Packaging Design for Lawrence Berkeley National Laboratory High Resistivity CCDs

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ABSTRACT

The Lawrence Berkeley National Laboratory has been developing fully-depleted high resistivity CCDs. These CCDs exhibit very high red quantum efficiency, no red fringing, and very low lateral charge diffusion, making them good candidates for astronomical applications that require better red response or better point spread function than can typically be achieved with standard thinned CCDs. For the LBNL 2Kx4K CCD we have developed a four-side mosaic package fabricated from aluminum nitride. Our objectives have been to achieve a flatness of less than 10 micrometers peak-to-valley and a consistent final package thickness variation of 10 micrometers or less in a light-weight package. We have achieved the flatness objective, and we are working toward the thickness variation objective.

Keywords: CCD, packaging, high resistivity

1. INTRODUCTION

The Lawrence Berkeley National Laboratory (LBNL) has been developing fully-depleted high resistivity CCDs[1]. These CCDs exhibit very high red quantum efficiency, no red fringing, and very low lateral charge diffusion, making them good candidates for astronomical applications that require better red response or better point spread function than can typically be achieved with standard thinned CCDs.

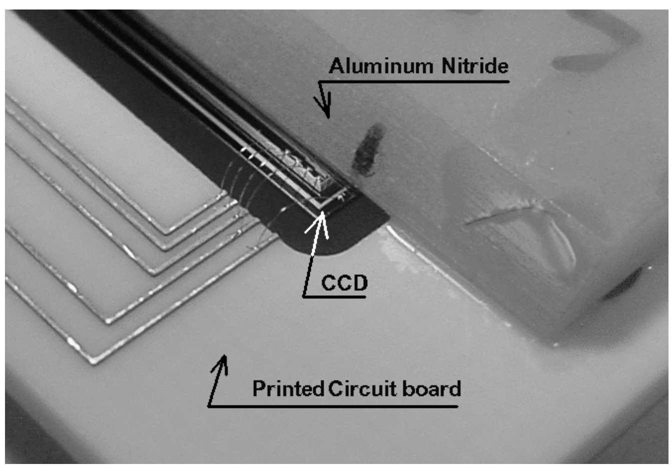

Fig. 1. One corner of a packaged 2Kx4K LBNL CCD is shown. This view is from the bottom side of the package, illustrating the overhang of the self supporting silicon beyond the edge of the aluminum nitride.

One of the characteristics of the LBNL high resistivity CCDs is that they are 200 and 300 micrometers thick which is thick enough to be self supporting. We used this property to develop relatively simple, inexpensive packaging techniques for these CCDs. We initially packaged the CCDs in a simple "picture frame" style. We begin by gluing the CCD to a piece of aluminum nitride. Aluminum nitride matches closely the thermal expansion characteristics of silicon

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at cryogenic temperatures and it is a very good thermal conductor. The electrical connections to the CCD are made via a set of bond pads which are located along the outer edge of the CCD on the longer sides of the device. The aluminum nitride is slightly narrower than the CCD, thus leaving the CCD bond pads exposed on the overhanging silicon.
Figure 1 shows one corner of a packaged 2Kx4K CCD. Five bond wires can be seen making connections between the printed circuit board and the bond pads on the overhanging silicon. As shown in the figure, the aluminum nitride extends beyond the CCD on the shorter two sides and this part of the aluminum nitride is glued to the printed circuit board. A finished 2Kx4K CCD is shown in Figure 2.

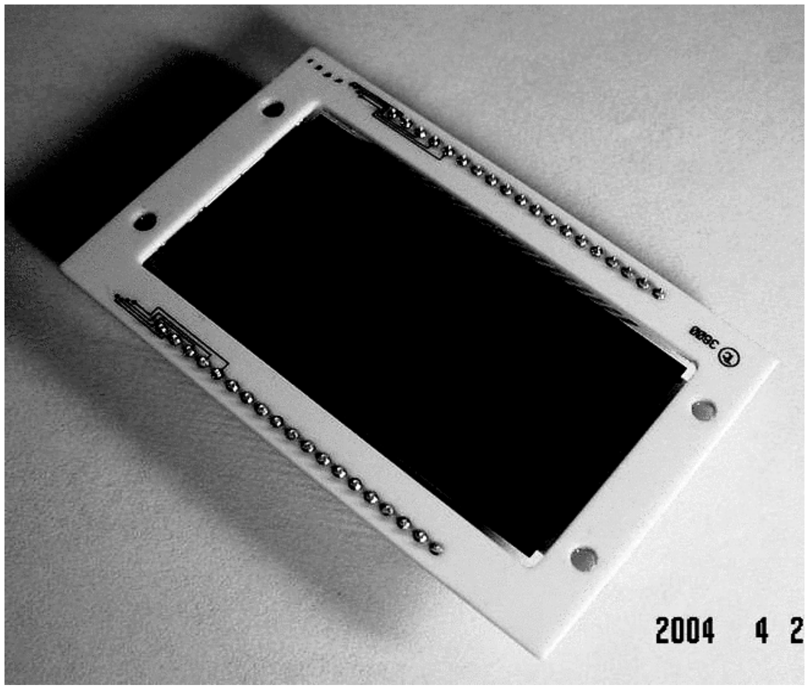

Fig. 2. An LBNL 2Kx4K CCD packaged in the picture frame style is shown.

The electrical connections are routed through traces on the circuit board to two rows of connectors that are 19 pins each. In Figure 2 the top ends of the pins are visible. The picture frame mounting is very simple and is adequate for single CCD applications.

To construct a mosaic of more densely arrayed CCDs a different type of packaging is required. To help meet this need we have developed a four-side-buttable mosaic CCD package which does not extend beyond the silicon on any side. With this package the spacing between the imaging areas of adjacent CCDs is determined by the size of the silicon die and not by the package. In designing the mosaic package we had as objectives an overall flatness of 10 micrometers, peak-to-valley, and a total package thickness consistency from device to device of no more than 10 micrometers.

2. FOUR-SIDE MOSAIC CCD PACKAGE

In the mosaic package we again make use of the self-supporting nature of the thick high resistivity CCD. In this design we combine the functions of the aluminum nitride and the printed circuit board of the picture frame package by producing a patterned 1mm thick aluminum nitride. To the patterned aluminum nitride we attach a flex cable socket, two load resistors, a temperature sensing diode and its decoupling capacitor, and four heater resistors. This is shown in Figure 3. The flex cable socket is a 0.5mm contact spacing, surface mount, zero-insertion-force type connector manufactured by Hirose Electric Company. The large square in the middle and the four large circles are metalized pads which provide various options for soldered-on thermal contacts or feet. In the present design we didn't use any of these.

Instead we chose an all aluminum nitride structure that provides both a mounting surface and good thermal contact. This mounting foot is shown in Figure 4. It consists of three layers of 2mm thick aluminum nitride, which are glued together. The middle two layers, glued to the patterned aluminum nitride, consist of three pieces of aluminum nitride which leave two slots. Into these slots are placed two rectangular nuts. These loosely captured nuts can be seen extending beyond the side of the aluminum nitride pieces in Figure 4. The foot is then capped by the third layer of aluminum nitride which has two clearance holes that align with the threaded holes in the captured nuts

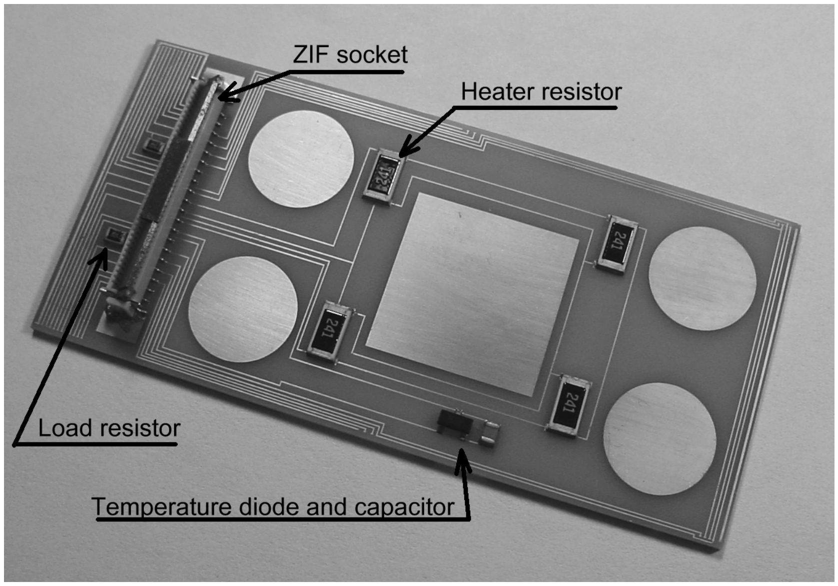

Fig. 3. The patterned aluminum nitride is shown with all of the surface mount components attached.

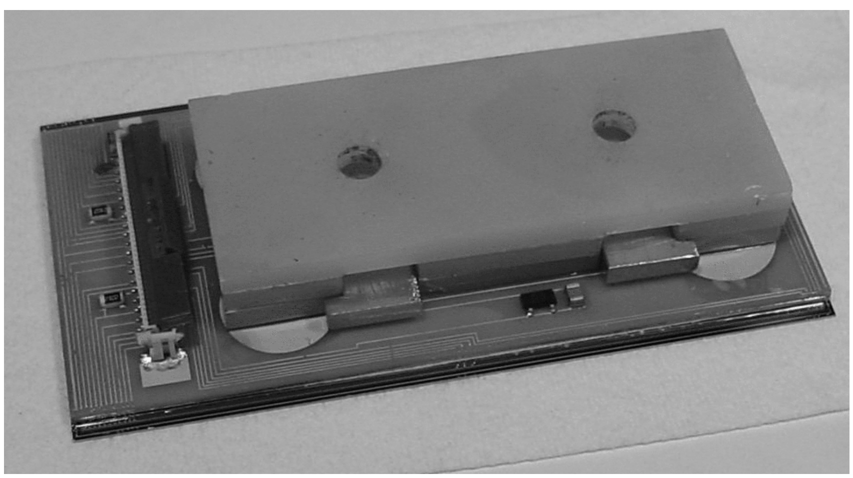

Fig. 4. The mounting foot consisting of three aluminum nitride layers is shown attached to the patterned aluminum nitride. The two captured nuts are visible extending beyond the sides of the mounting foot.

The patterned aluminum nitride has circuitry on one side only. There are no holes through the patterned piece. The CCD is glued to the blank side of the patterned piece and can be seen extending beyond the edge of the aluminum nitride in Figure 4. This can be seen even more clearly in Figure 5 which shows the wire bonds between the CCD and the patterned aluminum nitride.

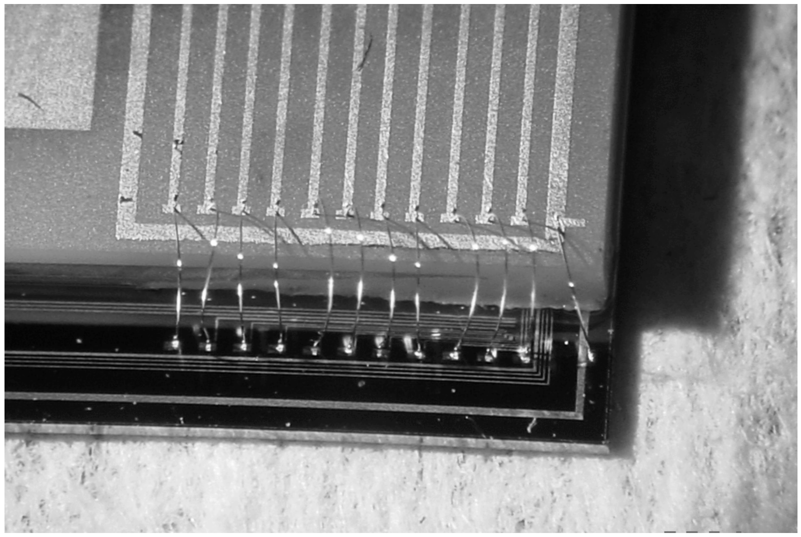

Fig. 5. Here seen from the bottom, the silicon extends beyond the patterned aluminum nitride and the wire bonds connect the pads of the CCD to the printed circuit pads.

3. PACKAGING TECHNIQUES

3.1 Gluing the CCD to the aluminum nitride

The mosaic package is simple in concept. But achieving the desired results is not trivial. The first step is to glue the CCD to the patterned aluminum nitride using epoxy glue. Aluminum nitride, after being exposed to air for a few days, becomes hydrophobic. A drop of water, or glue, placed on the surface tends to form a bead. However, we found that 20 minutes in a plasma cleaning oven turns the surface from hydrophobic to hydrophilic and glue placed on the surface spreads rapidly in all directions. In addition the glue adheres better to the aluminum nitride after plasma cleaning. To glue the CCD to the plasma cleaned aluminum nitride we first suspend the CCD above the surface of the aluminum nitride. We do this with two pieces of double-sided tape placed along the outer edge of the long side of the aluminum nitride. This tape is about 100 micrometers thick. Using an alignment vacuum jig, the aluminum nitride is positioned above the CCD and then lowered to contact the tape. The tape serves to hold the CCD and aluminum nitride in a fixed relative position and the tape acts as a barrier to the epoxy, preventing the glue from covering the CCD bond pads. Using Epotek 301-2 epoxy, we feed the glue into the 100 micrometer gap between the CCD and aluminum nitride. Surface tension wicks the glue into the gap and after about 20 minutes the entire void is filled with epoxy from one end of the CCD to the other. The hydrophilic nature of the aluminum nitride surface helps to eliminate the possibility of glue voids during this process.

We allow the epoxy to harden at room temperature which takes about two days to complete. If we do nothing to the CCD while the glue is hardening the CCD will have a bow in it because the epoxy shrinks slightly as it hardens. There can also be a bow ***before*** gluing of up to 80 micrometers due to stress in the silicon resulting from the CCD manufacturing process. Since the CCD is supported by the tape near its long edges the glued CCD takes on a concave barrel shape as the glue pulls the CCD down in the middle. The peak to valley variation is at least 10 micrometers. This is the upper limit for the flatness we wanted to achieve. We then investigated ways to improve this result. We tried holding the CCD flat with a standard vacuum chuck while the glue hardens. But we found a vacuum chuck with grooves tended to warp the CCD by pulling it slightly into the grooves. We then found a porous ceramic vacuum plate made by Tru-Stone Technologies. Our Tru-Stone chuck is 200 mm square and made from a porous ceramic with 6 micrometer pores. The ceramic surface is lapped to a flatness of 1 micrometer per 150mm of material. With this chuck we can hold the CCD flat uniformly over its entire surface. When released from the vacuum chuck after the glue is hardened the CCD remains flat to a few microns with no distortions introduced by the chuck. Figure 6 shows the CCD and patterned aluminum nitride being placed on the ceramic vacuum plate using a special handling fixture. The handling fixture allows us to safely position the CCD on the ceramic surface without the possibility of scraping the face of the CCD across the ceramic.

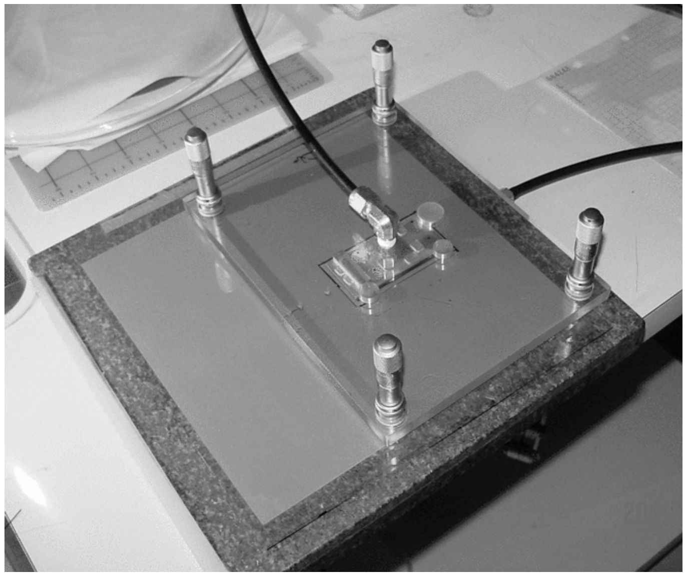

Fig. 6. The 6 micrometer porous ceramic vacuum plate is shown with a CCD handling fixture that allows us to safely position the CCD on the plate.

Figure 7 shows a recent example of the flatness achieved by this method. We believe the CCD is actually flatter than indicated because we know there are small systematic errors introduced by the flatness measuring equipment. The result shown in Figure 7 is for a completed picture frame style CCD package. Similar but slightly worse results are obtained for the mosaic package.

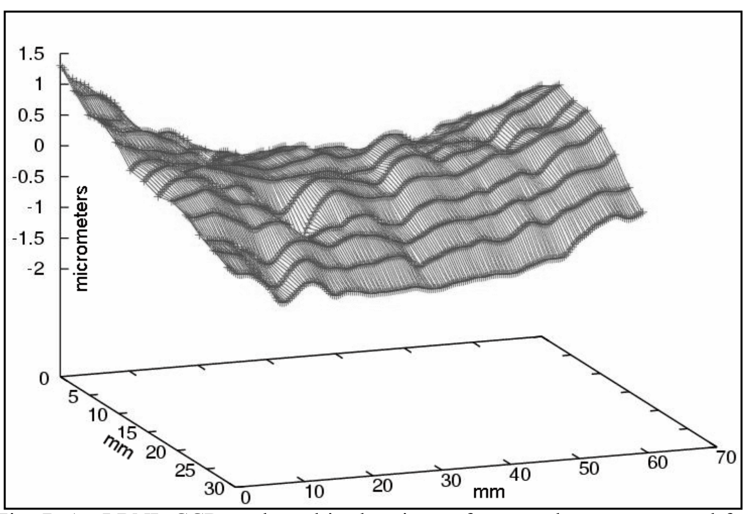

Fig. 7. An LBNL CCD packaged in the picture frame style was measured for flatness after being held with the ceramic vacuum chuck while the epoxy glue hardened.

For the picture frame package a similar procedure is followed and all that remains to be done is glue the aluminum nitride to the printed circuit board and complete the wire bonding. For the mosaic package more steps are required.

3.2 Completing the mosaic package

The bottom piece of aluminum nitride and the pieces holding the captive nuts are glued together with the same Epotek 301-2 epoxy and the same technique of spacing the parts with double-sided tape. The use of the tape assures a uniform bond line for all assemblies. The individual parts and the parts assembled as the completed mounting/cooling foot are shown in Figure 8.

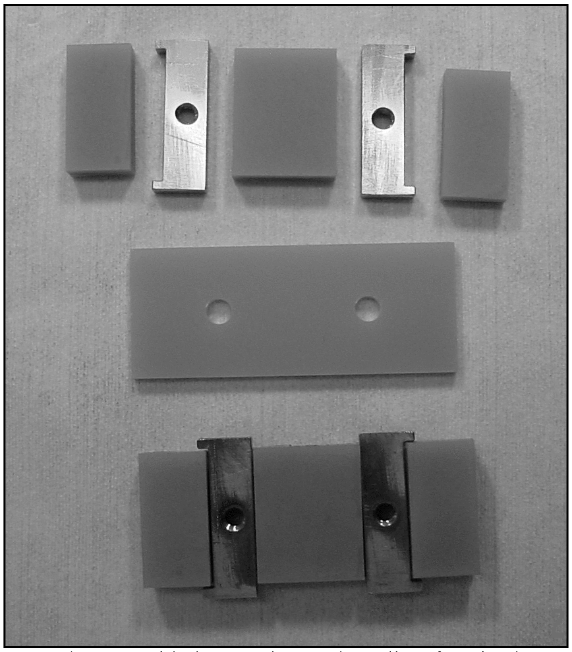

Fig. 8. The assembled mounting and cooling foot is shown at the bottom of the figure, with the individual parts shows above.

After the mounting/cooling foot assembly is complete the final step is to glue the foot to the patterned aluminum nitride. This step must be done precisely because the glue bond line thickness determines the final overall thickness of the packaged CCD. To obtain a consistent overall package thickness the final gluing is done with a jig that precisely defines the distance from the top of the CCD to the bottom of the foot. This jig is shown in Figure 9.

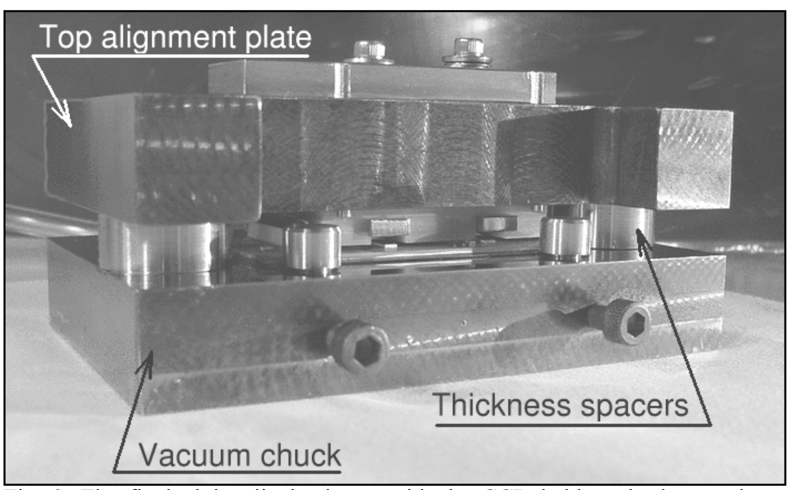

Fig. 9. The final gluing jig is shown with the CCD held to the bottom by a vacuum and the mounting foot held to the top using screws and the captured nuts. The spacers define the overall package thickness.

The small gap between the mounting foot and the CCD is seen more clearly in Figure 10. The spacers hold the two parts with a repeatable separation. In addition, alignment pins hold the CCD and the foot in a precise, repeatable horizontal alignment relative to each other. This makes it possible to use the side of the aluminum nitride foot as an index for positioning the CCD in a mosaic.

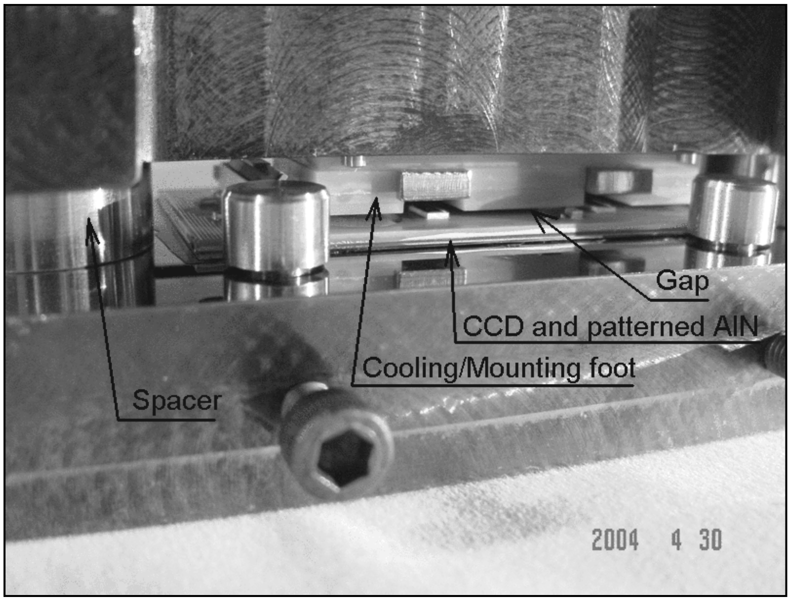

Fig. 10. The CCD and the mounting/cooling foot are held in precise alignment in preparation for the final gluing step.

The space between the patterned aluminum nitride and the foot is filled with epoxy glue using the same wicking technique used for all of the other assemblies. This completes the assembly of the CCD package. After two days the packaged CCD can be removed from the jig. Wire bonds are used to connect the CCD electrical pads to the corresponding pads on the patterned aluminum nitride, as shown in Figure 5.

3.3 Mosaic package results

Figure 11 shows the flatness measurements on the first CCD packaged with the techniques described here. The peak-to-valley flatness is about 6 micrometers. The flatness was measured with the CCD mounted on the gluing fixture (the top plate in Figure 9). The flatness of the gluing fixture was measured and it was found to be flat to 1 micrometer or better. When removed from the gluing fixture the CCD tends to bend in the long axis of the CCD by an additional 7 micrometers. But as Figure 11 shows this warp can be removed as long as the CCD is mounted on a flat surface. The second CCD packaged with the mosaic technique has a peak-to-valley flatness of about 8 micrometers.

Our results with package thickness uniformity have not been as good as hoped. We have completed packaging two CCDs. Although they are flat to better than 10 micrometers, peak to valley, both show an identical tilt in the plane of the CCD relative to the mounting surface of the aluminum nitride. The two packaged CCDs have the same average thickness within 3 micrometers but they both exhibit a tilt along a diagonal with a corner-to-corner difference of 55 micrometers. The source of this unexpected result is under investigation. But the observation that the average thickness is nearly identical is encouraging. Before we package any more devices we are carrying out additional tests to find and eliminate the tilt.

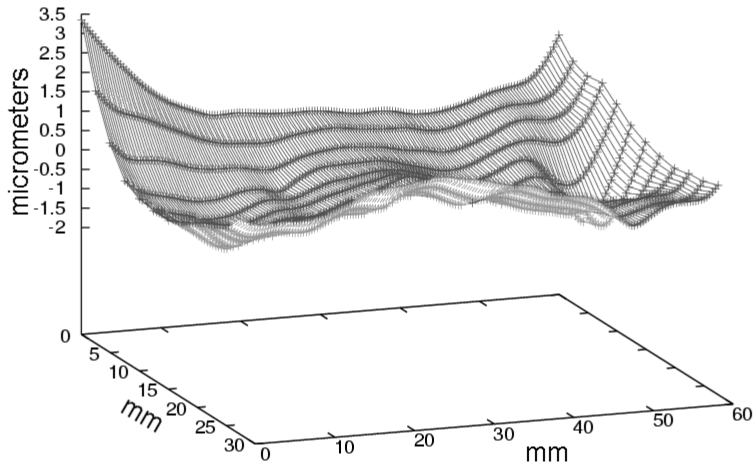

Fig. 11. The first LBNL CCD packaged with the techniques described in this paper has a peak-to-valley flatness of about 6 micrometers.

CONCLUSIONS

We have achieved our initial flatness goal and we are in the process of improving the package thickness uniformity. We plan to package at least four science-grade LBNL 2Kx4K high-resistivity CCDs in the near future. These devices will be available for Keck Observatory instruments. Modifications in the latest LBNL 2Kx4K CCD designs will require us to fabricate a new patterned aluminum nitride part. We will use that opportunity to improve on our initial design in several ways. The improvements we will investigate include:

- Relocate the heating resistors to make assembly simpler.
- Increase the patterned aluminum nitride thickness from 1mm to 2mm to increase stiffness.
- Replace captive nuts with threaded inserts to simplify assembly.
- Provide alignment pins instead of using the edge of the package for alignment purposes.
- Replace part or all of the aluminum nitride foot with Invar-36.

REFERENCES

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