Focal Plane Array Sensor for Imaging Infrared Seeker of Antitank Guided Missile

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ABSTRACT

Technological issues and processes for fabrication of mercury cadmium telluride detector arrays, charge coupled device readout arrays and integration of these into a focal plane array sensor have been discussed. Mini arrays of 16 × 16 size have been realised and tested to prove the technology and process schedule with a view to scaling up this for larger arrays to be used in the antitank guided missile.

1. INTRODUCTION

Infrared (IR) sensors continue to play increasingly important role in tactical and strategic military systems for target acquisition, identification and tracking. These applications include missile seekers, infrared search and track (IRST), forward looking infrared (FLIR), thermal imaging systems, etc. A unique feature of IR is its emission by all objects above absolute zero temperature. It is thus possible to see an object by detecting its IR emission, rather than detecting reflected radiations from illuminating source. Here the source of radiation is the object itself and the detection can be entirely passive.

There are three wavelength windows in the atmosphere that are transparent to the IR radiation, namely 1-2 μm short wavelength IR (SWIR), 3-5 μm medium wavelength IR (MWIR) and 8-14 μm long wavelength IR (LWIR). The IR emission from objects in typical ambient temperature of about 300 K peaks around 10 μm. For the imaging infrared (IIR) guidance system for the third generation antitank guided missile (ATGM) LWIR focal plane array (FPA) sensor has been configured.

The key component of any IR detection system is the IR sensor. The sensor converts the incident radiation into electrical signal and this is processed into an image. Because IR radiation levels incident on the MWIR and LWIR sensor arrays are characterised by a large ambient background, most IR images have a high background pedestal and low contrast. On the other hand, images in the near IR and visible regions have very little background and high contrast. Thus IR imagery is limited by the background photon noise

In this paper the technological and fabrication aspects of the FPA sensor are discussed.

2. IR DETECTOR STRUCTURES

The IR detector structures most commonly used in arrays are photoconductive and photovoltaic. The photoconductive arrays have comparatively low impedance for LWIR applications whereas, photovoltaic detectors can be fabricated with relatively high resistance and operated at near zero bias. Because of zero bias operation the heat generation is very much reduced, thereby reducing the burden on the cooling system.

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Photovoltaic detectors are based on *p-n* junction concept. Incident photons generate electron-hole pairs by intrinsic photon absorption and minority carriers diffuse to the junction where they are swept across by the built-in field in the reverse current direction.

3. IR MATERIALS

The most versatile material for IR sensor is *Hh Cd Te*, i.e. mercury cadminm telluride (MCT). By varying *Cd/Hg* ratio, the bandgap of this material can be varied from 1.65 eV to –0.3 eV. The most popular compositions are $x = 0.3$ for 0.25 eV bandgap at 77 K for MWIR and $x = 0.2$ for 0.1 eV at 77 K for LWIR applications. The detectors made out of this material can be operated only at cryogenic temperature (77 K) and therefore have to be encapsulated in a dewar and cooled to 77 K.

The MCT material, however, is not without its problems. Since it is a narrow bandgap semiconductor, with relatively weak interatomic binding, some of those problems are inherent to the material. For example, MCT is easily damaged and cannot be subjected to temperatures greater than 100 °C while unprotected due to formation of mercury vacancies in the material. The defects resulting from both damage and mercury vacancies are electrically active, thereby affecting the carrier concentration.

Until recently, MCT was available only as bulk crystals grown by a variety of methods, the most common being the solid state recrystallisation (SSR) and Bridgman growth. In these techniques the use of quartz ampules, high temperatures and high pressures have limited the ingot size of 1-2 cm diameter.

Epitaxy is the growth of thin single crystal films of material on an appropriate substrate. The first method developed for MCT, now more than ten years old and still the most common, is liquid phase epitaxy (LPE). In this technique, single crystal layers are grown on *CdTe* substrates from a supersaturated *Te* or *Hg* melt containing proper quantity of the other elements. LPE has been successfully employed in growing high quality, uniform MCT films consisting of one or two layers. The present problems with LPE are surface morphology, relatively high growth temperature, growth of accurate multilayer structures and scalability to large area surface. Two more recent epitaxial techniques that attempt to solve these problems are molecular beam epitaxy (MBE) and metal organic chemical vapour deposition (MOCVD).

4. DEVICE TECHNOLOGY AND PROCESSES

For large arrays containing hundreds of active elements either in the linear or two dimensional format, the preferred approach is to include the associated readout circuitry also with the array in the focal plane so that the individual elements can be connected to a common output and thus reduce the number of input-output connections. This helps in reducing the dewar size as well as heat losses through the connections. This approach of integrating a detector array with its associated readout circuit is commonly referred to as FPA. The readout circuit commonly used is either CCD or a CMOS multiplexer, and a photodiode is preferred over a photoconductor as sensor. Since the photodiode is operated near zero bias, the power dissipation is minimal and the photogenerated charge can be integrated to enhance the S/N ratio.

The photodiodes are fabricated using *p*-type MCT epilayer using a planar ion implant process. The starting *p*-type wafer is passivated with a thin layer of *ZnS*/ photo CVD SiO_2. After passivation active areas are defined by standard photolithography process and B^+ ions are implanted to form n^+ regions. Ohmic contacts are then made to the individual n^+ active regions and *p*-type epilayer. On these n^+ contacts indium bumps are grown for connecting to the multiplexer (Fig. 1).

For high density arrays based on MCT, the most common approach is a hybrid in which the MCT detector array is attached electrically and mechanically to the silicon multiplexer, e.g. CCD or MOSFET switch; by cold welding of matching indium metal interconnects (Bumps) at each detector element.

When linear array is used in imaging and if any element is defective, the entire line of information is lost when used in the parallel scanning mode. To overcome this problem and to additionally improve the detectivity and array uniformity, a method called time delay and integration (TDI) is used. This requires an $n \times m$ array format in which there are m lines of TDI. As the scene is scanned, each line of information in the non-scanned direction is delayed in time and integrated with the previous one. This gives m linear array, scanning the same scene with their output summed. The detectivity improves as $\sqrt{m}$ and uniformity improves due to averaging. Further, if any element is defective, there are more number of elements in the TDI direction. So the effect is only a loss of sensitivity rather than total loss of information. If the array size is increased to $n \times n$, then the entire scene can be viewed without the need for mechanical scanning. This, referred to as staring array, is the IR analogue of visible imaging CCD. This approach is followed for ATGM.

5. READOUT MECHANISM FOR FPA

In IRFPA, after the detectors convert the incident photons to electrical charges, the resulting signal must be injected into a readout mechanism for multiplexing. The most common types of readout currently in use are CCD and MOSFET switch for hybrid array applications. These are fabricated on silicon and the technology is fairly standardised. In the FPA under discussion, CCD approach is followed. The major design requirements for readout are high charge handling capacity, high transfer efficiency, low noise and low power dissipation.

5 CCD READOUT

The CCD readouts have been extensively used in hybrid and monolithic IR FPAs (Fig. 2). The readout is composed of MIS gates that shift analogue charge

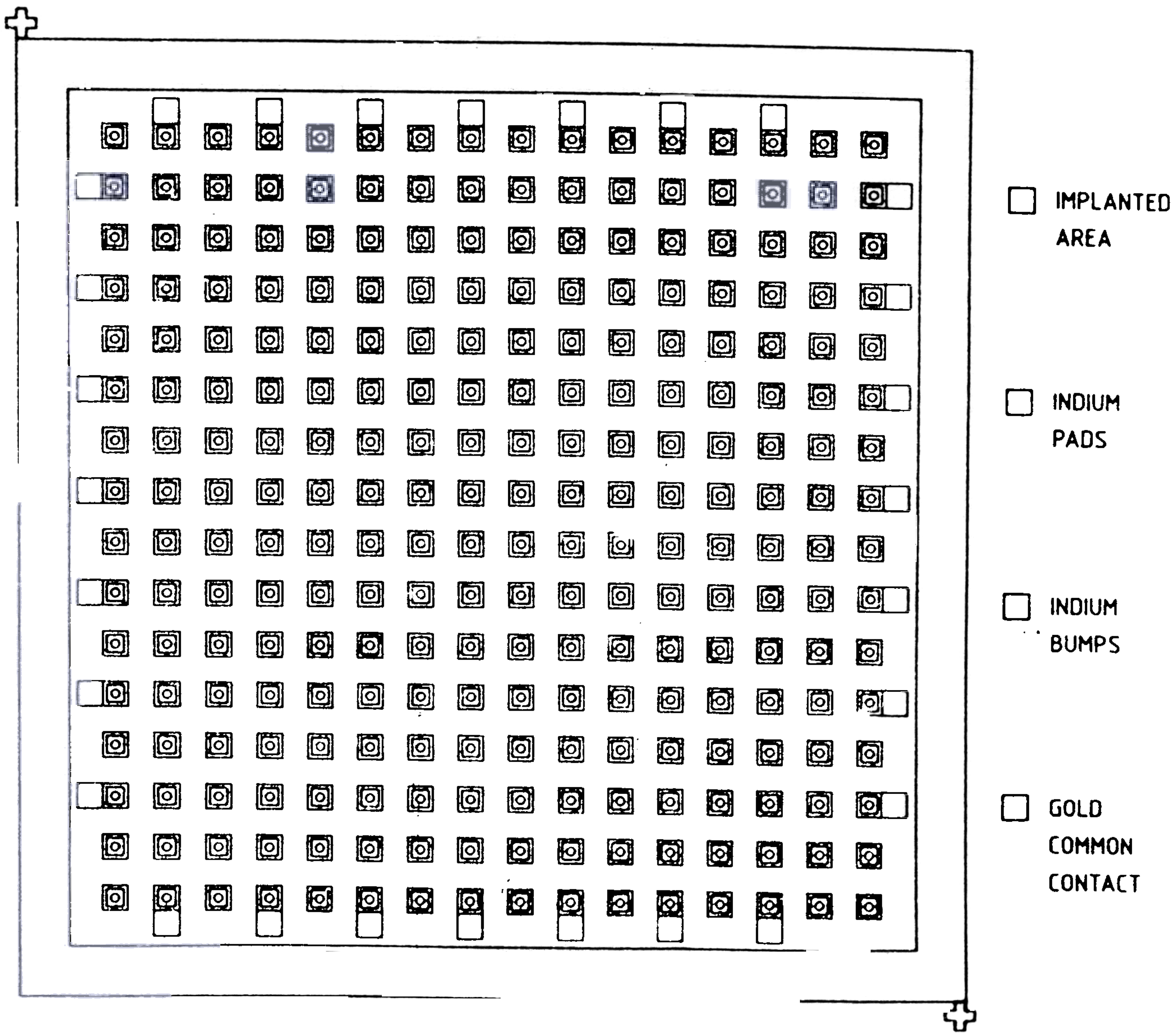

Figure Plan view of MCT diode mini array

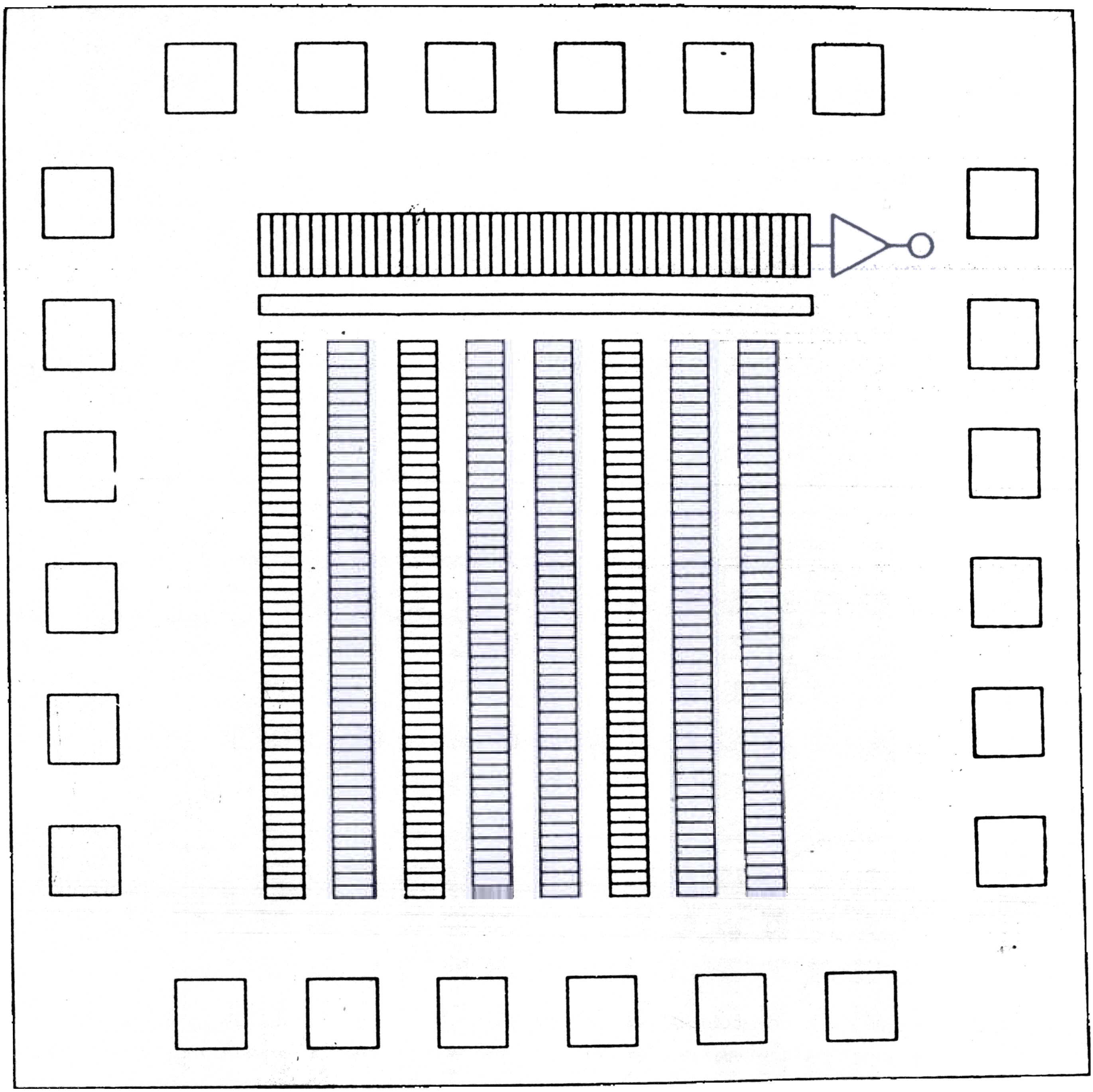

Figure 2. CCD MUX schematic for mini FPA sensor

packets systematically from one well to the other. The most successful use of CCD in large area IRFPA has been in *PtSi* Schottky barrier FPA and as a readout mechanism in hybrid MCT FPA. The advantages of CCD are (i) the response is highly linear and uniform, (ii) the random noise and 1/*f* noise are low leading to good stability, and (iii) the ability to fabricate large area arrays with small unit cells.

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