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SENSOR DEVELOPMENT FOR THE LARGE SYNOPTIC SURVEY TELESCOPE*

P. O'Connor, V. Radeka, and P. Takacs

Brookhaven National Laboratory
Upton, NY 11973-5000

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Sensor Development for the Large Synoptic Survey Telescope

P. O'Connor, V. Radeka, and P. Takacs
Brookhaven National Laboratory
Instrumentation Division, Bldg. 535B
20 N. Technology St., Upton, NY 11973

Abstract

The Large Synoptic Survey project proposes to build an 8m-class ground-based telescope with a dedicated wide field camera. The camera consists of a large focal plane mosaic composed of multi-output CCDs with extended red response. Design considerations and preliminary characterization results for the sensors are presented in this contribution to the Workshop.

Overview of the LSST project

The Large Synoptic Survey Telescope [1], now in the research and development phase, is designed to obtain sequential images of the observable sky every few nights from an observing site in northern Chile. With its 8.4m primary mirror, 10 deg^2 field of view, and fast readout and repointing, the LSST will yield contiguous overlapping imaging of 20,000 – 23,000 square degrees of sky in 6 optical bands covering the wavelength regime 350 – 1100 nm. Each field will be imaged thousands of times over the course of the planned 10 year survey with revisit times ranging from tens of seconds to years. The combination of wide and deep sky coverage, together with outstanding image quality provided by the site and actively-controlled telescope optics, will enable LSST to address some of the most pressing open questions in astronomy and fundamental physics.

Sensor requirements derived from science goals

The scientific goals of LSST place stringent demands on the optical, electrical, and mechanical properties of the focal plane sensors. The large field of view and plate scale of 52μm/arcsec lead to a flat focal surface of nearly 65cm diameter and 3.2Gpixels. This will be constructed as a mosaic of back-illuminated 4K X 4K CCDs having sixteenfold segmentation as shown in Fig. 1. The segmentation is chosen to allow fast parallel readout at reasonable pixel rates. The need for extended red response (> 25% quantum efficiency at 1000nm) leads to an unusually large silicon thickness. However, thick sensors require a high internal electric field to counteract diffusion. A detailed analysis of the behavior of QE and point spread function as affected by sensor thickness, resistivity, applied bias voltage, and temperature has been performed [2]. The baseline design point for LSST sensors is 100μm thickness, 10kΩ-cm resistivity, 5 kV/cm internal electric field, operating at 180K. Fig. 2 and Fig. 3 illustrate some of the tradeoffs involved. Fig. 2 shows the QE at λ=1000nm as a function of thickness and temperature, while Fig. 3 shows diffusion FWHM as a function of thickness and applied voltage.

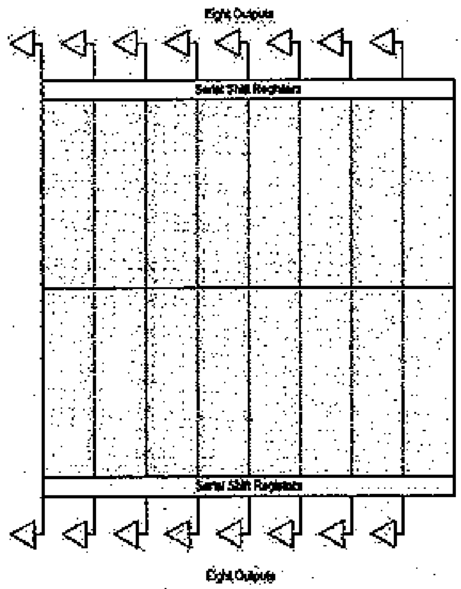

Figure 1: Proposed 4K x 4K sensor layout. Parallel clocking is vertically outward from center line. Serial registers on top and bottom shift charge to eight output amplifiers each, allowing 2s readout at 500 kpix/s.

The LSST optical system has a final focal ratio of 1/1.25; the resulting depth of focus is extremely small and both the individual sensors and the entire mosaic require careful attention to flatness. Fig. 4 shows the simulated defocus curves for sensors at three different wavelengths. To achieve LSST's PSF requirement, the sensors' entrance windows must conform to the ideal focal plane within a few microns, and the best focus must be adjusted for each band. Finally, the internal focus of the LSST's 3-mirror design constrain the camera electronics to lie directly in the shadow of the focal plane sensors. A concept for a 144Mpixel module with nine sensors and compact front end electronics has been developed in collaboration with M. Nordby at the

Stanford Linear Accelerator Center. A summary of the sensor requirements derived from LSST's ambitious survey goals is shown in Table 1.

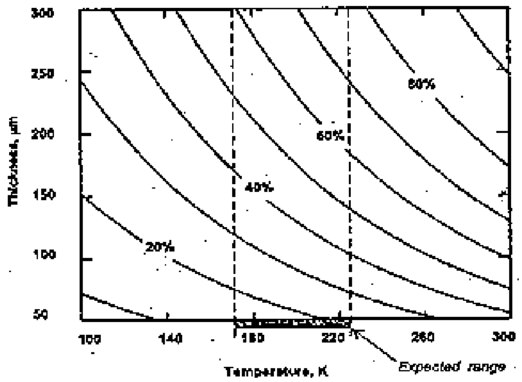

Figure 2: Quantum efficiency at 1000nm as a function of temperature and silicon thickness. LSST goal is > 25%.

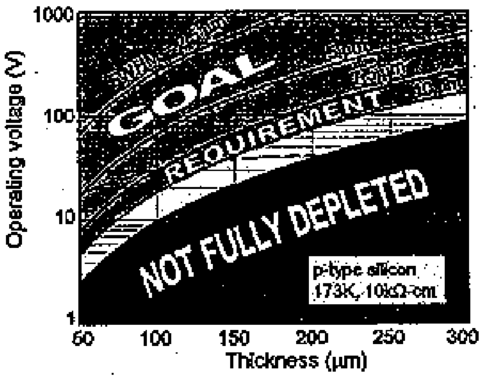

Figure 3: Diffusion FWHM as a function of silicon thickness and applied bias.

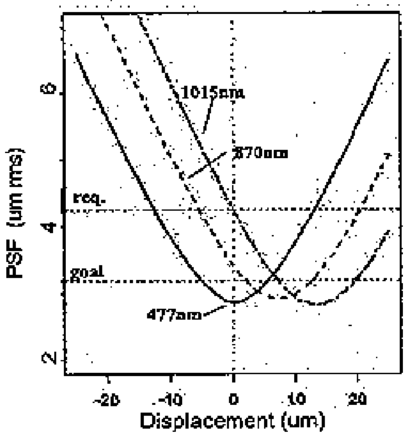

Figure 4: Defocus curves for 477nm, 870nm and 1015nm light. Position of optimum focus becomes wavelength dependent for weakly-absorbed near-IR light.

SCIENCE GOAL	SENSOR REQUIREMENT
High QE to λ=1000nm	Thick silicon (> 75µm)
Point spread function << 0.7"	Small pixel size (0.2" = 10µm) High internal field in sensor (~ 5kV/cm) High resistivity silicon (> 5kΩ-cm)
Fast f/1.2 focal ratio	Sensor flatness < 5µm pk-pk
Wide field of view (3.5°)	~3200 cm² focal plane ~ 200-CCD mosaic (~16cm² each) Industrialized production process required
High throughput	> 90% fill factor 4-side buttable package with sub-mm gaps
Fast readout (2s) with low read noise (5 e⁻ r.m.s.)	Segmented sensors (~3200 TOTAL output ports) 150 I/O ports per CCD

Table 1: Sensor requirements derived from science goals.

Sensor Development Program

The LSST collaboration has begun a multi-year development program with several commercial CCD vendors to produce devices satisfying all technical requirements. In the first phase of this study program, vendors have delivered test devices that address the key LSST goals. Fig. 6 shows a wafer having several exploratory 4K x 4K designs, and Fig. 6 shows flatness results obtained on a set of sensors produced by a second vendor. Results of optical and electrical tests on these devices will be reported at the Workshop.

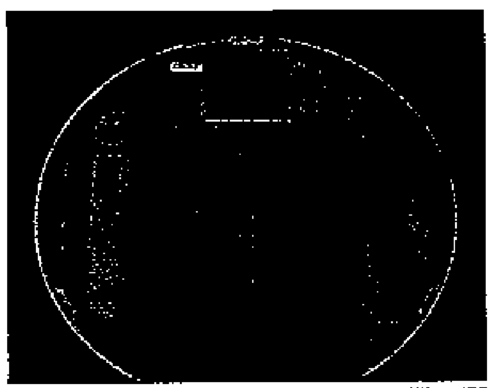

Figure 5: Test wafer having several 4K x 4K sensor designs, fabricated on high-resistivity silicon.

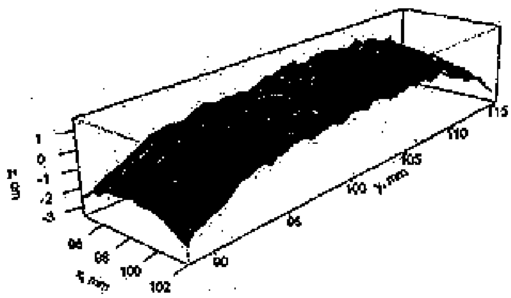

Figure 6: Flatness scan of a test device fabricated on high resistivity silicon. More than 90% of the area of each sensor is within LSST flatness specification.

References

[1] Tyson, J. A.; Wittman, D. M.; Hennawi, J. F.; Spergel, D. N., 2003, "LSST: a Complementary Probe of Dark Energy," astro-ph/0209632; Nuc. Phys. B 124, 21 (2003).

[2] P. O'Connor et al, Proc. SPIE 6276-75 (April 2006)