Effects of Hydrogen Annealing on 0.25-um CMOS Image Sensor

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Abstract

The effects of hydrogen annealing on the electrical and optical properties of CMOS image sensor fabricated by 0.25 um CMOS technology are investigated for the first time. Pixel performance is significantly improved by hydrogen annealing due to the passivation of surface traps, especially for the dark current in high-temperature operation and the photo-response of blue light at low illumination. Using hydrogen annealing combined with non-silicide and double diffusion source/drain (DDD) junction; the dark current can be drastically reduced (less than 0.1 fA per pixel).

I. Introduction

Recently, CMOS image sensor has caught much attention [1-3] due to low voltage, low power consumption, random access of the image data, compatibility with standard CMOS logic technology and realizing integrating single-chip camera. In the miniaturization of high-density sensor pixel, the major concerns are how to suppress dark current and increase photoresponse. However, as the CMOS technology is downscaled to 0.25 um, the fabrication of high performance CMOS image sensors will be limited due to surface etch damage, less thermal annealing and shallow trench isolation (STI) structure even if some process modifications (non-silicide and DDD junction) have been made [4-5]. It has been reported that hydrogen can be used to tie up dangling bonds at surface, interface and in crystalline silicon (c-Si) and thus to passivate p-n junction in c-Si [6-7]. In this work the dark current improvement in various temperature by using hydrogen annealing is reported for the first time. In addition, photoresponse at different wavelength and illumination is also discussed to evaluate the trap distribution.

II. Technology

The base technology is typical 0.25 um CMOS logic technology, including shallow trench isolation (STI), retrograde channel doping by high-energy implants, dual operation voltage by dual gate oxide, ultra-shallow source/drain junction and self-aligned silicide gate and S/D to reduce resistance. In addition, some process modifications, such as non-silicide and DDD junction, are used in pixel. A cross sectional TEM picture of the modified process and the pixel performance are shown in Fig.1 and Fig.2, respectively. These wafers were annealed in a hydrogen environment [8]. For photodiode study, we focused on NW/Psub diodes, which included large-area type and pixel types (pitch 3.6 um and 4.0 um).

III. Experimental Results

Fig.3 shows the leakage current density of two types NW/Psub diodes as a function of temperature varied from -10 ℃ to 70 ℃. Compared to large-area type, the leakage current density of pixel type shows more than two-orders-of-magnitude increase due to the sidewall area of photodiode in pixel. As temperature raises above 40℃, hydrogen annealing reduces pixel leakage density by a factor of two and leakage densities of different size pixel keep almost the same value. In the other hand, in lower temperature (-10℃~10℃) pixel leakage density is only slightly improved with hydrogen annealing. This is attributed that junction leakage dominates at higher temperature but process induced leakage dominates at lower temperature. Hydrogen annealing is more efficient for dark current improvement in higher temperature operation.

Photocurrent also increases with temperature as shown in Fig.4. By using hydrogen annealing, the photocurrent enhancements of large-area type and pixel type are 10% and 20%, respectively. The difference can be explained by the contribution of sidewall area of photodiode in pixel. Tungsten-halogen lamp with monochromator is used to characterize optical performance. Hydrogen annealed sample has the superior quantum efficiency (Q.E.) as shown in Fig.5.

Fig.6 shows the illumination dependence of Q.E. for different wavelength light. For 550-nm and 650-nm light, Q.E. is nearly independent of illumination. However, compared to the unhydrogenated sample, the sample with hydrogen annealing can improve Q.E. of 450-nm light from 31% to 42% as illumination down to 0.05 uW/cm^2. It means that surface traps impact the photoresponse of short-wavelength light at low illumination. Fortunately, the phenomenon can be mitigated by hydrogen passivation of surface traps as shown in Fig.6.

The parameters of pixel device w/i and w/o hydrogen annealing are summarized in Table I. Hydrogen annealed sample has superior performance, especially for the leakage current. Thus, the dark signal distribution of hydrogenated chip is much better than unhydrogenated one as shown in Fig. 7. Finally, we summarized the pixel performance in Table II. Dynamic range is 78 dB and dark current is 0.07 fA/pixel at 3.3 V.

IV. Conclusions

Hydrogen annealing has shown the superior performance of 0.25 um CMOS image sensor. Dark current in high temperature operation and photoresponse of blue light at lower illumination can be significantly improved by hydrogen annealing. This is attributed to hydrogen passivation of traps in interface and diode junction.

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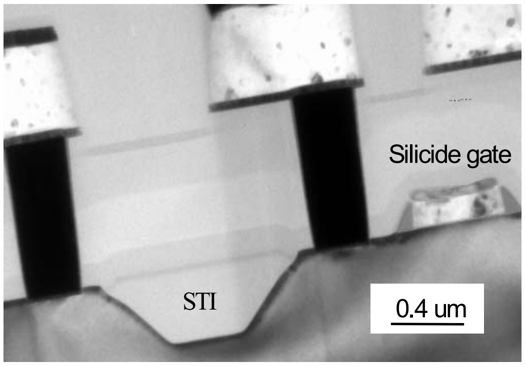

Fig.1 Cross sectional TEM photograph of pixel

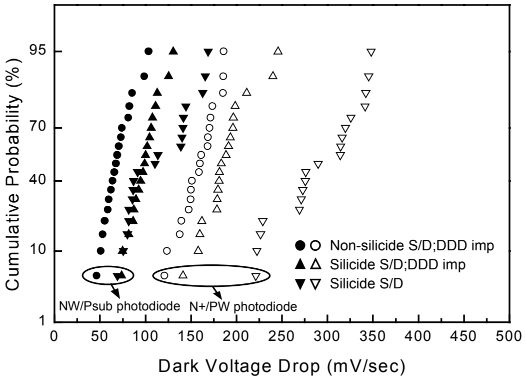

Fig.2 Cumulative plot of dark signal for different process modification

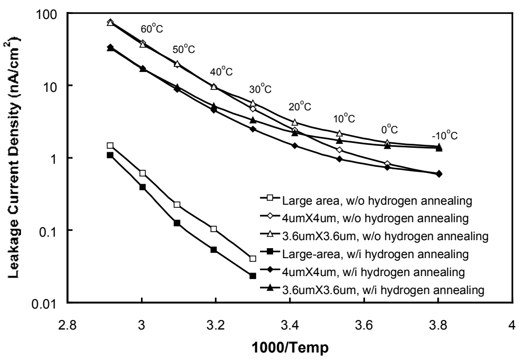

Fig.3 Dark current as a function of temperature

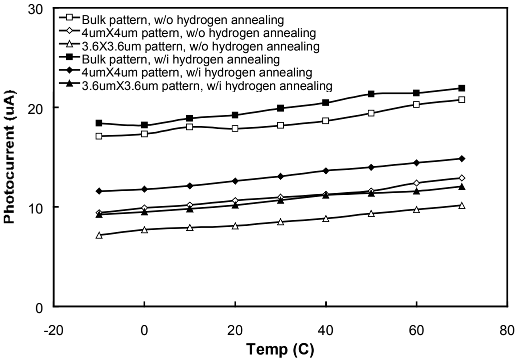

Fig.4 Photocurrent as a function of temperature

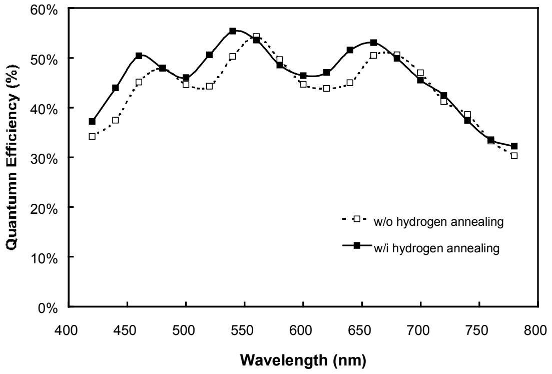

Fig.5 Quantum efficiency of NW/Psub photodiode

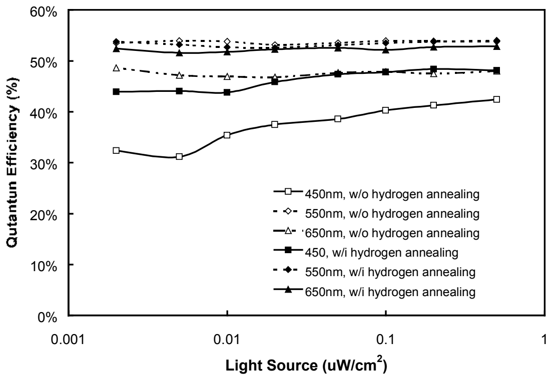

Fig.6 Quantum efficiency as a function of illumination for different wavelength

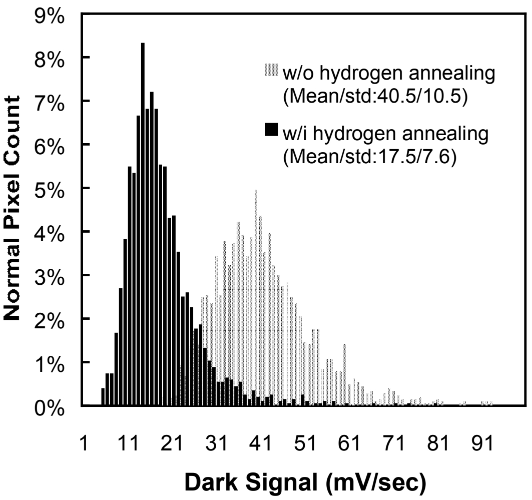

Fig.7 Dark signal distribution

Table I. Pixel Device Parameters (NMOS)

	Device Parametes	Non-hydrogenated	Hydrogenated
Design	Power Supply Voltage	3.3 V	
	Gate Oxide Thickness	7 nm	
	Channel Length	0.35 um	
	Channel Width	0.3 um	
	Photodiode	NW/Psub junction	
Experi-mental	Threshold Voltage	0.47 V	0.45V
	Saturation Current	164 uA	172 uA
	Subthreshold Slope	85.3 mV/dec	78.5 mV/dec
	Off-current	78 fA	60 fA
	Area Junction Capacitance	54.5 nF/cm^2	55.1 nF/cm^2
	Area Junction Leakage	40 pA/cm^2	23 pA/cm^2

Table II. Pixel Performance

Pixel size	4umX4um
Architecture	3 T & 1PD
Fill Factor	26%
Sensitivity @White w/i IR cut	1068 mV/lux-sec
Random noise @1lux	1.3 mV, rms
S/N ratio @1lux	30 dB
Maximum S/N ratio	48 dB
Conversion gain	40 uV/e-
Saturation level	1.2V
Dark current	0.07 fA/pixel
Random noise @dark	0.15 mV, rms
Dynamic range	78 dB
Crosstalk (R/G/B)	12%/7%/5%