Symmetrical P+PNPP+ Junction Pinned Photodiode Solar Cell With High Quantum Efficiency

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Abstract

Solar panels on the market today consist of cells made from a single semiconducting material, usually silicon. Since a typical solar cell has the asymmetrical N+PP+ junction type diode structure which absorbs only a narrow band of the solar spectrum, much of sunlight's energy is lost as heat: these panels typically convert less than 20 percent of that energy into electricity. This paper reports the symmetrical P+PNPP+ junction type Pinned Photodiode (PPD) which at least doubles the absorption band of the solar spectrum and more by utilizing the electron hole separation mechanism of the barrier electric field induced by the gradually sloped surface P+P doping profiles on both sides of the silicon wafer. The proposed solar cell structure may achieve more than 60 % quantum efficiency.

Conventional N+NPP+ junction type Solar Cell

Blue light cannot penetrate the silicon crystal more than 0.2 micron in depth while red light can penetrate more than 10 micron. If we can collect all the photons within 10 micron depth of the silicon crystal, more than 60% quantum efficiency is possible. A typical solar cell shown in Fig. 1 is very similar to the N+P junction photodiode used in classical MOS image sensors with poor quantum efficiency. Since the surface floating N+N region with no electric field has flat potential with stored photo electron charges, electron hole pairs at the surface cannot be separated and do not contribute to the quantum efficiency. See Fig. 2.

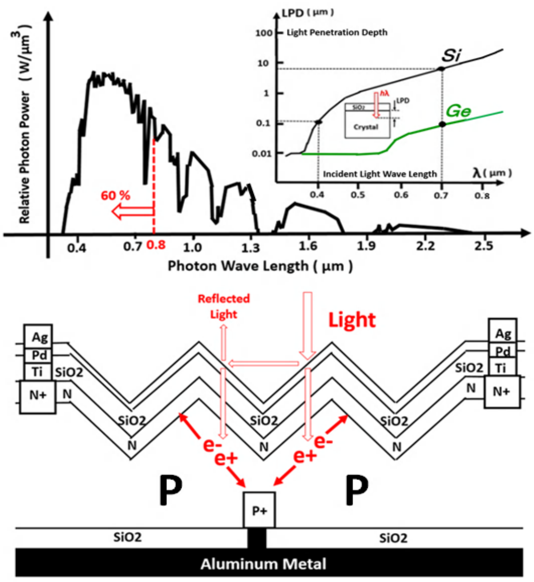

Fig.1 Sun Light Spectrum and Conventional Solar Cell

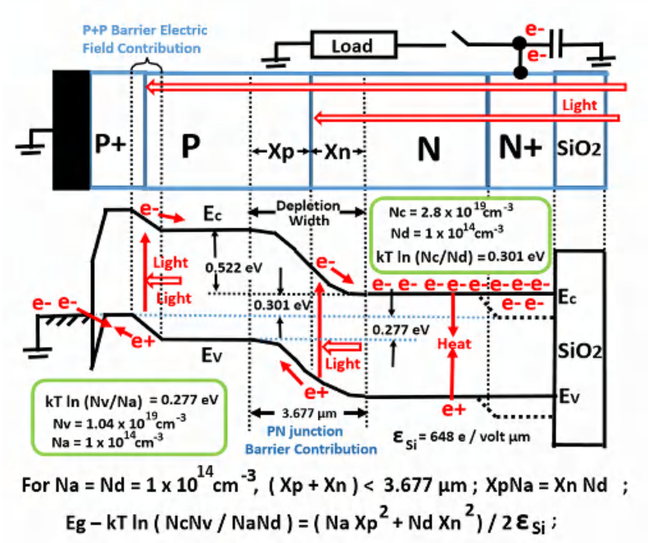

Fig. 2 Conventional Single N+NPP+ junction Solar Cell

Simple P+PNN+ junction type Photodiode

The depletion width of the PN junction is less than 3.7 micron. However, the P+P barrier electric field[1] can also separate the photon generated electron hole pair effectively.

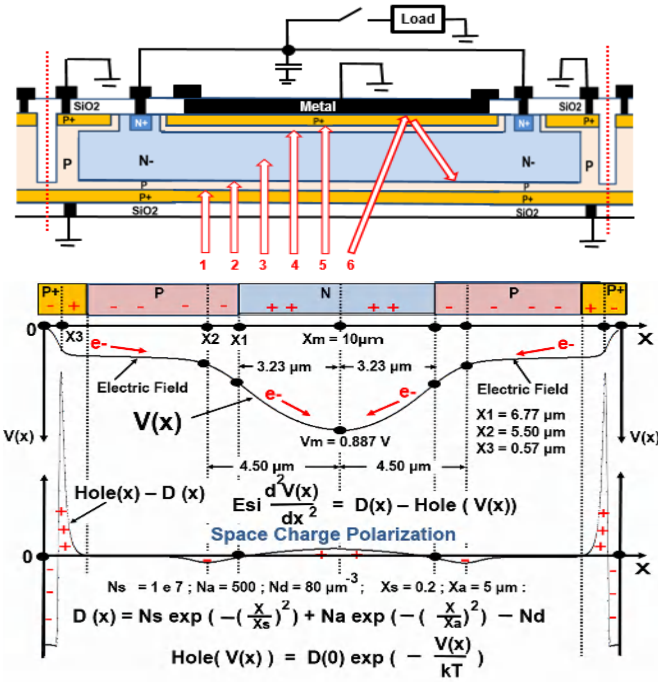

Fig. 3 Symmetric P+PNPP+ junction type PPD Solar Cell and Exact Numerical Calculation of Potential\and Space Charge Polarization.

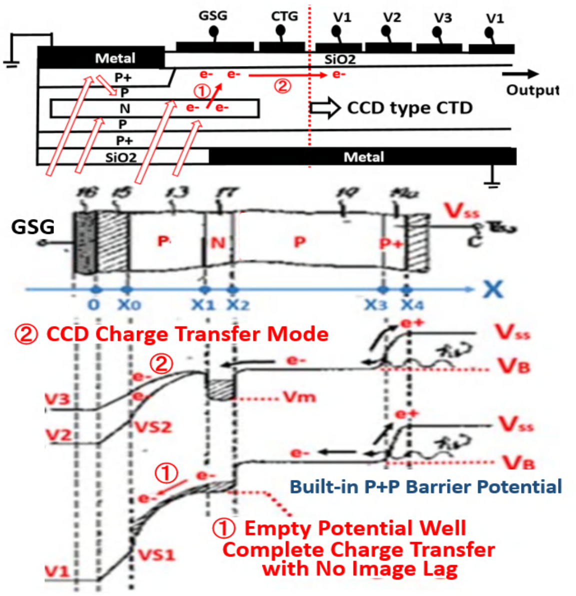

Fig. 4 the P+PNP junction type PPD with the surface P+P barrier electric field used for electron hole pair separation at the surface.

P+PNPP+ junction type Pinned Photodiode Solar Cell

However, the symmetric P+PNPP+ junction type Pinned Photodiode (PPD), as shown in Fig.3, has two PN junction depletion region side by side, and also with the P+P barrier electric fields in both sides. All of them contribute to quantum efficiency. And a solar cell with more than 60% quantum efficiency may not be a dream. The photoelectrons must be collected into the center lightly doped N region, but must be transferred quickly to the adjacent floating N+ heavily doped outlet, keeping the charge collecting N region always empty of electrons with a fixed or pinned empty potential, V_m .

This symmetric P+PNPP+ junction type Buried Depletion and Pinned Photodiode, originally invented for image sensors with back light illumination[2,3] scheme as shown in Fig. 4, is very useful and now applied, not only in the solar cell application as described above, but also modern CMOS image sensor applications as shown in Fig.5.

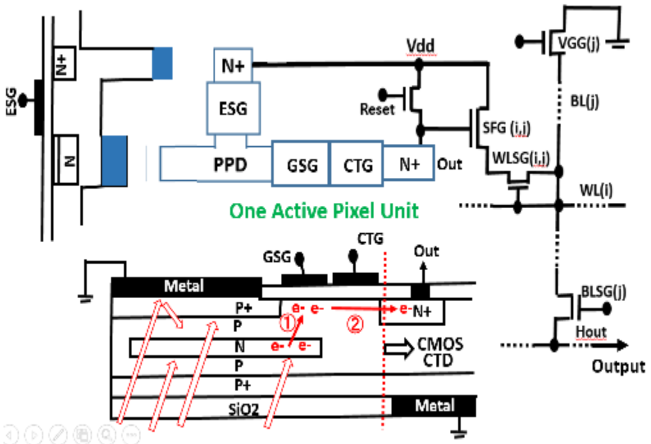

Fig. 5 the P+PNPP+ PPD used in active pixel CMOS image sensor

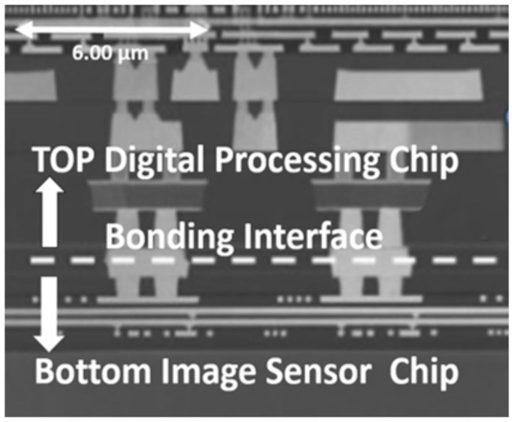

Fig. 6 CMOS image sensor Process applicable to Solar Cell

The symmetric P+PNPP+ junction type Pinned Photodiode (PPD) has three important features[4] of (1) the excellent blue light sensitivity, (2) no surface dark (leakage) current problem and (3) no serious image lag problem with completely depleted empty potential well with CCD like complete signal charge transfer operation mode. These important features are also applied for the proposed symmetric P+PNPP+ junction type PPD solar cell, keeping everywhere with barrier electric field to separate electron hole pairs in the silicon bulk. See Fig.3.

Thanks to the recent advancements of scaling technology of CMOS fabrication process, the modern CMOS image sensors now have, in each pixel, the electrical shutter gate (ESG), the GSG MOS Buffer Memory, and the active in-pixel source follower current amplifier circuits [5, 6]. Now, with the modern 3D stacked multichip integration technology and the very high quantum efficiency solar cell technology, a self-energy intelligent LSI system may not be a dream in near future.

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