Lawrence Berkeley National Laboratory 2Kx4K High-resistivity CCDs for the Keck 10-meter Telescope Low Resolution Imaging Spectrograph

R. J. Stover
M.Wei
W. E. Brown
L. B. Robinson

UCO/Lick Observatory
University of California
Santa Cruz, CA 95064

The Keck 10-meter telescope Low Resolution Imaging Spectrograph[1] (LRIS) is designed to operate from the atmospheric short-wavelength cut-off at about 320nm out to a wavelength of least 1000nm. To maximize performance over the entire wavelength range the instrument is divided into a "blue" arm and a "red" arm, with separate optics and detectors in each arm. On the red side we are replacing an old Site 2048X2048 CCD with two LBNL 2048x4096 high-resistivity CCDs. At wavelengths longer than about 800nm the quantum efficiency of silicon CCDs decreases because of the increasing transparency of silicon at longer wavelengths. Since LBNL high-resistivity CCDs are up to 15 times thicker than conventional thinned CCDs (like the Site CCD now in LRIS) there is a dramatic increase in long-wavelength quantum efficiency for the LBNL CCD and this can translate directly into increased observing efficiency for many astronomical programs.

UCO/Lick Observatory has been working with LBNL for about 10 years on the development of high-resistivity CCDs[2*]. At UCO/Lick we have developed packaging techniques that allow us to create a mosaic of devices in the focal plane, with gaps between the devices limited only by the geometry of the detectors and not by the packaging. In this paper we present the characteristics of the devices which are now candidates for the LRIS spectrograph. The CCDs have 4096 rows and 2048 columns of 15-micrometer square pixels and a single serial shift register on one of the 2048-pixel sides. The CCDs have a conventional single-stage on-chip amplifier at either end of the serial register. Utilizing high resistivity silicon the CCDs are backside illuminated, fully depleted and 250 to 300 micrometers thick. These CCDs were designed by Stephen Holland of LBNL and fabricated by him, Guobin Wang, and Nick Palaio in the Microsystems Laboratory of LBNL, primarily in 2003. Preliminary results from our packaging work were presented by Stover *et.al.*[3].

The goal of the packaging effort was to produce a lightweight package which would hold the CCD optically flat at all operating temperatures and which would be convenient to use in a focal plane tiled with multiple CCDs. To achieve the greatest focal plane coverage in a tiled focal plane we required that no part of the package extends beyond the edges of the silicon of the CCD. The basic structure of the CCD package is shown in Figure 1. There are three layers of aluminum nitride (AlN) that form a mounting/cooling foot. Each of these AlN pieces is 0.080 inches thick. Between the top and bottom AlN pieces there are two floating, but captured nuts, each with a threaded hole in its center. Holes in the bottom AlN provide access to these captured nuts and allow the CCD to be mounted on a flat cold plate. Cooling of the CCD is done through the mounting foot. The three-piece foot is attached to the fourth AlN piece, which has a single-layer circuit pattern on it. The pattern, not shown in Figure 1, provides traces from the zero-insertion-force (ZIF) socket to the bond pads along the long edge of the AlN. The patterning also provides attachment points for load resistors for the CCD's on-chip amplifiers, filter capacitors, heater resistors (for temperature control) and a temperature measurement diode.

The CCD is bonded to the patterned AlN. Because the CCD is about 300 micrometers thick it is sufficiently self-supporting that it can extend beyond the two long edges of the patterned AlN, as seen in Figure 1. All of the bond pads of the CCD are exposed along these edges and simple wire bonding is used to connect these pads to adjacent pads on the patterned AlN.

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* Visit http://www-ccd.lbl.gov for access to most of the publications about LBNL high-resistivity CCDs.

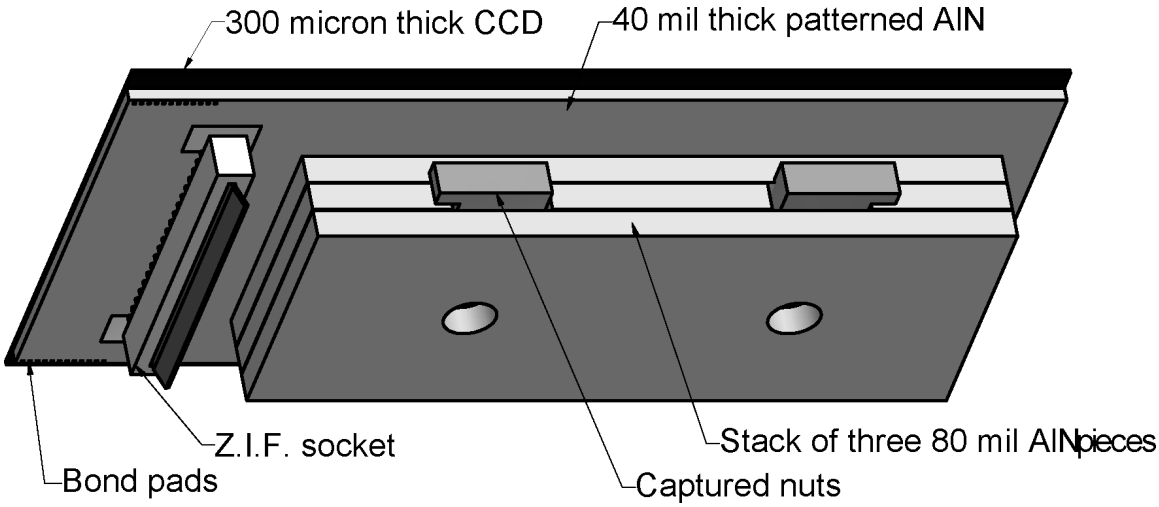

Figure 1. The structure of the CCD package consists of four layers of aluminum nitride with captured nuts that can be used for mounting the CCD to a cold surface. A zero-insertion-force (ZIF) socket accepts a ribbon cable.

All of the layers of this package are bonded to each other with Epotek 301-2 epoxy glue. The epoxy glue between each of the three AlN cold-foot pieces is about 0.004 inches thick, as is the epoxy layer between the patterned AlN and the CCD. The epoxy layer between the foot assembly and the patterned AlN is much thicker at about 0.030 inches.

The key to achieving a flat CCD is to hold the CCD flat while the epoxy glue hardens. We have achieved a high degree of flatness by holding the CCD against the face of a ceramic vacuum chuck while allowing the Epotek 301-2 glue to harden at room temperature over a two-day period. A typical grooved vacuum chuck tends to pull the CCD down into the grooves, producing a distorted CCD surface. The ceramic vacuum chuck avoids this issue with 6-micrometer pores instead of grooves. The vacuum chuck, TruVac 10”x10”, grade 1, by Tru-Stone Technologies is flat to one micron over a 150 mm length. Once the CCD and patterned AlN pieces are glued together they can be handled and held with a standard, grooved vacuum chuck without distortion.

To conveniently form a focal plane array of devices all of the CCDs should have the same thickness, measured from the top of the CCD to the bottom of the cold foot. To achieve this goal the CCD packaging procedure initially produces two sub-assemblies. The first sub-assembly is the CCD glued to the patterned AlN. The second sub-assembly is the three-layer AlN foot. The thickness of the individual sub-assemblies is controlled but not critical. Final assembly is done using a precision jig to achieve the desired package thickness uniformity. The jig consists of two heavy, polished steel plates held apart by three ground and polished stainless steel spacers whose thicknesses are the same. One of the steel plates has clearance holes that match the holes in the AlN foot while the other steel plate has a typical grooved vacuum chuck pattern cut into one of its faces. The CCD is held to be vacuum chuck and the AlN foot is attached to the other steel plate with mounting screws. The steel plates are then assembled, facing each other, and held apart by the three spacers. The spacers are made so that a small gap remains between the face of the patterned AlN and the top surface of the AlN foot. This gap is filled with Epotek 301-2 and the glue is allowed to cure at room temperature.

We have assembled eight CCDs with this procedure (and several others before the final procedure was established). The average thickness of the packages is 8.778 mm with an average deviation from this mean of 0.003 mm and a maximum deviation of 0.006 mm. We also measured tilt of the CCD surface relative to the bottom of the AlN foot. The average tilt, measured at the extreme outer edges of the CCD is 0.002 mm. All of these values are within our optical tolerances for the the LRIS spectrograph.

To test dimensional stability of the CCD package we baked one of the finished CCDs in a precise temperature-controlled oven for 88 ½ hours at 80°C. We then remeasured the CCD thickness. It uniformly decreased in thickness by 6 micrometers, possibly because the epoxy glue shrank slightly. This is acceptably small, and if all device thicknesses decrease by comparable amounts they will all remain coplanar within our limits.

We have measured the flatness of the packaged CCDs. One of the CCD contour plots is show in Figure 2. It shows a peak deviation from flat of about plus or minus 5 micrometers. Because the package is fabricated from AlN, which has a very close thermal expansion match to silicon, the CCD flatness does not change appreciably when cooled from room temperature to an operating temperature of -120°C to -140°C. We have verified this result by measuring the CCD flatness while the CCD is cold and mounted in our laboratory test dewar.

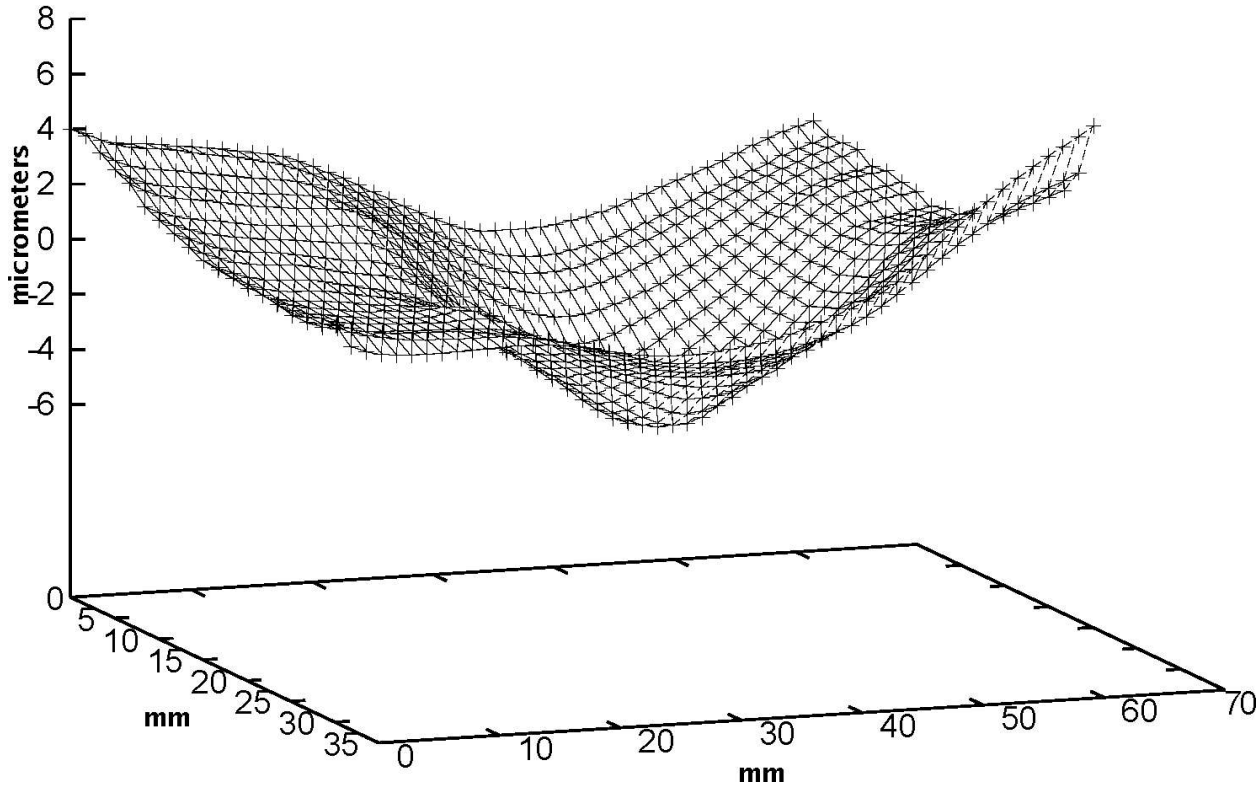

Figure 2. CCD flatness measured using a laser reflected from the CCD surface to trace the surface contour. These data show the surface shape of device 1-13 at a temperature of -137°C.

Of the packaged devices, there are three CCDs that may be good enough to be candidates for the LRIS spectrograph. Some of the other devices exhibit glowing pixels or other defects which make them unsuitable for a scientific instrument. Some of the devices have developed a very noisy amplifier and in fact we have only one device with two fully functional amplifiers. We don't know the reasons for the noisy amplifiers. Several other devices were unfortunately broken during the development of the packaging technology. Of the three best devices, one appears to be having connector problems and is functioning intermittently. We are working to understand and resolve these issues.

Once the CCDs are packaged we measure operational characteristics of all of the CCDs at cooled temperatures. In Figure 3 we show the measured quantum efficiency for device 1-13, the same CCD whose surface contours is show in Figure 2. Beyond about 800nm (8000 Angstroms) the quantum efficiency of these devices is superior to conventional thinned, backside illuminated CCDs. At 900 nm a typical thinned CCD has QE of about 20% while the device shown in Figure 3 has about 93%. At 1000 nm a typical thinned CCD has QE of about 5%, compared to 54% in the device shown.

The very high red QE also translates into another very useful characteristic, low fringing. As a conventional thinned CCD becomes transparent at the red end of the optical spectrum thin-film interference patterns develop within the CCD. These patterns are very sensitive to the exact optical illumination and to very small mechanical flexure of the instrument, and in the LRIS spectrograph changing fringe patterns is an important obstacle to the proper calibration of astronomical spectra. In the LBNL high-resistivity CCDs fringing is almost completely eliminated.

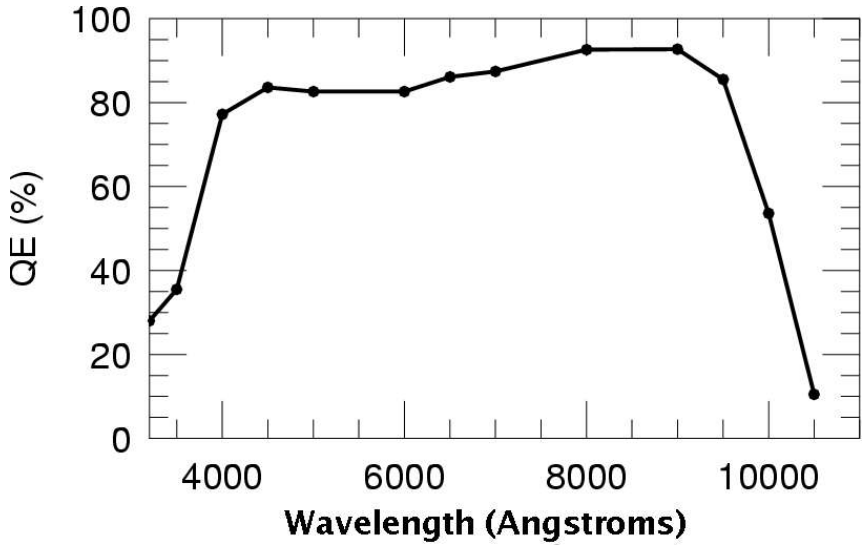

Figure 3. The quantum efficiency of device 1-13 measured at a temperature of -137℃.

We have undertaken this work to produce CCDs suitable for the Keck Observatory LRIS spectrograph. During the period of this work the understanding, design, and technologies of high-resistivity CCD manufacturing has continued to advance. CCDs produced now have superior on-chip amplifiers, a potential smaller point-spread function, and other desirable characteristics. In addition an LBNL 4Kx4K CCD may soon be available. Even with our package design there is still about a 2mm gap between active image areas of two adjacent CCDs. The use of the new 4Kx4K CCD would eliminate the gap altogether. So in the end the CCDs we have produced may end up in other applications. That decision has not yet been made.

References

1. Instrumentation at the Keck Observatory, Ian S. McLean and David Sprayberry, *S.P.I.E.*, **4841**, 1-6, 2003.
2. S. E. Holland, D. E. Groom, N. P. Palaio, R. J. Stover, and M. Wei, "Fully Depleted, Back-Illuminated Charge-Coupled Devices Fabricated on High-Resistivity Silicon," IEEE Trans. Electron Dev. 50 (3), pp. 225-238, Jan. 2003.
3. Packaging design for Lawrence Berkeley National Laboratory high-resistivity CCDs., R.J. Stover, W.E. Brown, L.B. Robinson, D.K. Gilmore, M. Wei and C. Lockwood. *S.P.I.E.*, **5499**, 518-525, 2004.