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Electrical / piezo-resistive effects in bend Alpide - Monilitic Active Pixel (MAP) sensors

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Upcoming upgrade of the ALICE Inner Tracking System (ITS3) foresees the use of wafer-scale MAPs bent into a cylindrical shape. Test beams employing the current ALICE Alpide chips, bent to foreseen ITS3 radii, showed that MAPs remain fully functional. However, some electrical effects, like (PS) power supply current changes and voltage shifts, were observed. The results suggest that these are caused by "piezo resistive effect" and FET threshold shifts, probably occurring in the pixel transistors. Some design architectures showed to be less susceptible to these effects and detailed investigations could help in design optimization. This contribution discusses latest test results.

Summary (500 words)

The ITS3 design foresees the replacement of the three innermost layers of the current ALICE tracker (ITS2) with wafer-scale stitched MAP sensors (65 nm) bent to truly cylindrical shapes. Multiple (beam) tests with the existing ITS2 MAP (=Alpide chip, 180 nm) in bent state showed that the Alpide remains fully functional and performance is mostly unaffected.

However, compared to the strain (≈0.1%) induced by bending, there was a relative large (≈10%) change in analog PS current, corresponding to a gauge factor (fractional resistance change / strain) of ≈+83 bend along the long axis and ≈-46 bend along the short axis. Observations can be explained by the "piezo resistive effect" . The gauge factor size and sign reversal are indeed compatible with the known piezo resistive coefficients for N-silicon. It is shown how piezo resistance depends on strain, current and lattice orientation which could eventually be used for design optimization.

The analog PS current change is more dominant than the digital current change, probably originating from the repetitive pixel structure. As the analog pixel section PS current strongly depends on its (transistor) operation point which is set by bias currents and voltages generated by an on-chip DAC, the question arises if the PS current changes originate from changes in the on-chip DAC outputs or occur in the pixel transistors themself. As the Alpide allows forwarding the output signal of a selected DAC to an analog monitoring pin, it can be measured directly how the DAC output is affected by bending and if these changes are responsible for the PS current changes.

A dedicated measurement setup with monitoring pin access was built allowing convex and concave bending over long and short axis. Convex uses a plastic sheet for bending the Alpide over a mandril with curvature radii of 18, 24 and 30 mm as foreseen in ITS3. Concave bending employs porous aluminum profiles where vacuum keeps the Alpide in a bent state.

The DAC outputs indeed change when bent, but this explains only 25% of observed PS current change. Therefore, the main part should occur in the pixel transistors themself. Bent Alpides also show a small pixel threshold shift. The measured DAC outputs even change in the reverse direction, so also here the pixel transistors are likely responsible for the pixel threshold shifts.

The Alpide has 3 types of DACs showing different behavior when bent:
1) Voltage DAC with opamp: No change measured («1%). Unaffected as the resistor ladder divides out changes in individual resistors. The opamp feedback corrects errors in the output stage.
2) Voltage DAC with source follower: Small shift (<1%). Assuming resistor ladder remains unaffected again,

the source follower stage should introduce this shift, which differs from what is expected from the piezo-resistive effect. It seems that another physical mechanism is responsible, i.e. FET threshold shift. Literature reports FET threshold shifts of similar size.
3) Current DAC: Changes ≈2%. No correction mechanism is present.

For the future ITS3 development, additional tests with 65nm test structures are foreseen.

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