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# Wide Dynamic Range Active Pixel Sensor Using a High-Sensitivity Gate/Body-Tied Photodetector with an Overlapping Control Gate

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## 1. Introduction

Recent commercial CMOS image sensors (CISs) require the high-sensitivity and wide dynamic range performance. Some equipments for high-sensitivity applications use photomultiplier tubes or charge-coupled devices. However, these photodetectors consume a large amount of power and cannot be integrated with CMOS circuits. Also, their sensors have narrow dynamic range due to high-sensitivity. For this reason, several approaches to improve both the sensitivity and dynamic range are being researched [1-5].

A high-sensitivity gate/body-tied (GBT) PMOSFET photodetector with an overlapping control gate was proposed [1]. Active pixel sensor (APS) using the high-sensitivity GBT PMOSFET-type photodetector is difficult to apply to the imaging applications due to very narrow dynamic range. However, the proposed APS in this paper has the control gate and output voltage feedback structure that makes it possible to have not only high-sensitivity but also extension of dynamic range. Maximum dynamic range of the proposed sensor was greater than 110 dB. The proposed APS was designed and fabricated using a 2-poly 4-metal 0.35 μm standard CMOS process and its optical responses were measured.

## 2. Operational principle

Fig. 1(a) and (b) show symbol and cross-section of the high-sensitivity GBT photodetector, respectively. A GBT photodetector occupies only an area of 3.8 x 4.4 $\mu m^2$, which is about 24 % smaller compared to the conventional GBT PMOSFET-type photodetector with a transfer gate [1]. Fig. 2 and Fig. 3 show the schematic of the proposed APS and its timing diagram, respectively. The sequence of operation is as follows. First, GBT photodetector is resetted by a negative reference voltage ($V_{REF}$ = -1.5 V) as shown in Fig. 4(a). When the light incident occurs through the polysilicon, electron-hole pair (EHP) is separated by the built-in potential of the n-well and p-type silicon substrate. The holes are attracted to the channel and drift to the $p^+$ drain. On the other hand, the electrons are accumulated in the n-well region which decreases the potential of the floating gate because of the n-well/gate connection, acting as a negative gate voltage. This feedback mechanism significantly amplifies the photocurrent that flows from the source to the drain of M1 as shown in Fig. 4(b). At that time, the feedback transistor M2 is under sub-threshold region. After a certain time of charge accumulation period, M2 is gradually turned on due to the increased output voltage which is connected to the gate of M2. During that time, sensitivity slope is decreased due to the feedback current of M2 as shown in Fig. 5. When a positive voltage is applied to the gate relative to the source voltage of M2, negative charges are induced in the underlying the gate of M2, by formation of a depletion region and a thin surface region containing mobile electrons. These induced electrons form the channel of M2, and allow feedback current to flow from the source to the drain as shown in Fig. 4(c). There is significant current flow from the source to the drain of M2. This indicates the improvement of dynamic range at high illumination.

## 3. Measurement results

The proposed APS using a GBT photodetector has high-sensitivity at low illumination. To determine the optical sensitivity, a halogen lamp was used as the light source with color temperature of 2,856 K ± 150. Fig. 5 shows the variation of the output voltage with light intensity when integration time is 0.8 ms. Although the conventional APS using a GBT photodetector has a good sensitivity at low illumination, it has a very narrow dynamic range as shown in Fig. 5. However, the proposed APS using a GBT photodetector can not only improve the sensitivity at low illumination but also extend the dynamic range to 110 dB, according to the feedback structure. With a capacitor structure between the control gate and the floating gate the photodetector is able to increase the sensitivity by varying the control gate voltage. For instance, negative bias of the control gate ($V_{CG}$ = -3 V) is induced that amplifies the photo current to go from the source to the drain. Thus the sensitivity of the proposed APS becomes higher at low illumination compared with the conventional APS using a GBT photodetector as shown in Fig. 5.

## 4. Conclusions

In this paper, a new high-sensitivity CMOS APS has been designed and fabricated. The proposed APS has an overlapping control gate which can enhance the sensitivity at low illumination and output voltage feedback structure for extension of dynamic range. Maximum dynamic range of the proposed sensor was greater than 110 dB. Therefore, the proposed high-sensitivity and wide dynamic range APS might be useful for image sensor applications.

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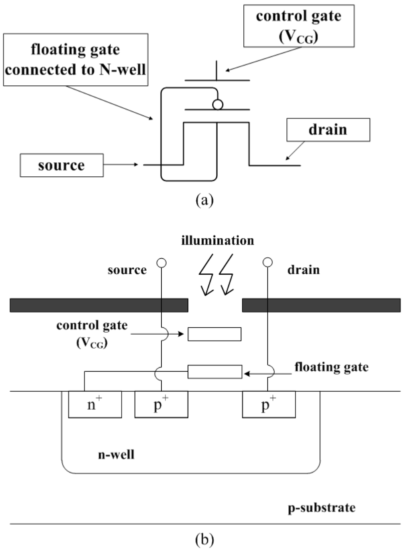


Fig. 1 (a) Symbol and (b) cross-section of GBT photodetector with control gate.

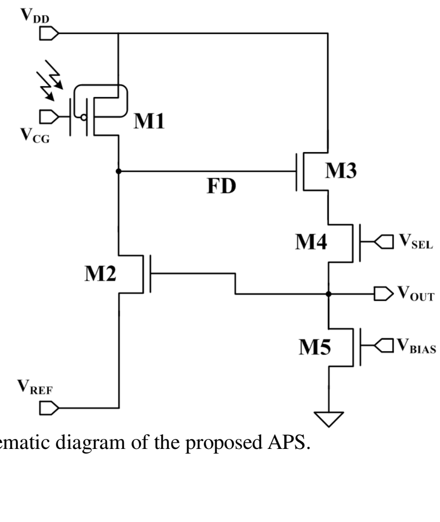


Fig. 2 Schematic diagram of the proposed APS.

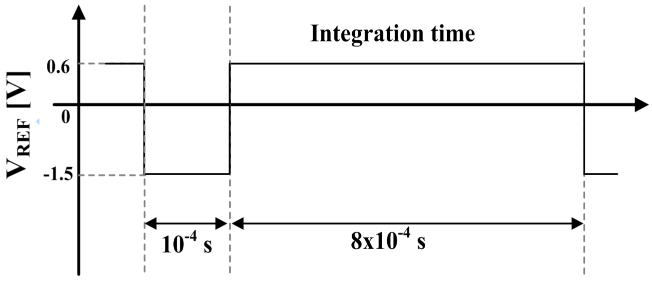


Fig. 3 Timing diagram of the proposed APS. ($V_{CG}$ = -3 V, $V_{SEL}$ = 3V, $V_{BIAS}$ = 0.7 V)

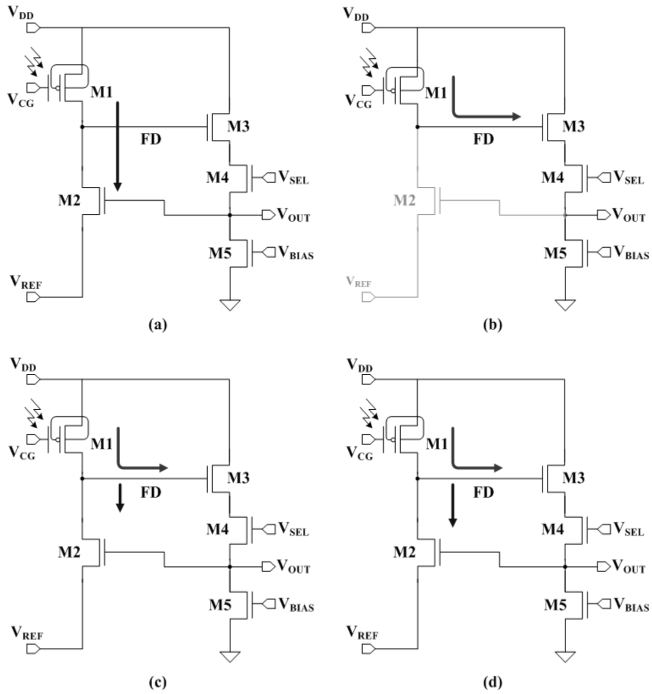


Fig. 4 Operational sequence of the proposed APS.

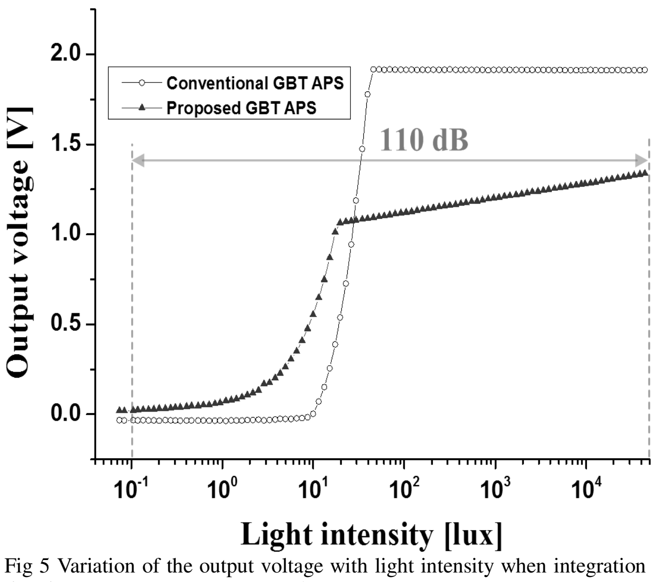


Fig 5 Variation of the output voltage with light intensity when integration time is 0.8 ms. (Measurement results)