Surface cleaning of CCD imagers using an electrostatic dissipative formulation of *First Contact*™ polymer

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ABSTRACT

We describe the results obtained cleaning the surface of DECam CCD detectors with a new electrostatic dissipative formulation of *First Contact*™ polymer from *Photonic Cleaning Technologies*. We demonstrate that cleaning with this new product is possible without ESD damage to the sensors and without degradation of the antireflective coating used to optimize the optical performance of the detector. We show that *First Contact*™ is more effective for cleaning a CCD than the commonly used acetone swab.

1. INTRODUCTION

Charge Coupled Devices (CCDs) are extensively used as photon detectors in optical astronomical instruments. They are the key components of imagers and spectrometers all around the globe. State of the art detectors have a quantum efficiency (QE) approaching 100% in some wavelengths and noise levels of a few electrons which allow for a statistically significant detection of very low signal levels. Future projects, such as DES [1] and Pan-STARRS [2], expect to produce photometric measurements of astronomical objects with less than 1% uncertainty using CCDs. The surface of the detectors exposed to light must be extremely clean to avoid degrading the performance of the CCD. Both light collection efficiency and precision are affected by contamination in the surface. For these reasons, CCDs are typically handled in clean rooms, and extreme care is taken to avoid contamination of any kind.

In the event of contamination, for example, condensation of particles on the CCD surface in the event of a vacuum accident, the illuminated back-side surface of the CCD can be cleaned with acetone using a static-dissipative polyester-tipped cleanroom swab. This has been done by addition of a small amount of acetone to the tip of the swab and then manually brushing the surface, with frequent swab changes. Although mostly effective, this technique is not fully satisfactory. It does not always remove all contaminants. Some spots have been observed to be well-adhered to the CCD surface and have resisted removal.

A special formulation of the *First Contact* ™ [3] surface cleaning and protection product has been investigated at Fermi National Accelerator Laboratory (FNAL) as a potential tool for CCD cleaning. This product, originally developed for the cleaning of precision optics, can be dabbed on as a liquid polymer and allowed to harden. The resulting plastic film can then be peeled off and has been developed such that it removes dust, fingerprints, and residues from the surface. The standard formulation of this product, however, is not static-dissipative and can generate several thousand volts when the film is peeled from a surface. With the extreme sensitivity of the CCDs to electrostatic damage, this characteristic of its performance makes it unsuitable for this work. However, a research effort by the manufacturer has resulted in a revised formulation of this product that includes the addition of carbon nanotubes in order to add a small amount of electrical conductivity to the polymer. Inspection of the film's surface resistivity indicates that it has a value of $10^{10}\Omega/\text{sq}$, which puts it slightly into the static-dissipative category. A sample of the film without the carbon nanotubes was found to have a resistivity of greater than $10^{12}\Omega/\text{sq}$, classifying it as an insulator.

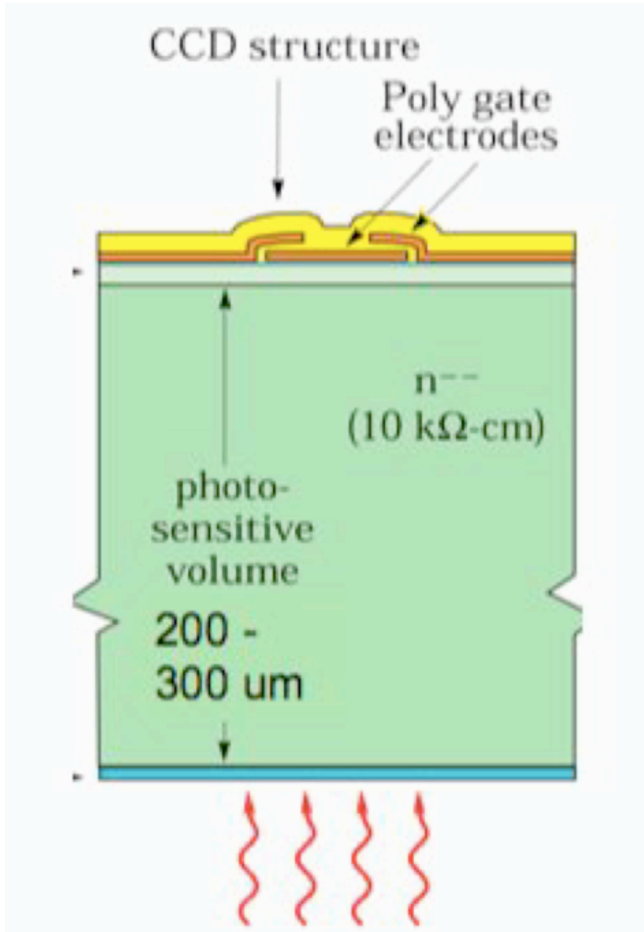

Figure 1. Schematic of a DECam detector. Back illuminated, 250-micron thick, p-channel CCD. For more details see Ref. [4]

2. THE DETECTORS

Recent advances [4] in CCD technology allow the fabrication of devices approximately 300 microns thick which are fully depleted at relatively low voltages. These CCDs have a significantly higher efficiency in the near-IR and for this reason are the optical detectors chosen by several groups building new mosaic cameras for astronomy, such as DECam [1,5] , SNAP [6] and HyperSuprime [7].

The DECam CCDs are 2k x 4k, 15 micron format devices that are designed, fabricated and cold-probed by Lawrence Berkeley National Laboratory, then provided in die form to FNAL for packaging and final characterization. A cartoon of the devices used in the cleaning tests is shown in Fig. 1. It is a back illuminated, p-channel CCD thinned to 250 microns and biased from the back side to be fully depleted. An antireflective (AR) layer is applied to the back of the detector to optimize its performance in a wide range of wavelengths. The CCDs used in most astronomical instruments until now are thinned to <40 microns to reduce charge diffusion. For the DECam CCDs, a substrate voltage of up to 80 V is applied to the back surface to control diffusion and obtain acceptable image quality in 250-micron detectors.

Here, we present the results obtained with a new cleaning technique used on the DECam detectors [5,8,9]. DECam is the instrument currently being built for the Blanco 4m Telescope at CTIO [10] that will be used for the Dark Energy Survey (DES) and will be available as a facility instrument at CTIO.

3. CLEANING WITH *FIRST CONTACT* ™ POLYMER

First Contact ™ optics cleaning polymer has been used to clean the light-collecting surface of several DECam CCDs. The cleaner is a proprietary liquid polymer that is dabbed directly onto the CCD surface where it hardens into a solid elastic film. When peeled off, small particles and organic residues on the surface are removed along with the film.

During the CCD cleaning process, a small quantity of the polymer was first dispensed into a conductive dish that could be positioned in the work area close to the module. A long-bristled brush was then dipped in the solution and withdrawn, leaving a droplet at the end of the brush. This droplet was gently brought into contact with the surface of the CCD in such a way that the polymer droplet, not the brush itself, contacts the surface. Lateral brush motion then drags the droplet around, coating a section of the surface. Initially, the polymer was carefully applied around the perimeter of the sensor. The care required with this technique when working near the sensor edges, along with the desire to avoid having any of the polymer flow over the edge of the silicon, meant that the applied polymer did not always reach the diced edge of the sensor. The DES sensors have a perimeter of about a millimeter of inactive silicon around the edge of the active pixel area, which reduces the criticality of this issue. Once the polymer was successfully applied around the perimeter, the interior portion bounded by the dam can be coated using the same technique but with less application precision. Care was still taken, however, to keep the polymer droplet, and not the application brush, in contact with the CCD surface.

Once coverage was complete, some type of feature had to be added to the coating to aid removal once it has solidified. For this purpose, a short length of cotton string was placed on the coating such that a portion of the string extended off a corner of the sensor. Additional polymer was applied on top of the string in order to encapsulate it in place. The polymer was then permitted to solidify overnight. An example of a CCD at this stage is shown in the middle panel of Fig. 2.

Removal of the resulting solid polymer film was initiated in the corner with the string, first with a sharp tool inserted into the polymer encapsulating the string in this region. Once the corner has been started, the string can be pulled back very slowly to peel the polymer off the CCD surface.

4. RESULTS

4.1 Cleaning of an inactive region of a CCD wafer

Our first experience with *First Contact* ™ consisted of cleaning an inactive corner of a CCD wafer. For this experiment we used the standard *First Contact* ™ polymer, not suitable for detector cleaning because it is not conductive and could build up a significant amount of electrostatic charge.

The wafer corner piece was first cleaned using an acetone swab. Several drops of acetone were applied directly to the silicon (something not commonly done for CCDs) and allowed to dry before the residue was swabbed off as much as possible, resulting in several remaining residue features when viewed under magnification. We then recorded images of 15 locations on the CCD using a microscope with an X/Y coordinate positioning system. The piece was then cleaned with *First Contact* ™ and imaging of the same 15 regions was repeated. An example image is shown in Fig. 3, where the efficiency of *First Contact* ™ in removing the acetone residues is evident.

4.2 Electrostatic safety of the cleaning process

A modified version of *First Contact* ™ was doped by the manufacturer with carbon nanotubes to give a small amount of electrical conductivity, making it static-dissipative. The next step before cleaning a scientific grade CCD with *First Contact* ™ was to certify the ESD safety of this product specially developed for electrostatic sensible components. We cleaned 4 engineering grade 0.5 k x 1 k detectors using *First Contact* ™ with carbon nanotubes. These small devices are part of the production wafer of DECam detectors and are usually used as test detectors since they are too small for the DECam instrument. Three of the sensors showed no problem after cleaning, which gave us confidence in the ESD safety of the procedure. The fourth detector had a problem with one amplifier after cleaning, but this problem could have been produced during handling steps not directly related to the cleaning. Based on these tests, we gained enough confidence in the static charge dissipation provided by the carbon nanotubes and decided to start using *First Contact* ™ for detectors of greater value.

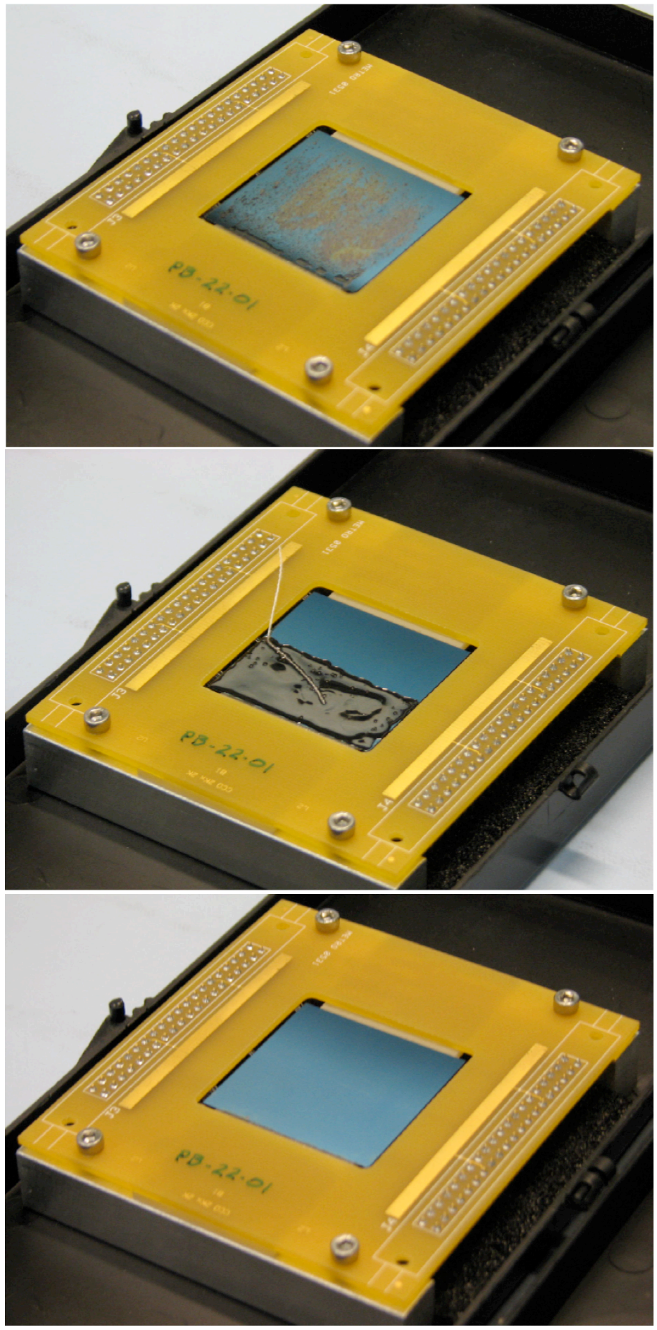

Figure 2. Cleaning of the DECam 2k x 2k picture frame CCD. Detector after losing vacuum while cold (top), detector being cleaned (middle), and the result of the cleaning process (bottom).

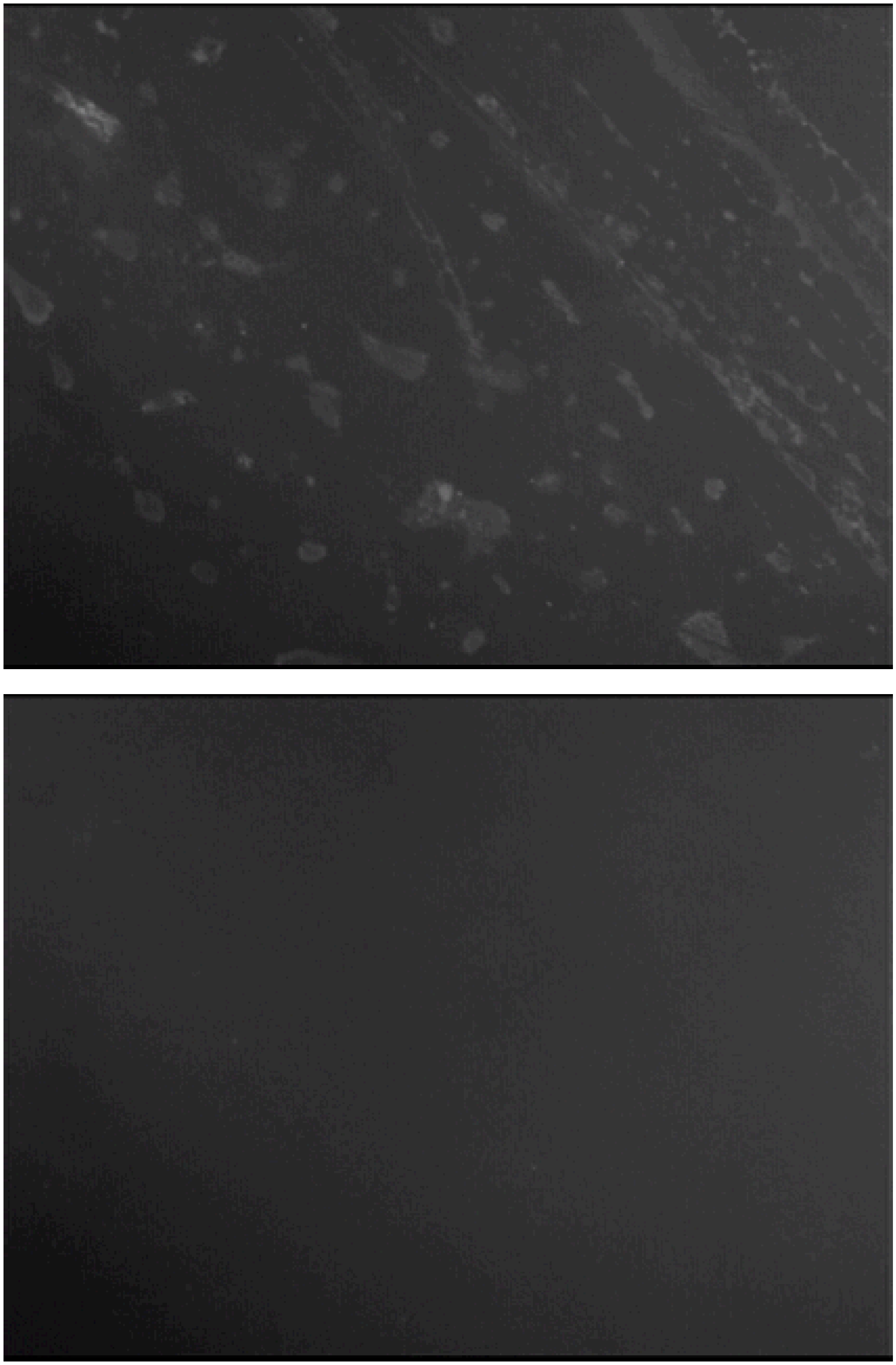

Figure 3. Microscope images of a wafer after cleaned with acetone (top) and after the application of *First Contact* ™ (bottom). The image width is approximately 340 microns.

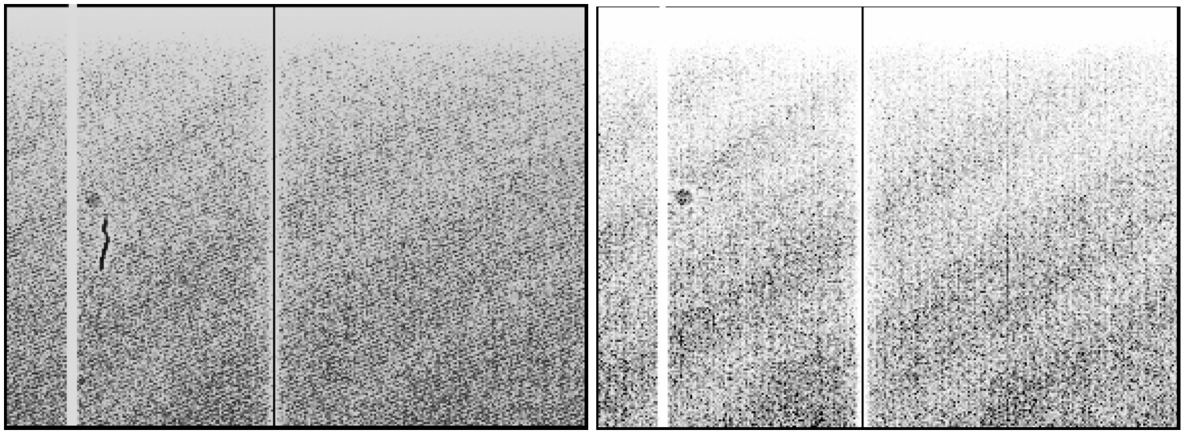

Figure 4. 300 pixel wide region of a CCD image before (left) and after (right) cleaning with *First Contact* TM
. A small fiber is efficiently removed from the surface during the cleaning process. Each pixel is 15 microns x 15 microns. Both images show a hot column and a blocked column. These are produced by cosmetic defects in the Si.

4.3 Cleaning of 2k x 2k detector

After certifying the ESD safety of *First Contact* TM with nanotubes, we decided to use the product to clean a 2k x 2k scientific grade detector. The detector was operational after the cleaning process and we investigated the incidence of cosmetic defects in the image before and after cleaning. An example of the type of artifacts coming from contamination removed by *First Contact* TM is shown in Fig. 4.3.

Another concern when cleaning a CCD imager with any product is the possible damage to the surface exposed to light. This surface has an antireflective coating to produce optimal performance in a desired wavelength range. We investigated the effect of *First Contact* TM on this AR coating by measuring the QE of the detector before and after cleaning. The results are shown in Fig. 5, demonstrating no degradation of the surface after cleaning with *First Contact* TM.

4.4 Cleaning of 2k x 2k detector after vacuum accident

The dewar where we operated a 2k x 2k DECam CCD lost vacuum while the detector was at 173 K. The pump accidentally vented, allowing air to come into the detector chamber while the detector was still cold. This produced condensation of the humidity in the air, and any contaminants in the air, onto the cold surface of the detector. This type of accident is a potential cause of contamination in astronomical instruments.

After this accident, the surface of the detector looked extremely dirty as shown on the top panel in Fig. 2. The detector was cleaned using two techniques. The upper half was cleaned with an acetone swab and the lower half was cleaned with *First Contact* TM. The bottom panel in Fig. 2 shows a photograph of the detector after cleaning.

The cleaned surface was inspected using an optical microscope and the results are shown in Fig. 6 and Fig. 7. The width of each microscope image is about 340 microns.

Figure 6 shows the results of cleaning using both methods in the bulk (central region) of the imager. For the acetone swab there is some residue of the original contamination, seen as white spots in the image. For the region cleaned with *First Contact* TM there is no remnant of the original contamination.

Figure 7 shows the results for the edge of the CCD. When the edge is cleaned with the acetone, the results are very similar to that observed in the bulk of the detector. However, it was more difficult to apply the *First Contact* TM polymer all the way to the edge of the sensor. Some small amount of contamination at the very edges therefore still exists, as can be seen in Fig. 7.

The QE was measured for the region cleaned by *First Contact* TM and the region cleaned with acetone. The results shown in Fig. 8 indicate that, when compared to the region cleaned with acetone, there was no

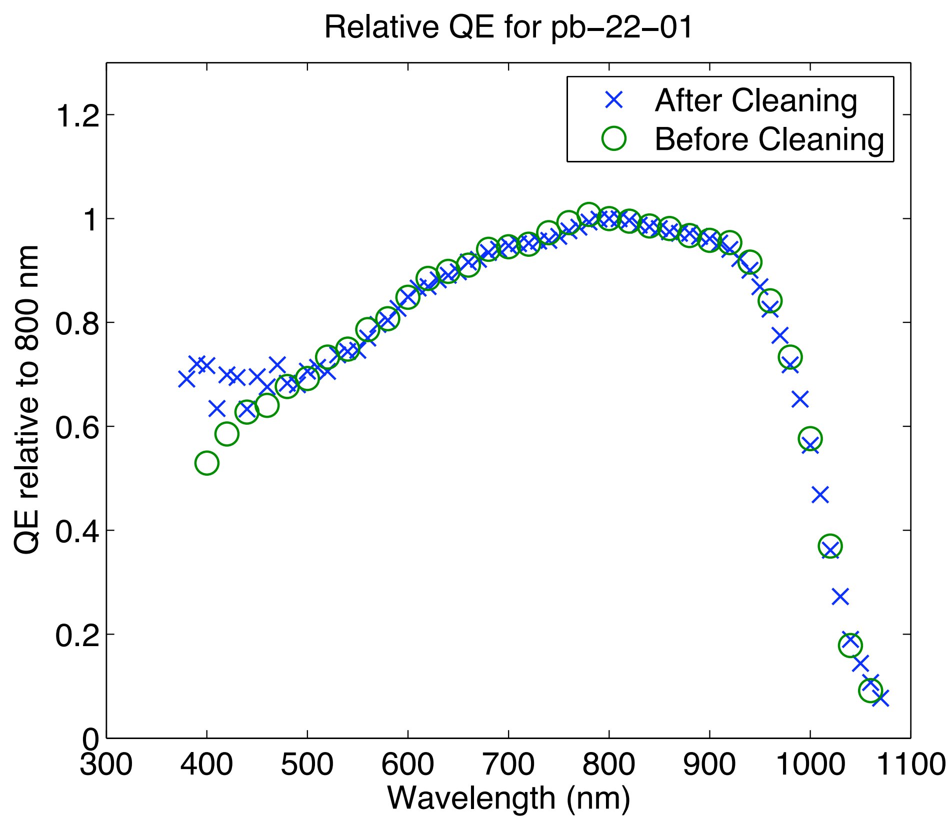

Figure 5. Relative Quantum Efficiency mesurement before and after cleaning with *First Contact* ™. There is no evidence of any degradation in the AR coating after the cleaning.

degradation of the QE (therefore no damage to the AR coating) by cleaning with *First Contact* ™. Also, the device still meets the DECam technical requirements for QE.

5. COSMETIC DEFECT STATISTICS

CCDs used for astronomical devices are typically graded according to the fractional area compromised by cosmetic defects. This grading is used to select the best detectors to be used in an instrument.

Cosmetic defects in CCDs are isolated pixels, groups of pixels, or columns that exhibit poor image quality. Defects include pixels that generate charge at a higher rate than the average in an array (white spots) and pixels with lower photo-response than average (black spots). The black spots are measured in high signal to noise images of detectors uniformly illuminated (flat field), and white spots are detected using long dark exposures at the operating temperature.

White spots may be caused by impurities in the silicon, lattice defects, or shorts through the gate oxide. Mechanical damage is one cause of oxide shorts. On back-illuminated devices (like those used in the *First Contact* ™ tests), black spots can be caused by scratches or imperfections in the anti-reflective coating. Therefore, the number of cosmetic defects can be used as a measure of whether the *First Contact* ™ cleaning procedure caused any damage to the CCD. Black spots may also be caused by opaque dirt or dust on the surface of the CCD. Again, a count of cosmetic defects can be used to indicate the effectiveness of cleaning with *First Contact* ™.

An example of a cosmetic feature removed with *First Contact* ™ is shown in Fig. 9. The dark areas are on the order of 3% below background. Cleaning this 2k x 2k device (mentioned above) with *First Contact* ™ reduced the percent of pixels whose response was more than 3% below background by one half: from 1.6% to

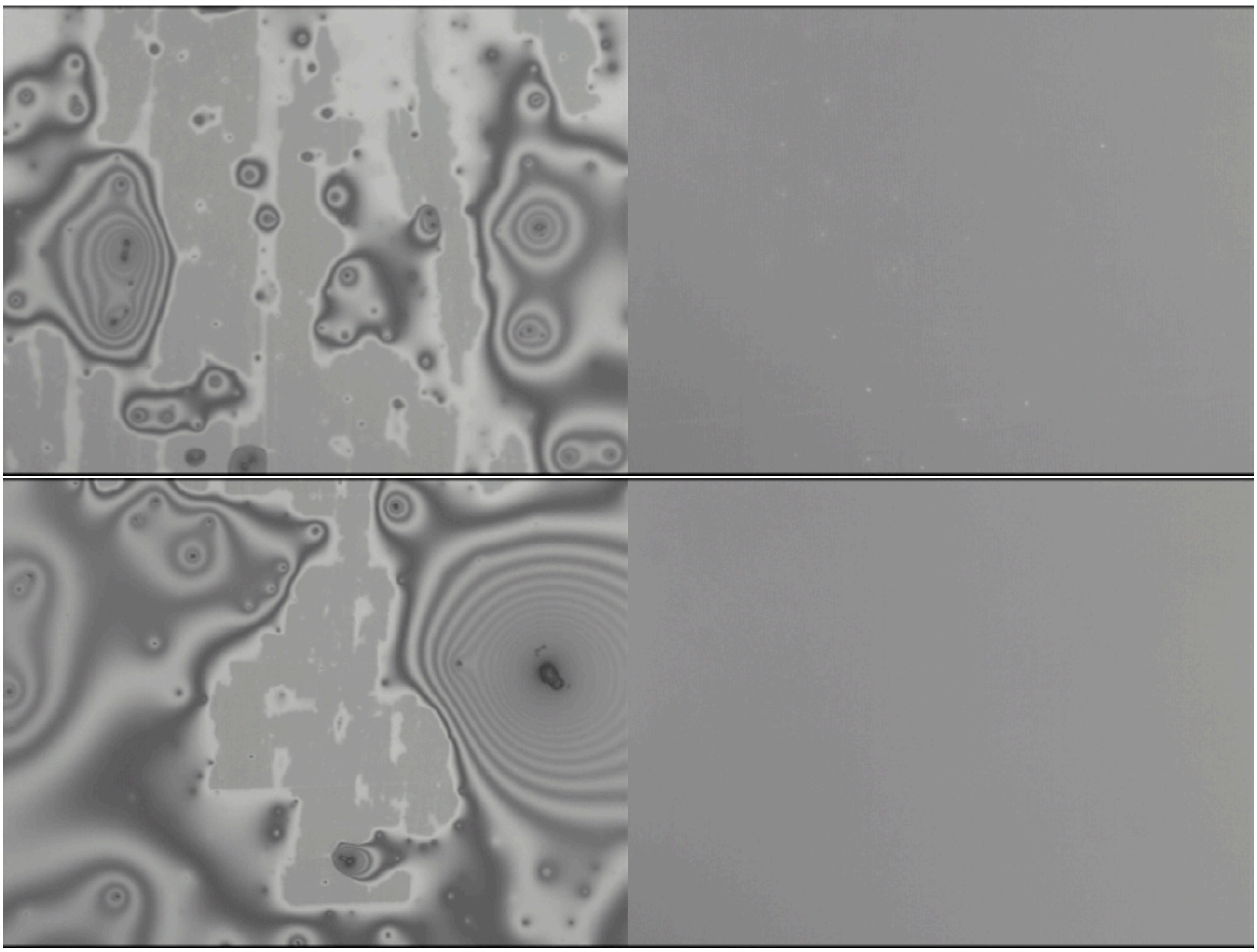

Figure 6. Results of cleaning with acetone (top) and with *First Contact* ™ (bottom) on the bulk (central region) of the CCD imager. The left images are before cleaning; the images on the right are after cleaning. After the acetone cleaning one can see some contamination as white features in the image, that are completely removed with *First Contact* ™ .

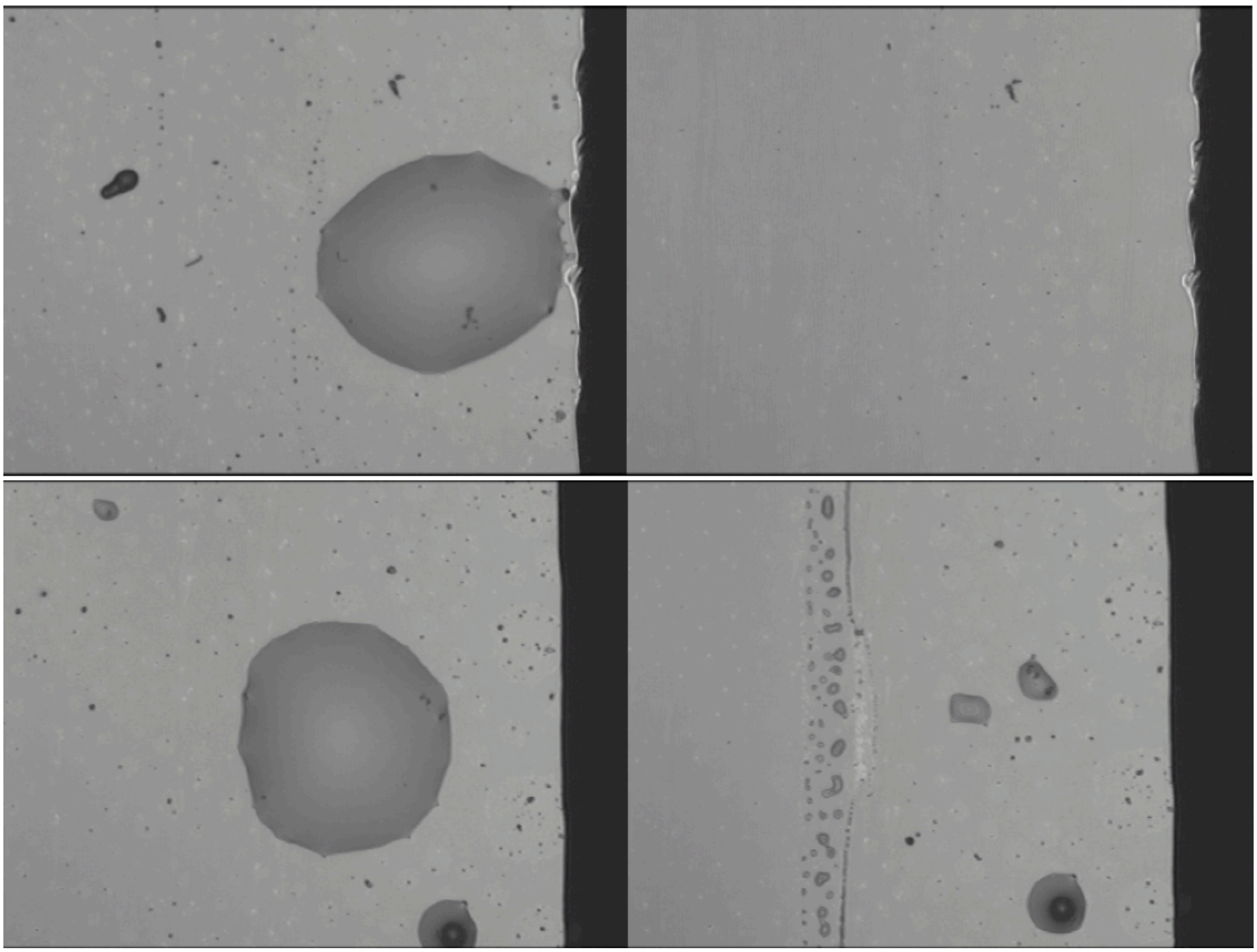

Figure 7. Results of cleaning with acetone (top) and with *First Contact* ™ (bottom) on the edge of the CCD imager. The left images are before cleaning; the images on the right are after cleaning. The application of *First Contact* ™ to the edge of the detector is difficult and some residue remains compared with the acetone swab.

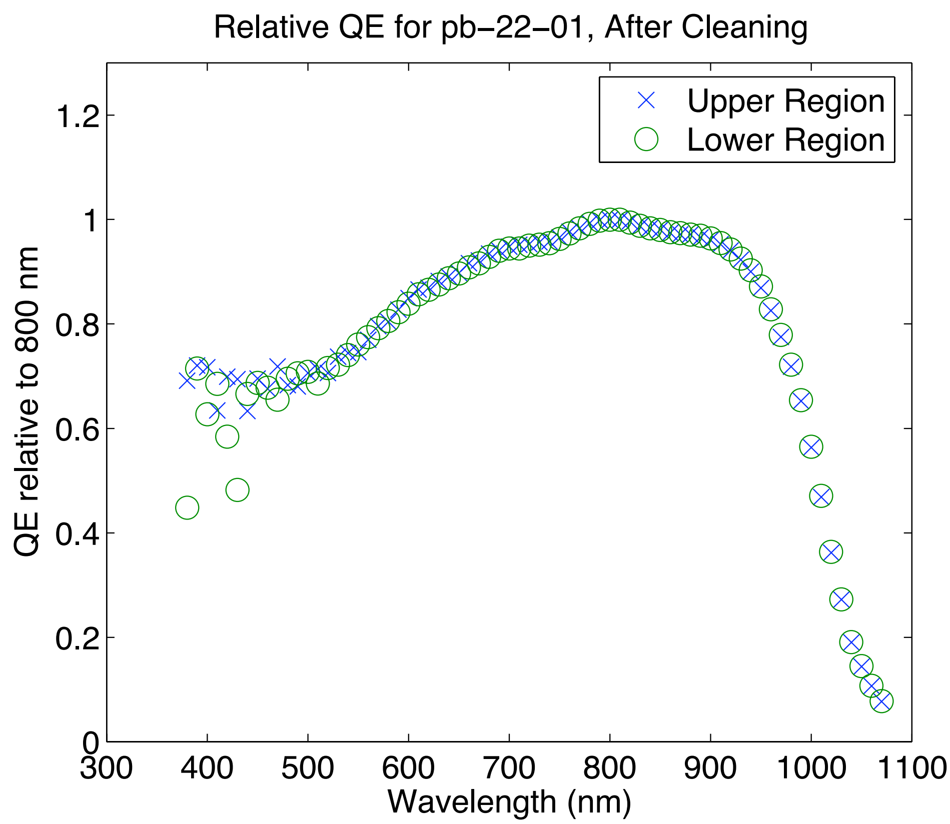

Figure 8. QE of the upper half of the CCD which was cleaned with acetone and QE of the lower half of the CCD which was cleaned with *First Contact* ™

0.8%. Note that our standard cosmetic analysis defines dark pixels as those with a response more than 20% below background.

The fraction of pixels affected by cosmetic defects for the CCD that was cleaned after the vacuum accident was 0.09%, well below the DECam requirement of less than 2.5% per CCD. The defects counted were white spots (pixels with dark current greater than 6300 e-/pixel/hour) and black spots (pixels with a response more than 20% below background). While the total number of white spots was similar for both the top half (cleaned with acetone) and the bottom half (cleaned with *First Contact* ™), all of the black spots were located on the half cleaned with acetone. This implies that *First Contact* ™ may be more effective than the acetone swab for removing opaque dirt or dust on the CCD surface and that cleaning with *First Contact* ™ did not damage the CCD. Cleaning with *First Contact* ™ converted the dramatically contaminated detector shown in Fig. 2 into a scientific grade CCD.

6. CONCLUSION

We have tested the recently-developed ESD-safe version of the *First Contact* ™ cleaning polymer on several DECam CCD devices and found improvements in image cosmetics with no degradation of collection efficiency. The charge dissipation of the product provided by the addition of carbon nanotubes is effective in reducing the risk of ESD damage during the cleaning of these very sensitive devices. During these tests we also verified that, as expected, cleaning did not degrade other performance parameters of the CCDs, such as linearity or charge transfer efficiency.

In our tests, the product removed contamination from the CCD surface more effectively than swabbing with acetone, which does not remove all contaminants and which can leave behind some residue. Tests on a sensor

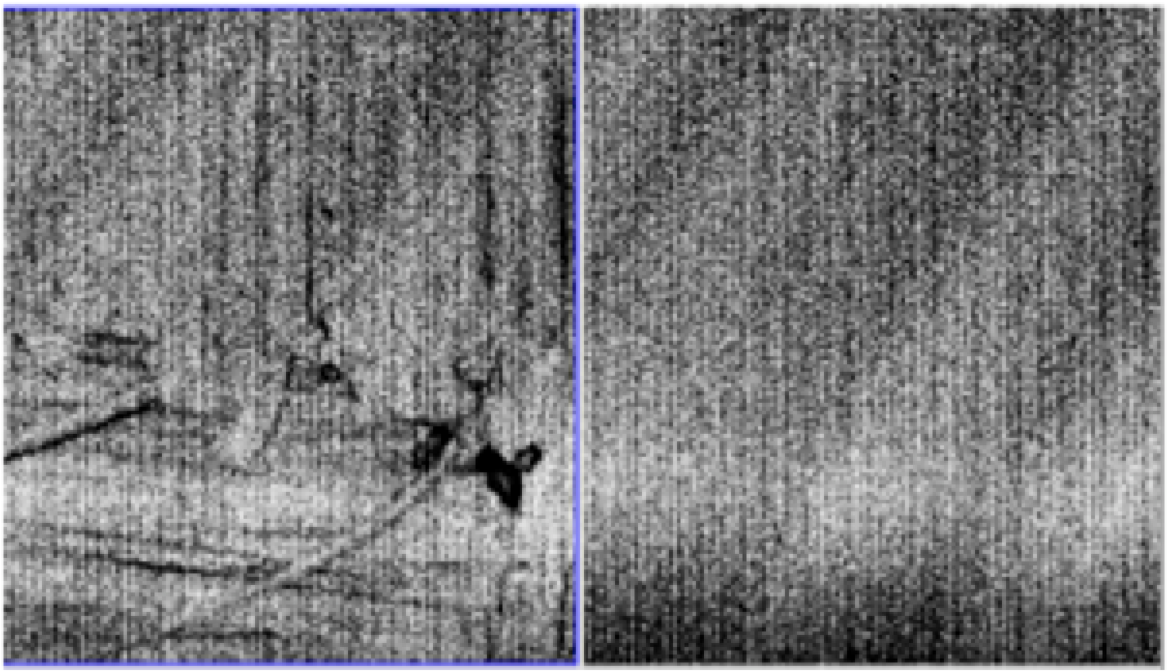

Figure 9. CCD image resulting from a flat field illumination of a 2k x 2k CCD before cleaning with *First Contact* ™ (left) and after cleaning with *First Contact* ™ (right).

which had been contaminated by loss of vacuum while cryogenically cooled found that the contaminants were effectively removed except near the very edge of the sensor, where complete coverage with the polymer was found to be difficult due to the delicate nature of the CCD module and the care necessary in this area.

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