Development and Test of Micro-Cables for Thin Silicon Detector Modules in a Prostate Probe

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***Abstract*–Recent progress in the development of micro-cables for very densely packed silicon pad detector modules to be used in a Compton Prostate Probe is reported. The purpose of this development is to optimize the packaging and interconnection of 1mm thick silicon sensors with their readout electronics in such a way that the assembly thickness is dominated by the sensor thickness. The sensor-chip interconnections are based on aluminum polyimide micro-cables.**

Development of micro-cables demonstrate that TAB technology can replace wire bonding technology, which does not allow optimally dense packaging, with TAB bonded modules which have electronically equally good performance. That gives us a motivation for the development of a detector-cable and chip-cable assembly TABed to a very thin PCB module by a two layer detector cable achieving a total height of only 1.2mm.

I. Introduction

The development and construction of a very thin detector module for Compton Prostate Probes requires packaging of several silicon detectors of 1mm thickness in a very compact stack. The packaging and the heat removal will be important issues for the Compton Prostate Probe. Tape automated bonding (TAB) avoids wire-bonds technology and allow coupling the sensors with the readout electronics using thin, flexible micro-cable. Therefore, the front-end electronics can be moved further away from the silicon sensor, which can be densely packed. A possible realization of such a probe is shown in Fig. 1.

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This technology consists of connecting the pads of an object directly to aluminum printed traces, at the appropriate design, on a kapton flexible cable that carries the electronic signals to the next connection pads. The soldering is done by using special ultrasonic wedge bonding.

The initial material is a lacquer-foiled dielectric, produced by coating thin aluminum foils with a polyimide lacquer. This material without an adhesive layer is particularly suited to our application, since it allows for a wide range of thicknesses of both the aluminum foil (8 micron to 30 micron) and the polyimide foil (10 micron to 70 micron) and for a very small pitch of traces.

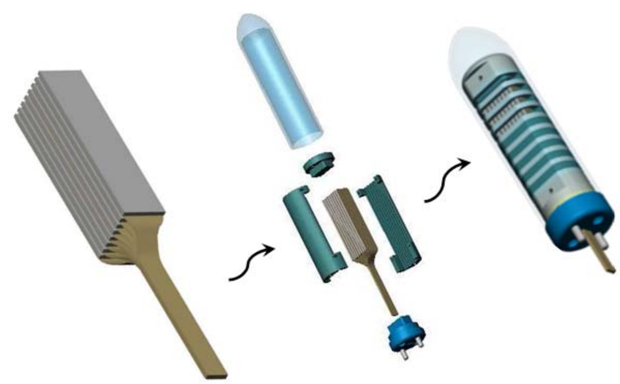


Fig. 1. A possible realization of an intra-rectal prostate probe. The core of device is a stack of densely packed silicon sensors.

The use of a polyimide layer of 70 micron thickness was essential to reduce the load capacitance of the traces on the input of the amplifier to acceptable values. In a previous development the trace capacitance was too high and it caused an increase of electronic noise of a factor 5 compared with standard PCB assembly [5].

For the Compton probe prototype we used 1mm thick silicon sensors, manufactured by SINTEF [7] with 256 1.4 x 1.4mm^2 pads, on a 1.4 cm x 4.6 cm substrate. The pad detectors were fully tested using a standard IC51-3244 socket (Yamaichi, Japan). The detector cable was clamped to this socket and each of the 256 pads was tested separately using a specially designed PCB.

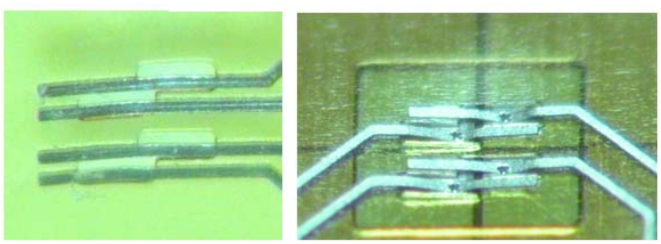
In a similar way 128 channel VATAGP3 [6] readout chips have been connected to a chip-cable implementing the TAB technology. Then the chip-cables were held in a supporting frame and clamped in a standard socket (IC51-4364). For the test we used another custom designed PCB.

After the successful test of the chip-cable and the detector-cable, the 256 pads of the sensor were connected to the input pads of two readout chips by TAB bonding. Finally this detector and chip cable assembly was TABed to a very thin PCB (total height including components of 1.2mm) with a kapton cable soldered to the PCB for connection to the data acquisition system.

II. MICRO-CABLE TECHNOLOGY

The micro-cable technology described here was originally developed by SRTIIM as a low-mass interconnect system for use in space electronics. They used micro-cables with minimum pitch of 45.6 microns and bus assemblies with up to 10 layers.

A micro-cable was made up of a polyimide foil with thickness of 14 microns aluminum traces. Bonding windows were etched in the polyimide foil (see Fig. 2 (a)), so as to be able to press the traces through these windows and bond them directly to the bonding pads beneath.



a) b)

Fig. 2 TAB technology. Bonding windows etched in the polyimide foil a) and Tape Automates Bonding traces on the sensor pads b).

The technique is similar to Tape Automatic Bonding (TAB) but with several important differences. In TAB, traditionally, (1) copper is used instead of aluminum producing more rigid and, hence, fragile traces, (2) gold bumps are used on the pads and all connections are gang bonded in one go while micro-cables are bump–less, and (3) the polyimide foils are much thicker and the required bond forces are much higher than in the micro-cables [1].

The micrograph of connections using TAB technology to bond pads on the silicon sensor, shown in Fig. 2 (b), illustrates the high quality of the TAB bond connections achieved on this module. In particular noise performance and connectivity yield was nearly identical to the performance reached with conventional wire bonded modules.

III. SET UP OF THE ASIC MODULE

In a first step, we produced a chip cable compatible with the 128 channel VATAGP3 front-end chip developed by IDEAS [6]. This chip has been used by our collaboration in prototype Compton probes to readout analog data from silicon pad detectors and, therefore, we have already made extensive studies on its performance when wire-bonded [2].

TABed chips were held in a supporting frame (see Fig. 3) that was mounted on a standard socket IC51-4364 (commercially available from Yamaichi, Japan). The socket itself was mounted on an intermediate board and the latter was connected to the DAQ board in charge of generating the readout sequences.

This setup provides the possibility of testing and evaluating different ASICs and chose the more appropriate before the building of the final module.

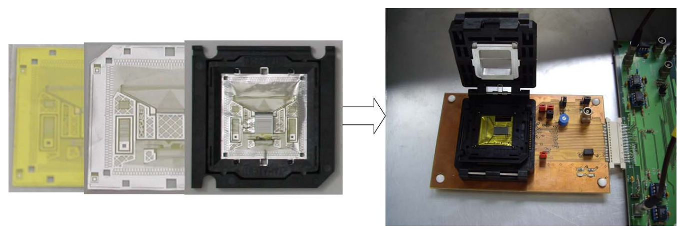
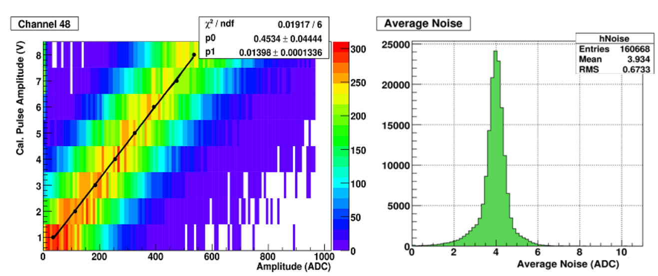


Fig. 3 Setup for test the ASIC module. Simple chip cable: backside, front side and TABed chip in supporting frame (left). Clamp module mounted in to intermediate board and connected to the DAQ boars (right).

A. *Results of the ASIC module test*

To check the functionality of the front-end ASIC we used a calibration pulse, generated by an external pulse generator, which was injected on the calibration pad of the chip. This allowed to measure the response curve of the ASIC.

Fig. 4 (a) shows the chips response, in ADC units, as a function of the of the input test amplitude. Fig. 4 (b) shows the average value of the noise also in ADC units. The results are fully compatible with the measurements made on wire bonded VATAGP3 chips [2]. This result, therefore, demonstrates that TAB technology does not introduce any performance penalty. That allows us to proceed to the next phase in the project and produce a full module including two TABed ASICs on the chip cable.



a) b)

Fig. 4 Gain curve (left) and average noise (right) of the VATAGP3 chip using TAB technology for the connections between the ASIC and the DAQ board.

IV. SET UP OF THE DETECTOR MODULE

A silicon detectors (46 mm long, 14mm wide and 1mm thick) [3] was TABed and held in a supporting frame. The frame was housed in a standard socket IC51 – 3244 (Yamaichi, Japan). The clamp was mounted on a custom designed board for the test of the detector cable shown on Fig 5. Each switch allows us to connect each individual pad either to a test output or to ground. In this way we can test each of the 256 pads separately.

By connecting a particular pad to the test point (with all its neighbors to ground) we measured the leakage current on that pad avoiding contributions from other pads, as shown in Fig. 6.

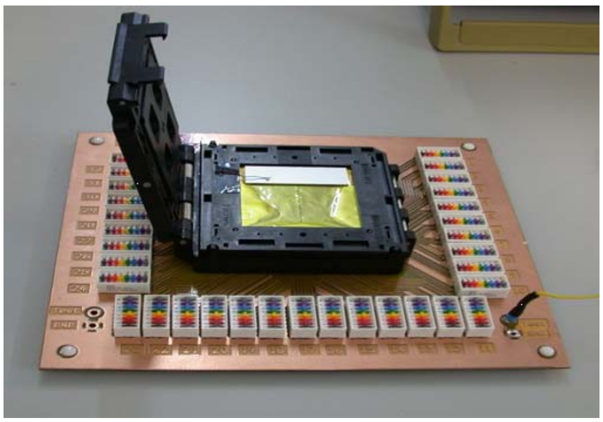


Fig. 5 PCB with clamp for testing the detector cable.

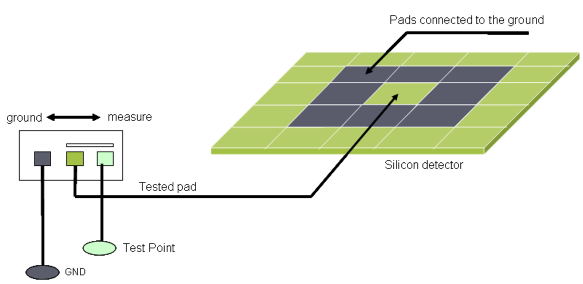


Fig. 6 Sketch of the leakage current measurement of individual pads.

A. *Results of the detector module test*

Fig. 7 (a) shows a collection of single pad IV curves measured on the TABed sensor. The detector bias voltage was scanned from 0 to 155V. The results are also compatible with previous measurements [8, 9] on the same type of sensors made on a probe station. In this case, though, the measurements could only be made on a corner pad while connecting to ground the three surrounding pads and the guard ring. Most of the pads produce a leakage current of about 34 pA at 150 V bias voltage. The measurements were made at room temperature (24ºC).

Fig. 7 (b) shows a map of the sensor pads where each cell represents the leakage current measured on each pad. The number of pads drawing currents compatible with zero (that is, unconnected channels) represents a small percentage and they are concentrated on the periphery. We believe that this failure is due to mechanical stresses produced by handling after the TAB process. The yield is, in any case, as high as 82% according to our measurements. With improved precaution in handling the TABed sensors before the assembly this number would certainly be much higher

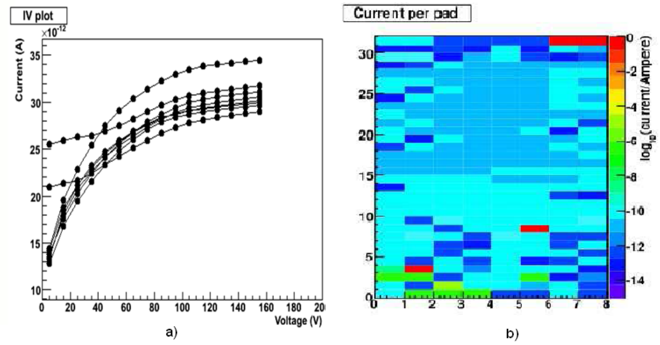


Fig. 7a) IV curves of individual pads measured as described in the text. b) Map of sensor pads where each cell shows in a color scale the leakage current per pad.

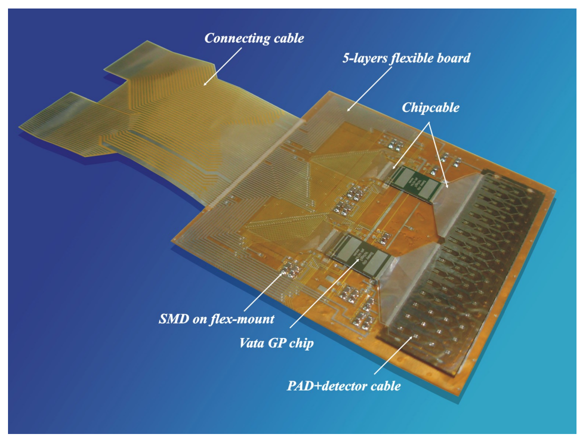


Fig. 8 Detector cable and chip cable assembly TABed to a very thin PCB

V. THIN SILICON DETECTOR MODULE

The next step in the project was to build a module where sensor and two readout chips were connected with micro-cables and only TAB technology was employed. Fig. 8 show a built module which consist of five–layer flexible, thin board, one pixel array detector (with 256 pixels and thickness 1000 µm), two layers detector cable, two VATAGP3 readout chips, two chip-cables and one connecting cable. The last one has a connector at the end, which connect the module to the DAQ system. This module is currently under test.

VI. CONCLUSION

The development of a Compton probe requires improving the package process and that on the other hand involves the construction of very thin micro-cables. The implementation of micro-cables permit to stack silicon detectors one on top of each other to form a detection volume filled with more than 90% of active detector. The gap between detectors can be as thin as the micro–cable plus a glue layer.

For the investigation of the micro-cable technology we developed and tested different micro cables for different modules. First we built the chip module and the detector module implementing micro-cables and TAB technology. The results were encouraging so we proceed to build a thin detector module where the sensor and the two readout chips were interconnected by means of micro-cables. New tests need to be carried out in order to determine the final performance of the last module and start building the thin silicon detector modules for the prostate probe.

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