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A Peltier-cooled CCD Camera

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Abstract: We describe the application of Peltier effect cooling to charge coupled device (CCD) detectors. We are developing this technique to produce a CCD camera which requires low maintenance, yet has sufficiently small dark-current for long exposure imaging. This camera will be used in an automated imaging telescope at Siding Spring Observatory. The design principles used to maximise cooling of the detector, and hence minimise dark-current, are discussed. A small dark-current can be obtained only if great care is taken to reduce or eliminate convective, conductive and radiative heating of the chip. In addition, a path of high thermal conductivity must be provided for the heat removed from the CCD. A recent laboratory test of our cooling system demonstrates that careful design can lead to sufficiently low CCD dark-current for many astronomical applications.

1. Introduction

The charge-coupled device (CCD) is an almost ideal astronomical detector. Even in complete darkness, however, the CCD suffers a build-up of electronic noise arising from thermally generated current within the chip (see McLean 1989 for an introduction to this topic). To reduce the dark-current the CCD is cooled, usually with liquid nitrogen. A more convenient method for some applications, however, is to use Peltier effect (thermoelectric) cooling (e.g., Petrick 1987). Thermoelectric coolers (TECs) are small solid-state heat pumps with 'cold' and 'hot' surfaces, and can be cascaded to produce temperature differences up to ~ 130 degrees. They are reliable and maintenance-free and only require a simple DC power source to operate. On the other hand, a TEC can only provide effective cooling if the heat load at the cold junction is very small ($\lesssim 1$ W).

We are developing a CCD camera which uses thermoelectric cooling of the CCD. This camera is to be used on the UNSW Automated Patrol Telescope at Siding Spring Observatory. Because the telescope's focal surface is inside the tube, the CCD must be suspended there in a lightweight, compact 'camera head' with the camera control electronics located elsewhere. Our aim is to make a low-maintenance, compact CCD camera which has sufficiently low dark-current to permit long exposure imaging.

2. Design

The crucial part of our camera design is to make a camera head in which we can best cool the CCD. In this respect, our design follows the guidelines of Petrick (1987) and Wurtz (1980). Our camera head is shown in Figure 1. It is built around a vacuum chamber of simple two-part cylindrical design, a light aluminium cover (with a glass window) and a copper backplate of high thermal conductivity. The WG280 glass window is fixed in place by a low vapour-pressure epoxy ('Torr-Seal' from Varian Associates). The CCD sits inside atop the TEC, which is a Cambion module #801 1055 01 with 75 couples arranged in four stages (49 in the first stage, 17 in the second, then 7, then 2). Since TECs can only handle small heat loads, maximum cooling of the CCD can be obtained only if great care is taken to reduce (a) convective, (b) conductive and (c) radiative heating of the CCD and TEC. In addition, the CCD is properly cooled only if (d), the considerable amount of heat generated by the TEC has a path of excellent thermal conductivity away from the camera head. We have paid attention to these points in the following manner.

(a) Convection

Convective heating of the CCD and thermoelectric module can be eliminated if the camera head has a properly evacuated chamber for the CCD and TEC. Our camera head can be evacuated to well below 10^{-5} Torr, where convective heating is negligible. Vacuum sealing is done using Viton o-rings; the o-ring grooves were accurately dimensioned and polished free of scratches to ensure effective seals. The chamber can be baked to ~ 100°C to outgass and remove any residues while the chamber is being pumped. The interior surfaces were highly polished to minimise the surface area that is exposed to vacuum (and hence to reduce outgassing). In addition, an ion pump is to be permanently fitted to this unit to maintain a good vacuum while the telescope operates.

(b) Conduction

Heat conduction from the warm exterior of the camera head along the wires to the CCD can easily be the dominant source of heat into the cold junction. The use of Manganin metal wires of fine diameter (125 μm), instead of copper wires, minimises this effect. Manganin also has a low thermoelectric effect against copper and is easily soldered, in contrast to commonly-used constantin. In addition, by affixing the wires to an intermediate stage of the TEC, so that they are thermally and not electrically connected, the heat load is reduced still further.

(c) Radiation

As seen by the cold CCD, the surroundings, which may look 100 degrees warmer, represent a significant source of heating of the CCD. To minimise this heat load a radiation shield, cooled by the second stage of the TEC, covers all but the optically sensitive part of the CCD. The vacuum chamber window is only as large as necessary to prevent vignetting of the incoming starlight, so the CCD only sees as much field of view as it needs. Inside the radiation shield and vacuum chamber the highly polished aluminium provides surfaces of low thermal emissivity. The copper backplate was gold plated (at a cost of $A12) both to lower its thermal emissivity and to prevent tarnishing. Roth (1989) has an interesting discussion on a 5-step surface treatment procedure for reducing emissivity.

(d) Thermal transfer

Low heat load on the CCD is of little use unless heat is efficiently transferred away from the CCD. Best thermal contact is made when the surfaces to be joined are soldered together; however, this is not always practical. In our design a thin (~ 1.5 mm) copper mounting plate is fixed with epoxy to the CCD using Torr-Seal. The plate is screwed into a copper mounting block. The block is itself soldered to the cold surface of the TEC using a low temperature solder which avoids melting the TEC's internal solder. This arrangement makes it possible to change CCD chips by simply unscrewing the plate from the block, yet still provides good thermal contact between the CCD and the cold surface of the TEC. The hot surface of the TEC module is soldered to the copper backplate using low temperature solder—a

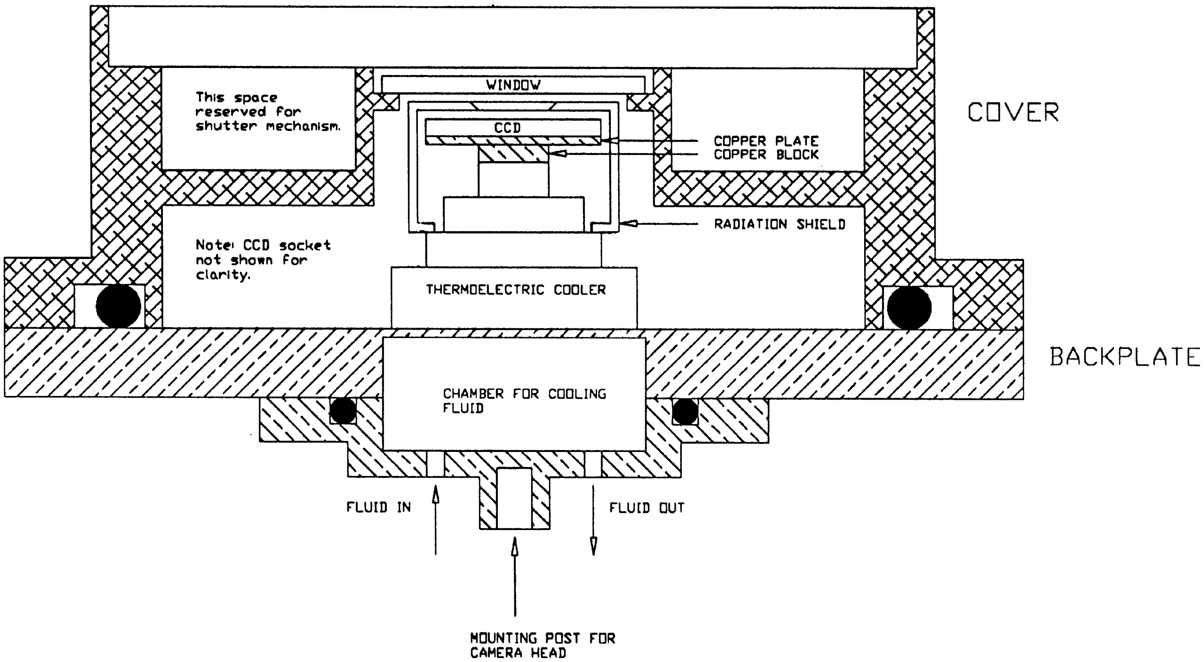

Figure 1 – The design of the camera head, showing layout of the components inside the vacuum chamber. The figure is greater than life-size: the maximum width of the camera head is 114 mm.

difficult operation due to the need to avoid unsoldering the internal junctions within the TEC. Finally, the backplate next to the TEC is kept cool by the flow of cold water mixed with automotive antifreeze. It is important to keep the hot junction at a constant temperature to avoid fracturing the TEC due to differential expansion.

3. Results

To measure the cold junction temperature we used the temperature dependence of the forward voltage drop across a silicon diode supplied with a constant current of 100 μA. Specifically, a surface-mount diode package was chosen with dual series diodes giving a 4.8 mV/°C slope linear within ±1°C over the range 150 K to 300 K (verified by comparison with a calibrated diode from Lakeshore).

The results of the laboratory cooling tests are shown in Table 1. They indicate that we can achieve cold junction temperatures of −89°C with a hot junction temperature of 24°C. Thus we can reduce dark-current to $\lesssim 1e^-$ per pixel per second with a GEC P8603 CCD, permitting exposures of many minutes before noise degrades the signal/noise in typical astronomical imaging. We should be able to get at least ten degrees colder by maintaining the hot junction temperature close to 0°C, with a consequent threefold or more lowering in dark-current. We may expect an additional factor of three reduction in dark-current by running the CCD in Multi-Pinned-Phase mode (Janesick *et al.* 1988, 1989).

Interestingly, the radiation shield made only ~ 2.5°C difference to the cold junction temperature. Lining the inside of the camera head with superinsulation (partially-aluminized mylar film) made no measurable difference.

In summary, we believe that a compact, thermoelectrically cooled, CCD camera operating at below −100°C can readily be built, thereby eliminating the need for liquid nitrogen cooling for many astronomical applications.

Table 1. Cold junction temperature versus TEC power for a 24°C hot junction temperature.

TEC power W	Min. cold temp. °C
5	−63
20	−83
30	−89

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