Design of a Compact MT Compatible High Speed Optoelectronic MCM.

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Abstract.

Compact parallel very high speed optical links will soon be essential components in telecommunication and data transmission systems. The complexity, costs as well as performance of multi-channel optoelectronic modules relates to a large extent to the method of aligning fibers to optoelectronic conversion components, i.e. pin-diodes, lasers, etc..

The optoelectronic multichip module, MCM, building concept we have developed offers a high speed MT (mechanically transferable) compatible and very compact multi-channel device with passive alignment. The size is not much more than an MT connector itself, which constitute makes the mechanical base of the module. The substrate used is a flexible MCM substrate, consisting of a polyimide foil double sided coated with copper, which is processed using the thin film and photolithography methods used for the MCM-D technology. The principle for the alignment is the following: To align the substrate to the MT connector, the copper layer on one side of the substrate is used as mask to etch or laser drill holes fitting the guide pins of an MT ferrule base. Then, for an exact positioning of the optoelectronic component, flip-chip mounting is used. The active area is positioned such that the light travels only a distance corresponding to the thickness of the substrate, i.e. it is coupled directly without any mirrors.

The present optoelectronic MCM is a 12 channel receiver module with pin-diode and transimpedance amplifier arrays, and decoupling capacitors. The substrate also has solder bumps for ball grid array, BGA, type connects to printed circuit board, PCB, which together with controlled impedance of transmission lines offers good signal integrity. This paper gives a description of the optoelectronic MCM design and manufacturing.

Introduction.

The rapidly increasing market for optoelectronic systems implies increasing requirements upon the performance, reliability and cost of optical components for application areas such as optical signal transmission for high performance signal processing, fiber-optic communication networks and sensors. The interfacing between fiber-optic and electronic systems needs increased functionality of optoelectronic devices and improved packaging solutions. The cost of the packaging is often high due to complex substrate manufacture and

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assembly processes. A key task is the procedure to align the optoelectronic conversion chip to the fibers. Active alignment, V-groove substrates, pig-tail components etc. are all costly methods, which have been avoided in the present design.

The original driving force for the development of a compact low cost optoelectronic MCM is a project to design a first-level calorimeter trigger system intended for the new particle physics experiments at the Large Hadron Collider, LHC, ATLAS detector at CERN [1,2]. In the proposed system, 4096 optical fibers transmit the trigger data from the front-end detector electronics at 800 Mbit/s via fiber splitters to 256 processing ASICs distributed over 16 processing boards. Using standard 9U boards with 512 fibers connected along one side of the board implies a space of 0.72 mm/fiber, i.e. an extremely compact packaging of the optoelectronic receiver component is required to implement such a system. For symmetry reasons, it is desirable to group 8 fibers together in each connector, which means that it may not be wider than about 5 mm.

Any commercially available product is far from simultaneously meeting all these requirements on size and bit rate, and reasonable cost per data channel. For example, Motorola offers a 10 channel parallel optical link, OPTOBUS II, working up to 800 Mbit/s per channel. The package, a 196-pin pin grid array, PGA, contains both receiver and transmitter components, but it is however far too large for the above application. There is also a considerable R&D activity within this area. For example, under an ESPRIT project a 12 x 2.5 Gbit/s receiver array module based on a silicon V-groove substrate for passive fiber alignment has been developed and evaluated [3]. In early stages we also used V-grooves in silicon MCM-D substrates for passive alignment and light coupling via mirrors, but found such a receiver concept complex to manufacture and assemble in a very compact package.

Low cost in combination with high performance and compact design of an optoelectronic receiver module can be realized by using a flexible substrate and thin film processes, i.e. a component often referred to as an MCM-D/L. A specific advantage of using a flexible substrate is that it can be folded into a 3-dimensional structure thereby minimizing the package volume. Using the MT standard for optical connectors, the present concept will be attractive for many optoelectronic application areas. The same generic design may be used for both transmitters and receivers for multi as well as single mode optical links.

Concept and Design.

An MT-ferrule (3.0 mm thick) is the basic mechanical building-block of the device as shown in Fig. 1. It defines a frame-work where the optic and electronic components are incorporated in cavities. The use of a flex-foil based MCM substrate folded around the ferrule enables package miniaturization in all three dimensions, saving space and reducing transmission losses. The dies are flip-chip mounted to save space and increase the electrical performance of the module. A key feature of the design is the self-alignment incorporated with this assembly technique, which provides sufficient alignment accuracy between the photo-detectors and the mating MT-connector. The electrical signals are transferred from the module through a BGA-like interface to a PCB.

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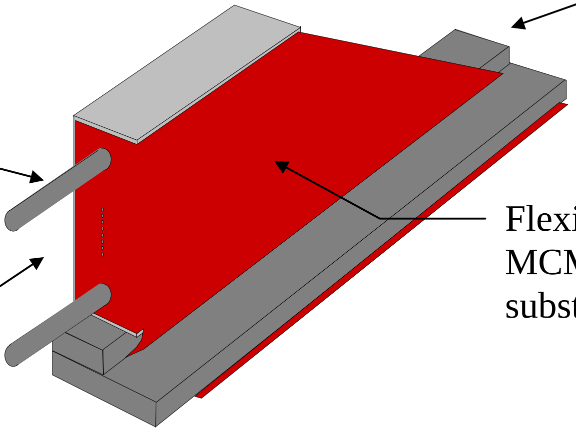

Fig. 1. Assembled MT compatible optoelectronic MCM.

The MCM is a 12 channel receiver module consisting of two dies, a pin-diode and a transimpedance amplifier array, which both are capable of operating at 2.5 Gbit/s per channel, and decoupling capacitors. The dies are identical with those used in the ESPRIT project mentioned above, and supplied by ETH Institute for Quantum Electronics, Micro- & Optoelectronics Laboratory. The performance has been verified with a sensitivity across all channels being better than -20dBm for error free operation at a bit error rate of 10^9 and bit rate of 2,5 Gbit/s [3].

The substrate is based on a 25 µm polyimide foil with 5 µm Cu plated on each side. One side serves as signal plane with controlled impedance transmission lines (50 Ω), and has a BCB (Cyclotene® supplied by DOW Chemicals inc.) passivation layer, which also defines flip-chip pads for the two dies. The solder reflow ensures the exact positioning of the pin-diode array. The Cu layer on the opposite side forms the ground plane. It is also used as hard mask for through-hole reactive ion etching, RIE, or laser drilling of electrical vias, alignment holes for MT guide pins, and light input. The copper layers on each side of the foil are patterned simultaneously with a relative position accuracy in the order of a few micrometers. Hence, there is an exact positioning of the substrate (carrying the pin-diode) on the MT ferrule, i.e. relative to the fibers in the mating MT-connector. A schematic cross-section is shown in Fig. 2 below. As the dies and decoupling capacitors have been mounted, the MCM is thread on the MT guide pins, folded around the MT base, and fixed with an epoxy glue as illustrated in Fig. 1.

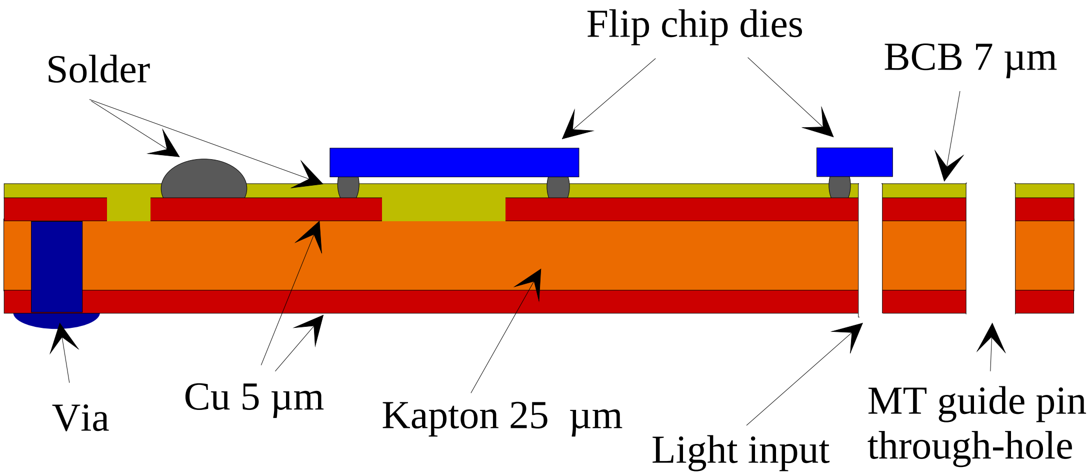

Fig. 2. Schematic cross-section of MT compatible optoelectronic MCM.

Process.

The polyimide substrate we use is a double-sided copper/ Kapton® adhesiveless flexible laminate supplied by Cirflex Technology. To be able to process the laminate by means of the MCM-D technology equipment, which is aimed at rigid substrate (e.g. silicon wafer) processing, the foils are mounted on 6 x 6 in. metal frames. The simultaneous double-sided patterning of the front-side (signal) and backside (ground) copper films is achieved through lithography using a double-sided mask-aligner and subsequent etching of the copper in ammonium peroxo-disulphate. The passivation layer is formed by photo-patternable BCB, which eliminates a dry-etch process step. Sputter deposition of a plating base of 0.1 µm Ti and 0.2 µm Cu enables the electro-plating of substrate solder bumps through a photo-resist mask. Using RIE the through-holes, defined by openings in the backside copper hard-mask, are etched in the Kapton foil (for detector windows, MT guiding-holes, and electrical vias). This implements the design concept of aligning the substrate conductor pattern to the MT guiding pins by defining the MT-holes in the same patterning step. The Cu/Ti plating base is saved to protect the BCB passivation during the RIE step. After removal of the plating base and reflow of the solder bumps, dies can be mounted and the module thread onto the MT-ferrule. The key process steps are depicted in Fig. 3.

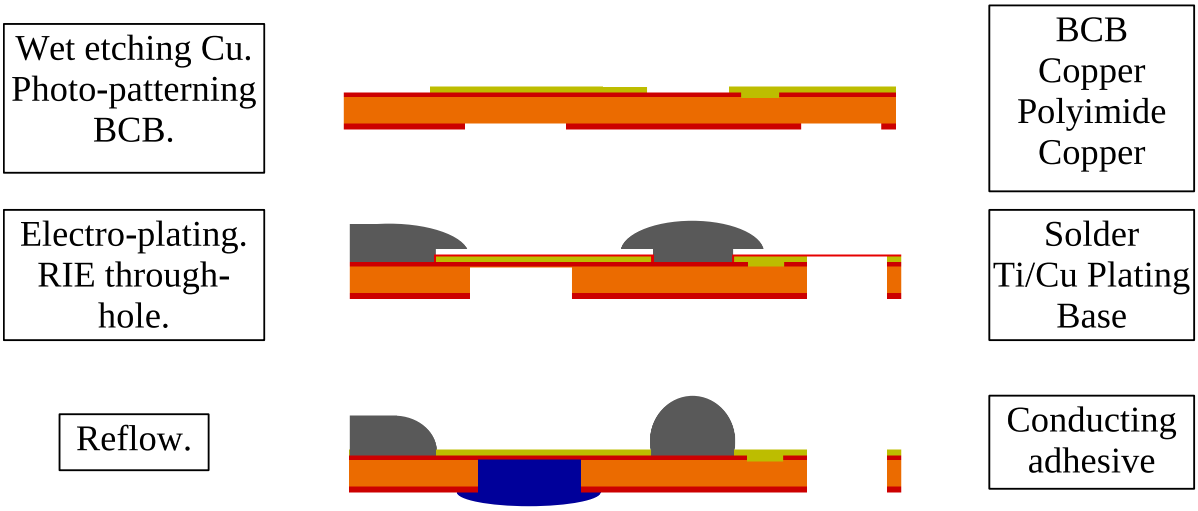

Fig. 3: Process flow and layer build-up.

An additional step to plate electroless nickel on the die pads is necessary to form a wetting surface for flip-chip assembly of the amplifier die, since it is delivered with Al pads for wire-bonding.

Discussion.

Despite the use of standard process techniques and commercially available materials, the substrate manufacturing involves several steps which are rather unconventional, and are still under development to obtain increased reproducibility and improved quality. One of the most important issues is the handling of the flexible substrate, which limits the performance of some MCM-D processes and implies sometimes unexpected pit-falls in the processing. Some other examples of process steps to be improved are; The photo-patterned dielectric (BCB) used for passivation to avoid conventional passivation lithography, RIE of through-holes and vias, and substrate solder bumping by electroplating. However, the results show that they do combine to a rather straight-forward process flow for manufacturing of the very compact building practice based on the present design and materials.

In Fig. 2 there are through-holes in the Kapton foil for the light input, but the loss passing through 25 µm Kapton at a wave length of 1.3 µm is very low, approximately -0.2 dB. Reflection may occur, but keeping a Kapton window will protect the optoelectronic component in an efficient way, and this will be further investigated.

The present module is a demonstrator for processability, functionality, and performance. In a commercial version the packaging would be more rigid and hermetic for mechanical and environmental protection.

The module described here is a receiver module, but the same design may be used also for transmitter modules. Using light emitting diodes as light source the alignment requirement is moderate, but with the described manufacturing concept it is in principle possible to also meet the requirements of laser diodes and single mode fibers.

Summary.

We have shown the feasibility of a promising technique to manufacture an optoelectronic receiver MCM with design having many advantages:

MT compatibility enables the use of standardized optical connectors and array components for optoelectronic conversion.

High precision passive alignment of components reducing assembly cost.

Direct light coupling without any mirrors, wave-guides, or pig-tails improves performance and reduces optical losses.

The combination of the MCM-D process technology with flexible substrate and flip-chip assembly offers an extremely compact device.

Flip-chip mounting of dies, impedance controlled transmission lines, and BGA type package interconnect offers very good electrical performance.

The process flow, materials involved, and the assembly method enable volume manufacturing at a very low cost per data rate.

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