論文 88-25-4-9

Blooming Suppression of an npn MOS Image Sensor

(npn MOS 영상소자의 블루밍억제에 관한 연구)

申炯澈,* 閔弘植,* 李鍾德*

(Hyung Cheol Shin, Hong Shick Min and Jong Duk Lee)

要 約

MOS영상 소자의 블루밍 억제 능력을 분석하기 위하여 시험용광다이오우드를 제작하였으며 소스팔로우어 회로를 접속하여 그 특성을 조사하였다. npn 구조의 블루밍 억제 능력을 np 구조와 비교하여 정량적으로 분석하고 실험적으로 측정하였다. 기판전압과 수직 MOS 게이트 전압과 비데오 전압에 대한 블루밍 전류의 의존도가 측정되었으며 블루밍 억제를 위한 최적 조건이 제시 되었다.

Abstract

In order to analyze the blooming suppression mechanism of a MOS image sensor, test photodiodes have been fabricated and characterized by attaching a source follower circuit. The blooming suppression ability of npn structure compared to that of np structure is quantitatively analyzed and measured by experiment. The dependency of the blooming current on the substrate voltage, the vertical MOS gate voltage and the video voltage is measured and the optimum condition for blooming suppression is presented.

I. Introduction

When a photodiode saturates due to the light of high intensity in a particular cell of an image sensor, the excess charge can overflow into the signal line while it is not accessed. This phenomenon is called blooming. It must be localized in the cell so as not to interfere with the operation of the remainder of the image sensor or spoil the detected image [1]. The blooming phenomenon in a solid-state image sensor has been a troublesome problem for a long time. To solve this problem, npn structure for a photo-element of the MOS image sensor has been proposed [2]. However, only qualitative clarifications for npn structure have been made. In this paper, the blooming suppression ability of an npn structure is analyzed quantitatively.

II. Description of Blooming Suppression

A conventional MOS image sensor is composed of pn junction photodiodes, vertical switching transistors (VMOS), horizontal switching transistors (HMOS), and vertical and horizontal shift registers as shown in Fig. 1 [3]. In Fig. 1, C_V and C_H is the parasitic capacitances of the vertical signal line and of the horizontal signal line respectively. The blooming mechanism in the np structure photo-element of a MOS image sensor is illustrated in Fig. 2, in which three components of

*正會員, 서울大學校 電子工學科

(Dept. of Elec. Eng., Seoul Nat'l Univ.)

接受日字 : 1987年 12月 14日

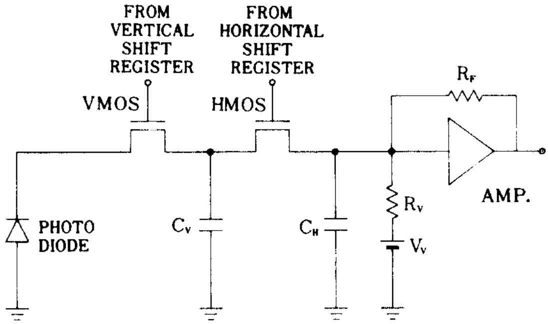

Fig.1. A schematic diagram of a MOS image sensor.

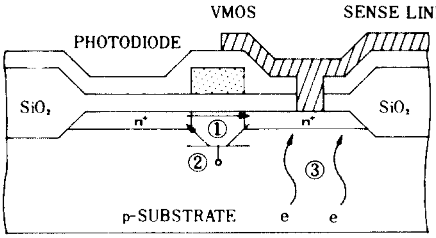

Fig.2. Blooming mechanism of a MOS image sensor.

the blooming currents are shown schematically [4];

1) tailing current from the photodiode to the vertical sense line through VMOS
2) current due to the horizontal npn bipolar transistor action
3) excess charges diffusing directly from the substrate to the output drain.

Among these currents, the second component is known to be dominant [4]. To reduce this component, npn structure shown in Fig. 3 has been proposed. In this structure excess carriers generated by the strong illumination, which cannot be stored any more in the photodiode capacitor, can be drained through the vertical bipolar transistor. Since horizontal npn bipolar transistor current is a dominant factor in blooming in the np structure photodiode as mentioned above, when we design a npn structure photodiode the ratio of the vertical current I_V to the lateral current I_H must be kept large[2], where I_V is the

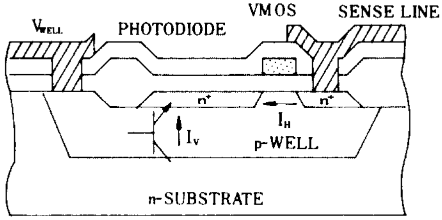

Fig.3. Structure of an npn type photo element.

current due to the vertical bipolar transistor action and I_H is the one due to the horizontal bipolar transistor action as shown in Fig. 3. The potential change of the photodiode with time is determined from the following differential equation [5,6].

$$C_{PD}\frac{dV_{PD}}{dt} = I_{OP} - I_H - I_V \qquad (1)$$

where C_{PD} is the capacitance of the photodiode, V_{PD} is the voltage across the photodiode and I_{OP} is the optically generated current. In steady state, the left term of Eq. (1) becomes zero. Assuming that I_V is much larger than I_H with VMOS cut off, the photo current is given approximately as follows;

$$I_{OP} = I_H + I_V \cong I_V = I_O \exp\left(\frac{qV_{PD}}{kT}\right) \qquad (2)$$

where I_O is the reverse saturation current of the photodiode. From Eq. (2), V_{PD} can be expressed by

$$V_{PD} = \frac{kT}{q}\ln\left(\frac{I_{OP}}{I_O}\right) \qquad (3)$$

In the npn structure, assuming that the vertical bipolar transistor is ideal, I_O is approximately given by

$$I_O = \frac{qAD_n n_p}{W_B} \qquad (4)$$

where A is the area of the photodiode, D_n is the electron diffusivity in the well, W_B is the base width of the vertical bipolar transistor and n_p is the electron concentration in the well. On the other hand, in np structure, the voltage across the photodiode is given by

$$V'_{PD} = \frac{kT}{q} \ln\left(\frac{I_{OP}}{I'_O}\right) \qquad (5)$$

Assuming that the photodiode is an ideal n+p diode, I'_O is expressed by

$$I'_O = \frac{qAD_n n_p}{L_n} \qquad (6)$$

where L_n is the electron diffusion length in the p region. Since the blooming current is exponentially proportional to the voltage across the photodiode, the ratio between the blooming current (I_B) in the npn structure and that (I_B') in the np structure is given by the expression;

$$\frac{I'_B}{I_B} = \frac{\exp(qV'_{PD}/kT)}{\exp(qV_{PD}/kT)} = \frac{I_{OP}/I'_O}{I_{OP}/I_O} = \frac{I_O}{I'_O} \qquad (7)$$

under the same condition for the lateral npn transistor and the optical generation. It indicates that the ratio is the same as the inverse ratio of two reverse saturation currents. By using the above equations and the parameters from Table 1, the calculated ratio in Eq. (7) is 10.4. In Table 1, in order to calculate L_n, we measured the electron lifetime in the well by observing the transitional decay of V_{PD} with no optical generation.

Ⅲ. Experimental Results

1. Reverse Saturation Currents

A cell for testing blooming characteristics has

Table 1. The parameters measured from the npn structure fabricated by omitting PMOS formation in a conventional p-well CMOS process.

parameters	values
n^+ concentration and junction depth	1×10^{20} cm^{-3}, 0.25 μm
p-well concentration and junction depth	2×10^{16} cm^{-3}, 6 μm
n-substrate concentration	3×10^{14} cm^{-3}
A, photodiode area	18,250 μm^2
W_B, base width in npn structure	5.75 μm
L_n, electron diffusion length in p-well	58 μm

been fabricated. The area of the photodiode is 18,250 μm^2, which is about 100 times larger than generally used size in an image sensor. Unless otherwise specified, in npn structure the pn junction between the well and the substrate is reverse-biased by 6V. Fig. 4 shows I-V characteristics of the photodiodes in npn structure and in np structure. From this figure, the saturation current for npn structure is 2 pA, while that for np structure is 0.2 pA. So the blooming suppression ability of npn structure is about 10 times as large as that of np structure.

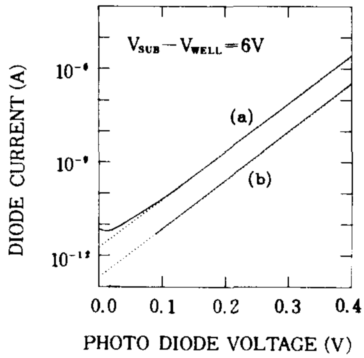

Fig.4. I-V characteristics of photodiodes for npn structure(a) and np structure(b).

2. Photodiode Voltages

The source follower circuit shown in Fig. 5 was constructed to measure the photodiode voltage. Fig. 6 shows V_{PD} in steady state as a function of light intensity. The short circuit photocurrent of the photodiodes for both structures are measured using large photodiodes which have an area of 1,700 μm x 300 μm and the results are plotted in Fig. 7. By combining Fig. 6 and Fig. 7, we can find that the photodiode voltage for npn structure is smaller than that for np structure by about 0.06V with the same photocurrent. Since the blooming current is exponentially proportional to the photodiode voltage, the blooming current of npn structure photodiode is about 1/10 of that of np structure. This result is same to that of Ⅲ.1. In Fig. 8, the photodiode voltage for npn structure measured at 610 LUX is shown as a function of the substrate bias voltage (V_{SUB}). As V_{SUB} increases, the reverse saturation current also increases. As a

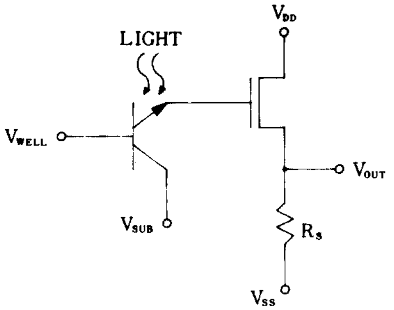

Fig.5. Measurement circuit of the photodiode voltage.

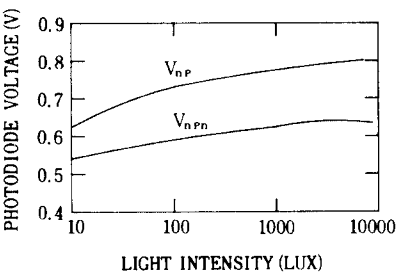

Fig.6. Photodiode voltage as a function of light intensity.

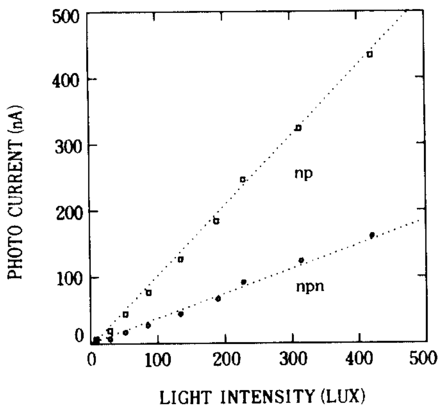

Fig.7. Photo current as a function of light intensity.

result of that, the photodiode voltage decreases. The figure indicates that only a linear increase of V_{SUB} leads the exponential decrease of blooming current.

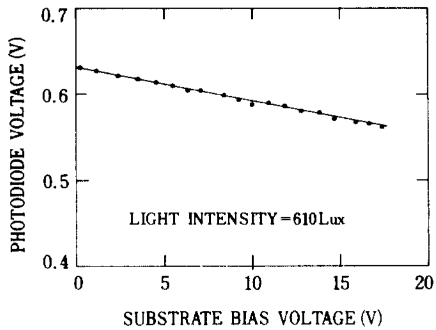

Fig.8. Photodiode voltage as a function of substrate bias voltage.

3. Blooming Current

In addition to the photodiode voltage, the blooming current is dependent upon the substrate voltage, VMOS gate voltage and the drain voltage (video bias) as shown in Fig. 9.

IV. Conclusion

The antiblooming ability of npn structure photoelement has been analyzed and compared with that of np structure photoelement. The ability is dependent on the reverse saturation currents and the photodiode voltages. In this study, the calculated value of antiblooming improvement is 10.4. A test cell has been fabricated and its blooming characteristics has been measured. The photodiode with smaller saturation current has higher steady state photodiode voltage. The measured reverse saturation currents and steady state photodiode voltage represented that the value of antiblooming improvement was 10, which was well matched with the calculated value. The blooming characteristics for various parameters are measured. The steady state photodiode voltage exhibits a linear decrease for increasing substrate bias voltage. To minimize the blooming current, the VMOS gate and the video bias voltage should be lower and the substrate bias voltage should be higher.

References

[1] Savas G. Chamberlain, "Technology progress and trends in solid-state silicon image sensors," *IEEE Custom Integrated Circuits*

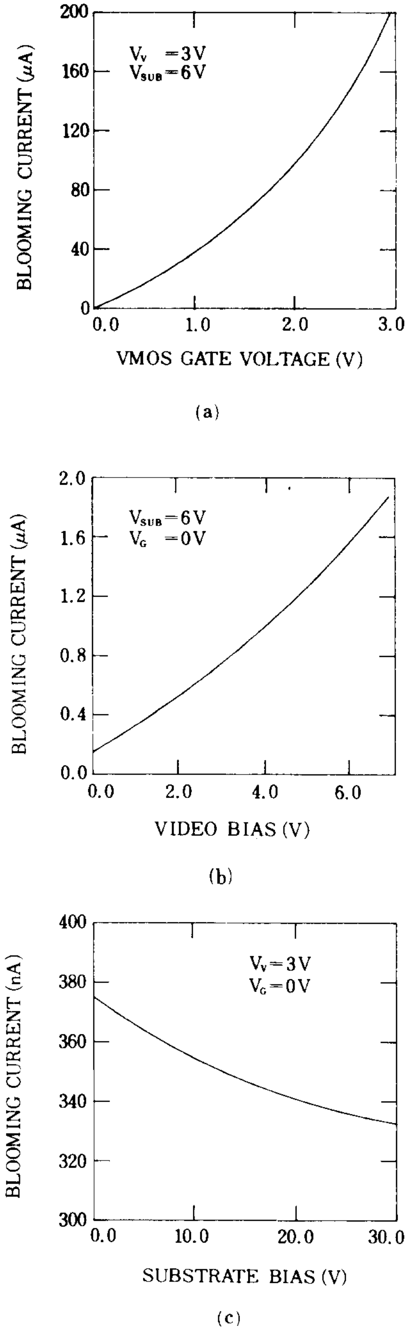

Fig.9. Blooming current depending on VMOS gate voltage(a), video bias(b) and substrate bias voltage(c).

Conference, pp. 112-118, 1985.

[2] N. Koke, I. Takemoto, K. Satoh, A. Sasano, S. Nagahara, and M. Kubo, "Characteristics of an npn structure MOS imager for a single chip color camera," *J. Inst. Tele. Eng. Japan*, vol. 33, no. 7, pp. 548-553, 1979.

[3] N. Koike, I. Takemoto, K. Satoh, S. Hanamura, S. Nagahara, and M. Kubo, "MOS area sensor: Part I-Design consideration and performance of an npn structure 484x384 element color MOS imager," *IEEE Trans. Electron Devices*, vol. ED-27, pp. 1676-1681, Aug. 1980.

[4] S. Ohba, M. Nakai, H. Ando, S. Hanamura, S. Shimada, K. Satoh, K. Takahashi, M. Kubo, and T. Fujita, "MOS area sensor: Part II-Low noise MOS area sensor with antiblooming photodiodes," *IEEE Trans. Electron Devices*, vol. ED-27, pp. 1682-1687, Aug. 1980.

[5] Kohji Senda, Sumio Terakawa, Yoshimitsu Hiroshima, Masahiro Susa and Takao Kunii, "Analysis of npn photodiode in p-well CPD image sensors," *IEEE Trans. Electron Devices*, vol. ED-31, no. 12, pp. 1873-1877, Dec. 1984.

[6] Eiji Oda, Yasuo Ishihara, and Nobukazu Teranishi, "Blooming suppression mechanism for an interline CCD image sensor with a vertical overflow drain," in *IEDM Dig. Tech. Papers*, pp. 501-504, 1983.

[7] Hiroaki Nabeyama, Shusaku Nagahara, Hiroshi Shimizu, Masaru Noda and Michio Masuda, "All solid-state color camera with single-chip MOS imager," *IEEE Trans. on Consumer Electronics*, vol. CE-27, pp. 40-44, 1981.

[8] Gene P. Weckler, "Operation of pn junction photodetectors in a photon flux integrating mode," *IEEE J. Solid-State Circuits*, vol. SC-2, no. 3, pp. 65-73, Sept. 1967.