

Curving a CCD
Technical Note 1: Overview and Goals

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Submitted: January 22, 2009

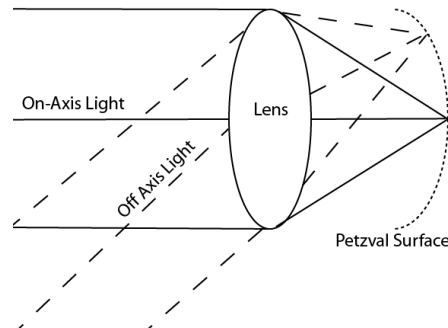
1 Why Curve a CCD?

Within a given optical system, the image will be in focus at a particular point on the optical axis, and this point is well defined in terms of the focal length of the system. However, the points that are in focus off axis are not coplanar with this on-axis point, instead the collection of all points where the image is in focus form a spherically curved surface. This is referred to as a Petzval surface, and for a singlet (single lens system) has a radius of curvature as follows:

$$R = n \cdot efl \tag{1}$$

Where n is the index of refraction of the glass, efl is the effective focal length of the singlet, and R is the radius of curvature of the resulting Petzval surface.

Figure 1: A singlet and the corresponding Petzval surface.



2 Design and Fabrication

2.1 Current Challenges

Achieving the desired radius of curvature on a CCD means overcoming a number of inherent challenges. These either stem from the intrinsic properties of the semiconductor itself, to complexities and design challenges introduced by working with a curved part. Enumerated, these challenges are:

1. Non-destructive, persistent curvature of the device
 - The imager must match the shape of some prefabricated chuck, and, after processing, keep this shape indefinitely. This will involve careful consideration of the orientation of the device (with respect to the crystal lattice), as well as what effect time and temperature have on achieving a permanent radius of curvature.
2. Creation of a flexible substrate and subsequent mounting

- This involves careful selection of a matching underflow epoxy with desirable properties. The most desirable of which are sufficient rigidity to make the device keep its intended radius of curvature, as well as the potential flexibility for dynamic shape-change in future.
- Mounting the CCD in such a way that sufficient thermal transfer takes place on a potentially curved substrate backside. This design will vary for one and two dimensional curves, respectively.

3. Characterization of changes in electrical-optical properties as a result of curvature

- It is unknown how the electrical properties of the silicon will change when the single-crystal lattice structure is stressed or disturbed by the curvature. Obviously, it remains unclear whether the lattice of the semiconductor will remain unchanged, or whether the curvature will introduce imperfections or polycrystalline defects which render it inoperable.
- Other questions arise regarding what effect field curvature will have on images themselves. Other than the desired elimination of 3rd order field curvature aberrations, more extreme radii of curvature may create circular aberrations in the resulting image brightness uniformity.

2.2 Goals

1. Determine an optimal and realistic radius of curvature suitable for respective one and two dimensional curved devices.
2. Formulate a procedure for achieving the desired curve (finding the suitable combination of temperature and time which allows the device to bend and remain so).
3. Fabricate a mounting mechanism, finalize substrate design and other mechanical constraints for an STA0520 part.
4. Achieve a one dimensional curve of some radius on an operational STA0520 “strip CCD” by mid summer. Characterize this device and understand how electro-optical properties have changed, if at all, due to the procedure.
5. Achieve a two dimensional curve of some radius on a nonfunctional 4K CCD by mid summer. Study and understand the additional complexity added by two dimensional curving.

2.3 Modeling Curvature

Clearly, having a flat imager attempting to match a curved surface of focus will result in some defocus depending upon the relative placement of the imager. If we could curve the imager to match the surface, we could get ideal focus for all points. Next comes the question: How much do we curve the imager? Sag is key to understanding this, as it will be the dimension we can actually measure on the curved device. Saggital depth is the difference in distance or depth along a given spherical or aspheric surface (imagine the top and edge of a dome, or rim and center of a bowl). For spheres and parabolas these are well defined in terms of the radius and distance from the axis (assuming the system is rotationally symmetric about the same axis).

Suppose we have a given spherical radius of curvature for the bend, R , with a lateral edge to edge distance in the longest dimension L . These quantities are illustrated in (Figure 2) and (Figure 3). After bending it to that curve, we can expect a saggital depth (henceforth referred to as sag) of:

$$Sag = R - \sqrt{R^2 - \left(\frac{L}{2}\right)^2} \quad (2)$$

Solved for the radius of curvature:

$$R = \frac{Sag^2 + \left(\frac{L}{2}\right)^2}{2 \cdot Sag} \quad (3)$$

Similarly, on a parabola the sag would be the following:

$$Sag = \frac{L^2}{8R} \quad (4)$$

Figure 2: Curvature and Sag on a Sphere

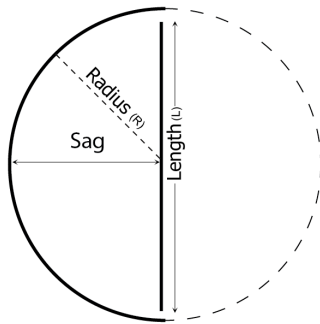
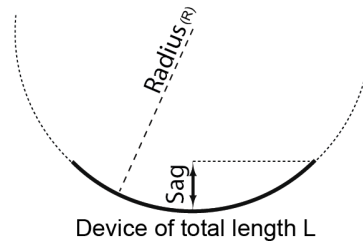


Figure 3: Curved Device Illustration



2.4 Design Characteristics of Porous Vacuum Chuck

There are a number of difficulties faced in effecting a permanent and uniform curve in silicon alone, never mind an entire CCD assembly. Sudden, localized, or excessive forces generally lead to broken or cracked parts. For this reason, the apparatus by which this curving will be accomplished is a porous aluminum vacuum chuck, with pore size approximately 0.0006" and porosity 15%¹ similar to the device shown in Figure 5. Experimentation has shown that it is possible to create a remarkably uniform, spherically curved depression in a piece of such aluminum using an automated milling machine fitted with a 1/8" ball cutter.

¹Available from McMaster-Carr, #8189K

Figure 4: A spiral of the type used to machine the porous aluminum chuck. Actual spiral has many more rotations within a given radius.

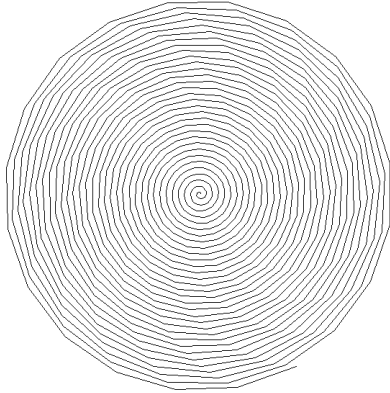


Figure 5: Photograph of vacuum chuck.



A long, dense spherical spiral cut (as shown in Figure 4) was shown to yield a sufficiently predictable and smooth surface that a CCD could be formed into the desired shape by drawing pressure through this chuck, pulling the part to assume the topology of the surface. This porous part would be placed inside an outer structure with an evacuated chamber beneath and open air above, causing all vacuum to be pulled through the top. A CCD would be placed over the center, and other pores would be covered, allowing for sustained, forced curving of the CCD. Porous aluminum proves a desirable material for this application not only for its machinability, but because a sudden change in pressure on the underside of the chuck would be reflected more slowly on the upper part, helping safeguard the integrity of the silicon under alteration.