

## History and prospect of the low-noise CMOS sensor

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This paper reviews the device and circuit technologies for low-noise CMOS image sensors (CISs) and discusses their future prospect. The first innovation in the low-noise CISs has been done by the CMOS active pixel sensor (APS) using an amplifier and a pinned photodiode in each pixel. The in-pixel amplifier eliminates a large stray capacitance in the signal detection and increases the charge-to-voltage conversion gain. The pinned photodiode and the technique of in-pixel charge transfer allow us to greatly reduce dark current noise and cancel kTC noise. In global shutter CISs, the two-stage charge transfer using pinned diodes has solved their noise problems. In the past 10 years, efforts are devoted to the reduction of noises due to the in-pixel transistor and peripheral readout circuits. The introduction of low-noise transistors as the in-pixel amplifier and high-gain noise reduction techniques used in the column readout circuits has effectively reduced the thermal, 1/f and RTS (random telegraph signal) noises of transistors and a sub-electron noise level has been attained. This paper also discusses the possibility of true photon counting by further reduction of readout noise and very high charge-to-voltage conversion gain.

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