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Signal Height and Shape Improvement in TPC Read-out

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Abstract: A read-out chamber for Time Projection Chamber with "C" shaped cathode (pad) like was built and tested. It offers a low gas gain operation, good pulse shape and lightweight constuction. With help of small TPC with moveable field cage and track produced by alpha particle pad response function, cathode to anode pulse hight ratios and pad impulse shapes of the new structure was measured and compared with structures with planar cathodes and two different wire geometries. Cathode to anode ratio was improved from 0.2 (0.4) up to 0.7. Metod for aluminium pad mass production based on precise cold forging was developed and tested.

1. Introduction

Our group is developing Time Projection Chambers (TPC) for several years [1]. Cathode pad read-out is often used for the second coordinate measurement. The cathode to anode signal (C/A) ratio for planar pads is usually of 0.2 0.4. In this paper we describe our development of TPC read-out with C-pads, which allows to increase the C/A ratio up to 0.7. It is necessary for proper signal to noise ratio to use a higher gas gain, which cause, a higher production of positive ions near the anode. It is evident, that a higher C/A ratio will be generally advantageous. There were attempts to increase C/A ratio by ring cathodes [2]. There was an idea to use ring cathodes, or C-pads for TPC Alice, where number of pads exceeded 500 000. We developed a technology of cold forging for mass production of aluminum C-pads.

2. Signals from flat pad and C-pad cathode read-out

Read-out chambers with three different cathode structures (see Fig. 1) were used. Geometry Drift Chamber (DC) had flat pads and alternated anode and cathode wires in the anode plane. Read-out chamber with MWPC geometry had only anode wires in anode plane. In the C-pad geometry aluminum pads were used. The size of all pads (6 6 3 mm) was the same in all read-out chambers.

A precisely movable field cage for drifting electrons from beam of particles from ^{241}Am source was used in the test chamber. The beam was collimated by mechanical collimator and also a small proportional counter with narrow entrance window to the width of 1 mm in respect to the direction along anode wires. Signal from proportional counter triggered the read-out system. Beam to anode distance used in the measurements was 40 mm. It was possible to move the beam along anode wires with precision of 0.1 mm.

Devoted to Prof. Pavel Povinec 65-th anniversary

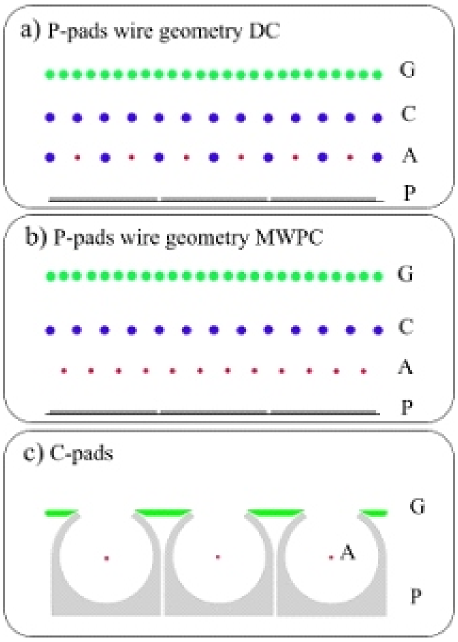

Fig. 1. Read-out structures: a) Planar pads, geometry Drift Chamber-DC, b) Planar pads, geometry MWPC, c) C-pads.

Specially designed fast preamplifiers of the type SR 445 SRS built by SMD technology provided equal response to positive and negative signal, no shaping, equal gain and noise level and also high long term stability of working characteristics. Input and output impedance of preamplifier were 50 . Signal amplitudes were further amplified and measured with oscilloscope and ADC.

3. The shape of signals from P-pad and C-pad cathodes

Large TPCs, e.g. ALICE TPC, working in high track density environment usually use only cathode read-out. Secondary particles identification requires particle energy loss measurements on the level of a few percent, which is a very difficult task. In high track density environment the pile-up from undershoots of hundreds of signals will completely spoil the dE/dx measurements. The solution is to keep the signal undershoot as soon as possible less than 1 ‰ during the whole acquisition time of the TPC (up to 90 μs in ALICE TPC). The signal from planar pads has an undershoot lasting several tens of microseconds. ALICE TPC uses a costly solution with digitizing signal by on-line digital filters in fast digital signal processor (DSP). Amplifier-shaper with RC cir-

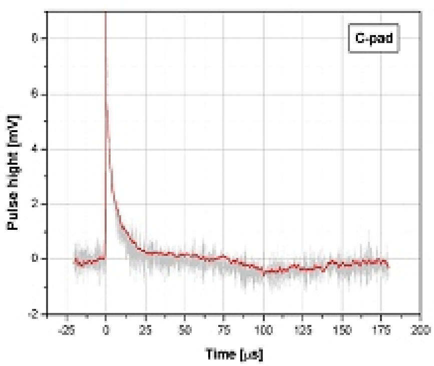

Fig. 2. Pulse shape from C-pad.

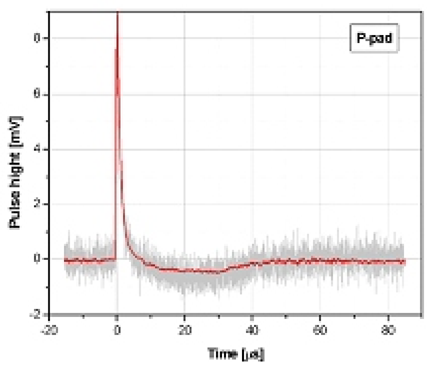

Fig. 3. Pulse shape from P-pad.

cuits, produced by VLSI technology, is not able to cope with this kind of undershoot due to restricted values and precision of usable capacitors. This type of amplifier can process, with required precision, only signals with the 1/t (t is the time of developement of the impuls) shape of the signal tail, which cannot be obtained from planar pads. We studied the possibility to get 1/t shape signal from C-pads.

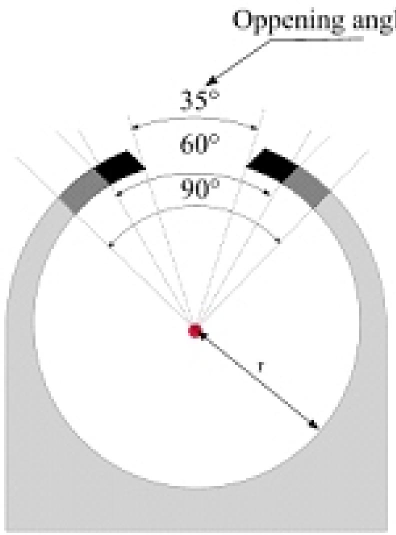

Fig. 4. C-pad used for simulations and measurement.

Measurement of undershoots of the order mV on the main signal with 1 V amplitude is a difficult task. The noise level has to be suppressed well under 1 mV. A special wide band amplifier with 50 impedance symmetric for positive and negative signals was used. The source of ^{241}Am was used in the chamber with drift field described above. The signals from 3 connected pads were measured by a digital oscilloscope with signal averaging function. The shape of measured signals shown in Figs. 2 and 3 qualitatively corresponds to ours expectations and simulations. However, the measured time, when signal is crossing zero and going to undershoot, is 8 μs while simulations gave 6 μs for flat pads. The measured time, when signal is going to undershoot is 70 μs while simulations gave 35 μs for C-pads. We think that the reason is the constant ion mobility, which was used in the simulation, while the real ion mobility in the high intensity field close to anode is lower.

The measurements showed that pulses from C-pads are much more convenient for standard RC chain filtration than pulses from planar pads, as in our geometry they have 1/t shape up to 70 μs.

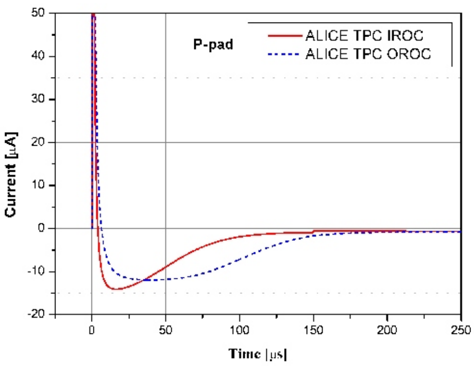

Fig. 5. Signal shape from flat pads from ALICE TPC IROC and OROC with anode-cathode distance 2 and 3 mm, respectively.

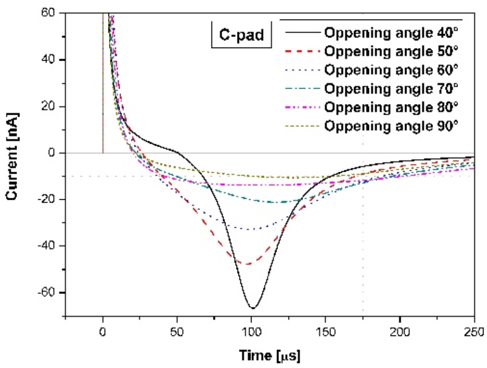

Fig. 6. Signal shape from C-pad with anode-cathode distance 3 mm respectively for different opening angle.

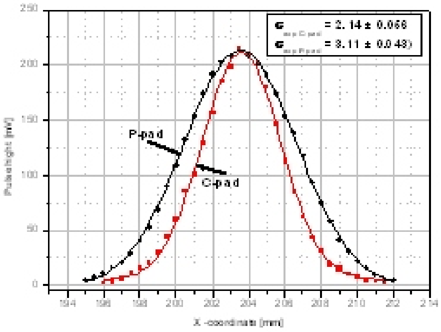

Fig. 7. Pad Response Function for P-pads and C-pads with anode-pad distance 3 mm.

The form of cathode signal from different type of pads and read-out chamber geometry was calculated by the Garfield code [4], which calculates the shape of direct and induced signals in 2 dimensional space. The signal shape was calculated for different C-pad openings angles (35 , 50 , 60 , 70 , 80 and 90) and C-pad radius of 3 mm (see Fig. 4). For the smallest opening angle of 35 the signal shape is close to 1/t as we would get from the cylindrical counter (Fig. 6). For larger opening angles the signal is getting larger undershoot and its shape is more and more similar to the shape of signals from planar pads (Fig. 5). For the opening angle of 35 and Ar + 10 % CO_2 gas mixture the 1/t shape lasts less than 90 µs. We supposed that the undershoot starts only when the ions are going out of C-pad, but as a consequence of complicated field shape inside C-pad, it occurs closer to the C-pad center, so the undershoot starts earlier.

4. Changes in pad response function

Pad Response Function (PRF) was measured in read-out chambers with flat pads and in C-pads. The signal was measured on a fixed pad, while particle beam with the field cage was moved along the anode wire with 0.5 mm steps. The standard deviation of measured charge density distribution $_{exp}$ is determined by the standard deviation of pad response to the point space charge $_{PRF}$, standard deviation of charge expansion caused by diffusion $_{Diff}$ and standard deviation of the beam (track) width $_{track}$

$$^2_{exp} \quad ^2_{PRF} \quad ^2_{Diff} \quad ^2_{track} \tag{1}$$

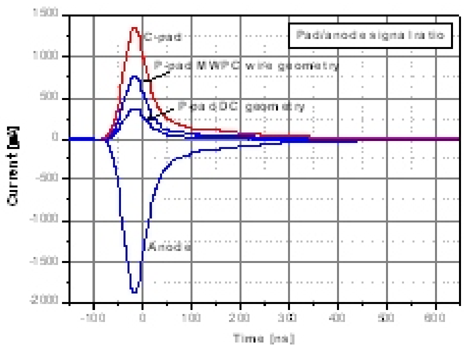

Fig. 8. Signal from anode and signals from three different cathode pads geometries.

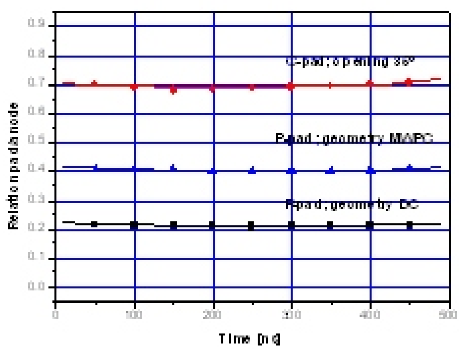

Fig. 9. Cathode to anode signal ratio vs time developement of the signal for three different cathode pads geometries.

In our experiment $_{track}$ = 290 m. For Ar + 10 % CO_2 transversal diffusion $_{t}$ = 250 m/ cm and 40 mm drift $_{Diff}$ = 500 m. High ionization density of particle tracks allowed to reach precision of amplitude measurement on the level of 1 ‰.

The measured pad response functions in Ar + 10 % CO_2 for planar pads and C-pads of the same anode-cathode distance *d* are shown in Fig. 7. For C-pads the measured value $_{\mathrm{exp}}$ (C-pad) = 2.14 0.06 mm brings to $_{PRF}$ (C-pad) = 2.06 0.07 mm. For planar pads $_{PRF}$ (P-pad) = 3.06 0.05 mm. In the case of C-pads PRF width corresponds to *d*/ 2 where *d* is the pad-anode distance, while PRF is close proportional to *d* for planar pads. Narrower PRF from C-pads is by no mean advantageous for high track density environment in a TPC.

5. Enhancement of cathode to anode signal (C/A) ratio

Amplitude of cathode signal is important for a good signal to noise ratio in the TPC. We measured C/A ratio for three different cathode read-out systems shown in Fig. 1. Input time constant of the front-end electronics for a TPC is typically around 200 ns. C/A ratio was measured by the oscilloscope as a time dependence of the amplitude. The signals from three different cathode geometries and also signal from anode is shown in Fig. 8. The ratio of cathode to anode signal in different integration times is shown in Fig. 9. C/A ratio is practicaly constant with small increase caused by the decrease of space charge shielding by the anode as ions are moving out from the gas gain space inside the critical radius around the anode. C/A ratio is ~0.2 for DC geometry often used in TPC chambers, C/A is 0.4 for MWPC geometry and it is 0.7 for C-pad geometry. From the charge distribution in a C-pad with 35 upper opening, C/A ratio should be up to ~0.9. However, the shape of the electron avalanche at the low gas gain range (~10^4 which are often used in TPCs) is shaped drop-like around direction of the primary ionization arrival on the top of anode wire. As positive ions drift back along the same field lines it is shown that 30 % of signal is induced by the ions on the other electrodes than the C-pad (e.g. on the gating strips).

6. High precision cold forging of aluminum C-pads

Large Time Projection Chambers (as Alice TPC) may require hundreds of thousands pads precisely produced and positioned in the chamber. For this purpose we developed a technology of a high precision cold forging of aluminum C-pads. For TPC geometry C-pads were designed with dimensions 6 6 3 mm with ±0.02 mm production and positioning precision, which should allow the maximum signal fluctuation along the anode wire %. A scheme of two C-pad rows with gating strips is shown in Fig. 10.

High precision cold forging was developed for production of aluminum C-pads. We learned by simulation and also in practice that it is very difficult to forge a high precision C-pad by one stroke. C-pad production has a sequence of several steps. In the first step a precisely defined portion of aluminum is cut. In the second step a U-pad, higher then the final one, is produced. In the next step the height of the pad is cut with the angle of 15°. The last step is bending of the U-pad arms to the inner radius of 3 mm. All these procedures are made in one semi-automat, from which ready-to-use C-pads are falling to the container. Schematics of the developed devices are in Figs. 11 and 12.

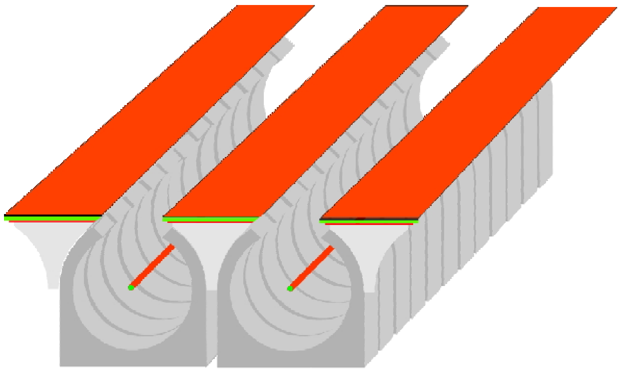

Fig. 10. TPC readout structure with C-pads and gating strips.

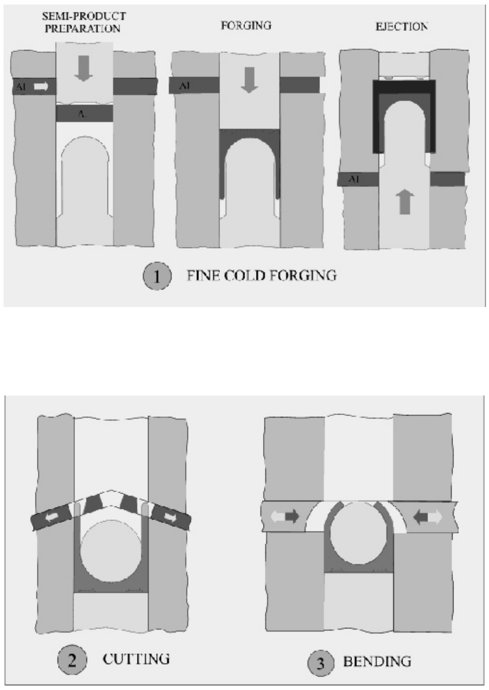

Fig. 11. Devices for C-pads mass production with multistep approach.

Each C-pad has two holes in the bottom side, which allows its positioning to the board with precision of ±0.02 mm. Several thousands of aluminum C-pads were produced by high precision cold forging technology and several cathode read-out systems were produced and tested. A precise positioning was made by pins in the board and holes in pads. The bottom part of C-pad was gold plated by sputtering and then fixed to the board by conductive glue. A part of cathode read out board with aluminum C-pads is shown in Fig. 13.

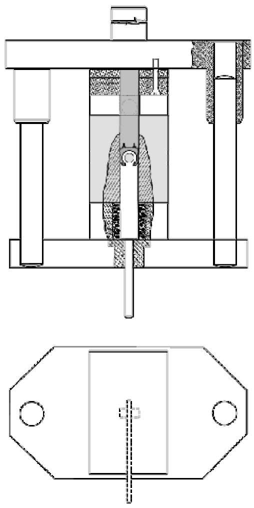

Fig. 12. Scheme of the tool for C-pads mass production.

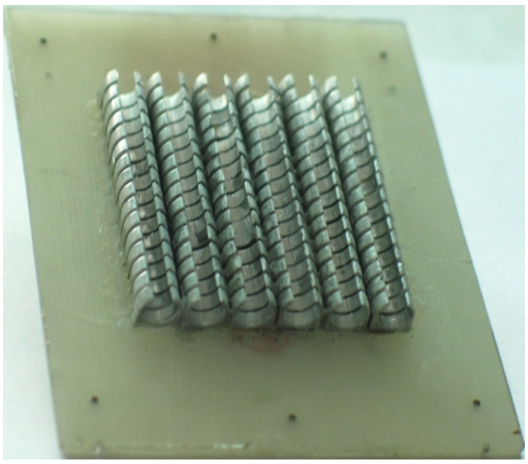

Fig. 13. A part of cathode read-out structure with aluminum C-pads.

Tests showed that aluminum C-pads could be produced in large quantities and they are good quality elements for cathode read-out of large TPCs.

7. Conclusions

Simulations and measurements showed that change of classical planar pads to C-pads allow to create readout structure for TPC working in large track density environment.

Pulse hight and shape are good enough for making tracking and particles identification in such a hard conditions. Gating is also possible using gateing strips lying on bars situated between too pad rows. Gateing voltage is hovewer higher (250 V) in comparison with gateing mesh (50 V) used in majority of the classical TPC readout structures.

References

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