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Large area near infra-red detectors for astronomy

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Abstract

The technology of Infrared detectors has made significant advances over the last decade evolving from their small size and number of pixels to the present large format $2k \times 2k$ pixel devices. These large format near infrared detectors ($1-2.5\,\mu m$) are now routinely available to the astronomical community and are based on HgCdTe grown by either an LPE or MBE process on silicon or CdZnTe substrates. The performance of these devices, such as quantum efficiency, dark current generation and read noise, etc. has also been significantly improved. The advent of these devices in buttable packages has prompted the build of large focal plane mosaics for wide field imaging in which the UK is a world leader. Four Hawaii-2 ($2k \times 2k$) detectors mounted in a 2×2 sparse mosaic have recently been commissioned in the Wide Field Camera at UKIRT on Hawaii. More ambitiously, the VISTA IR camera currently being built in the UK for an ESO telescope in Chile, will have a sparse mosaic of 16 ($2k \times 2k$) VIRGO detectors mounted at its focal plane. We present details of the performance and characteristics of the Hawaii-2 and VIRGO detectors based on test results measured at the UKATC. We also present brief details on the requirements for the next generation of detectors.

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1. Introduction

The technology of Infrared (IR) detectors has advanced rapidly over the last decade, closely mirroring those advances made in size and performance of optical CCD detectors. This paper reports on the latest generation of these astronomical IR detectors which specifically operate in the $1-2.5\,\mu m$ regime. We summarise the technology used to manufacture these detectors and their typical performance with specific regard to the HAWAII-2 detectors from the Rockwell Science Centre [1] and the VIRGO detectors from Raytheon Vision Systems [2]. We also detail some of the problems and issues associated with this detector technology. We then look to the future and summarise some of the requirements for the next generation of detectors required in the era of Extremely Large Telescopes (>10 m diameter primary mirrors).

2. HgCdTe on sapphire arrays

A typical large IR detector for astronomy has $2k \times 2k$ pixels each of size $18-20\,\mu m$ square. The photo-sensitive region of the pixels are manufactured from mercury–cadmium–telluride (HgCdTe), which is prepared by first growing a thin buffer layer of cadmium telluride on a sapphire (Al_2O_3) substrate using an industrial standard processes such as metal organic chemical vapour deposition (MOCVD). The photo-sensitive HgCdTe material is then grown by liquid phase epitaxy (LPE) onto the buffered sapphire substrate from a tellurium rich melt to produce, typically, 3 in. wafers. Sapphire is used because it is commercially available in large wafers and is also an effective first-order anti-reflection coating for HgCdTe. The photovoltaic detectors are then formed by the required ion implantation at room temperature followed by annealing at higher temperatures. The junctions are passivated using ZnS or CdTe and then metal pads are deposited to allow electrical contact to the detector. Finally, indium columns are evaporated onto the detectors to provide an

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electrical interface between the detector and a silicon multiplexer circuit. Fig. 1 shows this structure in more detail.

3. HgCdTe on CdZnTe arrays

In recent years there has been a move by the manufacturers away from the LPE process to a Molecular Beam Epitaxy (MBE) process and also to the use of lattice matched cadmium–zinc–telluride substrates instead of sapphire. The reasons for these changes are many but are driven by thermal cycling issues, improvements in detector sensitivity, higher pixel operability and lower defect densities. Also, with MBE, the band gap of HgCdTe can be precisely controlled and modified on a run-by-run basis simply by modifying the CdTe temperature to achieve the desired cut-off wavelength. The MBE process also allows for HgCdTe to be grown on alternative substrates such as silicon, available in much larger sizes.

Whatever technology is used to manufacture the IR material, the final devices are manufactured by flip-chip hybridising a silicon multiplexer circuit to the IR detector array using indium interconnects rather than solder bumps. The main advantage of this hybridisation process is that it allows for the constituent parts to be independently optimised for particular applications. It also allows one particular multiplexer design to be used with different detector arrays. Modern multiplexers utilise the latest 0.25 μm CMOS technology with the most recent devices having more than four million pixels and 13 million transistors. Each IR pixel is mated to a three transistor unit cell in the silicon multiplexer as shown in Fig. 2. The photocurrent generated from the incoming photon is stored directly on the detector capacitance, requiring the detector diode to be reversed biased to maximise the dynamic range.

The detector voltage then modulates the gate of the source follower FET via the indium bump bond connection. The other transistors in the unit cell are used to reset the pixel and allow the source follower output to be multiplexed onto a bus structure so that many pixels can share one single output. The multiplexer architecture also allows the pixels to be readout in a nondestructive manner

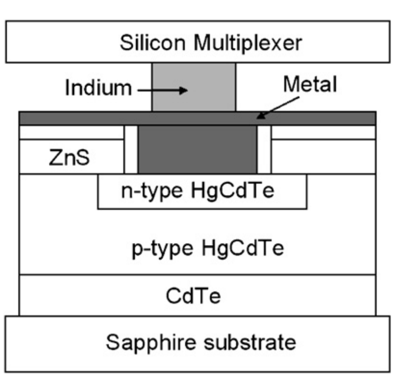

Fig. 1. Typical IR pixel structure.

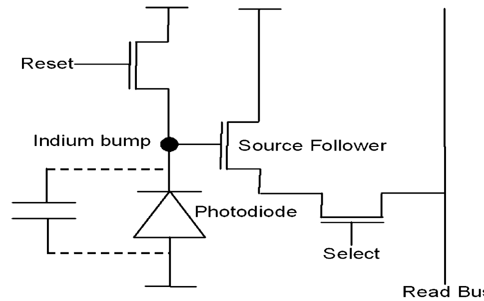

Fig. 2. Typical pixel circuitry.

Fig. 3. WFCAM focal plane mosaic.

so that complex readout schemes such as multiple sampling up the ramp can be implemented to beat the readout noise down further if required for low background applications.

4. Rockwell HAWAII-2 detector

The Rockwell HAWAII-2 detectors are HgCdTe detectors on sapphire substrates with $2k \times 2k$, 18 μm square pixels. The devices have 32 outputs read in parallel as vertical strips. It requires 12 clocks and six biases for operation and the electrical and thermal interface is through a 400 pin PGA package. A typical application for such a device is the Wide Field Camera [4] (WFCAM) recently commissioned on the UK Infrared telescope (UKIRT) in Hawaii. This instrument contains four of these detectors mounted as shown in Fig. 3 with a centrally mounted co-planar CCD used for star tracking purposes (Table 1).

5. Raytheon VIRGO detector

The Raytheon VIRGO detectors are HgCdTe detectors on CdZnTe substrates with $2k \times 2k$, 20 μm square pixels. These devices have 16 outputs also read in parallel as vertical strips. It requires five clocks and 15 biases for operation and is electrically interfaced through a 3-edge