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DETECTORS

(Report by M.J. Cullum, Chairman of the Detector Working Group)

The possibility of CCD detectors with 2048x2048 pixels was first mentioned in a Detector Working Group report in 1985, although the available technology did not then permit the manufacture useful devices of this size. In the intervening period CCD technology has steadily evolved and matured to the extent that today, chips of this format are becoming the one of the mainstay optical detectors in all the major observatories.

Several trends can be observed in present developments, both on the part of manufacturers as well as users. These include the increased popularity of foundry runs, improvements in thinning techniques and back surface treatment, and the development of large mosaics.

Many of the large format CCDs currently in operation at the telescope have been produced by so-called silicon foundries. To date almost all of these have been produced by Loral, although other firms, such as Orbit, are now offering similar services. Instead of marketing individual tested CCD chips, foundries manufacture batches of wafers on a best effort basis according to standard or custom designs. Although it is likely that the majority of the chips produced in this way will not be suitable for astronomical applications, the significantly reduced unit cost and the generally acceptable production yields in recent years have made it worthwhile for many large institutes to go in this direction. A few have also designed their own CCDs to cater for special instrumental requirements. Even circular CCDs have been produced in this way.

The largest CCDs that are in widespread astronomical use have 2048x2048 pixels of 15 micron square. Larger single chips have been manufactured, and several institutes have tested chips of 4096x4096 pixels with 7.5 or 15 micron pixels. CCDs of the latter dimension are about the largest that can be accommodated within the 4 inch wafers used by many manufacturers. Efforts to achieve even larger formats have mainly concentrated on making mosaics of chips that are designed to be buttable with a gap of less than 0.5 mm between the butted sides. These devices may either be two-side buttable (either adjacent sides for 2x2 mosaics, or opposite sides for 1xn mosaics) or three sides (for 2xn mosaics). Several institutes are developing 2x2 mosaics of Loral chips giving 4096x4096 pixels (ESO, NOAO, IFA/Hawaii, RGO, amongst others). Existing plans even include a 2x5 mosaic with a total of 8190x10240 pixels for direct imaging applications (Japanese Nat. Obs.). For some specialised applications 'sparse mosaics' have been assembled using conventional CCD designs.

Major efforts have been made by a number of manufacturers and individuals to improve the sensitivity of CCDs, especially at UV wavelengths. Nevertheless, the fact that the large format CCDs now in use still have widely varying sensitivity figures show that these techniques have not yet been fully mastered. Of the major chip manufacturers only Tektronix produces thinned large format CCDs on a commercial basis, although even here the supplies have been erratic. EEV, Reticon and Thomson

all have on-going thinning development programmes for their large format devices. M. Lesser (Steward Obs.) has successfully thinned Loral CCDs and supplied these to a number of observatories. It is worth noting here that if the rear surface has not received a permanent implant during manufacture, thinned CCDs usually require a UV flood prior to use to achieve a good short-wave sensitivity, thus adding to operational headaches. Also important for improving the sensitivity of a back-illuminated CCD is the anti-reflection coating. Both Tektronix and Lesser have demonstrated considerable advances in this area. Peak RQE figures exceeding 90% have been recorded in some cases, and over 50% at 300 nm. Even 40% RQE at 400 nm has been measured with front illuminated CCDs using the thin gate technology developed at JPL. Sadly, the RQE of CCDs in operational use at observatories today is generally significantly less than these figures suggest.

The readout noise of CCDs measured at the telescope at observatories around the world show a fairly consistent picture. Values in the range of 3 - 4 e^- are routinely observed with many recent types of CCD, with values up to 7 - 10 e^- with some chip types. The use of mpp implants in many chip designs to reduce the dark current can allow integrations of several minutes at room temperature.

There are several avenues of development that promise performance benefits in the near future. These include the improvement of skipper readout techniques to the point where single photo-electrons can be unambiguously detected (although at the expense of longer readout times), improved low signal CTE using super-notch designs (JPL), and advances in fast readout and/or low noise CCDs (EEV, JPL, Kodak, MIT Lincoln Labs, Sarnhoff). Fast parallel readout CCDs with smaller formats (32x32 to 256x256) are available from several manufacturers for applications such as fast guiding and wavefront sensing.

Developments in photon-counting detectors have generally been motivated by far UV applications or for those requiring high temporal resolution, for example adaptive optics and speckle interferometry. At the time of writing, the 1024x1024 MAMA detectors for the STIS have successfully passed the NASA technology demonstration test, and two engineering tubes are being assembled. The STIS will be equipped with two types of MAMA tube with solar blind CsI and Cs_2Te cathodes. The DQE of the demonstration Cs_2Te tube was 17% at 200 nm. The MAMA is also available with visible light cathodes.

LEP in Paris has developed an electron bombarded CCD tube (EBCCD) which is able to distinguish up to 10 electrons per pixel per CCD readout, thus increasing the dynamic range by the same amount compared to a normal ICCD detector with the same frame rate. The device is presently employed as a wavefront sensor in the Come-On-Plus adaptive optics system at ESO. The format is 604x288 pixels, although larger formats are planned. At the present time CCDs still cannot compete with photon-counting detectors for fast wavefront-sensing applications at very low signal levels, but the recent advances in fast readout CCDs indicate that this situation may change in the future.

In the field of infrared array detectors substantial progress has been made during the last three years. Detectors with up to 256x256 pixels are now in fairly widespread use at observatories. In the wavelength range between 1 and 5 microns, two types of material are dominant: HgCdTe and InSb. Rockwell's 256x256 NICMOS-3 arrays (HgCdTe) are employed for wavelengths up to 2.5 microns. They have a pixel size of

40 microns, an RQE of 40 - 60%, and a read noise of around 30 e^- for a single readout, and down to 15 e^- with multiple non-destructive readouts. The full-well capacity is about 2.10^5 e^-. The dark current can be under 1 $e^-.sec^{-1}.pixel^{-1}$, but existing versions of these 256x256 devices have shown a slight persistence effect in which the dark current is dependent on the previous light exposure. This can be problematic, for example, in instruments that switch between imaging and spectroscopy on the same detector.

The SBRC 62x58 InSb array, which has been a workhorse for infrared astronomy over a number of years, has now been displaced by a new 256x256 array. This detector, which has 30 micron pixels, has a very high RQE of typically 80% out to 5 microns. The read noise, dark current and full well capacity are broadly similar to those of the NICMOS-3 detectors. Both the Rockwell and SBRC arrays are in use at many observatories, in many cases in instruments that have been specifically designed for the new large arrays.

Another InSb detector that has recently appeared on the market is a 256x256 array from Cincinnati Electronics. Although this device has not yet reached the astronomer, an interesting feature is the promised high well capacity of 10^6 e^-. Amber Engineering also produces an InSb array with 512x512 pixels, but this has a higher dark signal and is primarily intended for thermal imaging applications. Both Rockwell and SBRC have begun to develop 1024x1024 infrared arrays. One potential problem with arrays of this size is that the full-well capacity is likely to be similar to, or possibly even smaller than, present 256x256 arrays. With 16-times as many pixels to readout, this will require complex parallel readout electronics when used at longer wavebands.

In the mid-infrared region (10 - 30 microns), the situation has also changed rapidly. Doped silicon photo-conductor arrays have now been displaced by more sensitive Impurity Band Conduction (or Blocked Impurity Band) detectors. Gallium, Arsenic or Antimony doped silicon devices are common, and the readout structures are similar to the near IR arrays. Aerojet Electrosystems has produced a 96x96 array, Hughes has made a 256x256 array, and Rockwell can provide 128x128 or 256x256 detectors. Available reports indicate that the performance of these detectors is excellent, although the larger devices have yet to be used on a telescope. Germanium IBC arrays are also being developed for the far infrared region.

Two major meetings on infrared array detectors took place in 1993. The first of these was a SPIE meeting in Orlando, Florida in April on 'Infrared Detectors and Instrumentation'. The proceedings of this meeting are published as SPIE Vol. 1946 and edited by A Fowler. The second conference took place in July 1993 at UCLA under the title 'Infrared astronomy with arrays; the next generation'. The proceedings of this meeting will be edited by I. McLean and published by Kluwer by mid-1994. The IAU Symposium 167 ('Advances in Array Technology and Applications') will take place between 15 - 19 August 1994, and will cover both optical and infrared array detectors. The Chairman of this symposium is D. Philip.

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