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Development of a large-area, light-weight module using the MALTA monolithic pixel detector

F. Dachs [a,*], P. Allport [b], I. Asensi Tortajada [a], D.V. Berlea [c], D. Bortoletto [d], C. Buttar [e], E. Charbon [f], V. Dao [a], H. Denizli [g], D. Dobrijevic [a,h], L. Flores Sanz de Acedo [a,e], A. Gabrielli [a], L. Gonella [b], V. Gonzalez [i], G. Gustavino [a], M. LeBlanc [a], K.Y. Oyulmaz [g], H. Pernegger [a], F. Piro [a,f], P. Riedler [a], M. van Rijnbach [a,j], H. Sandaker [j], A. Sharma [a], W. Snoeys [a], C.A. Solans Sanchez [a], T. Suligoj [h], M. Vásquez [i], M. Vicente Barreto Pinto [k], J. Weick [a,l], S. Worm [c], A.M. Zoubir [l]

[a] *CERN, Switzerland*
[b] *University of Birmingham, United Kingdom*
[c] *DESY, Germany*
[d] *University of Oxford, United Kingdom*
[e] *University of Glasgow, United Kingdom*
[f] *EPFL, Switzerland*
[g] *Bolu Abant Izzet Baysal, Türkiye*
[h] *University of Zagreb, Croatia*
[i] *University of Valencia, Spain*
[j] *University of Oslo, Norway*
[k] *University of Geneva, Switzerland*
[l] *University of Darmstadt, Germany*

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ABSTRACT

The MALTA pixel chip is a 2 cm × 2 cm large monolithic pixel detector developed in the Tower 180 nm imaging process. The chip contains four CMOS transceiver blocks at its sides which allow chip-to-chip data transfer. The power pads are located mainly at the side edges on the chip which allows for chip-to-chip power transmission. The MALTA chip has been used to study module assembly using different interconnection techniques to transmit data and power from chip to chip and to minimize the overall material budget. Several 2-chip and 4-chip modules have been assembled using standard wire bonding, ACF (Anisotropic Conductive Films) and laser reflow interconnection techniques. These proceedings will summarize the experience with the different interconnection techniques and performance tests of MALTA modules with 2 and 4 chips tested in a cosmic muon telescope. They will also show first results on the effect of serial power tests on chip performance as well as the impact of the different interconnection techniques and the results of mechanical tests. Finally, a conceptual study for a flex based ultra-light weight monolithic pixel module based on the MALTA chip with minimum interconnections is presented.

1. The MALTA family of radiation hard monolithic silicon pixel detectors

The goal of MALTA is to develop a radiation hard (2.0×10^{15} 1 MeV n_{eq}/cm^2, >100 Mrad), high-granularity (36.4×36.4 μm) and large-area (2×2 cm^2 realized, 3×2 cm^2 foreseen) monolithic silicon pixel detector with a small charge collection electrode design. Two full-sized versions, MALTA and MALTA2, have been produced with the third generation, MALTA3, currently under design [1–3].

Within CERN EP R&D WP1.3 and followed also by AIDAinnova module development studies are done with MALTA and MALTA2. These detectors feature the necessary periphery to be assembled into modules using wire bonds or potentially other interconnection techniques currently under study.

2. Fully integrated 4-chip module telescope

Multiple 2-chip and 4-chip modules have been assembled integrated into a mini-telescope setup for testing as well as firmware and software development (Fig. 1). A 40 MBq Sr-90 source was mounted 115 mm over the top plane to restrict incoming particle tracks to a narrower

* Corresponding author.
E-mail address: florian.dachs@cern.ch (F. Dachs).

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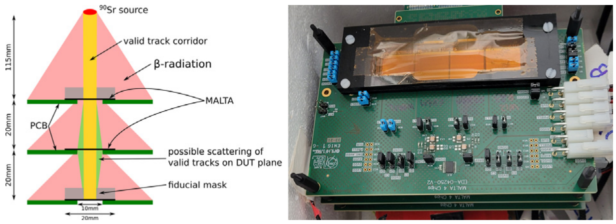

Fig. 1. Photo and sketch of the MALTA 4-chip module telescope setup.

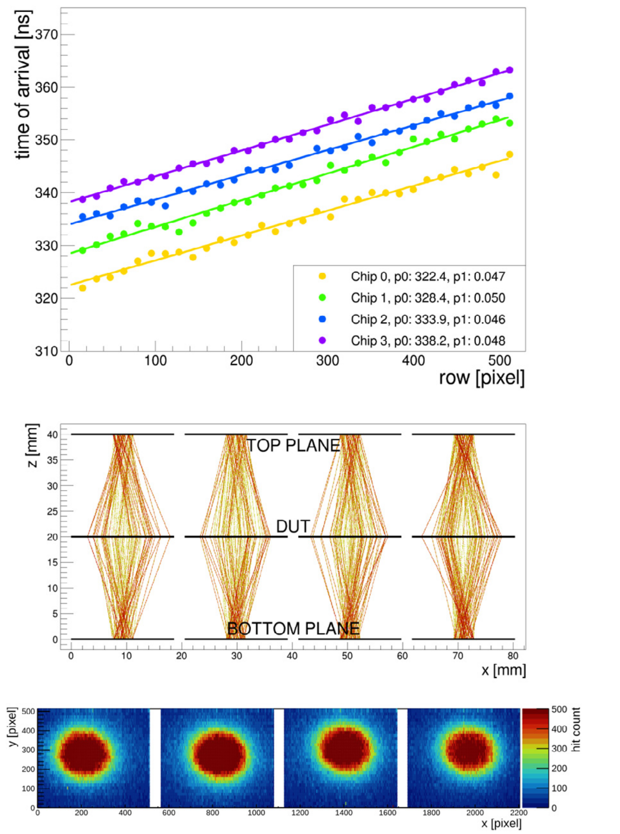

Fig. 2. Top: Time of arrival of signals from different locations on the module. Middle: Reconstructed tracks from a Sr-90 source. Bottom: Sr-90 source scan of a 4-chip module under constrained power conditions.

angle. Additionally, fiducial masks were applied to the chips of the top and bottom modules to reduce the active area of their pixel matrix to the central 100×100 pixels. The middle module acted as a device under test (DUT) with the full pixel matrix enabled on all chips to maximize the number of recorded tracks despite the severe multiple scattering.

Signal timing tests were done for all individual modules (Fig. 2, top). The slopes of the linear fits show the time delay caused by the signal transfer across the pixel matrix of an individual chip which is 0.05 ± 0.005 ns per row and composed of the travel times of the trigger signal to the matrix and the pixel response to the periphery. The vertical offsets of all four fits show the delay caused by the chip-to-chip data transfer which is 5.5 ± 0.5 ns per transfer. To verify the trigger and readout chain, rudimentary particle tracking was done with an Sr-90 source. A visualization of the reconstructed tracks is shown in the middle of Fig. 2. Source scans were performed for each module in a full powering configuration (all chip-to-chip and chip-to-pcb connections active) and a constrained power configuration (serial power connection via the primary chip, parallel ground connections to the PCB for all chips, see Fig. 2, bottom).

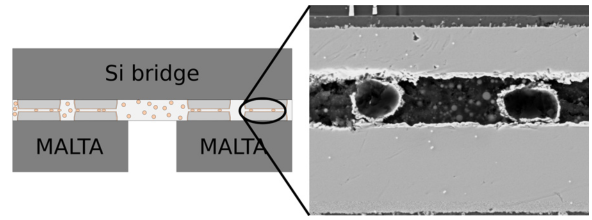

Fig. 3. A silicon interposer ("Si-bridge") in combination with ACF can replace chip-to-chip wire bonds.

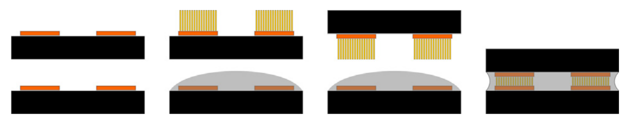

Fig. 4. Nano wires are grown on the pads of one or both devices that need to be interconnected. The assembly is done in a flip chip process and with an optional glue layer for better mechanical stability.

The presented tests demonstrated the full functionality of multi-chip MALTA modules using ultrasonic Aluminium wedge wire bonding to establish chip-to-chip connections for data transfer. The modules are now being tested in a high momentum particle beam at CERN.

3. Alternative interconnection techniques

Anisotropic conductive films (ACF) and nano wires are studied as possible alternatives to chip-to-chip wire bonding with the possibility to reduce the package size and material budget, improve mechanical stability and scale more favourably with a high number of densely packed connections.

Specifically for MALTA, a silicon interposer (Si-bridge) is delivered together with the chip on the same reticle. This Si-bridge can be used with ACF to form a mechanical and electrical chip-to-chip connection as shown in Fig. 3. The ACF module production process has by now been fully set up and mechanically intact modules can be produced routinely. Electrical tests are still ongoing.

For a light-weight flex module design (introduced in Section 4) nano wires may offer another promising alternative. This technique offers a very low resistivity for interconnections and is less susceptible to the planarity of the ENIG (Electroless Nickel Immersion Gold) layer of the pads compared to ACF (Fig. 4). The technique can be combined with a glue layer to improve the mechanical stability of the connection.

4. Development of a super light-weight demonstrator flex module

Using flip chip mounting a more compact module with reduced inactive regions can be assembled. A dedicated flex circuit has been developed using an very fine pitch fabrication technology based on a photo-lithographic process. The interconnection between MALTA chip pads and the flex can be achieved using ACF or nanowires, both processes currently being under evaluation. The design of the flex circuit has been finalized with a thickness of only 50 μm and is now in production. It features traces with a 17 μm width and clearance which is compatible with the high pad density of MALTA2, length matched connections for the 40 bit parallel LVDS (Low Voltage Differential Signal) readout and back-side contact pads to ensure proper sensor biasing. Extensive debug capabilities are included which allow to trigger pixels on each chip for readout tests, monitor all DACs and configure the power supply for each individual chip.

5. Conclusion

The MALTA monolithic pixel chip offers a radiation hard large-area detector with high granularity and a module-compatible pad layout with chip-to-chip data and power transfer. Several 2-chip and 4-chip modules have been assembled and extensively tested for the first time in preparation for beam tests at the SPS test beam area at CERN. In parallel, new interconnection techniques, anisotropic conductive films and nano wires, are studied as possible alternatives to chip-to-chip wire bonds. Both techniques offer improved mechanical robustness and scale favourably with a large number of densely packed contact pads. The design of an ultra-light 50 μm thin flex circuit to package four MALTA2 chips has been finished and production is currently ongoing. This flex module will be assembled in a full flip chip process with the possibility to use either ACF or nanowires for interconnection.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] E.J. Schioppa, et al., Measurement results of the MALTA monolithic pixel detector, NIM:A 958 (2020) 162404, http://dx.doi.org/10.1016/j.nima.2019.162404.

[2] H. Pernegger, et al., Radiation hard monolithic CMOS sensors with small electrodes for High Luminosity LHC, NIM:A 986 (2021) 164381, http://dx.doi.org/10.1016/j.nima.2020.164381.

[3] F. Piro, et al., A 1-μW radiation-hard front-end in a 0.18-μm CMOS process for the MALTA2 monolithic sensor, IEEE Trans. Nucl. Sci. 69 (6) (2022) 1299–1309, http://dx.doi.org/10.1109/TNS.2022.3170729.