Tree Rings on LSST production sensors

its dependence on radius, frequency, and back bias voltage

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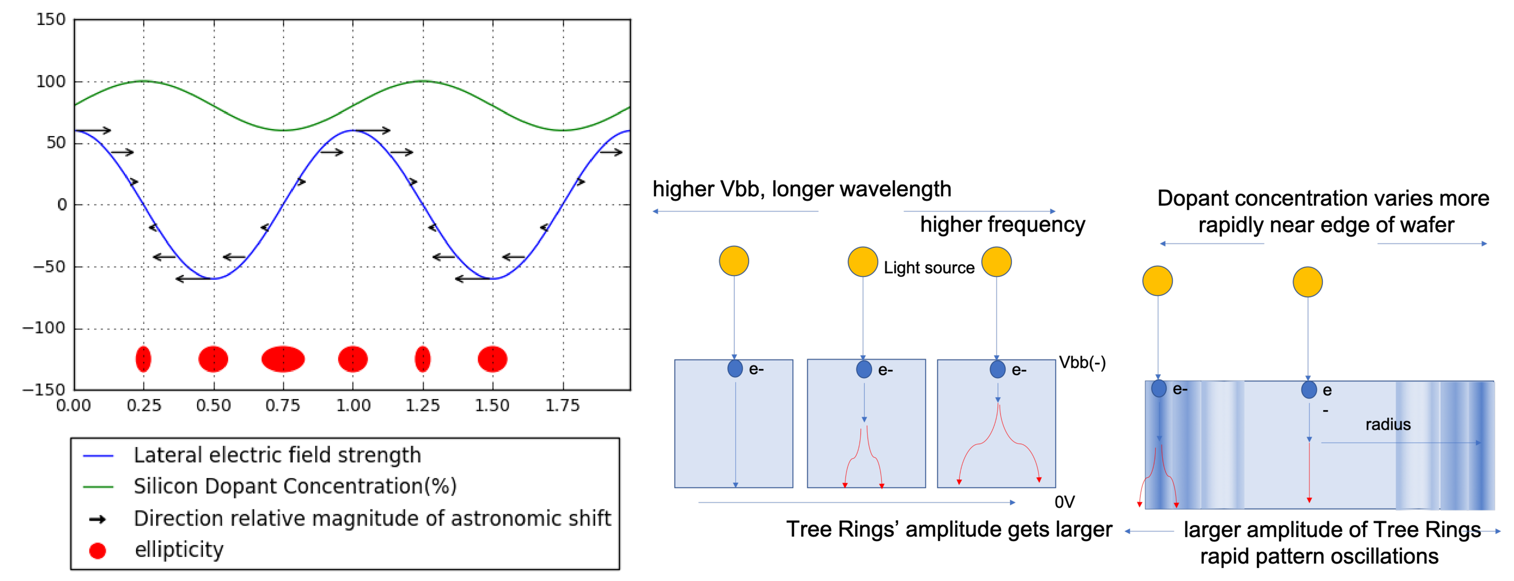
Introduction

History of Astrophysics was developed along with precise measurement of astronomical parameters. Especially CMB polarization and shear need to be measured precisely with high accuracy, since they are dealing with faint objects and weak distortion in the shapes in order of 1%. We have studied CCD sensor effects using the data taken in the cleanroom at BNL to correct them from the simulations.
Tree Rings effect is one of the sensor effect caused by silicon concentration variation from the wafer manufacturing process. When silicon concentration varies due to foreign object, electric field in the direction orthogonal to the drift of photoelectrons changes, hence the shape of sources could be distorted based on their location on the sensor. (Fig.1-(a)) The amplitudes and periods of the Tree Rings effect can depend on radius (distance from the center of the wafer/rings), frequency of the light source, and back bias voltage settings. We expect more dynamic variation of the dopant concentration on the edge of the wafer, and electrons penetrates deeper into the silicon wafer with higher back bias voltage and with longer wavelengths. (Fig.1-(b)) Therefore we expect to have larger amplitude on larger radius, higher frequency, and lower back bias voltage.



(a) Origin of Tree Rings effect **(b)** Tree Rings dependence on radius, frequency, and back bias voltage.

Figure 1: Theoretical explanation for Tree Rings effect.

Methods

We used sflat (super flat) images from the single sensor EO (electro optics) tests and flat images from the raft EO tests. "sflat image" is set of 25 images with wavelength 500nm and with same exposure time. We used 90 singel sensor EO test (52 ITL, 38 E2V) results, and one raft EO results with different back bias voltage settings to see back bias voltage dependence with same sensors. For RTM EO, flat images are taken with wavelength 675nm, and exposure time of 100 seconds. Each image had overscan subtraction and mean flux subtraction. After adjusting contrast, we found the center of the rings then mean flux over the radius were calculated. Amplitudes of the Tree Rings were measured by subtracting lower peak from higher peak of the flux. Scale for amplitudes is in %, compared to mean flux over the sensor.

Results

Radius dependence

Tree Rings' amplitude starts to increase when distance from the center of the ring (radius) is near 4000 pixel. (Fig.2) Bright and dark pattern appears more often, which means period of the pattern gets smalleron the outer part of the wafer also. (FIg.3)

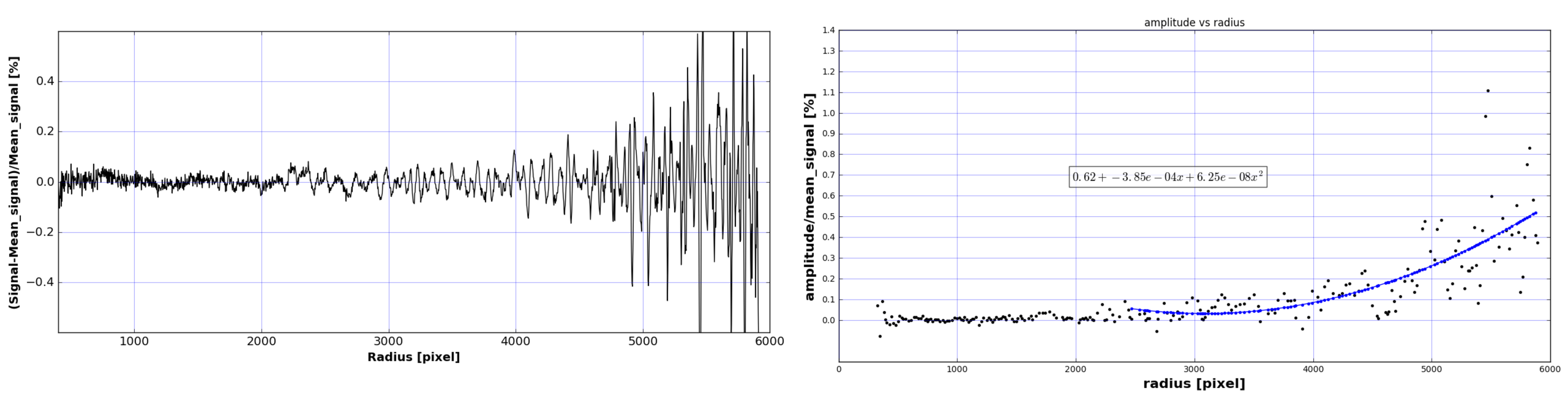
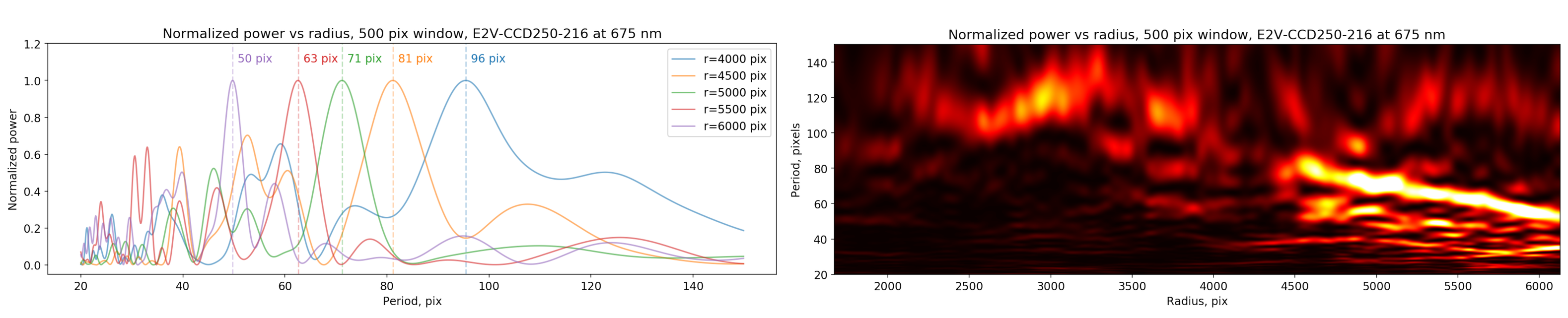


Figure 2: Peak-to-peak amplitude of Tree Rings gets larger as gets further from the center of the rings.



(a) Periods for radius 4000, 4500, 5000, 5500, 6000pix **(b)** Periods dependence on radius

Figure 3: E2V-CCD250-216, 675nm, Tree Rings' amplitude and period on radius.

Frequency dependence

Fringes in IR originate from the varying thickness of the silicon wafer. In the shorter wavelength region, before fringes start to dominate, the tree rings are visible. Fringe pattern starts to dominate over tree rings around 880 nm and shows maximum impact around 970 nm. Amplitude of the Tree Rings gets smaller for longer wavelength (shorter frequency).[1]

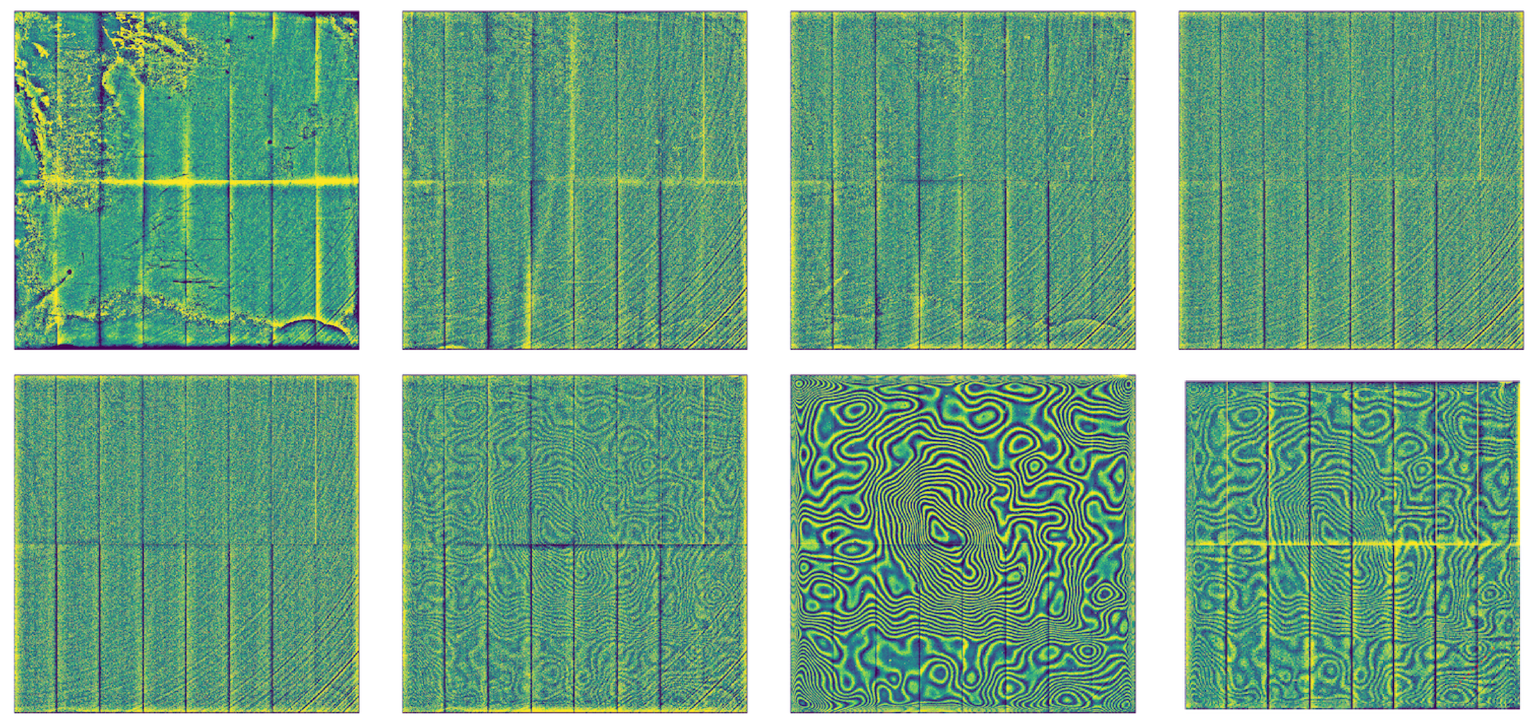


Figure 4: Uniformly illuminated images for the sensor ITL-3800C-017 taken at different wavelengths: 320, 400, 540, 770, 850, 900, 970, and 1080 nm (from top-left to bottom-right).

Back bias voltage dependence

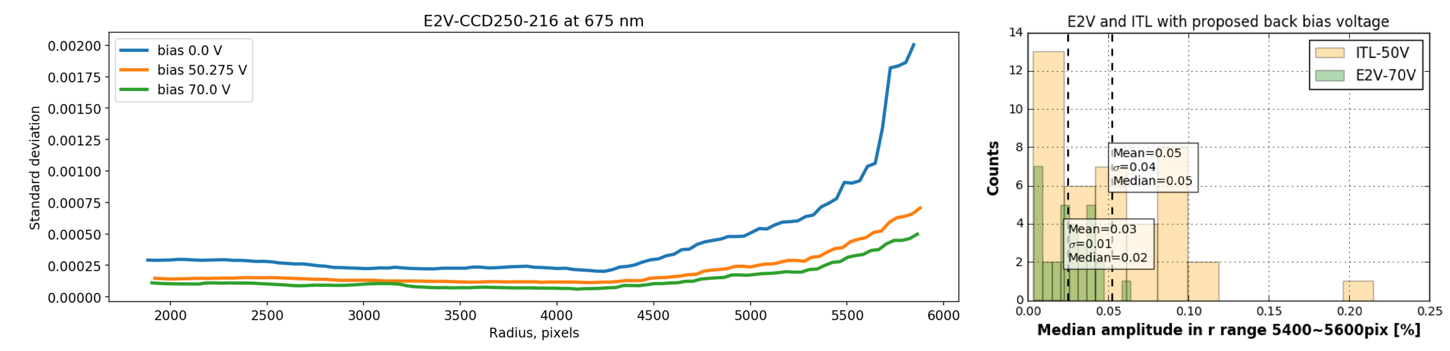
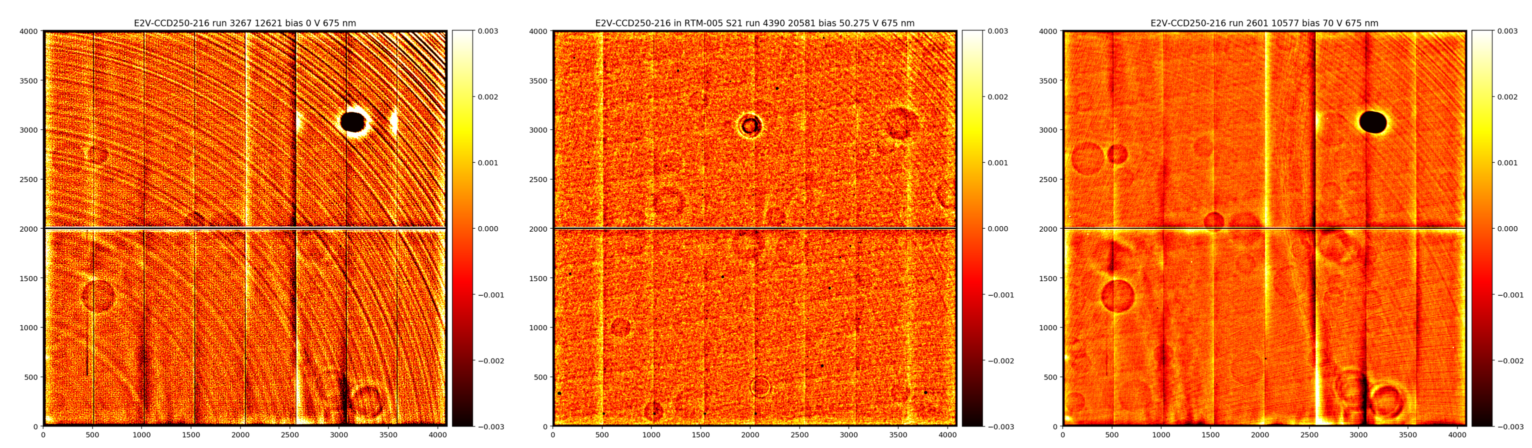


Figure 5: Tree Rings' amplitude over radius with different back bias voltage (left) and histogram for E2V and ITL's Tree Ring amplitude with proposed back bias voltage settings (right)

sensor type	0V	30V	35V	50V	70V
ITL(5400∼5600pix)	0.8	-	0.19 ±0.11	0.05 ±0.04	-
ITL(5800∼6000pix)	1.53	-	0.31 ±0.15	0.1±0.06	-
E2V(5400∼5600pix)	-	-	-	0.05 ±0.03	0.02 ±0.01
E2V(5800∼6000pix)	-	-	-	0.1±0.05	0.04 ±0.03
E2V_675nm(5400∼5600pix)	0.11 ±0.05	0.03 ±0.02	-	0.01 ±0.01	0.02 ±0.01

Table 1: Median peak to peak amplitude (%) for each back bias voltage settings with wavelength 500nm for single sensor EO, and wavelength 675nm for raft EO

Amplitude of Tree Rings effect gets smaller as increasing back bias voltage. With proposed back bias voltage settings.



(a) **(b)** **(c)**

Figure 6: E2V-CCD250-216, 675nm, with back bias voltage (a)0V, (b)50V, and (c)70V.

Conclusions

- Tree Rings' amplitude gets larger and period gets smaller as gets further from the center because dopant concentration is more unstable on the edge of the silicon boule.
- Tree Rings' amplitude gets larger for higher frequency and lower back bias voltage since lower frequency light with higher voltage penetrates deeper into the silicon wafer.
- With suggested back bias voltage settings for ITL and E2V, Tree Rings' amplitude is negligible, 0.05% for ITL (50V) and 0.02% for E2V (70V).

Forthcoming Research

The result of this study is applied to Phosim, Galsim, and Imsim, the simulation tools LSST-DESC is using. Using the simulations, changing the variables for Tree Rings effect, we are planning to compare the shape distortion from the Tree Rings effect on cosmic shear measurment.

References

[1] HY.Park, A.Nomerotski, and D.Tsybychev *Properties of tree rings in LSST sensors* Jinst, 2017
[2] https://confluence.slac.stanford.edu/display/LSSTDESC/Tree+Ring+effect+in+LSST+CCD+sensors
[3] https://github.com/karpov-sv/lsst-misc/blob/master/Tree_Rings_Analysis.ipynb

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