Flip-chip Interconnection of 100k Pixel Hybrid Detectors

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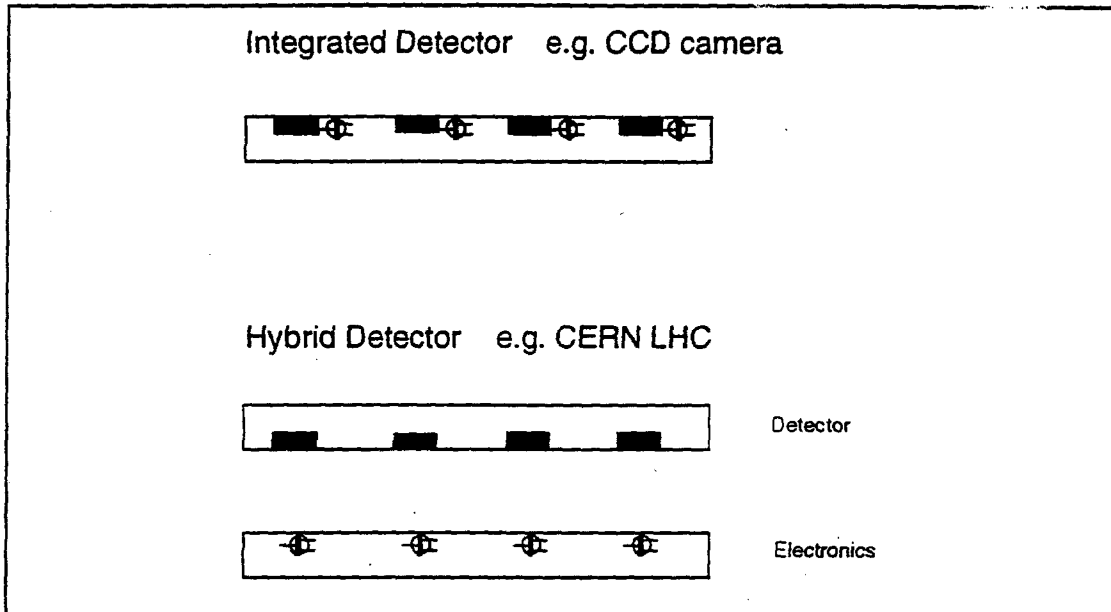
Abstract

Hybrid detectors use different components for the sensor element and read-out electronics. This approach allows the detector to be optimised for collection efficiency and the read-out electronics for functionality, but places severe demands on the interconnect technology, especially if the detector is pixelated in two dimensions. Interconnection of fine-pitch (<50um), 2D hybrid pixel arrays is usually accomplished by either flip-chip compression bonding or flip-chip solder bonding.

GEC-Marconi Materials Technology offers a commercial portfolio of fine-pitch flip-chip interconnect technologies specifically for pixel detector manufacture. The service includes the option for each interconnect to be sub 10um diameter at below 20um pitch. The technology is discussed and application examples are presented including the CERN Omega-3 device and an advanced infra-red detector array containing over 100,000 elements.

Introduction

Sensors can be made in two configurations. These are illustrated in Fig. 1, below.



Integrated detectors are single component devices that combine the sensing element and the read-out electronics on a single substrate, usually silicon. A common example of this technology is the solid state optical detector (ccd) used in camcorders and digital cameras.

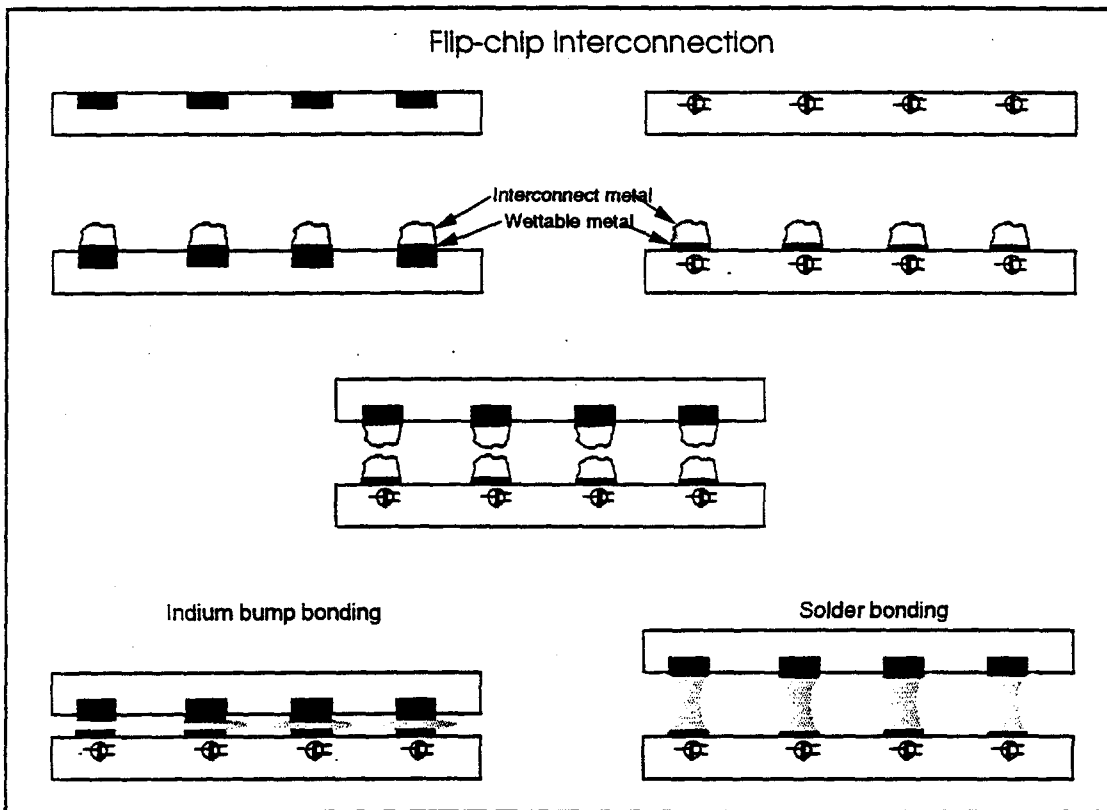
Hybrid detectors use different components for the sensor element and the read-out electronics. This approach allows the detector to be optimised for collection efficiency and the read-out electronics for functionality. A household example of this sensor type is the infra-red detectors used for burglar alarm systems. In these, the detector is a pyroelectric material (i.e. converts thermal energy to electrical charge), while the electronics system comprises a low noise amplifier and threshold gate.

Each pixel element in a hybrid detector needs to be connected to a separate electronics channel. If the hybrid detector is pixelated in two dimensions this places severe demands on the attachment and interconnect technology. Electrical interconnection and physical attachment of 2D hybrid pixel arrays is usually accomplished by flip-chip bonding.

Flip-chip bonding

Flip-chip bonding is the leading method for attachment and interconnection of high performance semiconductor devices, including multi-chip modules (MCM), monolithic microwave integrated circuits (MMIC) and pixelated imaging detectors.

There are two process variants, flip-chip compression bonding (commonly known as indium bump bonding) and flip-chip solder bonding. The principle of these two process is shown schematically in Fig 2, below.



Both processes involve applying a "wettable metal" to the surface of the components to be joined. This is often a multi-layer metallisation, designed to provide ohmic contact to- and metallurgical compatibility between the contacts on the detector and read-out electronics. To the wettable metal on one or both component is then applied the interconnect metal. One of the die is then inverted (flipped over) and mating pairs of contact pads are aligned. This operation is performed on a flip-chip bonding machine. To perform flip-chip compression bonding the two components are then simply pressed together until interconnect metal welds. For flip-chip solder bonding, the assembly is heated until the interconnect metal melts and wets.

Although flip-chip compression bonding and flip-chip solder bonding superficially appear similar processes, they actually require very different

materials and process conditions, and the interconnects so formed have significantly different characteristics. The key features of each process and properties of the resulting interconnects are given in the following Tables.

	Indium Bump Bonding	Solder Bump Bonding
Process	Solid state diffusion	Solid-liquid alloying
Materials	In, Au, Pb, Pb/Sn	Any solder
Temperature	20-200°C	Solder melting point
Pressure	10 - 100 MPa	0 MPa
Max Height:Pitch	1 : 5	3 : 1

Technology Characteristics

Indium Bump Bonding	Solder Bump Bonding
Short (coin) interconnects	Tall (pillar) interconnects
Closed interconnect gap	Open interconnect gap
Fluxless	Flux required
Low residual stress	Residual stress
Service temp > bonding temp	Service temp < bonding temp
Alignment as placed	Self aligning (±2um X, Y ±0.5um Z)
Planar substrates	Topology tolerant

Fine-pitch Flip-chip

High resolution detectors require large numbers of small and densely packed pixels. If the interconnects can be larger than about 100um diameter, a wide diversity of methods can be used to apply the wettable and interconnect metals to the components. The lowest cost option for volume manufacture is predominantly wet plating. For substantially smaller interconnects, especially those below 10um diameter, the preferred approach is to exploit conventional semiconductor processing equipment and use photolithography to define features and vapour phase deposition to apply the wettable and interconnect metals.

GEC-Marconi Materials Technology, at Caswell, has over 25 years experience in fine-pitch flip-chip bonding and offers a state-of-the-art commercial service. Highly toleranced interconnections can be made for operation at over 40GHz on either whole wafers or individual known good die (KGD). Bumps can be made as high as 50um, for direct connection of integrated circuits to printed circuit boards, or smaller than 10um diameter for 2D detector arrays. Bump pitches can be below 20um. Equipment and facilities exist to provide advanced flip-chip bonding on a prototype scale through to volume production. This service is underpinned by extensive R&D resources, enabling one-off and highly specialised customer requirements to be met. An outline of this Service is given below.

Process	Indium- and solder-bump bonding
Feature size	10-100um dia., >10um between features, <50um high
Substrates	Single die - 6" wafers (300mm BY 1999)
Interconnect	Any commercially available metal or alloy
Fluxes	Reflow in choice of atm., custom flux design capability
Flip-chip	Full 5-axis alignment, 4 equipments
Component size	0.1mm to 100mm
Underfill	Any commercially available product
Environment	ESD protected Class 100 clean rooms
Modelling	RF, thermal, mechanical, static and transient

GMMT Fine-pitch Flip-chip Service

Process Yield

Flip-chip is attractive for volume manufacturing applications because it is an inherently high yielding process. As an example, GEC-Marconi manufacturers a pixelated sensor that contains approximately 10,000 elements, in batches of 10 units. Of this batch of ten it would normally be expected that six have all interconnects made and functioning, while the remaining four units have a few isolated dead pixels. The pixel yield per batch therefore routinely exceeds 99.99%.

During process development, or occasionally during manufacture, it is obviously possible to produce pixelated devices with substantial numbers of non-working elements. Because flip-chip assembly is a well understood and characterised process, most failures can be readily diagnosed to a particular process deficiency, enabling corrective measures to be applied.

Application Examples

LHC Omega-3 Pixel Sensors

CERN has designed a family of pixel sensors to track the path and momentum of sub-atomic particles. These sensors essentially comprise an array of P-N junctions in silicon, GaAs or diamond, each of which is connected to an individual silicon electronics readout circuit. Because the detectors are relatively simple structures they can be physically large yet made with very low defect rates. The readout electronics, by contrast, are extremely sophisticated chips and producing die to the required specifications clearly presents a challenge to the wafer manufacturer. For this reason the sensor has been designed so that six readout die are used to populate each detector and the die are fully probe-tested before bonding.

In the current generation of Omega-3 prime sensor, electrical connection between the detector and the electronics chips requires approximately 13,000 flip-chip interconnects, each 18um diameter on a 50um by 500um pitch. As an additional complication, the interconnects are required to provide the maximum possible physical separation between the two components, to minimise electrical cross-talk. For this reason flip-chip solder bonding, using eutectic lead-tin solder, is employed by GEC-Marconi Materials Technology for the assembly process. Despite the complexity of this product, the yield of useable 'ladders' currently stands at about 75% and it is anticipated that some planned process enhancements will further improve this figure and decrease the cost.

100k Pixel Hybrid Detectors

A thermal imaging camera responds to heat, as opposed to light. The majority of thermal imaging cameras operate in the 8-14um wavelength of the infra-red band because the image is then not degraded by either smoke or rain. The quality or precision of the image that can be obtained from an infra-red camera is simply a function of the number of pixel elements (exactly as for a computer monitor albeit working in reverse!). However, if the sensor is too large then the quality of the picture again degrades due to deficiencies in the camera optics. The technology drive is therefore to pack the maximum number of pixels into the smallest possible area.

The infra-red detector used in this example is a pyroelectric ceramic. This approach has the merit that the camera can operate at room temperature. Traditional infra-red detectors must be cooled to about -200°C in order for them to function. The ceramic is manufactured in large blocks, then sliced and polished to eventually yield 8um thick wafers, which are then diced by laser into individual pixel elements. Electrical connection between each pixel element and the custom read-out electronics is achieved by flip-chip solder

bonding. To minimise thermal leakage from the detector to the electronic die the solder interconnects are made as small as possible, and in this instance below 10um diameter. By exploiting fine-pitch flip-chip as the interconnection and assembly method it is possible to realise sensors that measure no larger than 1cm^2 but which contain in excess of 100,000 individual pixels. A lower resolution variant of this product is sold by GEC-Marconi Infra-red Limited for use by firemen, police and the rescue services.