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Characterization of LTO coating on microlens of CMOS image sensor

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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].

To improve light sensitivity, resist microlenses are used to focus light on the photo-diodes (Fig. 1) [2]. The resist microlenses generally have to be protected by an inorganic coating, to facilitate the removal of particles associated with the dicing process [3,4]. The most commonly used coating is low-temperature oxide (LTO), an SiO_2 film that is deposited at temperatures below 250^{o}C, to minimize degradation of the optical properties of the resist.

The previous reports on LTO coatings of microlenses focused on process yield [3] and adhesion issues [4]. In this paper, we report on the effect of LTO coatings on dark current, quantum efficiency, and reliability of CMOS image sensors.

2. Experiment

CMOS imagers were fabricated using a 4T-shared pixel architecture, with 0.18 μm foundry process for the devices and a 0.13 μm foundry process for the Cu wires [5]. The LTO coatings were deposited by plasma-enhanced chemical vapor deposition, after microlens formation, and just prior to final via formation.

The quantum efficiency and dark current were characterized for samples with and without LTO coatings. The test chips consisted of 704x1024 imager arrays with 2.2 μm pixels, that were tested at wafer level. The reliability was evaluated using humidity stresses and thermal cycle stresses (Table I). After the stresses, the image sensor arrays were tested for functionality, dark current, and sensitivity. In addition, visual inspections were conducted to evaluate LTO adhesion to the microlenses.

3. Results and Discussion

The LTO coating introduces an additional interface in the film stack that potentially can reflect some incident light, and reduce photodiode sensitivity. Therefore, simulations were performed to optimize the transmission properties of the LTO coatings. The transmission is maximized for the LTO thickness that results in minimal reflectance. This can be achieved by using an LTO has a thickness corresponding to ¼ of the thickness of the incident light [6] (Fig. 3). The reflectance varies sinusoidally as a function of LTO thicknesses (Fig. 2), due to thin film interference effects. Based on the modeling, the optimal thickness for maximum light transmission is ~ 80 to 100 nm.

The quantum efficiency can be improved by using LTO coatings on the microlens (Fig. 4). The biggest improvement is achieved for a “non-webbed” lens process (i.e., when adjacent microlenses are not touching). For a non-webbed lens, the LTO increases the effective lens size, thereby capturing more light and improving sensitivity.

The dark current is an important parameter for image sensors, because it affects the dynamic range of the camera [7]. The dark current can be increased by plasma processes, so it was characterized for image sensors with and without LTO coatings on the microlenses (Fig. 5). The dark current is increased for the LTO process, because the no LTO process has a forming gas anneal after the final via etch (which is not possible with the LTO process, due to degradation of the microlenses).

The functionality, dark current, and sensitivity of the image sensor with LTO coatings were not affected by humidity stresses of thermal cycle stresses. However, adhesion failure was observed with the initial process after a humidity stress (Fig. 6). The adhesion failure is due to peeling of the LTO from the resist microlens, perhaps due to an increase in the compressive stress in the LTO film from absorption of water. Note that the delamination stops at the edge of the microlens array; the topography from the microlens apparently acts as a crack stop for the delamination.

A number of different processes were investigated for improving the adhesion of the LTO to the resist. In previous reports on adhesion of inorganic films to polymers, improved adhesion was achieved by increasing the deposition temperature of the coating layer [4] or performing a sputter clean prior to deposition of the coating [8]. However, these methods were ineffective for improving LTO adhesion. LTO adhesion could be improved by reducing oxygen exposure of the resist during the initial stages of the deposition. A similar result was observed for SiO_2 deposition on a low-k polymer [9]. It is proposed that excessive oxygen in the plasma during the initial LTO deposition produces weak C-O bonds at the interface. By minimizing oxygen concentration in the plasma during the initial deposition, strong Si-C bonds are formed at the interface between the resist and the LTO, thereby resulting in strong adhesion.

4. Conclusions

CMOS image sensors with an LTO coating on the microlens have been characterized for dark current, quantum efficiency, and reliability. Quantum efficiency is increased with LTO coating for non-webbed microlens processes

Dark current is increased with the LTO process because the final via etch has to be moved after the forming gas anneal. The adhesion of the LTO to the resist lens is degraded by a humidity stress. Oxidation of the resist during the initial stages of LTO deposition must be minimized to ensure good adhesion.

1. B. Dipert, Electronic Design News, Sept. 2004, p. 40.
2. D.A. Baillie et al., Proc. SPIE, vol. 5377, 2004, p. 953.
3. H.S. Oh, IEEE Asia Pac.Conf. ASICs, 2000, p. 259.
4. K. Park et al., SSDM Proc., 2008.
5. J. Adkisson et al., Proc. IEEE Workshop Charge Coupled Devices Adv. Image Sensors, 2005, p. 1.
6. http://en.wikipedia.org/wiki/Anti-reflective_coating
7. N.Loukianova., Trans. Elec. Dev., 50, 2003, p. 77.
8. E.O. Shaffer et al., IITC Proc., 1998, p. 223.
9. J.G. Song et al., IITC Proc., 2000, p. 55.

Stress	Conditions	time
uHAST	130°C / 85% RH	192 hours
T&H	85°C / 85% RH	500 hours
DTC	-40°C to 125°C	500 cycles

Table I. Reliability tests; unbiased highly accelerated stress test (uHAST); temperature and humidity (T&H); deep thermal cycle (DTC).

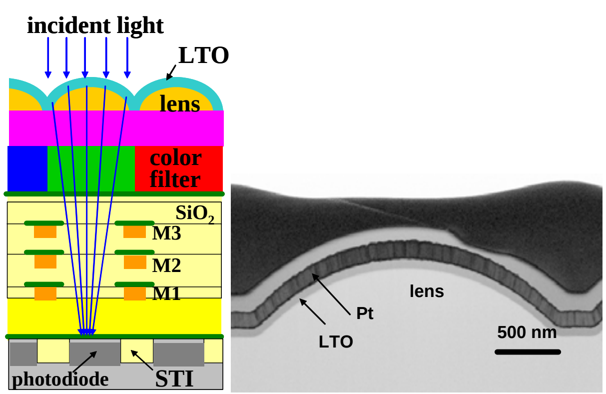

Fig. 1. (a.) Schematic cross-section of CMOS image sensor pixel with LTO coating on polymer microlens. (b.) TEM cross-section of LTO coating on polymer microlens. Pt layer is used for TEM sample preparation.

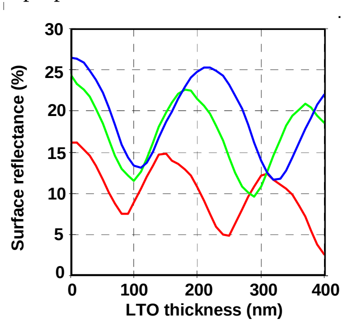

Fig. 2. Simulation of reflectance versus LTO thickness on microlens for red, green, and blue light.

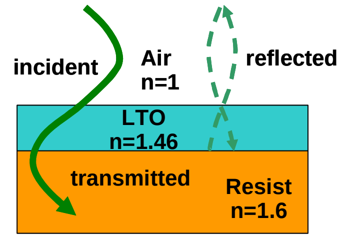

Fig. 3. Reflectance is minimized by using an LTO thickness that is ¼ of the wavelength of the incident light, due to destructive interference of the reflected light.

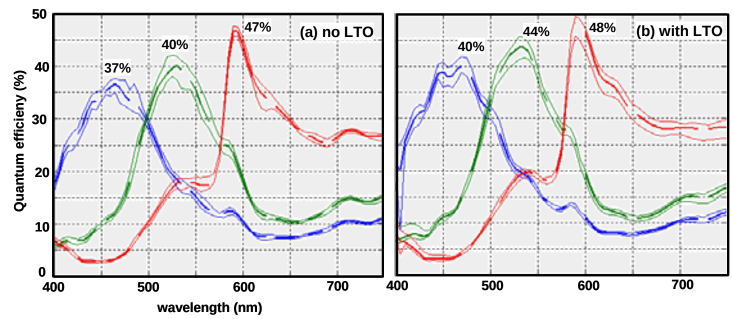

Fig. 4. Quantum efficiency for CMOS image sensor (a) no LTO coating and (b) with LTO coating on microlens.

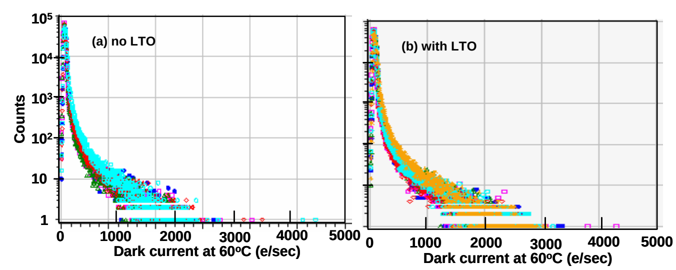

Fig. 5. Dark current distribution at 60°C for CMOS image sensor with (a) no LTO and (b) with LTO.

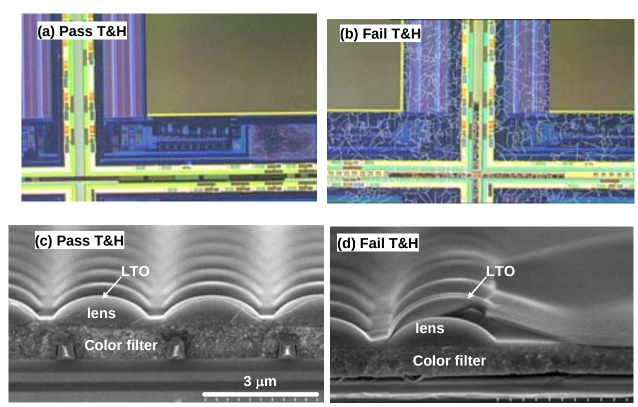

Fig. 6. Optical micrographs and SEM images of CMOS image sensor after humidity stress; (a) and (c) passing wafer; (b) and (d) failing wafer.