Lawrence Berkeley National Laboratory High Resistivity CCDs in Ground Based Astronomy

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UCO/Lick Observatory has been involved in the development and testing of LBNL high resistivity CCDs from the first, small 200x200 test CCDs in 1996 right up to the present.

Figure 1 show the very first astronomical image ever obtained with a CCD that had quantum efficiency >50% at a wavelength of 1000nm.

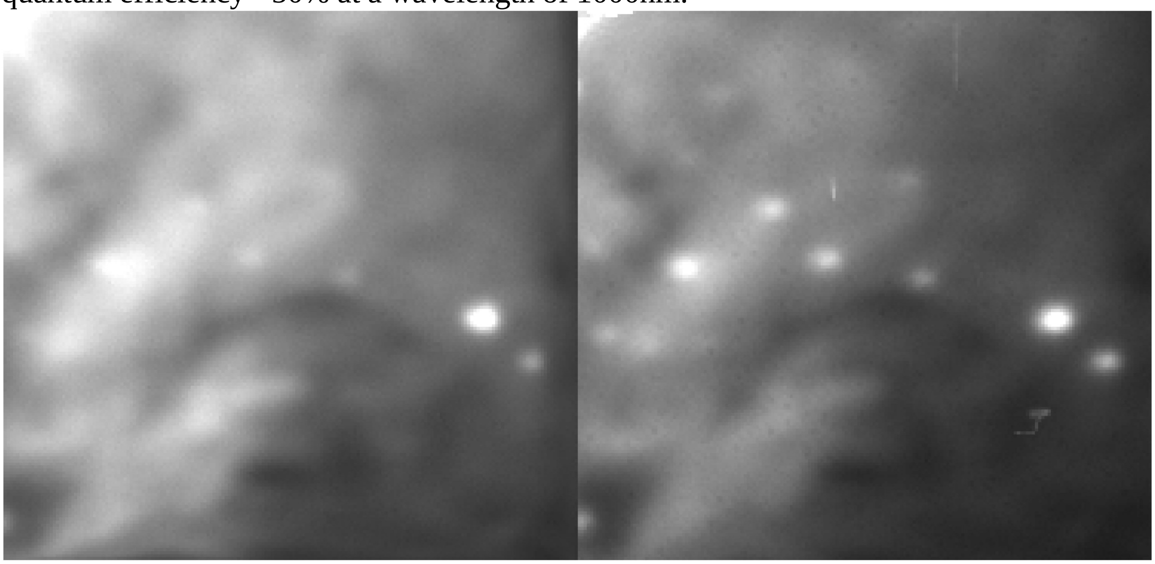


Figure 1. Left image: through a wide-band filter centered at about 700nm. Right image: through a narrow-band filter centered at 1000nm.

At the UCO/Lick Detector Development Laboratory on the University of California Santa Cruz campus we have developed the equipment and processes necessary to test and package CCDs and we have applied theses capabilities to almost every type of LBNL high resistivity CCD yet produced.

Equipment at the Detector Development Lab includes a cold wafer prober where we can test CCDs that are still on the wafer or which have been cut from the wafer but not yet packaged. A refrigerated liquid is circulated through the vacuum chuck which holds the wafer or the CCD in place, and we typically cool the CCD under test to about -40C. Figure 2 shows the wafer prober with a 150-mm LBNL wafer on the chuck.

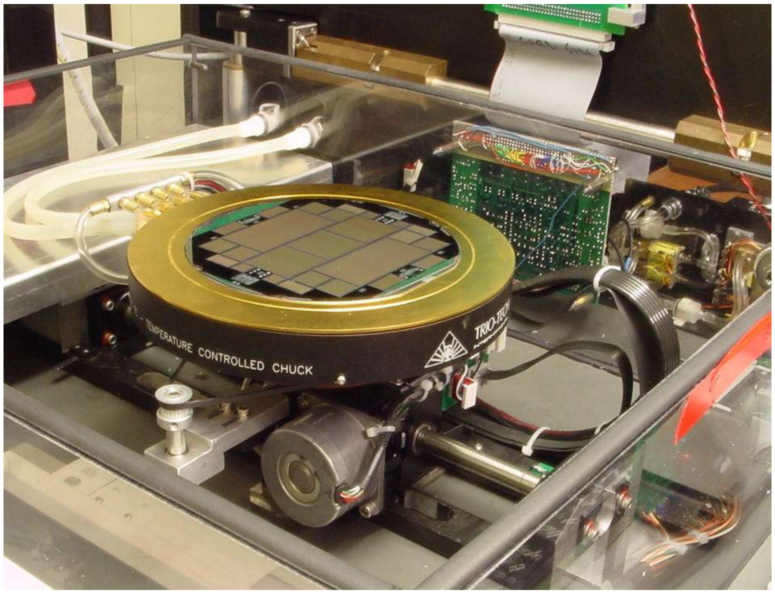


Figure 2. 150mm LBNL CCD wafer on vacuum chuck of UCO/Lick cold probe station.

The Detector Development Lab also has a wafer saw, a wire bonder, a laboratory dewar and CCD controller for completed CCD testing and characterization, and a small class 100 cleanroom where we do CCD packaging and instrument assembly. Figure 3 shows the cleanroom.

Figure 3. The UCO/Lick cleanroom is used for CCD packaging and metrology and for instrument assembly.

Figure 4 shows the variety of LBNL high resistivity CCDs packaged in the Detector Development Lab.

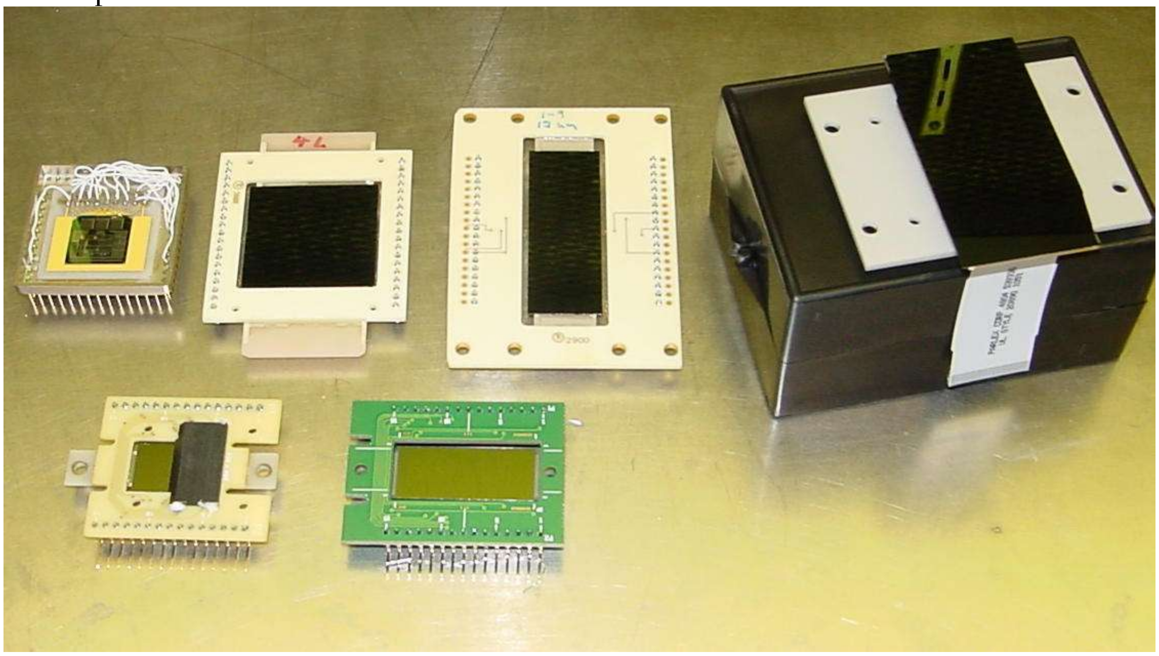


Figure 4. LBNL CCDs packaged at Lick. Top row from left to right shows (with pixel side in parentheses): original 200x200 (15 μm), 2048x2048 (15 μm), 1294X4196 (12 μm), 2048x4096 (15 μm). Bottom row: 400x690 (24 μm), and 470x1264 (24 μm).

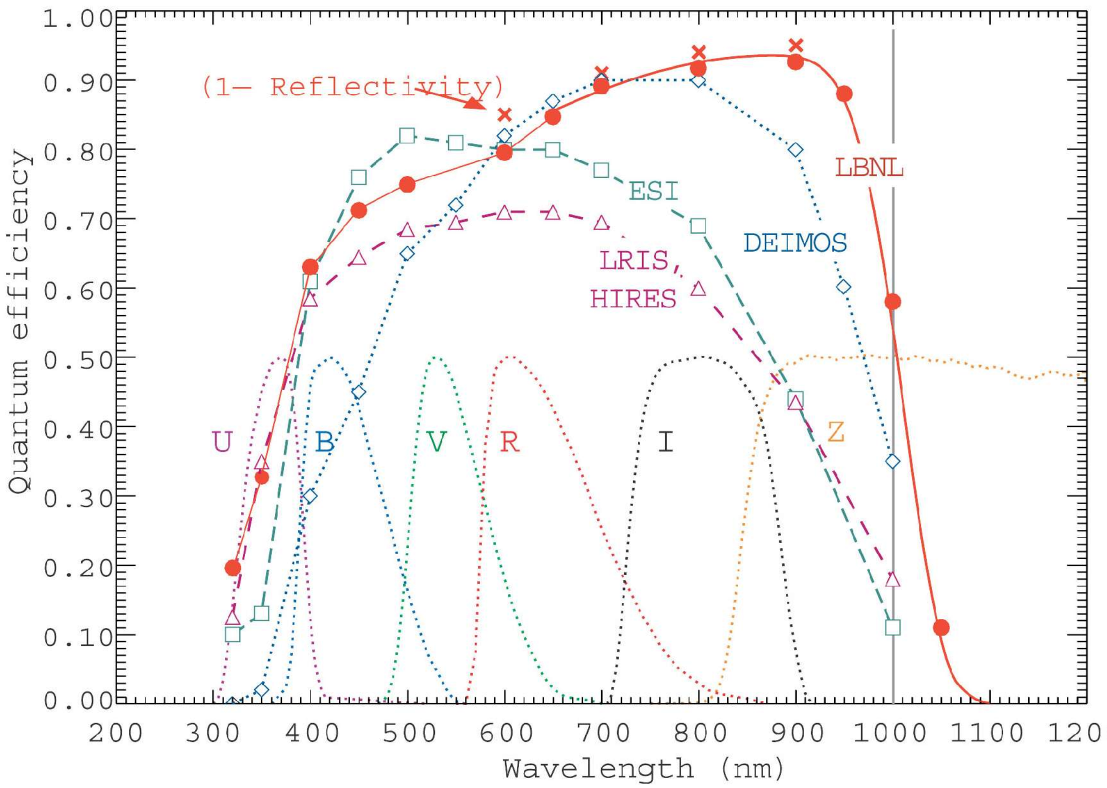
Advantages of high resistivity CCDs.

The LBNL high resistivity CCDs offer three advantages for ground-based astronomical imaging compared to previous CCDs.

1. Very high quantum efficiency at wavelengths greater than about 700nm.
2. No internal interference fringes.
3. Reduced charge diffusion.

High quantum efficiency

Figure 5 (assembled by Don Groom at LBNL) shows the quantum efficiency of the LBNL high resistivity CCDs compared to some other CCDs which have been used with various spectrographs on the Keck Observatory 10-meter telescopes in Hawaii. Longward of about 750 nm wavelength most CCDs start to become transparent and their quantum efficiency begins to fall. Because the LBNL CCDs are around 250 μm thick, compared to a typical CCD thickness of about 20 μm, the LBNL quantum efficiency remains high to much longer wavelengths. Thus for applications requiring high efficiency at the longest wavelengths attainable by CCDs the high resistivity CCD provides a big advantage.



(Keck data from Beletic, Stover, & Taylor, assessment document 19 Jan 2001)

Figure 5. Measured quantum efficiency for the LBNL high resistivity CCD and other standard CCDs in use at Keck Observatory. (Figure produced by Don Groom, LBNL.) The HIRES spectrograph was recently upgraded with a combination of ESI and DEIMOS style CCDs. The LRIS spectrograph will soon be upgraded with LBNL CCDs.

No internal interference fringes

As soon as CCD begins to become transparent at longer wavelengths light reflected internally from the far side of the CCD begins to create interference patterns. Figure 6 shows a figure produced by Don Groom at LBNL from a spectrum obtained with the Keck Observatory LRIS spectrograph (using the CCD whose QE is shown in Figure 5). The amplitude of the fringes varies from about 1% at 800nm to about 5% at 950nm. Because these interference patterns sensitively depend on illumination patterns and geometry the patterns are not stable and they their removal from the spectrum often represents the limiting factor in spectral calibration and accuracy. Similar fringing problems arise when normal CCDs are used for direct imaging applications at long wavelengths.

Because the LBNL CCDs are so thick there is essentially no fringing, or it is at such a low amplitude that it can be removed from the data to high accuracy.

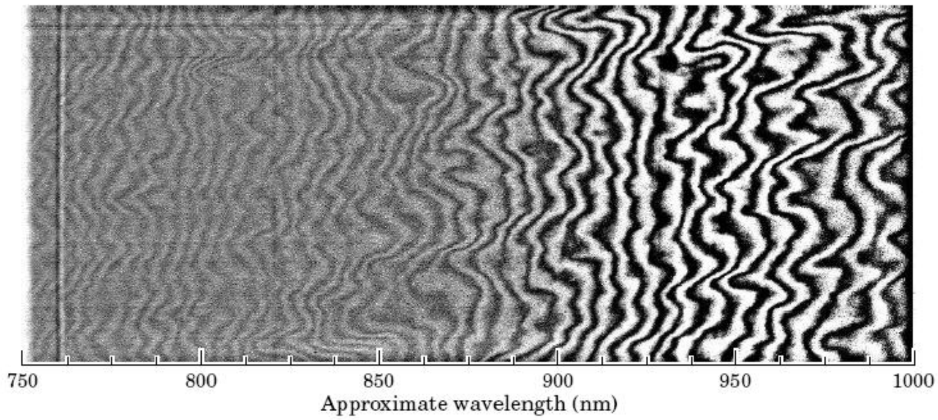


Figure 6. A flat-field spectrum obtained by I. M. Hook was processed to illustrate the interference patterns produced in the CCD of the Keck LRIS spectrograph.

Reduced charge diffusion

Standard thinned CCDs are fabricated on highly doped, low resistivity silicon. Although these CCDs are only about 20 μm thick electric fields penetrate into the low resistivity silicon only a few microns. Typically this leaves about 10 μm of field-free material at the center of the device. Photo-electrons created in this field-free region (or beyond) are free to wander in any direction until they finally encounter a pixel potential well and are drawn into that well. Thus electrons tend to spread out within the CCD and it is not possible to obtain sharp images.

Because electric fields can penetrate the entire thickness of an LBNL high-resistivity CCD photo-electrons are constantly accelerated toward the pixel potential wells and the charge-spreading problem is much reduced. The net result is higher resolution spectra when an LBNL CCD is used in a spectrograph and higher spatial resolution in direct images.

Ground-based astronomy applications of high-resistivity CCDs

UCO/Lick Hamilton echelle spectrograph (one 2Kx2K CCD)
UCO/Lick Kast Cassegrain spectrograph (planned)
UCO/Lick Nickel Telescope direct camera (planned)
UCO/Lick guide cameras (one 400x690 or 470x1264 CCD)
NOAO MARS spectrograph (one 1980x800 CCD)
NOAO RC spectrograph (one 1980x800 CCD)
Keck LRIS spectrograph (red-side) (planned, 3 2Kx4K CCDs)
Fermilab DES camera for Cerro Tololo 4-m Blanco telescope (planned, 62 2Kx4K CCD)

Non-LBNL high resistivity CCD projects:
HyperSuprime Camera for Subaru telescope (planned, 176 2Kx4K Hamamatsu CCDs)