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Embedded pitch adapters: A high-yield interconnection solution for strip sensors

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A B S T R A C T

A proposal to fabricate large area strip sensors with integrated, or embedded, pitch adapters is presented for the End-cap part of the Inner Tracker in the ATLAS experiment. To implement the embedded pitch adapters, a second metal layer is used in the sensor fabrication, for signal routing to the ASICs. Sensors with different embedded pitch adapters have been fabricated in order to optimize the design and technology. Inter-strip capacitance, noise, pick-up, cross-talk, signal efficiency, and fabrication yield have been taken into account in their design and fabrication. Inter-strip capacitance tests taking into account all channel neighbors reveal the important differences between the various designs considered. These tests have been correlated with noise figures obtained in full assembled modules, showing that the tests performed on the bare sensors are a valid tool to estimate the final noise in the full module. The full modules have been subjected to test beam experiments in order to evaluate the incidence of cross-talk, pick-up, and signal loss. The detailed analysis shows no indication of cross-talk or pick-up as no additional hits can be observed in any channel not being hit by the beam above 170 mV threshold, and the signal in those channels is always below 1% of the signal recorded in the channel being hit, above 100 mV threshold. First results on irradiated mini-sensors with embedded pitch adapters do not show any change in the interstrip capacitance measurements with only the first neighbors connected.

1. Introduction and motivation

The interconnection of sensors and readout electronics is a subject of critical impact in the module design for High Energy Physics experiments, such as ATLAS. The sensors are made progressively larger, and the readout ASICs smaller, and both contain increasingly more channels. On the other hand, the pitch between bonding pads is usually very different between sensors and ASICs, which leads to unrealizable wire-bonding angles between them. With all this, the actual design of the electrical connection between sensors and ASICs is not trivial and it becomes a yield issue when the experiment contains tens or hundreds of millions of strip channels. The question is not anymore if the wire-bonding can be done, but if it can be done reliably enough to build a whole tracker in the required production time.

In the case of the current ATLAS experiment the interconnection was solved by adding external pitch adapters which facilitated the bonding at both sides, sensor and ASIC, and made the pitch adaptation by routing with metal tracks on a high-density metal-on-glass technology [1]. The downside of this solution is that, although the bonding is very much facilitated, the number of bonds is doubled. On top of that, an extra piece is added to the module, increasing the total mass, assembly complexity, and costs. The groups involved in the developments of the ATLAS Upgrade Inner Tracker (ITk) want to avoid this solution. Several studies have been made in order to identify the maximum angle that can be achieved by direct wire-bonding between detectors' and ASICs' bonding pads [2]. Angles below 20° are considered safe, which results in that direct wire-bonding can be used for the barrel design, but for the End-cap a solution might be needed due to the larger pitch variations in the 6 different sensor layouts [3].

In this paper, a proposal to fabricate large-area strip sensors with integrated, or embedded, pitch adapters is presented for the End-cap part of the Inner Tracker in the ATLAS experiment. To implement the embedded pitch adapters (EPA), a second metal layer is used at the end of the sensor fabrication in order to form additional metal tracks which contact the top metal of the strip's coupling capacitor (where the standard AC pad is) with an "embedded pad" that is placed on the sensor right in front of the corresponding ASIC pad. In this way, the routing for the pitch adaptation from sensor to ASIC is done on the sensor itself, and direct bonding from sensor to ASIC is facilitated without the need to double the number of wire-bonds, making the wire-bonding faster and more reliable.

Nevertheless, there are some possible effects that have to be taken into account in the evaluation and use of the EPA:

Inter-strip capacitance: An increase of the inter-strip capacitance can be expected from the increase of the total metal length and from the additional coupling of the second-metal tracks with each other and with the first-metal tracks, especially taking into account that the second-metal tracks have to cross over several first-metal tracks. This increase in the inter-strip capacitance implies an increase in the overall *noise*, thus the sensor channels with EPA will show more noise than the standard one-metal channels. Also, as the inter-strip capacitance in the EPA will depend strongly on the particular design, the noise can also vary from channel to channel, resulting in larger *noise variability* through the sensor.

Cross-talk: Signal transmitted between first-metal tracks (standard detector strip metal) and second-metal tracks (EPA metal) due to the coupling between them. This can result in spurious signals in not hit channels and in loss of signal (*efficiency*) for the hit channel.

Pick-up: Charge that can be induced in the second-metal tracks directly from the bulk when a particle crosses the sensor and charge is created in the bulk. This can also induce spurious signals in channels that are away from the actual hit channel and in loss of signal (*efficiency*) for the hit channel.

Yield: From a technological point of view, as there is an increase of the number and length of tracks plus the addition of an extra photolithographic step with the EPA, this could increase the probability of a short-circuit between channels, or an open circuit in a channel during the processing. This means a possible reduction in the number of good channels per sensor, and consequently also a possible reduction of the number of good sensors in a whole production.

The EPA have been implemented on the sensors fabricated for the prototype of the End-cap part of the ATLAS Upgrade Inner Tracker (ITk), the "petalet" [4,5]. Initial results on these sensors, which had first-generation layout designs, have shown no indication of cross-talk or pick-up from laser tests [6]. Nevertheless an increase in noise and noise variability has been observed in the first modules fabricated with those sensors as can be seen in Fig. 1, where the noise results for petalet modules made with and without the first designs of EPA are shown. These tests were taken using threshold scans on a digital readout system to determine the noise level in electron noise equivalent. Fig. 1 shows the noise per channel comparing typical sensors of "One metal" and "Embedded" designs. The electrical noise stemming from the readout system alone (without the sensors) is 380+/−10 ENC and has not been subtracted in the figure. For a typical one-metal sensor, the ENC