

# Conclusions

The photo electron hole separation mechanism of the P+PNP junction type Pinned Photodiode was explained, which is unique and quite different from the conventional photo electron hole pair separation performed by the electric field inside the PN junction depletion region.

Related various historical photodiode structures are reviewed, including the 1971 work on the  $\beta$ -Ga<sub>2</sub>O<sub>3</sub> Schottky barrier photo sensor in search for the low leakage dark current device which led to the 1975 invention of the Pinned Photodiode with the surface P+ heavily doped hole accumulation (HAD) with the vertical overflow drain (VOD).



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Hagiwara proposed and invented in 1975 the double and triple junction type photo sensor as shown below with very excellent features including (1) an excellent short wave blue light sensitivity, (2) the very low surface dark current noise, (3) no serious image lag problem of the complete charge transfer capability shown by the empty potential well curve of the buried photo charge collecting storage region, (4) the triple junction photo thyristor with the punch-thru function that can be used for the VOD and the electrical shutter function and also (5) the in-pixel MOS capacitor buffer memory for the Global Shutter function needed in modern CMOS image sensors. Hagiwara also proposed in 1975 (6) Back light illumination type Pinned Photodiode as evidenced in the Japanese Patent Application 1975-127646.

## Japanese Patent 1975-127646

