A-9-06

Extended Abstracts of the 2022 International Conference on Solid State Devices and Materials, Makuhari, 2022, pp57-58

Novel Process Optimization for Higher SNR of Small Pixel Sized CMOS Image Sensor with FDTI Structure

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Abstract

With increasing market demand of high resolution CMOS(Complementary Metal Oxide Semiconductor) image sensors, its unit pixel size has dramatically decreased over the years [1][2]. Therefore, Number of photons entering unit pixel on an integration time have been decreased as unit pixel size decreases inevitably resulting in lower sensitivity of each pixel. Various technologies to increase the sensitivity have been researched and applied in recent image sensors with small sized pixel [3][4]. In this paper, we introduce optimization method for higher sensitivity in CMOS image sensor and inevitable side effects are successfully reduced.

1. Introduction

The overall optical performance of image sensors are commonly expressed as SNR(Signal to Noise Ratio) values. The SNR value is determined by synthesizing various characteristics. In pixel active area on Fig. 1(a), photoelectrons are generated and make a signal. Sensitivity is the amount of photoelectrons generated per unit time and unit illuminance.

FDTI(Front sided Deep Trench Isolation) is an isolation structure that can efficiently prevent optical and electrical inter-pixel cross talk. As shown in Fig. 1(a) Our FDTI structure is filled with poly Si and SiO_2 insulation layer. Fig. 1(b) shows negative bias applied to poly Si on FDTI suppress dark current by accumulating holes at Si interface cause an increase in electron-hole recombination probability. However, photons passing poly Si in FDTI can be absorbed because of poly Si's high light extinction coefficient (Fig. 2). Light loss in poly Si suppress sensitivity and SNR characteristic of image sensors. As the size of unit pixel shrinks, the proportion of light loss in poly Si is increasing among the total light loss of image sensor. We optimized FDTI process to reduce light loss in small pixel sized image sensors.

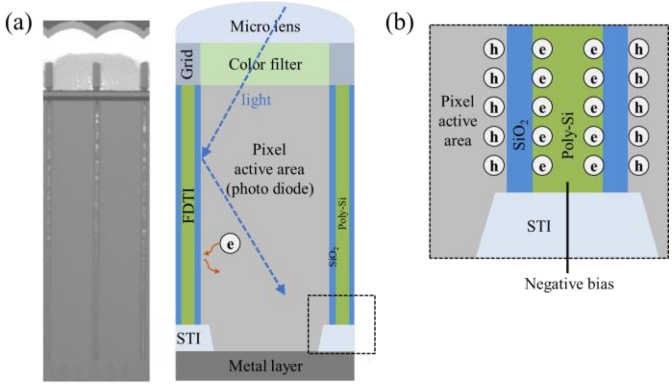

Fig. 1 (a)Schematic of CMOS image sensor and poly Si filled FDTI. (b)Negative bias on poly Si in FDTI.

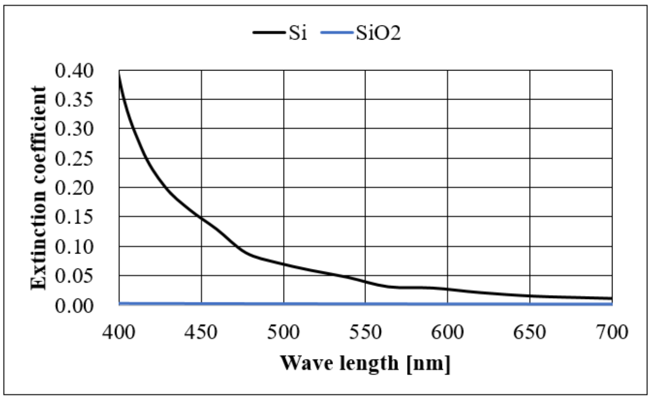

Fig. 2 Light extinction coefficient of Si and SiO_2

2. Result and discussion

Thickness of SiO_2 in FDTI structure affects the optical and electrical properties of the image sensor. Optically SiO_2 reflects light from entering poly Si in FDTI from pixel active area avoiding light loss in poly Si. In the total internal reflection condition SiO_2 can reflect every photon back to active area. However, if the SiO_2 layer is thinner than penetration depth of evanescent wave, light can pass through SiO_2 layer even in total internal reflection condition resulting optical sensitivity loss. As the thickness of SiO_2 increases, light transmission is decreased and the sensitivity would be increased. However, thick SiO_2 degenerates dark current. Electrically SiO_2 is a capacitor dielectric between poly Si and active area. Negatively charged poly Si can accumulate positive holes that can remove dark electrons by recombination in active area. As thickness of the SiO_2 decreases, dark currents are decreased by helping hole accumulation in active area. In other words, for high optical sensitivity thicker SiO_2 is needed, but for low dark noise thinner SiO_2 is better.

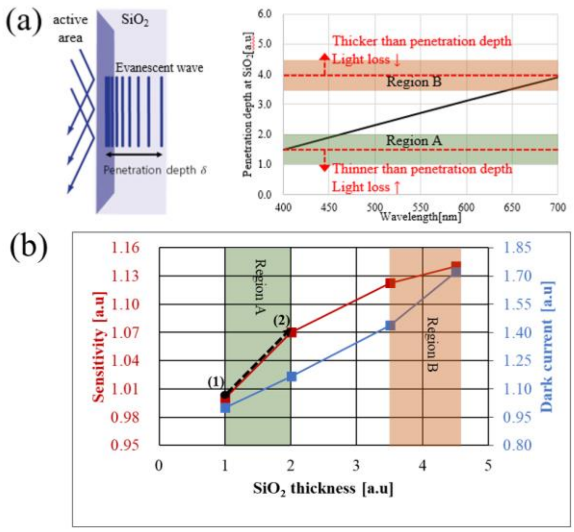

Fig. 3 (a)Evanescent wave and penetration depth at SiO_2.
(b)Sensitivity and dark noise along to SiO_2 thickness.

Fig 3(b) shows measured sensitivity and dark noise along to SiO_2 thickness. In region A, SiO_2 is thinner than penetration depth of visible light band. So sensitivity increases rapidly as SiO_2 thickness increases. On the other hand, in region B, SiO_2 is becoming thicker than penetration depth of overall visible light band. Sensitivity increase slowly in region B. Our image sensor was in region A past few years. Higher sensitivity can be easily obtained by increasing SiO_2 thickness from (1) reference to (2) increased SiO2 thickness in Fig3(b). As shown Fig. 4, Dark noise increase with thicker SiO_2 can be reduced by applying more negative bias on poly Si in FDTI. As a result, we were able to obtain high sensitivity without degradation of dark noise by increasing the SiO_2 thickness and negative bias. Finally, SNR characteristic is improved with thicker SiO_2(Table I）.

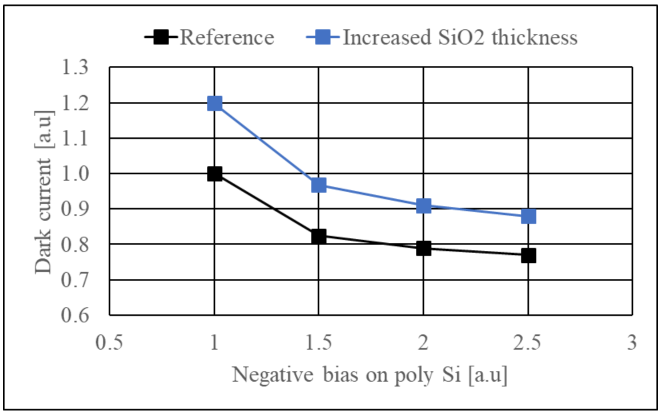

Fig. 4 Dark noise and White spot along to negative bias on poly Si.

Table I measured sensor characteristics

	Unit	Reference	Optimized DTI (thick SiO_2)	Optimized DTI (thick SiO_2 +Increased negative bias)
Sensitivity	%	100	107	107
Dark current	e-/s	-	+0.1	-
SNR	dB	-	+0.2	+0.2

3. Conclusions

According to recent pixel size shrinkage trend on CMOS image sensor business, new technologies have been developed to overcome demerits of small sized pixel. However, most of these new technologies suffer from increasing process steps and production cost. By optimizing SiO_2 thickness We successfully obtain higher sensitivity by optimizing SiO_2 thickness without no process cost increase. As the SiO_2 thickness was increased, the accompanying dark noise was suppressed by applying more negative bias on poly Si.

References

[1] Y. Kim et al., A 1/2.8-inch 24M pixel CMOS image sensor with 0.9㎛ pixels separated by full-depth trench isolation. *Proc. ISSCC (2018)*

[2] D. Park et al., A 0.8 µm Smart Dual Conversion Gain Pixel for 64 Megapixels CMOS Image Sensor with 12k e- Full-Well Capacitance and Low Dark Noise. *IEEE International Electron Devices Meeting (IEDM) (2019)*

[3] J. Park et al., Pixel technology for improving IR quantum efficiency of backside-illuminated CMOS image sensor. *International Image Sensor Workshop (IISW) (2019)*

[4] Y. Lee et al., World first mass productive 0.8㎛ pixel size image sensor with new optical isolation technology to minimize optical loss for high sensitivity. *International Image Sensor Workshop (IISW) (2019)*