R18

Image Artifacts in Backside Illumination CMOS Image Sensors Associated with Electrostatic Charge

Tom Frank, Tom Carducci, Bill Desjardin; *ON Semiconductor, Rochester, NY, USA*
David Price, Rick Jerome, Jeff Gambino; *ON Semiconductor, Gresham, OR, USA*
Rusty Winzenread; *ON Semiconductor, Santa Clara, CA, USA*
Thad Smith; *ON Semiconductor, Pocatello, ID, USA*

Introduction

CMOS image sensors with backside illumination (BSI) have higher sensitivity compared to those with frontside illumination, which is beneficial for imaging under low light conditions [1-3]. In order to achieve low dark current, the backside of the image sensor array must be passivated (Fig. 1) [4-6]. The SiO_2 layers typically used for Si passivation have a positive fixed charge, which results in a high recombination rate of electrons on the backside of the device (i.e. high dark current). In order to achieve low dark current in BSI image sensors, it is necessary to either use a p+ backside layer or a negative charge layer in the oxide passivation.

During the development of a BSI image sensor, it was observed that there were artifacts in bright field images after assembly. In this report, we describe the causes and the solutions to these imaging artifacts.

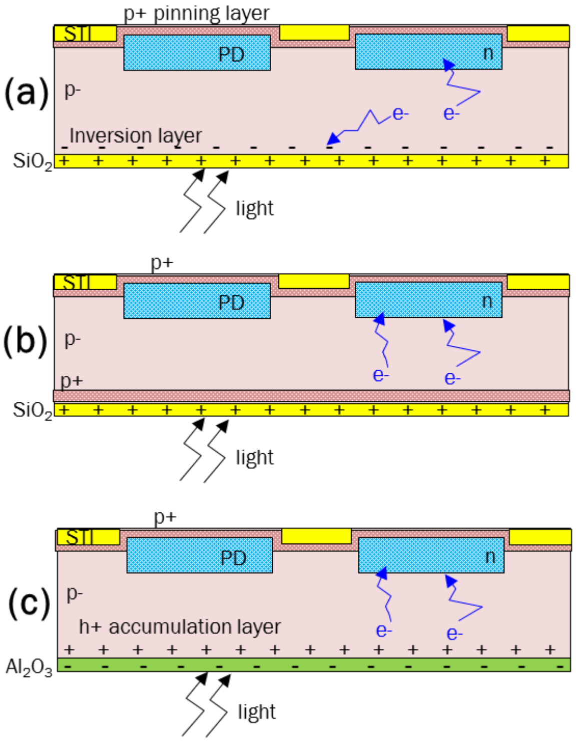

Figure 1: Backside passivation options for BSI image sensor (a) no backside passivation, (b) p+ doping layer, (c) dielectric with negative charge layer [4,5].

Experiment

The BSI image sensor wafers were fabricated on 200mm Silicon-On-Insulator (SOI) wafers, using a 0.18 µm CMOS process [7]. Key features of the wafer process include an optimized epitaxial Si thickness (8 µm thick, for red and infrared sensitivity), optimized B doping profile in the epitaxial Si layer (for blue light sensitivity), and both p+ doping and a negative oxide charge layer on the backside of the Si for low dark current. Note that image sensors for are used for a star tracker in satellites, so there are no micro lenses or color filters (i.e. the coating on the top of the photodiode array consists of oxide dielectrics). The image sensors are mounted in a ceramic pin grid array (PGA) package. The image sensor surface is protected by a cover glass (Fig. 2). The die size is ~17x18 mm^2 and the array size is ~13x13 mm^2.

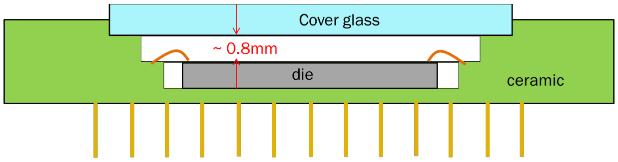

Figure 2. Schematic of package for BSI image sensor.

The image sensors were characterized under bright field and dark field conditions at (1) wafer level, (2) die level with no cover glass, and (3) die level with cover glass.

Results and Discussion

Bright field images at wafer level showed no unusual artifacts in the images (Fig. 3a). However, the die level bright field images often contained a large number of circular image artifacts (Fig. 3b) whereas dark field images were free of these artifacts. It was suspected that the bright field artifacts were due to a perturbation of the surface of the image sensor array, especially in the oxide layers. To test this idea, the dielectric layers were stripped using buffered HF for a die with imaging artifacts, then the die was remeasured (Fig. 4). The image artifacts are almost completely removed after the backside dielectrics are removed, indicating the image artifacts are due to a change in the backside dielectrics.

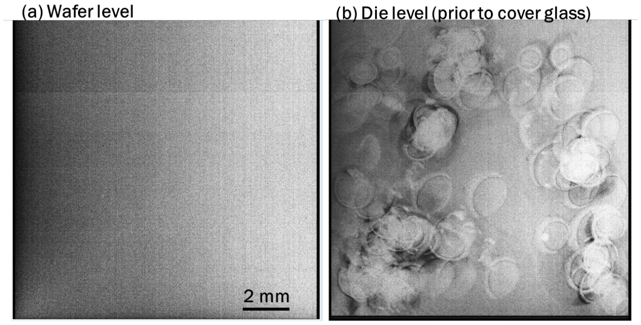

Figure 3. Bright field images for full array at (a) wafer level and (b) at die level. There are a large number of circular image artifacts at die level test.

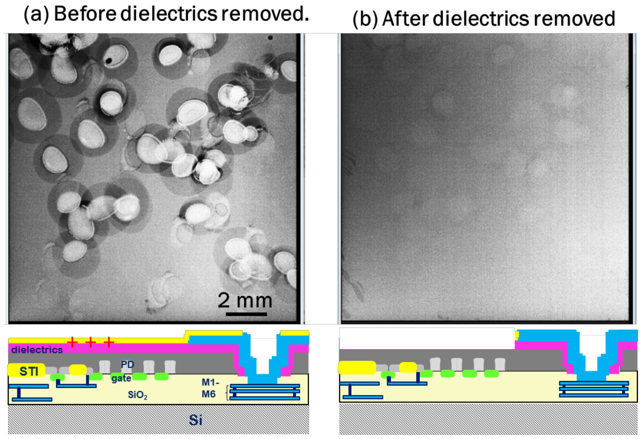

Figure 4. Bright field images at die level (prior to cover glass) for full array with (a) before and (b) after removal of backside dielectrics.

Two mechanisms were considered as the cause of the image artifacts during assembly; (1) contamination of the backside dielectrics or (2) electrostatic charging of the backside dielectrics (Fig. 5).

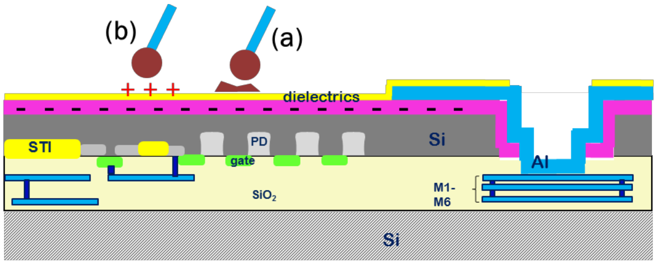

Figure 5. Possible mechanisms for imaging artifacts due to scrubbing with polymer-coated tip; (a) polymer residues and (b) electrostatic charging.

There are at least two possible sources of contamination during assembly. One is the polymer die protection layer that is applied prior to dicing, to protect the imager array from particles. The die protection layer is removed using organic solvents after dicing. An additional possible source of contamination is associated with the mechanical removal of particles from the array, using a polymer-coated tip. In fact, the circular and localized appearance of the artifacts is consistent with scrubbing by polymer-coated tip. If polymer residues remain on the surface of the array from either of these processes, perhaps the residues could cause image artifacts. Extended cleaning with the organic solvents was evaluated on die that exhibited image artifacts to test this hypothesis (Fig. 6). There was no significant improvement in the image artifacts with extended cleaning suggesting that polymer residues are not the reason for the imaging artifacts.

The hypothesis for electrostatic charging was tested by taking die with severe amounts of imaging artifacts and exposing them to an ionizer for 24h. The imaging artifacts are almost completely removed after the ionizer treatment, supporting the theory that the imaging artifacts are due to electrostatic charging (Fig. 7). An additional experiment was conducted by rubbing the cover glass on fully assembled die with a rubber glove. These die also had imaging artifacts, which could be removed by using an ionizer, consistent with electrostatic charging (Fig. 8).

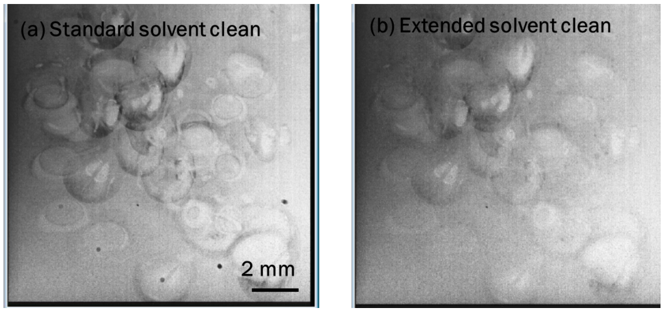

Figure 6. Bright field images at die level (prior to cover glass) for full array with (a) standard solvent clean and (b) extended solvent clean.

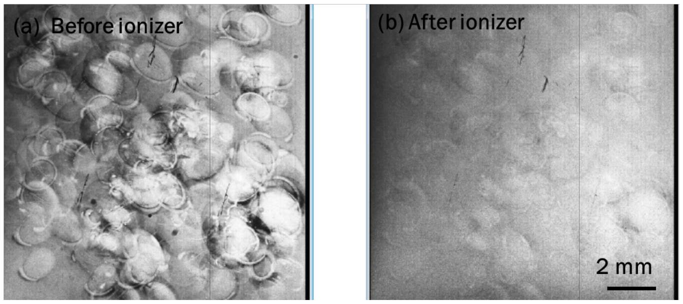

Figure 7. Bright field images at die level (prior to cover glass) for full array (a) before and (b) after exposure to ionizer for 24 h.

The imaging artifacts can be either brighter or darker than the background level under illumination (see Fig. 4 for example). A possible explanation for these results is based on band bending at the backside of the Si as a result of the electrostatic charge (Fig. 9). If the electrostatic charging increases the negative charge on the dielectric, the electric field is enhanced resulting in collection of more photogenerated electrons in the photodiode, leading to a higher signal in the affected pixels. In contrast, if the electrostatic charging increases the positive charge on the dielectric, the electric field is reduced resulting in collection of less photogenerated electrons in the photodiode, leading to a lower signal in the affected pixels.

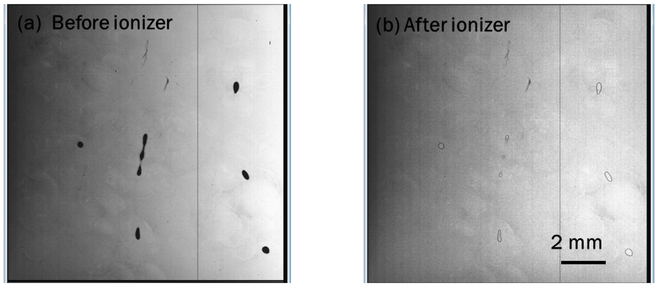

Figure 8. Bright field images at die level for parts with cover glass for full array (a) before and (b) after exposure to ionizer for 65 h.

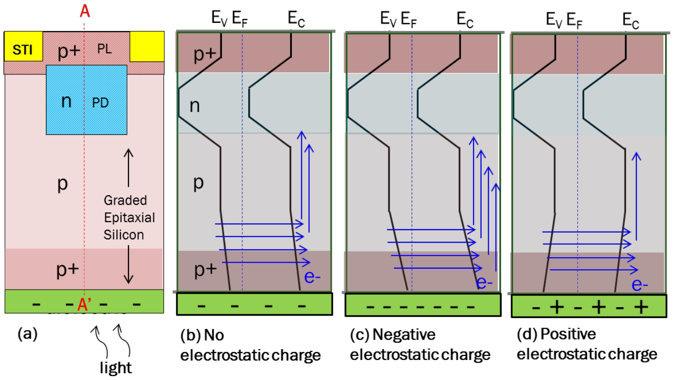

Figure 9. Band diagram in the vertical direction of the photodiode (A-A') showing the effect of electrostatic charge on the collection of photogenerated electrons; (a) No electrostatic charge, (b) negative electrostatic charge, and (c) positive electrostatic charge.

Clearly the imaging artifacts are undesirable and must be minimized. This work shows that precautions should be taken during assembly to minimize any electrostatic charging near the surface of the BSI image sensor.

Acknowledgement

The authors thank Rick Mauritzson, Oswald Skeete, Greg Bardel for helpful discussions. The authors also thank Ed Flanigan and Chuck Spinner for their support.

REFERENCES

[1] H. Rhodes, "The mass production of BSI CMOS image sensors," Proc. 2009 International Image Sensor Workshop.

[2] H. Wakabayashi, K. Yamaguchi, M. Okano, S. Kuramochi, O. Kumagai, S. Sakane, M. Ito, M. Hatano, M. Kikuchi, Y. Yamagata, T. Shikanai, K. Koseki, K. Mabuchi, Y. Maruyama, K. Akiyama, E. Miyata, T. Honda, M. Ohashi, T. Nomoto, "A 1/2.3-inch 10.3Mpixel 50frame/s Back-Illuminated CMOS Image Sensor," Proc. 2010 IEEE International Solid State Circuits Conf., pp. 410-412.

[3] G. Agranov, S. Smith, R. Mauritzson, S, Chieh, U. Boettiger, X. Li, X. Fan, A. Dokoutchaev, B. Gravelle, H. Lee. W. Qian, R. Johnson, "Pixel continues to shrink….Small Pixels for Novel CMOS Image Sensors," Proc. 2011 International Image Sensor Workshop.

[4] B. Pain, "Backside Illumination Technology for SOI-CMOS Image Sensors", Proc. 2009 International Image Sensor Workshop.

[5] G. Meynants, J. Bogaerts, X. Wang, G. Vanhorebeek, "Backside Illuminated Global Shutter CMOS Image Sensors", Proc. 2011 International Image Sensor Workshop.

[6] B. Vereecke, C. Cavaco, K. De Munck, L. Haspeslagh, K. Minoglou, G. Moore, D. Sabuncuoglu, K. Tack, B. Wu, H. Osman, "Quantum efficiency and dark current evaluation of a backside illuminated CMOS image sensor," Japanese Journal of Applied Physics, vol. 54, pp. 04DE09-1-6, 2015.

[7] D. Price, R. Jerome, A. Hasegawa, J. Gambino, R. Winzenread, K. Thomas, A. Piner, M. Wu, P. Guidash, T. Carducci, T. Frank, B. Desjardin, R. Brolly, T. Smith, B. Riebeek, E. Glines, G. Heims, T. Ebben, R. Marinelli, O. Di Cola, G. De Amicis, "Global shutter backside illumination CMOS image sensor for satellite navigation,", Proc. 2017 International Image Sensor Workshop.