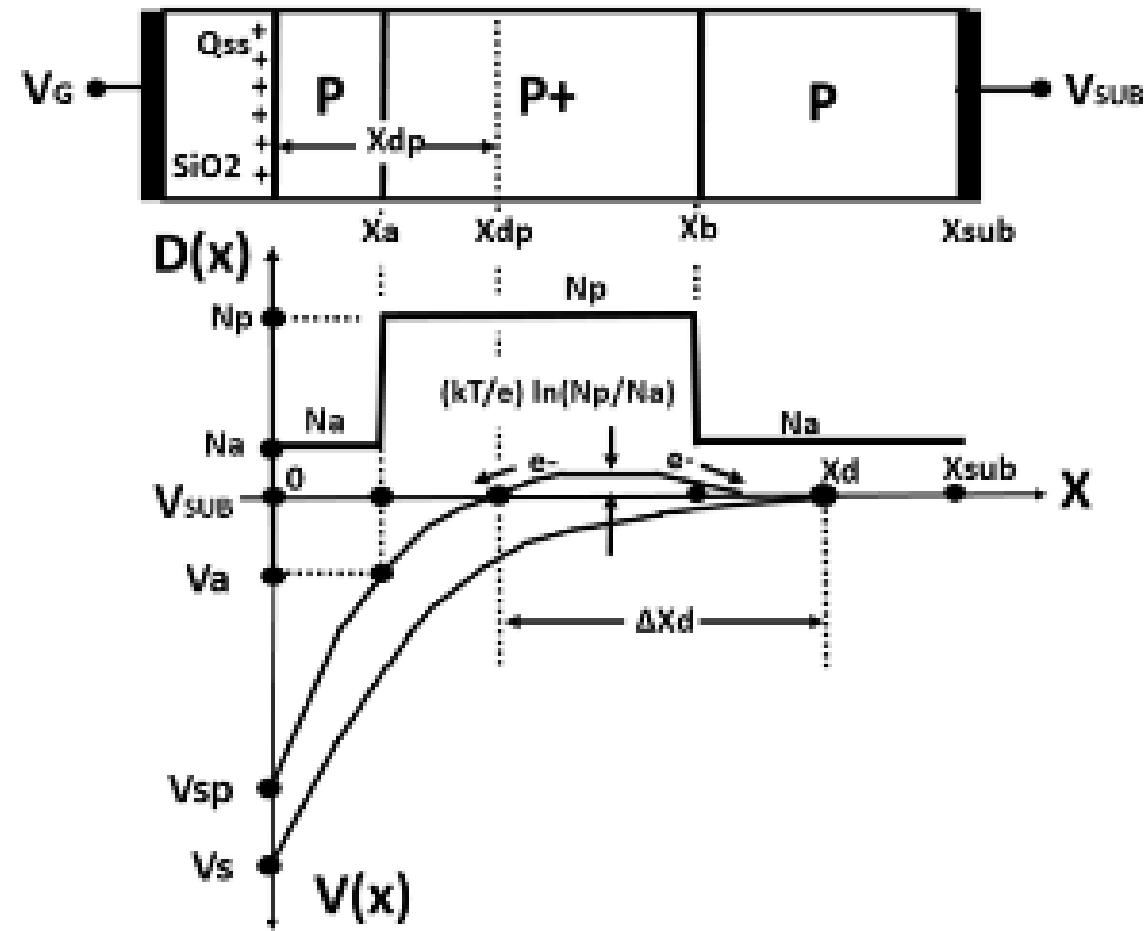


Figure 5

The impurity doping profile $D(x)$ for the heavily doped buried P^+ layer and the internal potential $V(x)$

The invention of Modern Photodiode by Hagiwara at SONY in 1975

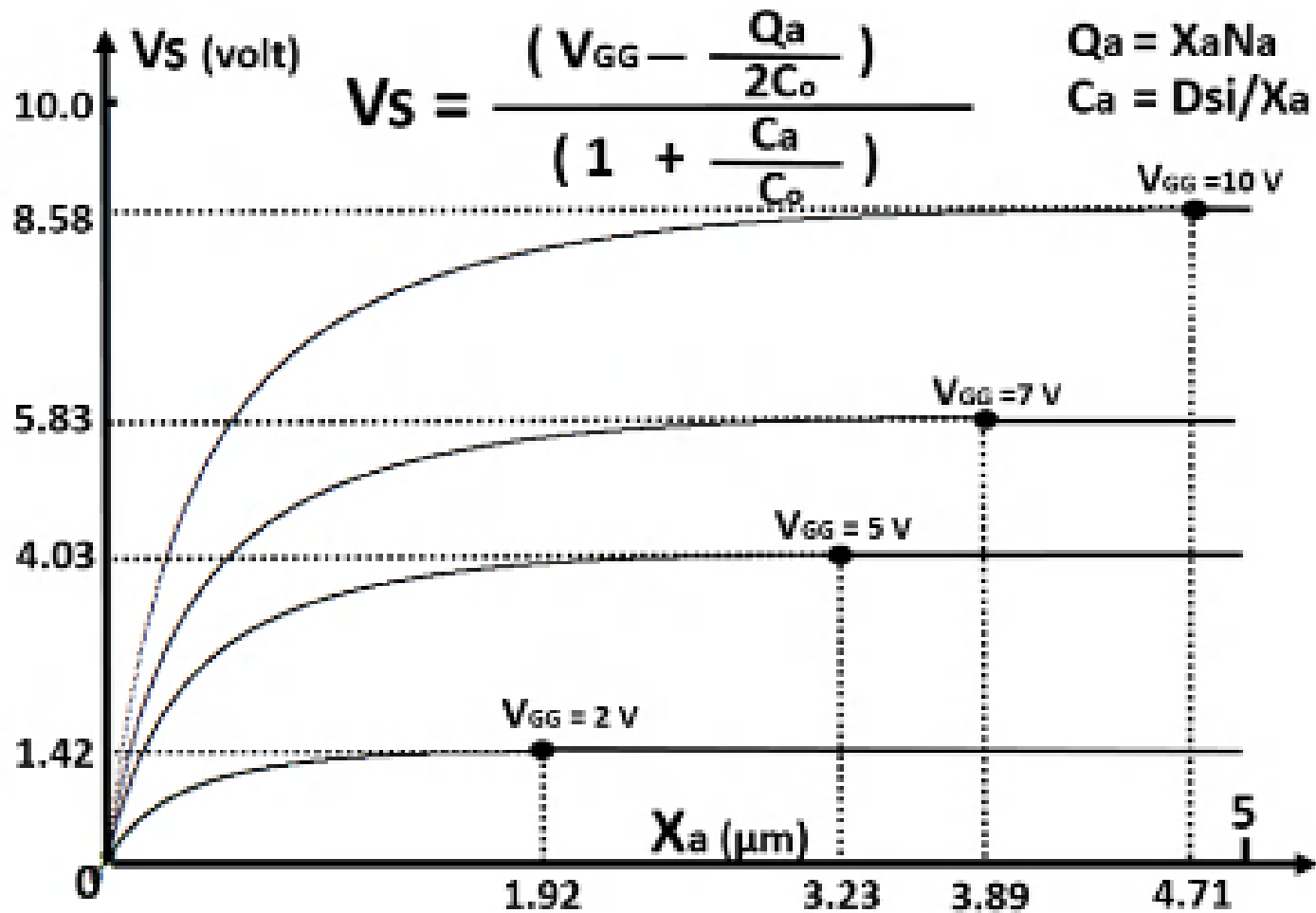


Figure 6

The surface potential plotted against the depth X_a of the buried P+ layer.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

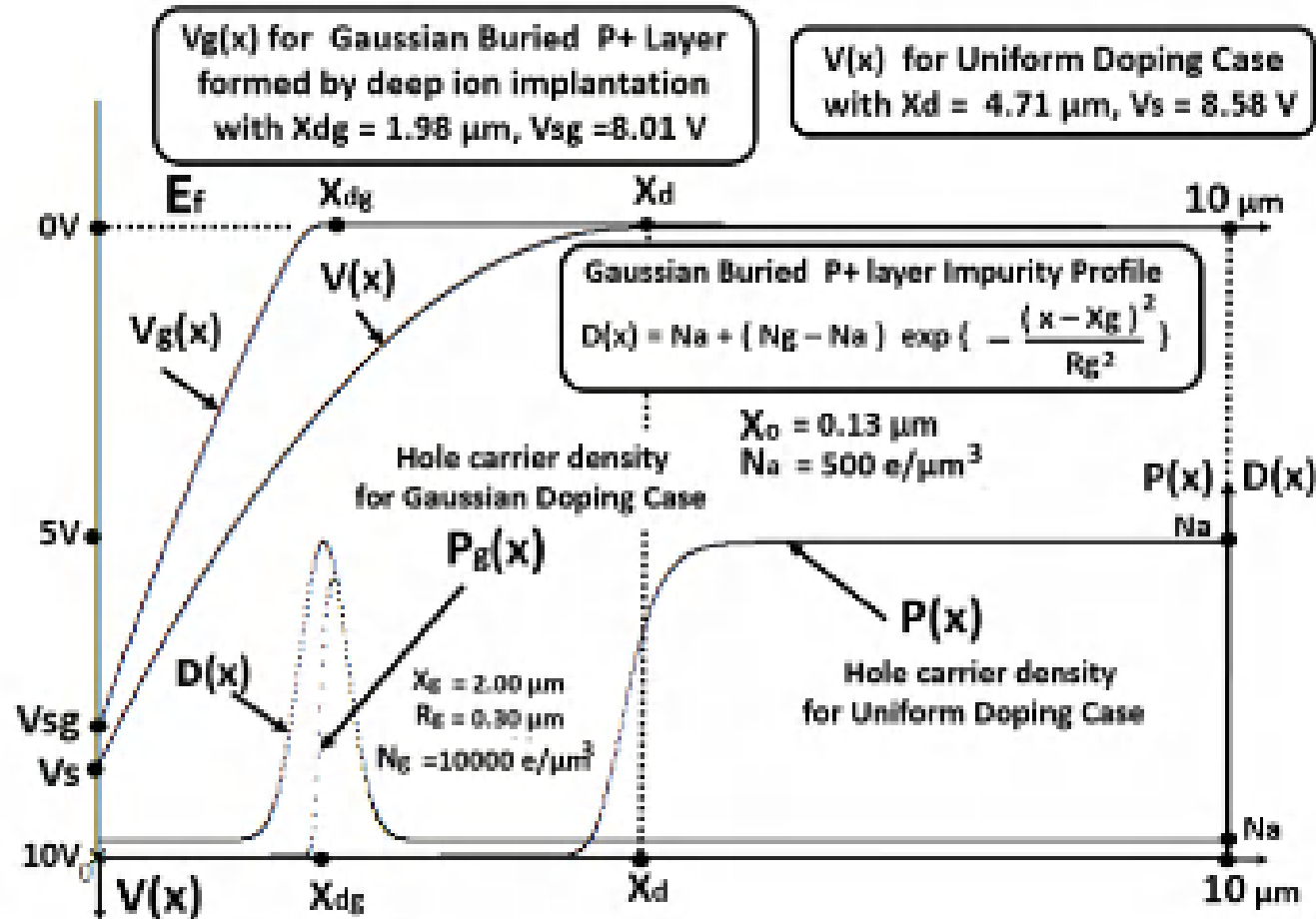


Figure 7

The internal potential profile $V_g(x)$ and the majority carrier hole density $P_g(x)$ for the case of Gaussian Buried P+ Layer are shown in comparison with the Uniform Doping Profile case

The invention of Modern Photodiode by Hagiwara at SONY in 1975

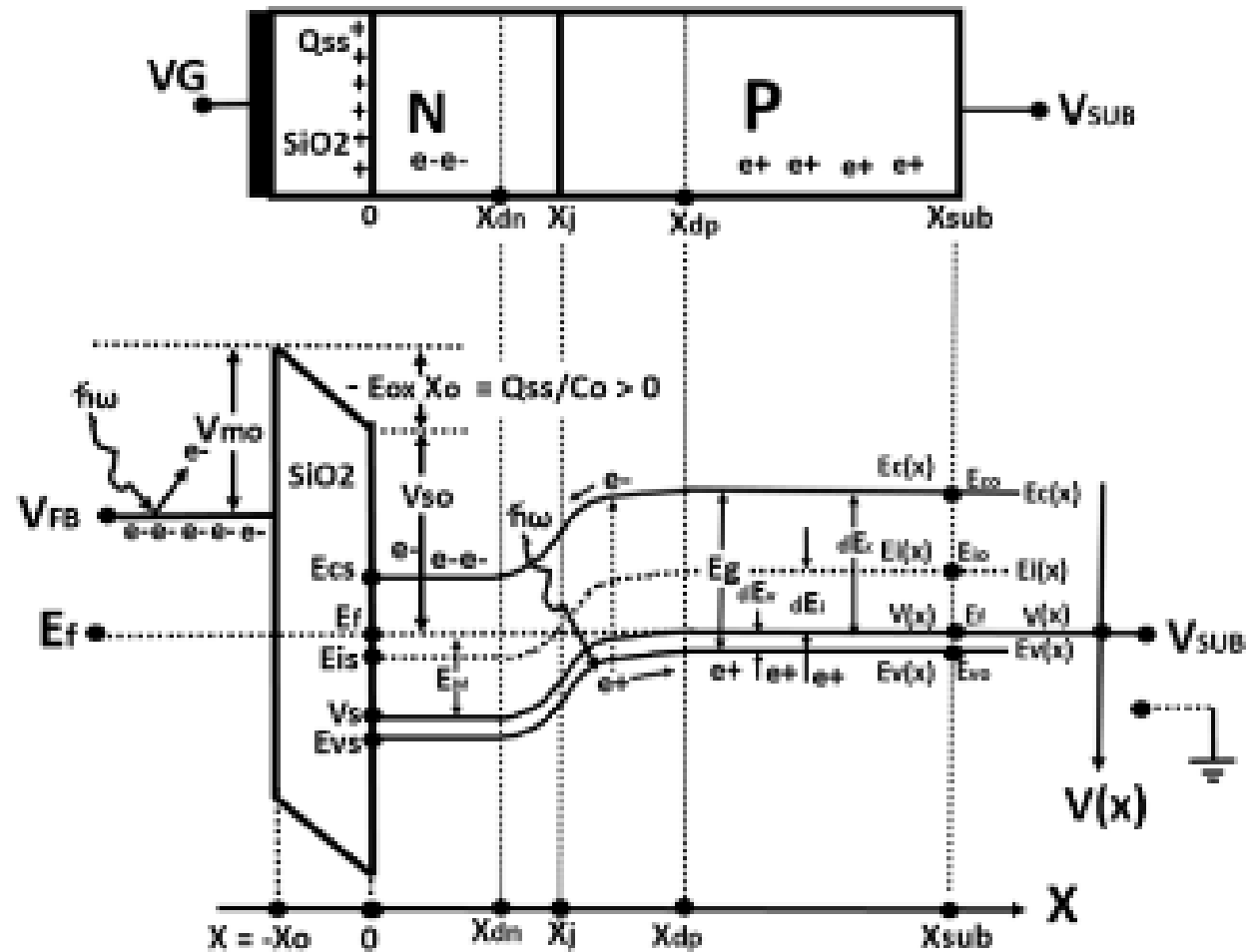


Figure 8

The NP junction type Buried Channel MOS Capacitor Structure with the flat band gate voltage

The invention of Modern Photodiode by Hagiwara at SONY in 1975

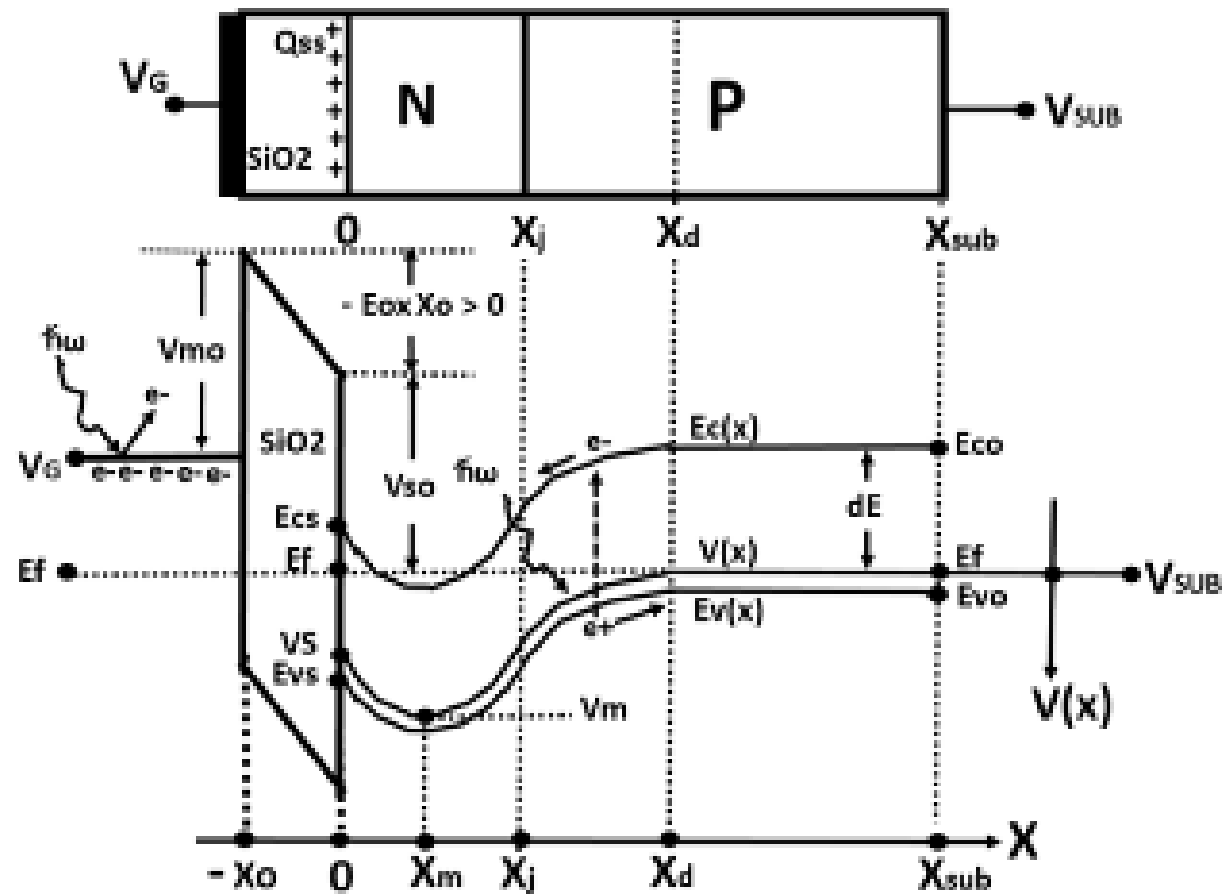


Figure 9

The NP junction type Buried Channel MOS Capacitor Structure at the dynamic operation mode when the buried channel layer is completely depleted of the majority carrier electrons.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

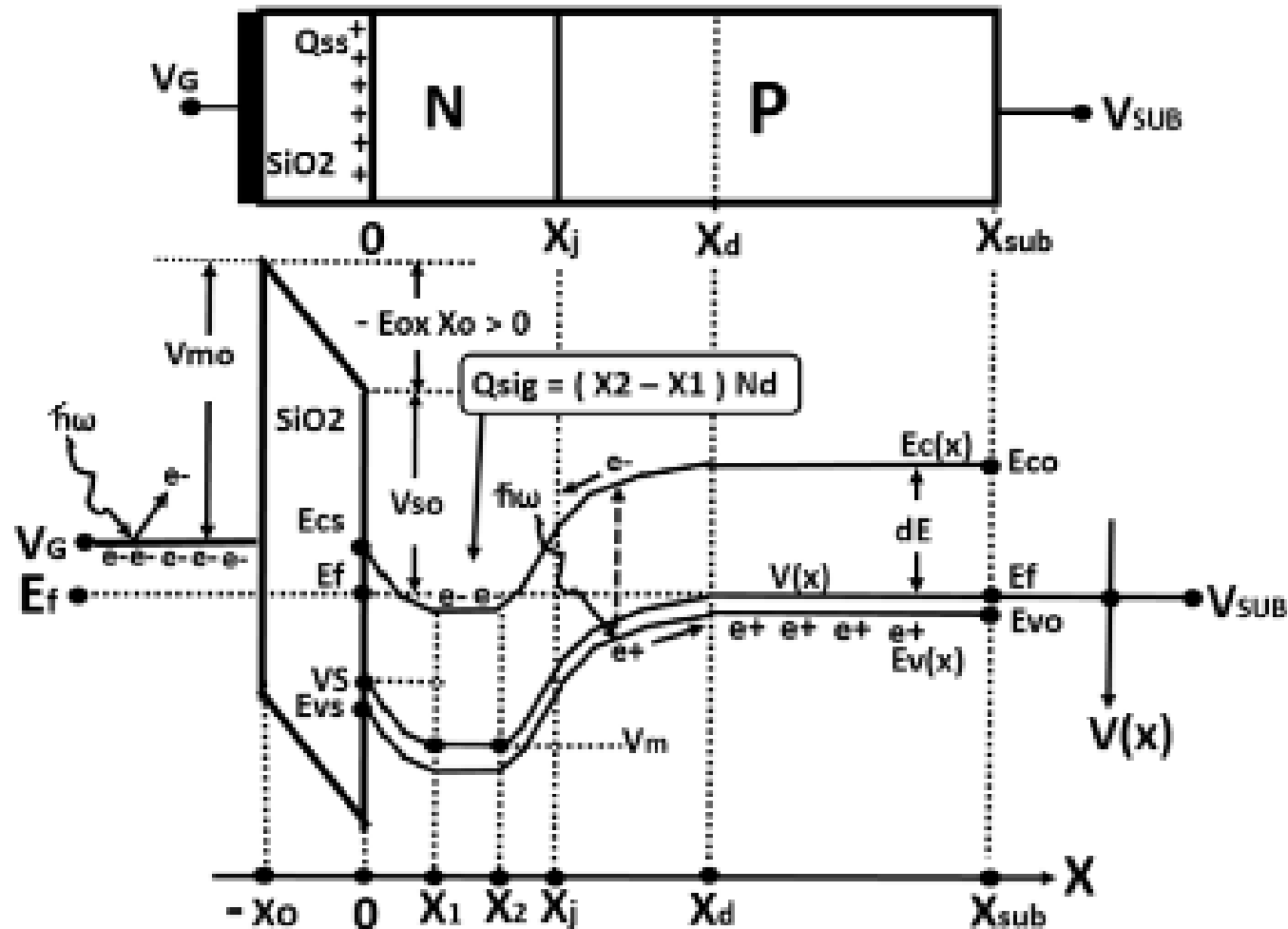


Figure 10

The NP junction type Buried Channel MOS Capacitor Structure at the dynamic operation mode with the majority carrier mobile electrons present in the buried channel layer.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

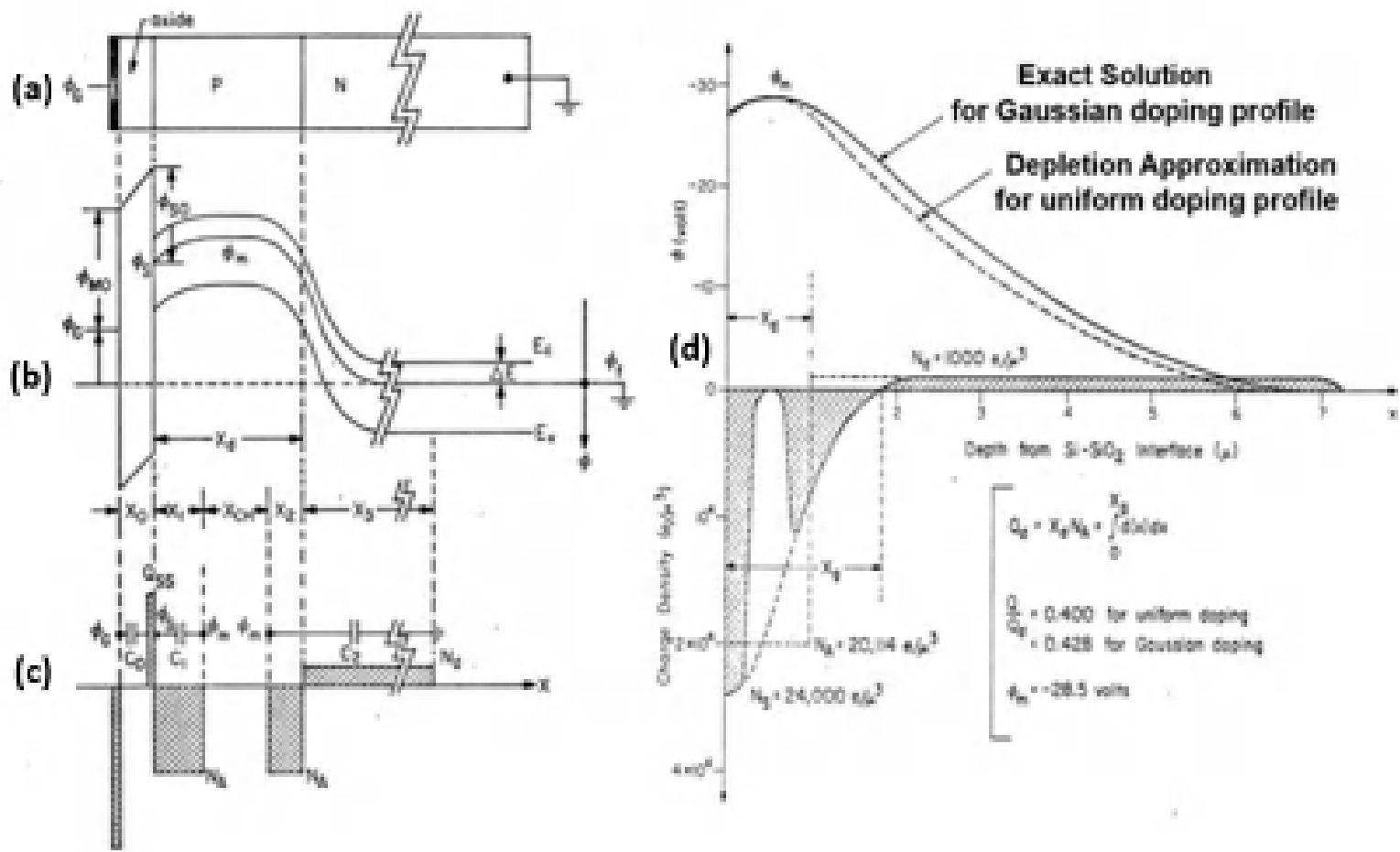


Figure 11

The electrostatic potential and the charge distribution in Buried Channel CCD with the Gaussian doping profile compared with the depletion approximation.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

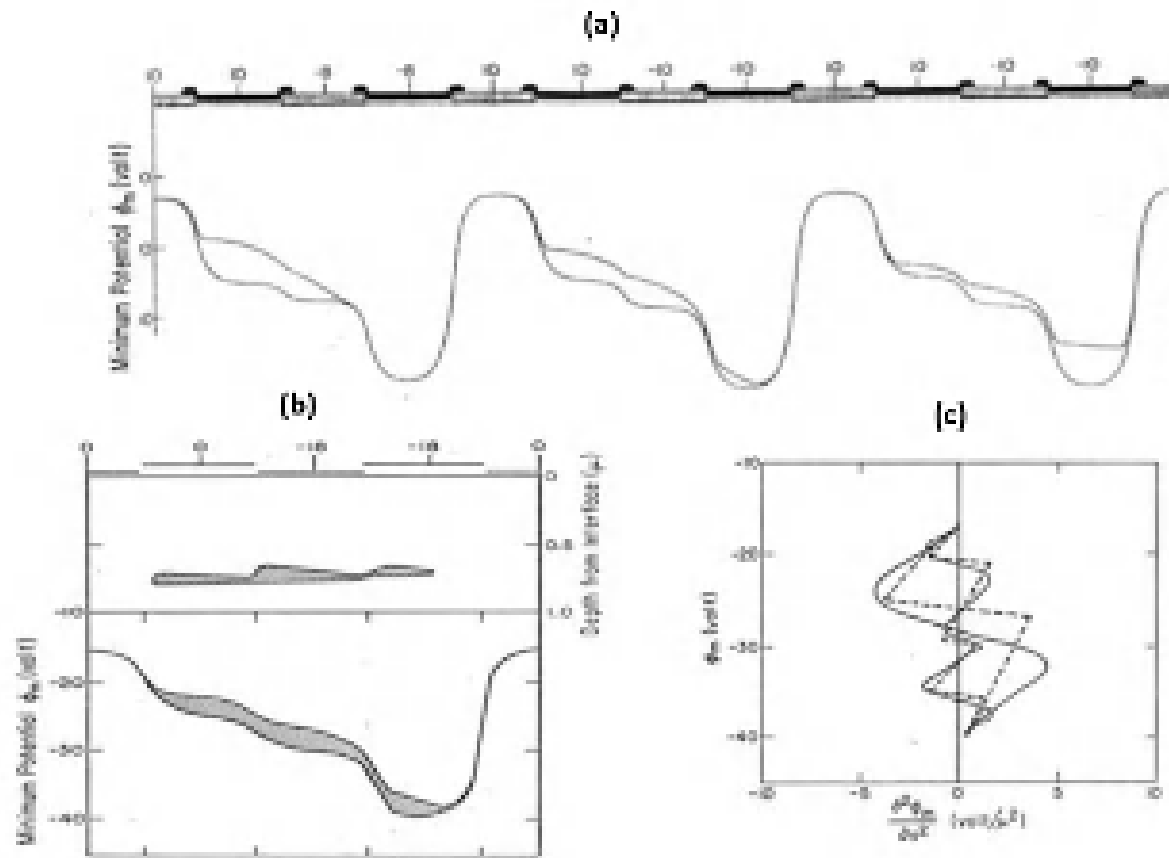


Figure 12

The electrostatic potential and the charge distribution in Buried Channel CCD obtained by time domain (t) and two dimensional (x, y) numerical computation solving simultaneously the Poisson Equation in the (x, y) domain and the continuity equation in the (t, x) domain.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

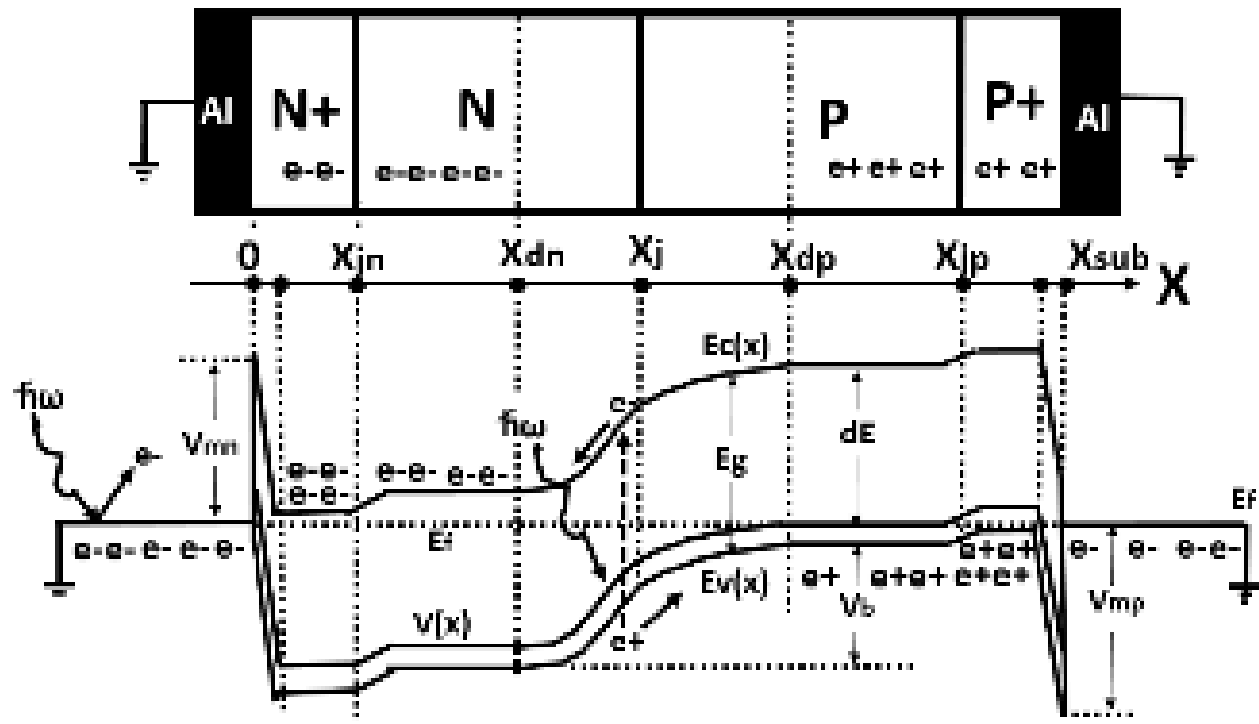


Figure 13

NP junction type photodiode at the thermal equilibrium with a heavily doped region in each side forming an Ohmic contact, pinned by the external aluminum metal terminal voltage. The charge carriers can pass thru the Schottky barrier by tunneling.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

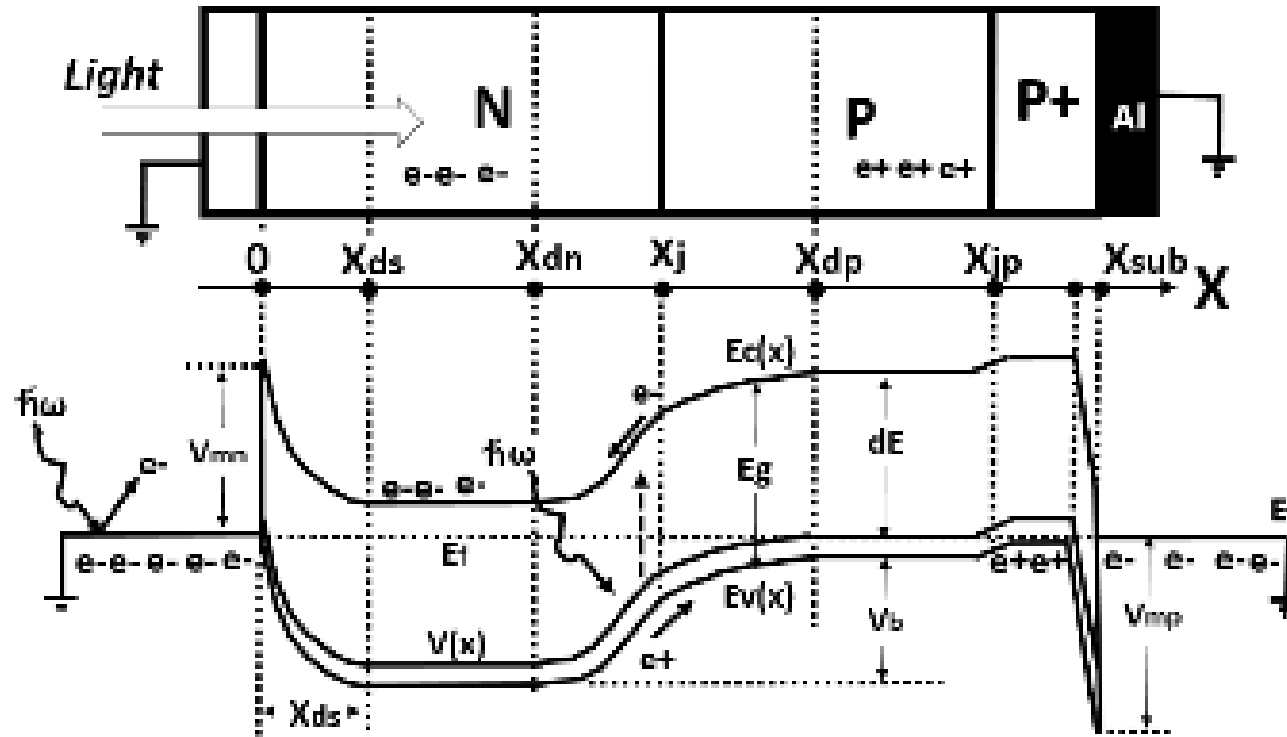


Figure 14

Schottky Barrier NP junction type photodiode with a transparent metal electrode with the N type buried channel charge collecting storage region at the thermal equilibrium

The invention of Modern Photodiode by Hagiwara at SONY in 1975

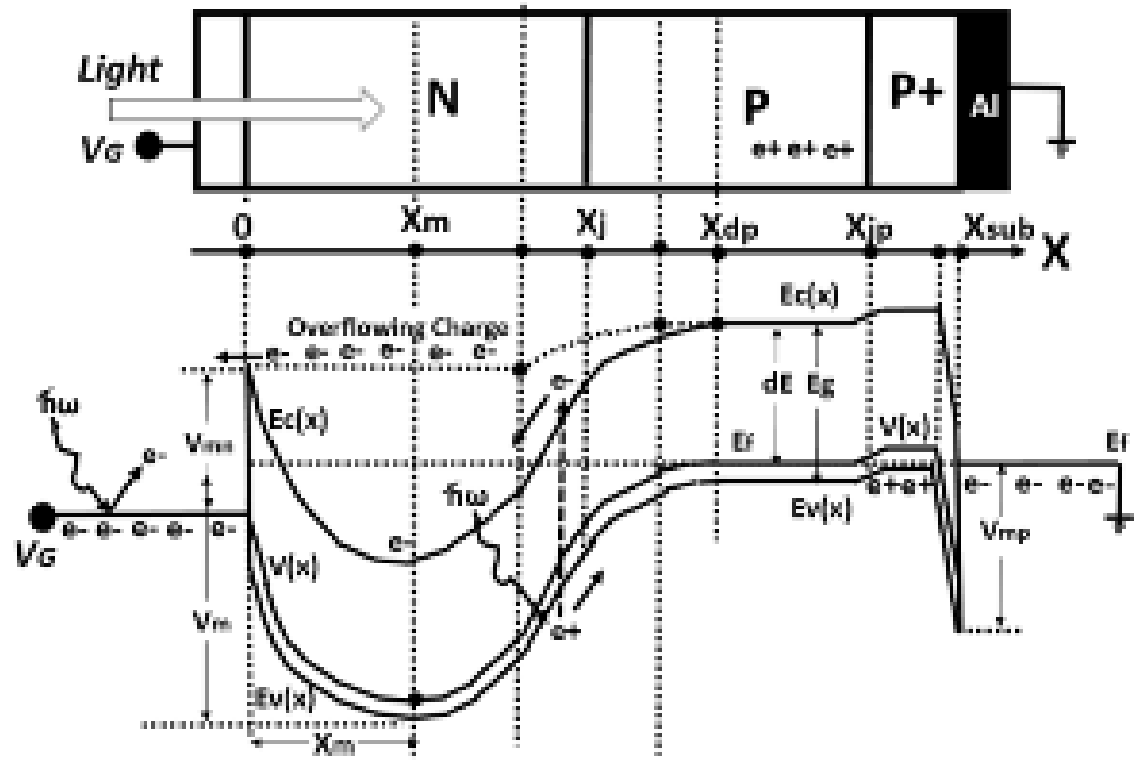


Figure 15

The NP junction type photodiode with the Schottky barrier with a transparent metal electrode, acting also as the overflow draining gate, and with the completely majority carrier depleted N type buried channel charge collecting storage region, by complete charge transfer with no image lag in the dynamic operation mode. When the N storage region is full, the excess charge can be drained by flowing over the Schottky barrier into the draining gate electrode.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

特 願 昭50-134985
 出 願 昭50(1975)11月10日
 公 開 昭52-58414
 昭52(1977)5月13日

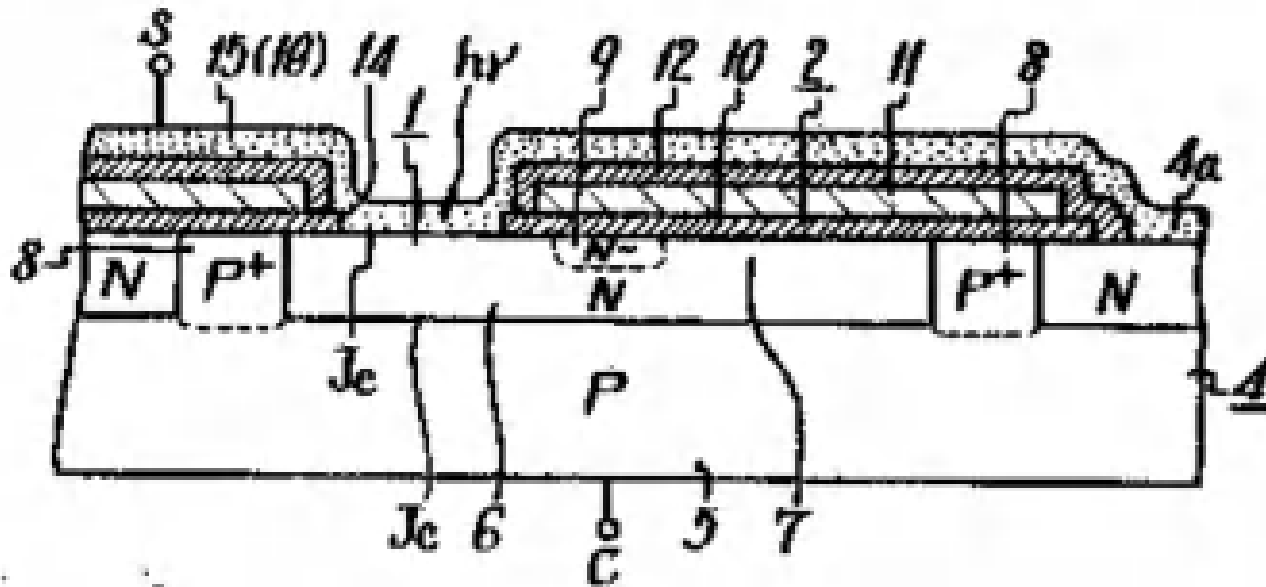


Figure 16

Schottky Barrier NP junction type Photodiode, drawn in Japanese Patent 1975-134985 by Hagiwara at Sony, used in Interline Transfer Buried Channel CCD image sensor.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

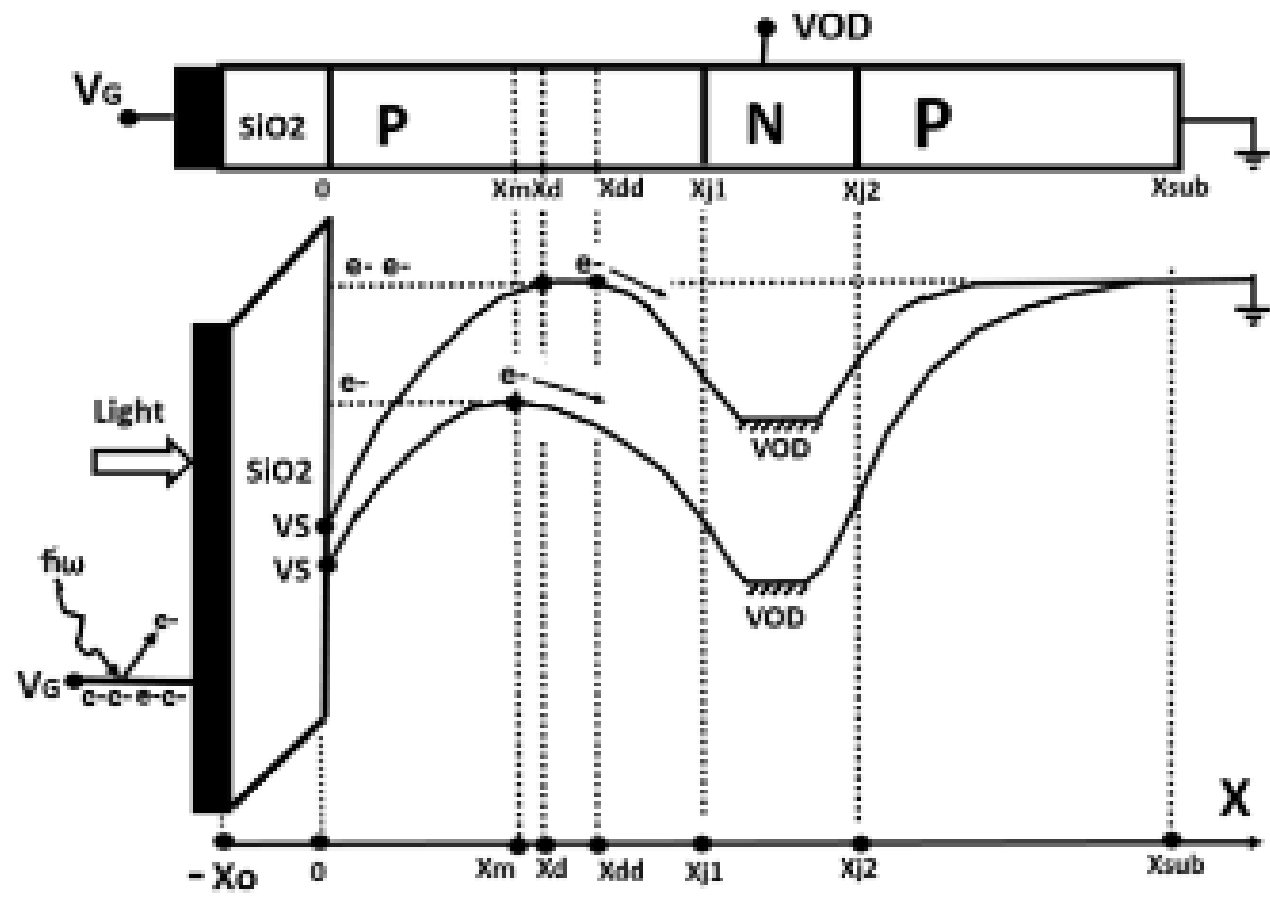


Figure 17

Surface Channel MOS Light Collecting Photo Capacitor with Buried Vertical Overflow Drain (VOD) protection

The invention of Modern Photodiode by Hagiwara at SONY in 1975

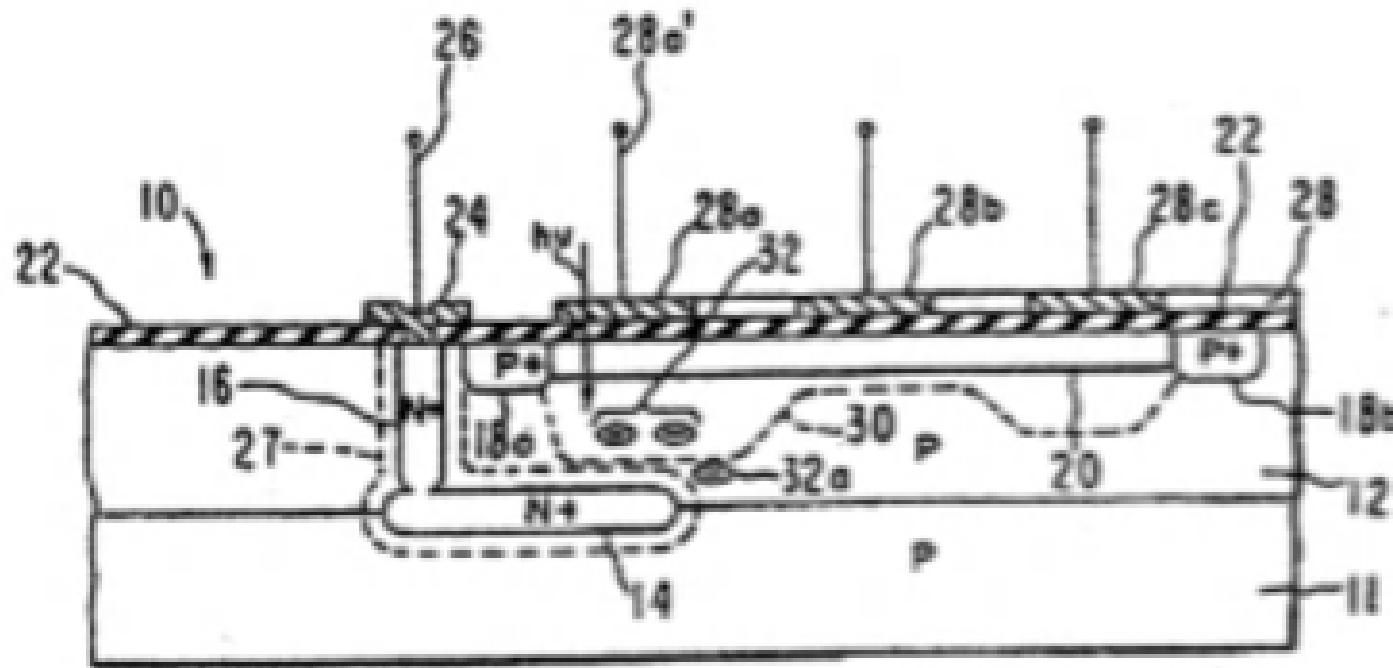


Figure 18

The Buried Vertical Overflow Drain (VOD) protection, drawn in the USA patent USP3896485 (July 22, 1975) by James M. Early at Fairchild, USA, applied in the Surface Channel CCD Image Sensor.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

①特開昭 52-51815
 ②公開日 昭52(1977) 4,28
 ③特開昭 50-127646
 ④出願日 昭50(1975)10, 23

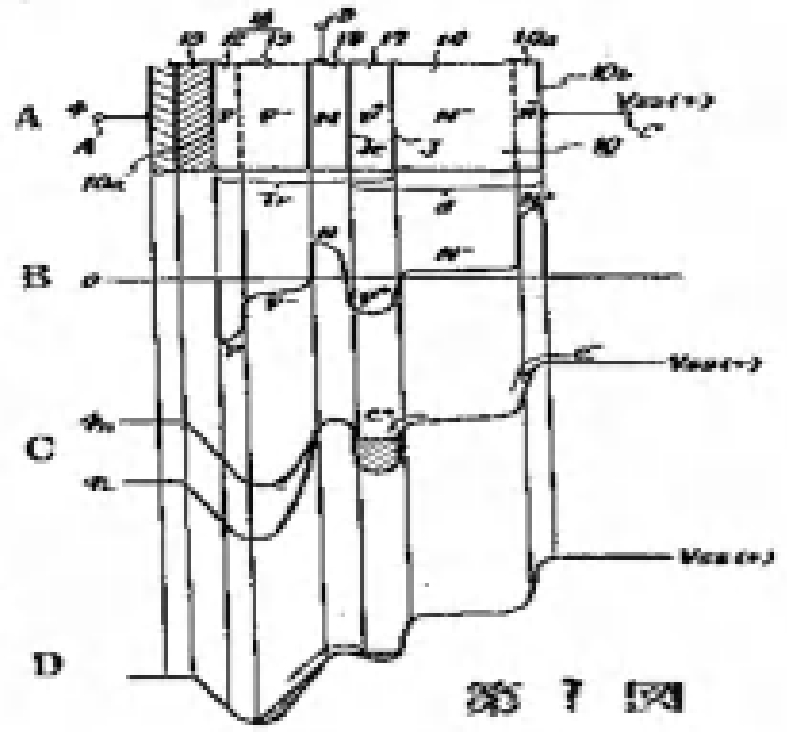
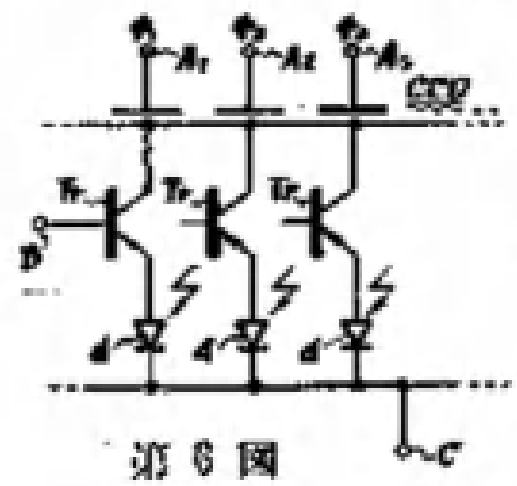


Figure 19

The N+N-P+ junction type Buried Photodiode, which has a charge collecting and storage buried P+ layer , drawn in Japanese Patent 1975-127646 (Oct 23, 1975) by Hagiwara at Sony, with a PNP bipolar transistor type Charge Transfer Gating (CTG) and with P-type Buried Channel MOS Capacitor used as the temporary storage buffer memory for Global Shutter operation in back light illumination scheme.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

Buried Photodiode (BPD) Signal Charge Remaining in Potential Well with Serious Image Lag

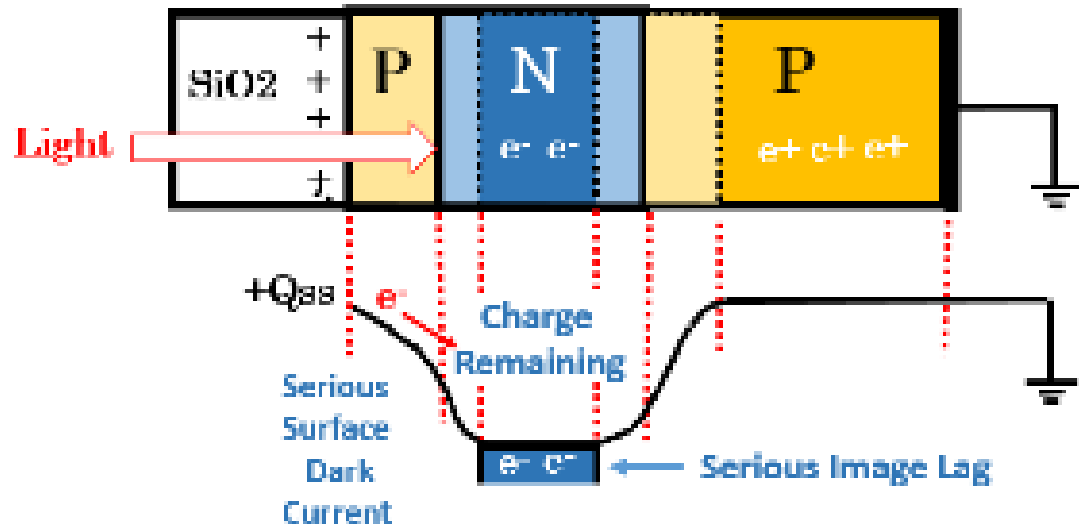


Figure 20

The original Buried Photodiode (BPD) invented by Hagiwara in Japanese Patent 1975-127646. The Buried Photodiode (BPD) is a simple PNP junction type photodiode that may still have the remaining electron charge in the charge collection region when reset, and also that the surface potential is not pinned. Therefore, the surface electric field and the surface fixed positive charge +Q_{ss} may generate the undesired serious dark current that degrades image output quality and also creates silicon chip yield problems. Buried Photodiode(BPD) is not by necessity Depletion Photodiode (DPD) that has no image lag. Moreover, Buried Photodiode (BPD) is not by necessity Pinned Photodiode (PPD) that has no dark current.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

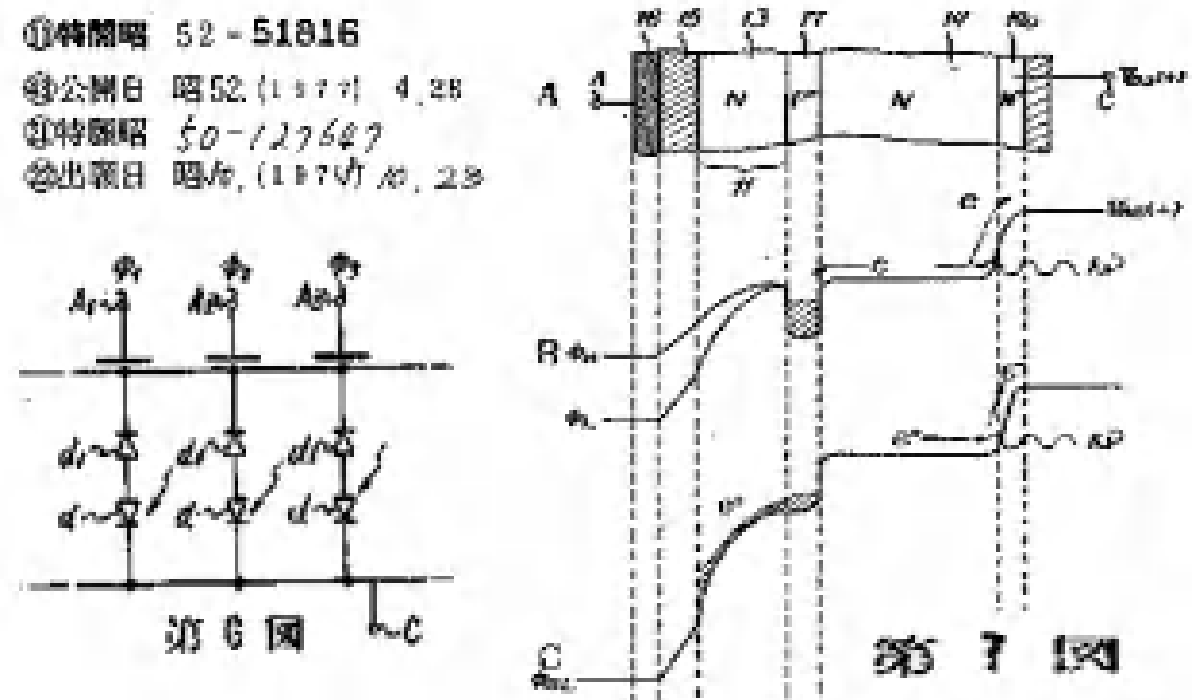


Figure 21

The N+NP+ junction type Depletion Photodiode, which is also a Buried Photodiode that has a charge collecting and storage buried P+ layer , drawn in Japanese Patent 1975-127647 (Oct 23, 1975) by Hagiwara at Sony, with N-type Surface Channel MOS Capacitor used as the temporary storage buffer memory for Global Shutter operation in back light illumination scheme.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

Depletion Photodiode (DPD)

Completely Depleted Empty Potential Well with No Image Lag

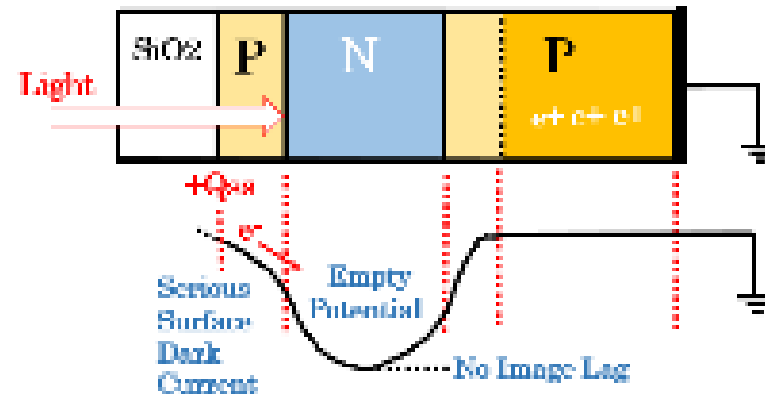


Figure 22

The original Depletion Photodiode (DPD), drawn in Japanese Patent 1975-127647 by Hagiwara at Sony. Depletion Photodiode (DPD) is a Photodiode that has no remaining electron charge in the charge collection region when reset by the complete charge transfer operation. Hence there is no image lag in DPD. However the surface potential is by necessity not pinned. Therefore, the surface electric field and the surface fixed positive charge $+Q_{ss}$ may generate the undesired serious dark current that degrades image output quality and also creates silicon chip yield problems. Depletion Photodiode (DPD) is by necessity Buried Photodiode (BPD). So, Depletion Photodiode (DPD) is always a Buried Photodiode (BPD). But Buried Photodiode (BPD) is not by necessity the Pinned Photodiode (PPD) that has no dark current.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

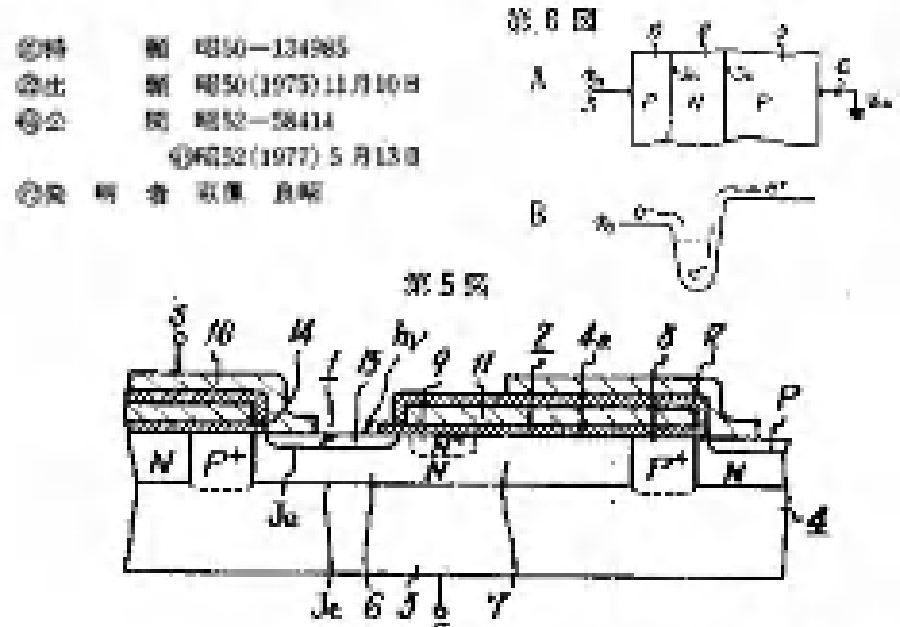


Figure 23

The Pinned photodiode with the heavily doped P+ surface layer, drawn in Japanese Patent 1975-134985 by Hagiwara at Sony , used for the Buried Channel Interline Transfer CCD image sensor. The surface hole accumulation layer is shown to have such a very heavily doped P+ region that can have a fixed or Pinned potential by the external metal Ohmic contact by option. The charge collecting region is a buried layer under the P+ surface layer. Hence, this is also a Buried Photodiode. The buried N type base region in the PNP junction type photodiode structure has the same doping level of the lightly doped buried channel CCD, and can be completely depleted of the signal charge to the adjacent buried channel CCD type readout charge transfer device (CTD) by the complete charge transfer so that we have no image lag picture. Hence this is also a Depletion Photodiode with complete charge transfer mode.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

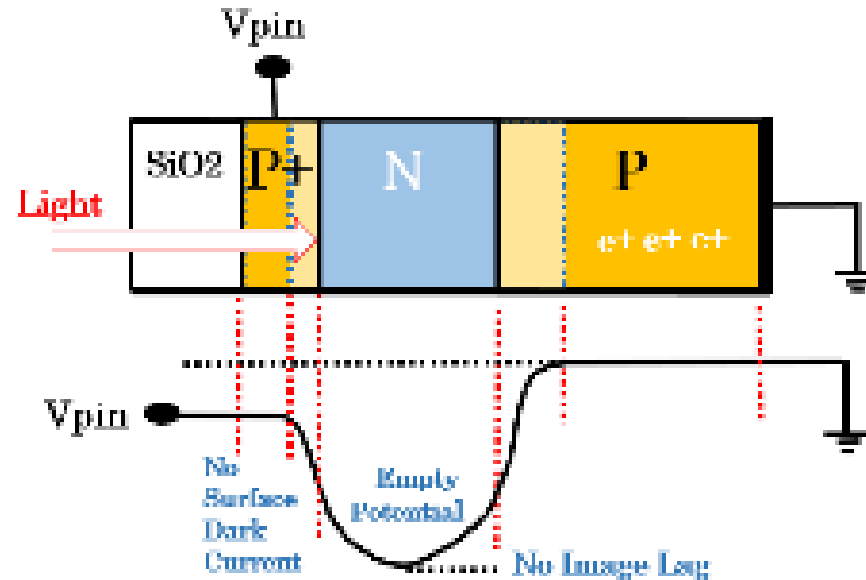


Figure 24

Pinned Photodiode (PPD), invented by Hagiwara in Japanese Patent 1975-134985, is a simple P⁺NP junction type Depletion Photodiode (DPD), which is also a Buried Photodiode (BPD) that has no remaining electron charge in the charge collection region by the complete charge transfer operation when reset. The surface potential is pinned by the heavily doped P⁺ hole accumulation surface layer. This is the original invention of SONY Hole Accumulation Diode (SONY HAD). There is no surface electric field and the surface fixed positive charge +Q_{ss} is quenched so that we do not suffer the undesired serious surface dark current that degrades the image output quality and also creates the serious chip yield problems. Pinned Photodiode (PPD) is by necessity Depletion Photodiode (DPD) and also by necessity Buried Photodiode (BPD).

The invention of Modern Photodiode by Hagiwara at SONY in 1975

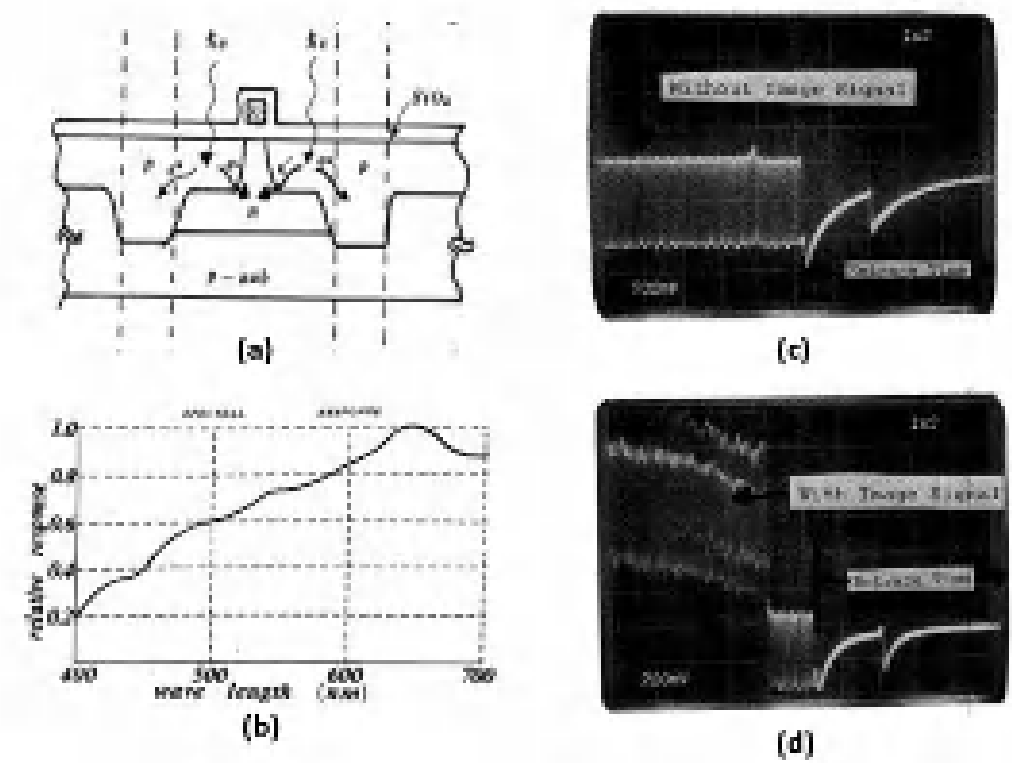


Figure 25

The original Pinned window (a) with the heavily doped P+ Pinned Surface potential connected to the substrate voltage by option with excellent blue light sensitivity (b). The P+NP junction type Pinned Photodiode with the self-aligned boron atom ion implantation, forming the P+ hole accumulation layer at the silicon surface to quench the surface dark current as shown in (c) and (d) . See "A 380Hx488V CCD imager with narrow channel transfer gates," by Y. Daimon-Hagiwara, M. Abe, and C. Okada, Proceedings of the 10th Conference on Solid State Devices, Tokyo, 1978; Japanese Journal of Applied Physics , vol. 18, supplement 18-1, pp. 335-340, 1979

The invention of Modern Photodiode by Hagiwara at SONY in 1975

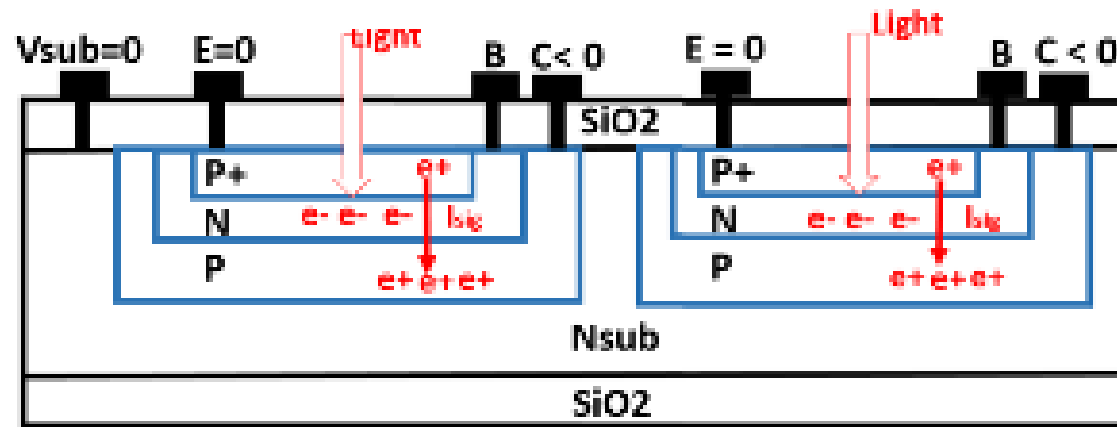


Figure 26a

Conventional Phototransistor in 1948. John Northrup Shive (February 22, 1913 – June 1, 1984) is best known for inventing this phototransistor in 1948 (a device that combines the sensitivity to light of a photodiode and the current gain of a transistor). But he also produced experimental evidence that holes could diffuse through bulk germanium, and not just along the surface as previously thought. This paved the way from Bardeen and Brattain's point-contact transistor to Shockley's more-robust junction transistor.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

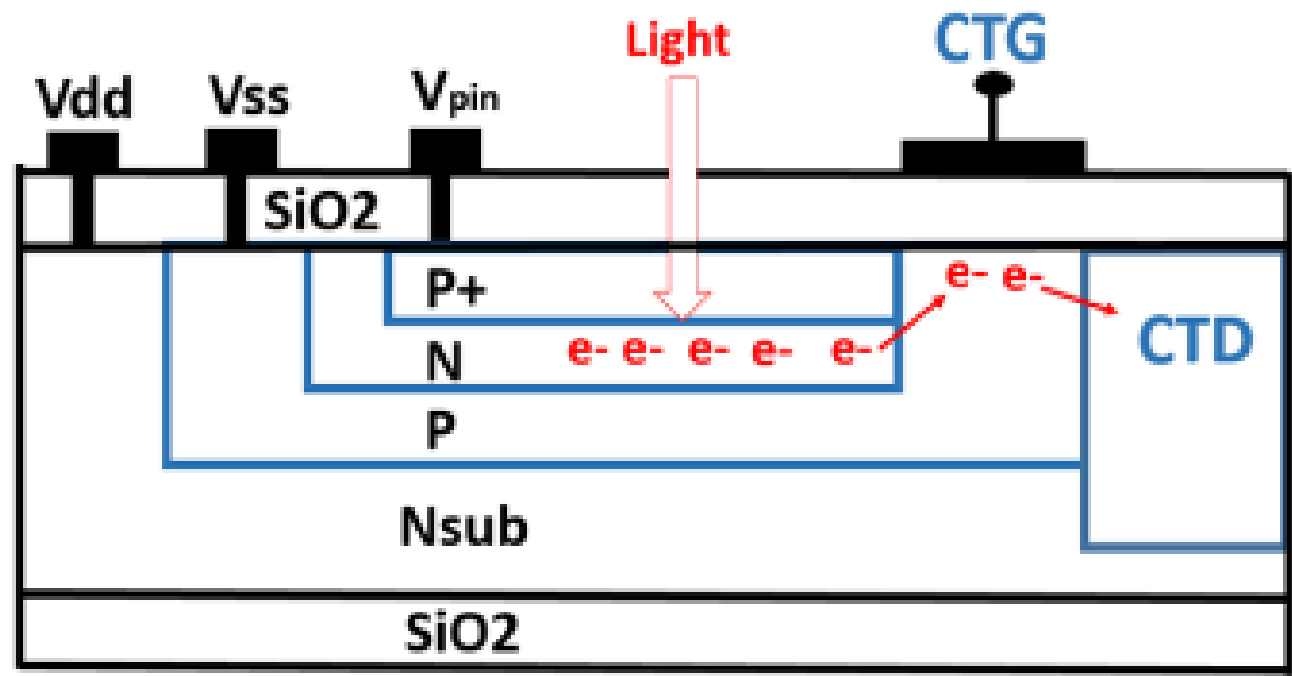


Figure 26b

Dynamic Phototransistor with Floating Base used as Signal Charge Storage Region, the original form of the P+NPNsub junction type Pinned Photodiode invented by Hagiwara at Sony in 1975. See Japanese Patent 1975-134985.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

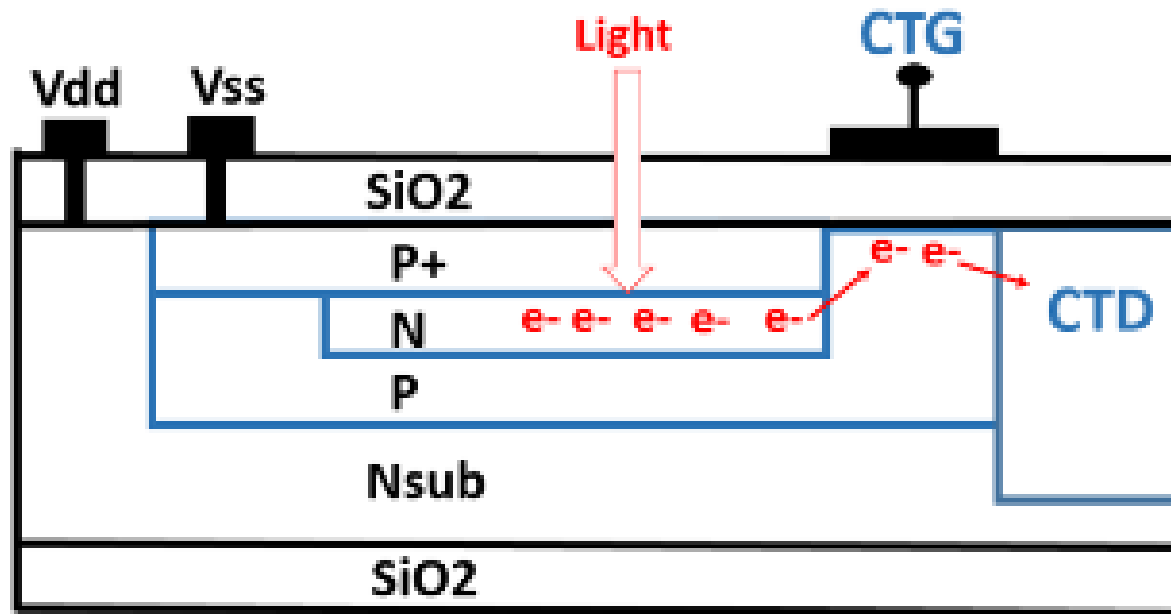


Figure 26c

Dynamic Phototransistor with Floating Base used as Signal Charge Storage Region, the P⁺NPN_{sub} junction type Pinned Photodiode with the Pinned Window with the Pinned surface Ppotential of the P⁺ hole accumulation layer pinned directly by the substrate voltage. This is the SONY original Hole Accumulation Diode (SONY HAD) invented by Hagiwara at Sony in 1975. See also the paper "A 380Hx488V CCD imager with narrow channel transfer gates," by Y. Daimon-Hagiwara, M. Abe, and C. Okada, Proceedings of the 10th Conference on Solid State Devices, Tokyo, 1978; Japanese Journal of Applied Physics, vol. 18, supplement 18-1, pp. 335-340, 1979

The invention of Modern Photodiode by Hagiwara at SONY in 1975

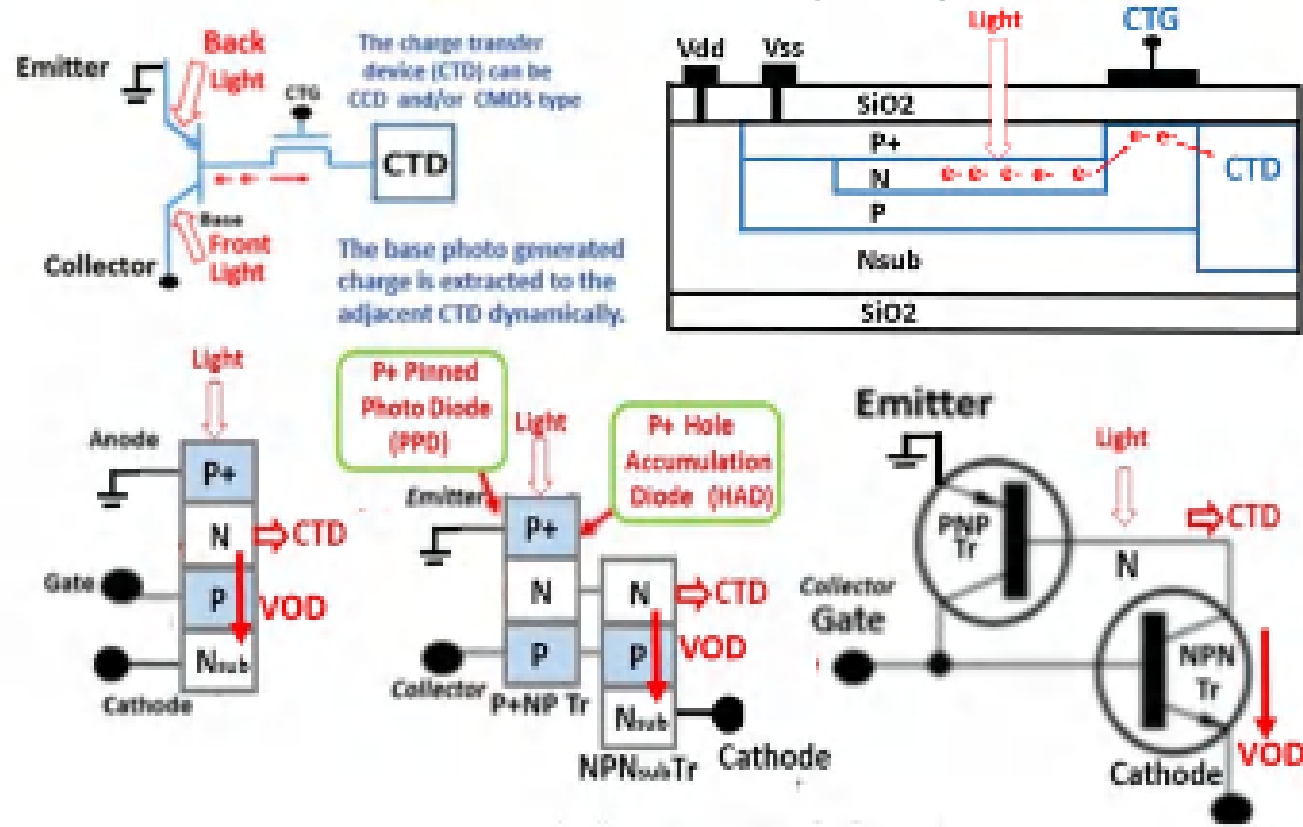


Figure 27

The P+NP_{sub} junction type Thyristor structure for the light collecting device, invented by Hagiwara in Japanese Patent 1975-134985, which is also the P+NP junction type Pinned Photodiode (PPD), Since this is a P+NP_{sub} junction type Thyristor structure which has a variety of device operation modes that includes the Thyristor punch thru action mode that can be applied for the vertical overflow drain (VOD) function controlling the overflowing signal charge at the high light beam.

The invention of Modern Photodiode by Hagiwara at SONY in 1975

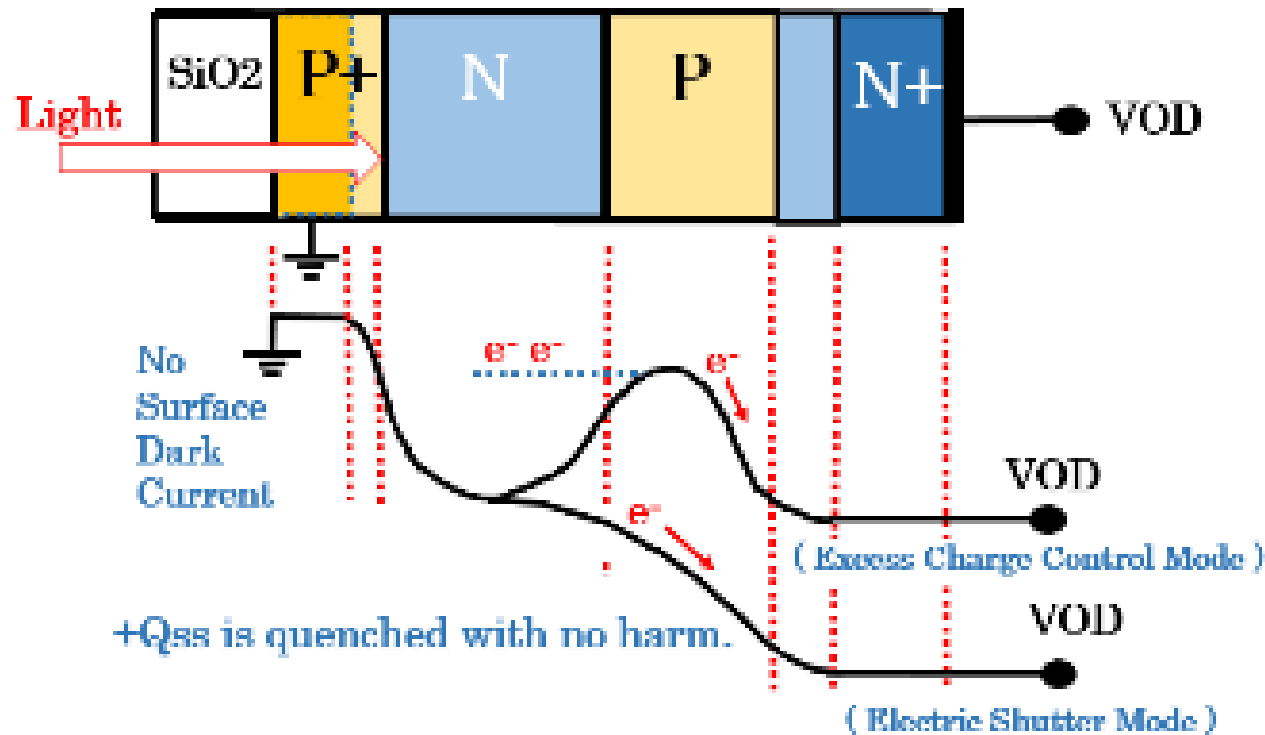


Figure 28

The $\text{P}^+\text{NPwell}/\text{Nsub}$ junction type Pinned Photodiode (PPD), invented by Hagiwara in Japanese Patent 1975-134985, is also by necessity a Depletion Photodiode (DPD) and also by necessity a Buried Photodiode (BPD). Since this is a $\text{P}^+\text{NPwell}/\text{Nsub}$ junction type Thyristor structure which has a variety of device operation modes that includes the Thyristor punch thru mode that can be applied for the vertical overflow drain (VOD).

Figure 29 P+NP/Sub junction type Pinned Photo Diode

invented by Hagiwara at Sony in Japanese Patent 1975-134985.

File	1975-134985	Filed	1975/11/10
Public	1975-058414	Public	1977/05/13
		Grant	1983/10/19

Patent Claim in Original Japanese

(1)半導体基体 (Nsub) に、第1電導型の第1半導体領域 (Pwell) と、(2) 之の上に形成された第2導電型の第2半導体領域 (N) とが形成されて (3)光感知部 (N/Pwell junction) とよりの電荷を転送する電荷転送部 (CTD) とが (4)上記半導体基体 (Nsub) の主面に沿う如く配置されて成る(5)固体撮像装置 (Solid State Image Sensor) に於いて、上記光感知部の上記第2半導体領域に 整流性接合が形成され、該接合をエミッタ接合 (Emitter) とし、(6)上記第1及び第2半導体領域間の接合 をコレクタ接合 (Collector) とするトランジスタ (P+NP Transistor) を形成し、(7) 該トランジスタのベース (Base) となる上記第2半導体領域(N)に 光学像に応じた電荷を蓄積し、ここに蓄積された電荷を上記転送部 (CTD) に移行させて、その転送を行うようにしたことを特徴とする固体撮像装置 (Solid State Image Sensor)。

第 6 図

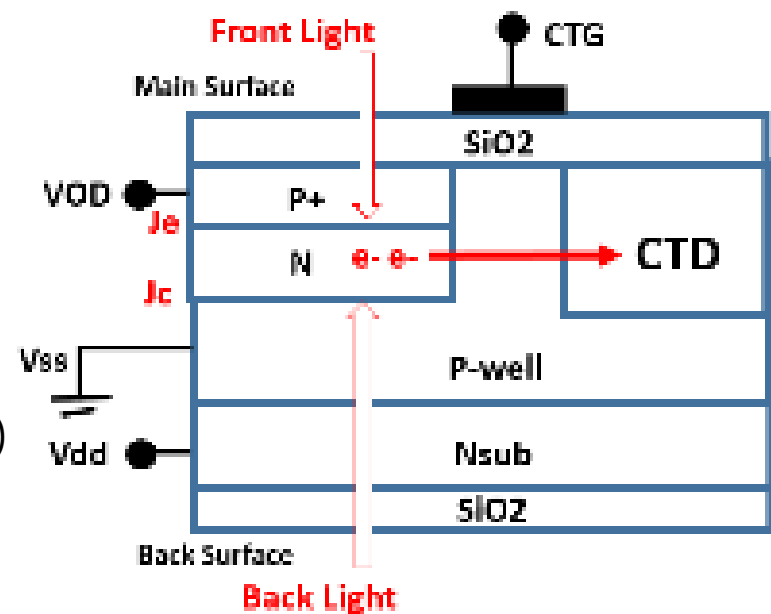
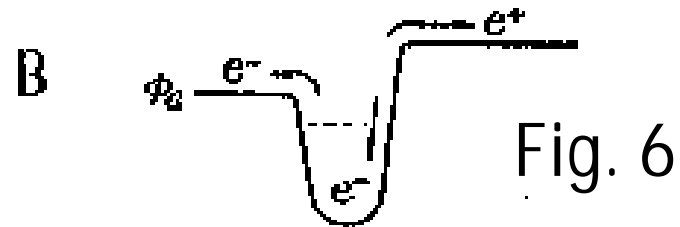
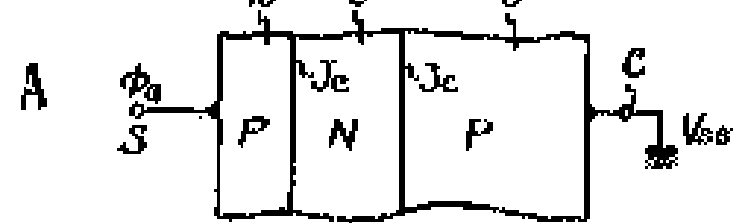


Figure 30

P+NP/Sub junction type Pinned Photo Diode

invented by Hagiwara at Sony in Japanese Patent 1975-134985.

File	1975-134985	Filed	1975/11/10
Public	1975-058414	Public	1977/05/13
		Grant	1983/10/19

Patent Claim in English Translation

(1) In the semiconductor substrate (Nsub), the first region (Pwell) of the first impurity type is formed, (2) on which, the second region (N) of the second impurity type is formed. (3) The charge (e-) from the light collecting part (N/Pwell Junction) is transferred to the adjacent charge transfer device (CTD). (4) Both are placed along the main surface of the semiconductor substrate. (5) In the solid state image sensor so defined, a rectifying Emitter junction (Je) is formed on the second region (N) of the light collecting part (N/Pwell), (6) forming a P+NP Junction type transistor structure with the N/Pwell junction as Collector junction (Jc). (7) The charge, stored in the Base region (N) according to the illuminated light intensity, is transferred to the adjacent CTD. The solid state image sensor so defined is in the scope of this patent claim.

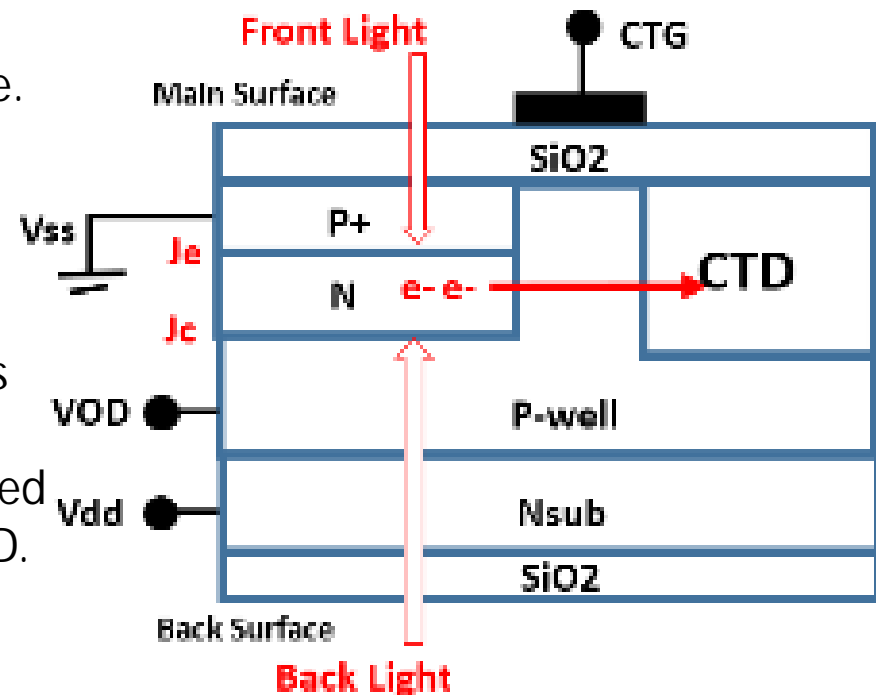
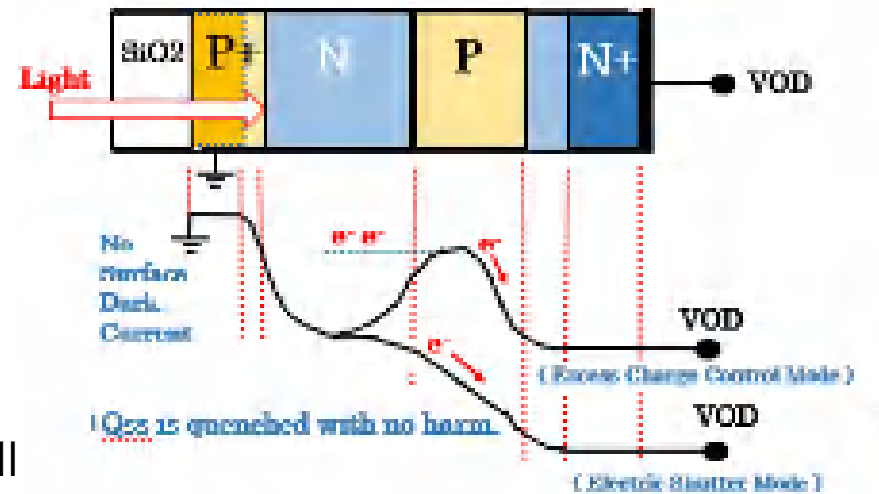
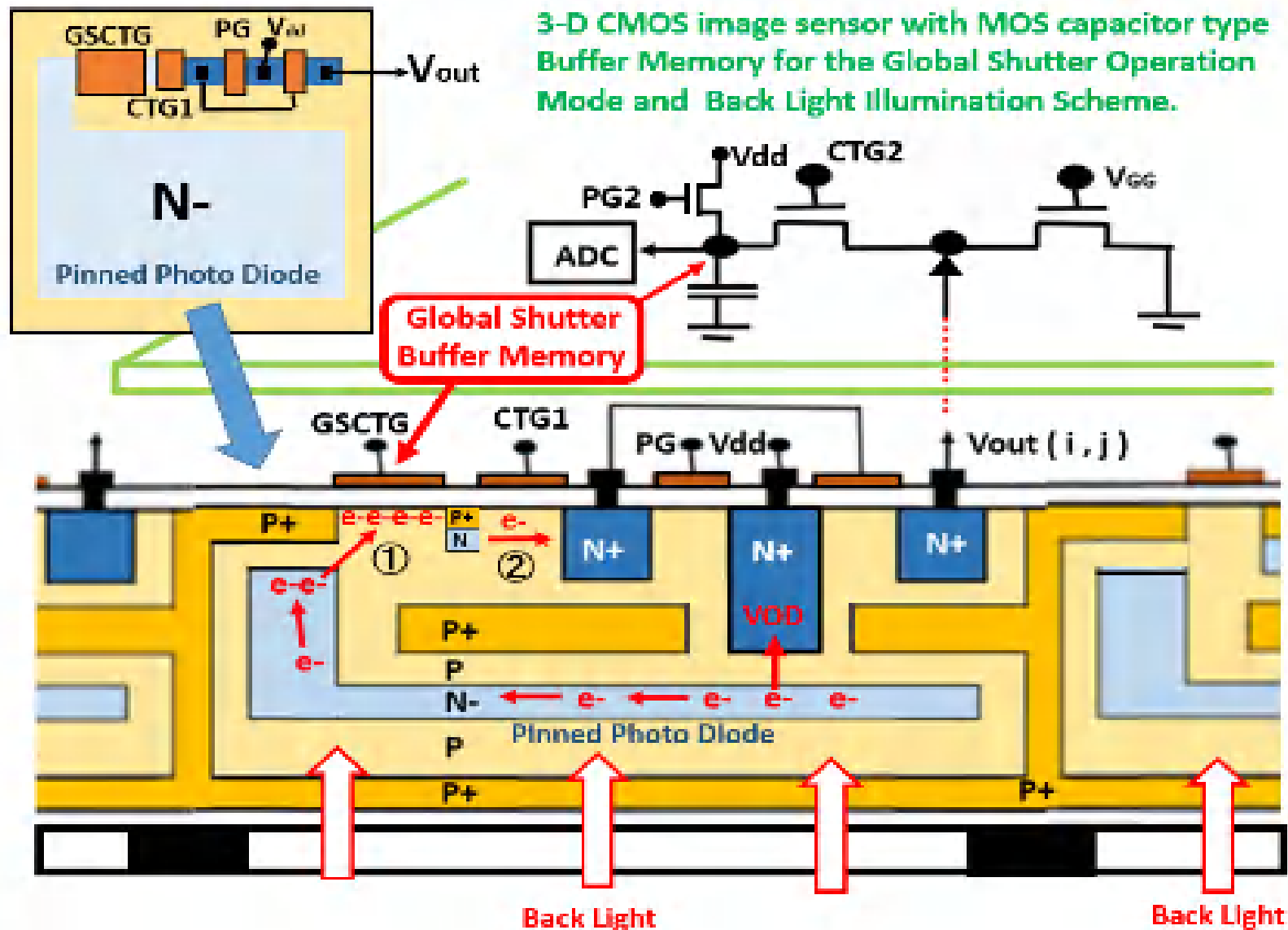


Figure 31



See Japanese Patent 1975-127649 of the original invention of the Pinned Photodiode by Yoshiaki Hagiwara at Sony in 1975. The visible light cannot penetrate more than 12 μm into the silicon crystal. We do not need blinds.

