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Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp92-93

Tantalum lightshield for CMOS image sensor with global shutter

J. Gambino, R.J. Rassel, A. Watts, C. Musante, R. Krishnasamy, B. Leidy, N. Lai, T.C. Lee, P. Razina, C. Walsh, B. Czabaj, R. Preston, D. Demuynck, J. Adkisson, J. Ellis-Monaghan, M. Jaffe

IBM Microelectronics, 1000 River Street, Essex Junction, VT 05452, USA
phone: 802-769-0433 fax: 802-769-9452 email: gambinoj@us.ibm.com

1. Introduction

CMOS image sensors are increasingly being used in consumer products instead of charge-coupled devices, because of lower power consumption, lower system cost, and the ability to randomly access image data [1].

There are three basic shuttering methods used with CMOS image sensors [2] (Fig. 1): mechanical shutter, rolling shutter, and global shutter. The mechanical shutter is expensive, adds to the size of the camera module, and is difficult to use in movie mode. The mechanical shutter can be eliminated using either a rolling shutter or global shutter. With a rolling shutter, the rows of the image are reset in sequence and read out in a rolling sequence (Fig. 1b). However, each row is exposed to light for a different time window with the bottom row being exposed significantly later than the top row. When the image is moving, significant motion related object distortion can occur [2].

Electronic global shutter is preferred for imaging moving objects [2-5]. The difficulty with implementing global shutter is that between the time that the charge is transferred to the floating diffusion until it is read out, the floating diffusion must be shielded both from incoming light as well as from electrons in the substrate which are created by light. Light shields (typically metal) and electron shields (typically made from implants which create an electric field which repels electrons) are added to protect the floating diffusion (Fig. 2) [2,5].

Light shields are frequently used in charge-coupled device (CCD) image sensors to minimize bright spots in the image under high illumination conditions (“light leakage smear”) [6-9]. Although it is well known that a metal lightshield is required for CMOS image sensors with global shutter architecture, there have been no publications on the process technology required to form the lightshield. In this report, we show results on a CMOS image sensor with a Ta lightshield.

2. Experiment

The CMOS imager sensors were fabricated using a five transistor (“5T”) pixel architecture (Fig. 3) [2,5], with a 0.18 μm foundry process for the devices [10,11] and a 0.13 μm foundry process for the Cu wires [12]. Functionality was tested on 124K arrays with a pixel size of 4.25 μm.

The Ta lightshield was formed in between M1 and the Si substrate. First, a thin SiO_2 etch stop layer was deposited over the SiN barrier layer that covers the gates and diffusions. Next, contact holes were formed in the array, which allows the Ta to be used as a local interconnect, as well as a lightshield. After a preclean, the Ta layer was deposited and then patterned using lithography and reactive ion etching (RIE). Note that it is desirable to have the lightshield as close to the Si as possible to minimize oblique light effects and waveguide effects [6].

3. Results and Discussion

Simulations were performed to look at lightshield options. The simplest lightshield in terms of processing is to use existing metal layers, such as M1. However, the simulations show that there is light leakage in between the gaps in the M1 layer that covers the floating diffusion (Fig. 4). Hence, it was determined that a lightshield between M1 and the Si substrate could be beneficial in minimizing the effect of stray light on the floating diffusion.

A number of different materials were considered for the light shield layer, including Al, Ta, and W. Simulations show that Al has the lowest light transmission (Fig. 5), in agreement with previous studies [7]. However, in addition to the pinhole problem with thin Al films, Al also has a low melting point, which is incompatible with the W contact process used in the logic devices. Hence, a refractory metal is required for this application. Tantalum was used because of a simpler patterning process for Ta compared to W.

SEM micrographs show adequate isolation between the Ta lightshield and the poly gates and the M1 interconnects (Fig. 6). This is confirmed by leakage current measurements on comb-serpentine structures, where the lightshield runs over poly gates and under M1 wires (Fig. 7a) Contact chains formed using the Ta layer as a local interconnect show low resistance, indicating good continuity (Fig. 7b).

The functionality of image sensor arrays was tested using bright field and dark field images, and by measuring dark current. Basic functionality was confirmed for arrays with the Ta lightshield. Another important parameter for image sensor arrays (with global shutter) is the shutter rejection ratio [5], which measures charge collection on the floating diffusion during the readout operation. Measurements of shutter rejection ratio are in progress.

4. Conclusions

CMOS image sensors with global shutter architecture have been fabricated with a Ta lightshield, formed between the Si subtrate and the M1 Cu interconnects. The lightshield is also used as a local interconnect in the pixel. Test structures show good isolation between the lightshield and the gates and M1 wires. Contact chains indicate good continuity for the local interconnects. Basic functionality has been demonstrated for 124K image sensor arrays with a Ta lightshield.

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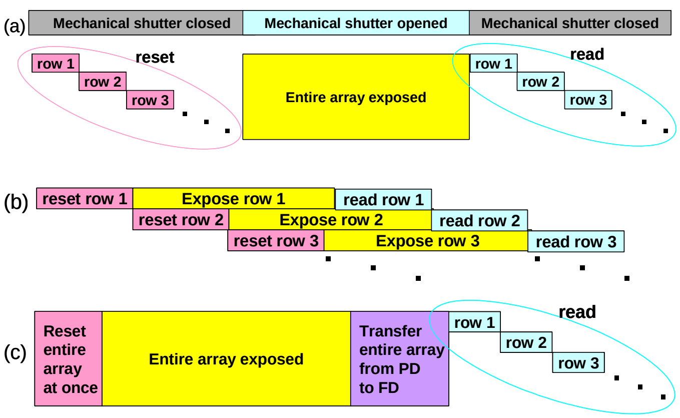

Fig. 1. Schematic of shuttering options for CMOS image sensors; (a) mechanical shuttter, (b) rolling shutter, and (c) global shutter [2].

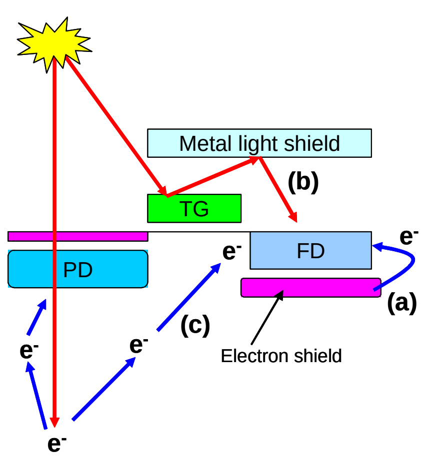

Fig. 2. Mechanisms for floating diffusion leakage in an image sensor with global shutter architecture; (a) junction leakage on floating diffusion (FD); (b) light directly hitting floating diffusion (for example, by scattering off the transfer gate, TG); (c) light hits the photodiode (PD) but absorbs deep in the Si, so it is collected by floating diffusion rather than the photodiode.

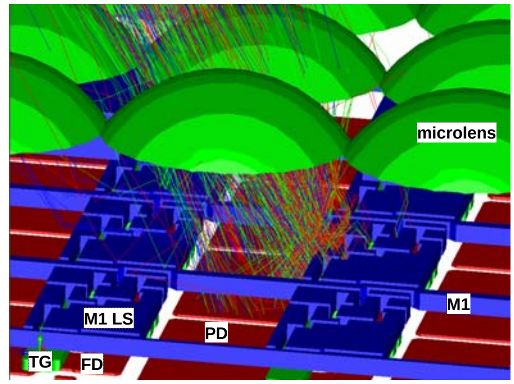

Fig. 3. Simulation of illumination in array with light at 30 degree incidence using M1 as a lightshield.

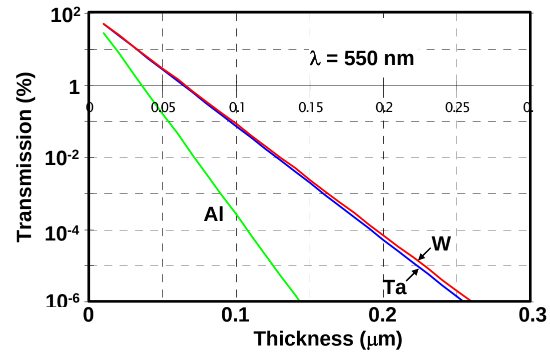

Fig. 4. Light transmission versus lightshield thickness for Al, W, and Ta.

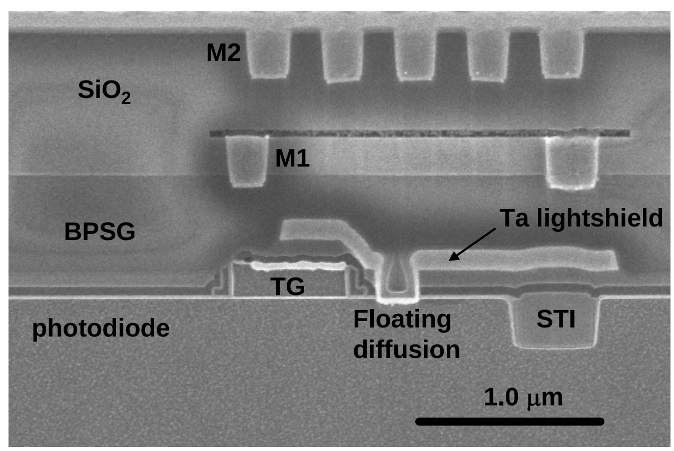

Fig. 5. SEM micrograph of Ta lightshield.

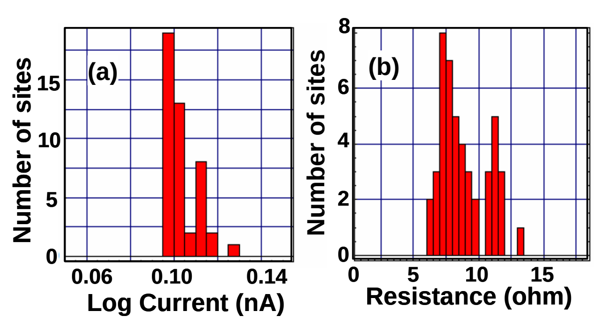

Fig. 6. (a) Gate-to-lightshield leakage and (b) contact resistance for Ta contact to n+ diffusion.