Contribution ID: **86** Type: **Poster**

Performance of a novel charge sensor on the ion detection for the development of a high-pressure avalancheless ion TPC

Thursday 5 October 2023 18:40 (20 minutes)

We will report the performance of Topmetal-S chip, a charge sensor specifically designed to directly sense ions for the high-pressure ion TPC of NνDEx experiment for neutrinoless double-beta decay search.The signal waveforms were investigated with various experiments and chip configurations.The equivalent noise charge of Topmetal-S is measured to be 120 e^-.Different ions species, both with negative or positive charges, could be detected by the sensor.The mobilities of majority ion charge carriers are measured for negative (positive) species in air and SF_6 respectively.The expected precision of the drift distance reconstruction using different velocities of ion species are discussed for NνDEx experiment.

Summary (500 words)

{\bf The chip.} Topmetal-S is a chip designed for NνDEx experiment, the goal of which is to search for the neutrinoless double beta decay signal of Se-82 using high-pressure gaseous TPC. The choice of using SeF_6 as the working gas means ion drift detection. The topmetal technique, thanks to its low noise, makes this possible while keeping high energy resolution. The chip now is in its second version and the test results look promising.
The classic single-end folded cascode structure is used in the chip. The bias voltages could be provided either from the internal DAC or from the external voltage sources. The discharge is controlled by an nMOS. The routing of each bias is surrounded by the shielded metal layers just as the coaxial-cable to reduce the interference.

{\bf The waveform.} Due to the small drift velocity, the waveform of the ion signal should be long enough. In the chip design, the decay time could be adjusted by tuning the bias voltage of the discharge nMOS. The rise time could be tuned in the range from 0.08 to 3.3˜ms, and the falling time in the range from 8˜ms to 1.6˜s, making it also work for high rate events.

{\bf The ENC.} The equivalent noise charge is measured using a test pulse injected from the guard ring, and it's found to be 120e. The dynamic range of the chip is 400 - 52000e. And it shows good linearity in this range. The ENC is also constant in this range. As a cross-check, an external capacitor is connected to the topmetal and by injecting reversed pulse from the external capacitor we can verify the capacitance of the guard ring.

{\bf Ion drift.} A small TPC is used to test the ion drift detection both in Air and Argon. A ^{241}Am alpha source is placed on the side of the field cage to provide the ions. With the drift E field from 200 to 800 V/cm, both positively and negatively charged ions in air are detected. Using a scintillator to provide the ionization time, the drift velocity of positively charged Argon ion is measured in the various pressures in the range 1-3 AMT. The measured mobilities are consistent with the numbers in literature.

{\bf Impact to the experiment.} The successful ion detection and good energy resolution provide a proof-of-the-concept for the NνDEx experiment. Further development of the chip is ongoing. In the next version, a module providing network readout will be added. And further tests using the chip to measure the mobility of the SF_6 gas are planned. Multiple species of the ions provide a unique way to measure the Z coordinate of the decay position, which is important to verify the 3D tracking capability for the NνDEx experiment.

Thanks to the good energy resolution and ion detection, we can foresee that there are wide applications for this type of chip, although the chip is not suitable for very high-rate events.

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Session Classification: Thursday posters session

Track Classification: ASIC