Properties of Groove Chambers

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Abstract

Groove chambers with different pitch and gap height have been tested. Gas amplifications of the order of a few times $10^3$ have been obtained. Combining a groove structure with a GEM pre-amplification foil a gas gain of $10^5$ was reached. The device is robust and can be produced at low cost in large sizes by a laser technique.

1 Introduction

Since the development of the Microstrip Gas counter [1] a large variety of detectors based on lithographic patterns and gas amplification have been invented. The expensive and fragile MSGCs with the thin anode lines have been replaced by simpler and more robust structures. Among the post MSGC developments (for a review see ref. [2]) the GEM [3] and its derivatives the Multi-GEM (MGEM) devices have become the dominant line. A disadvantage of MGEMs is the requirement of several gas gaps which increase the mechanical complexity and lead to longer drift times which in turn may cause overlapping signals at high rate.

The groove chamber [4] operates in a similar fashion as the GEM. Combining the readout board with the GEM it suppresses the disturbing last gas gap of a MGEM and provides in addition a two-dimensional readout. A schematic picture of a groove chamber is shown in Figure 1.

2 Construction of the chamber

The production steps are illustrated in Figure 2. A printed board with the anode lines, a partially polymerized prepreg of epoxy with aramid fibers and

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a copper foil are pressed together. Heating the system to a moderate temperature the prepreg is fully polymerized and glued to the printed board and the copper foil. With standard lithographic techniques cathode lines are produced perpendicular to the anode lines at the top copper layer. In the following step, a CO$_2$ laser removes the prepreg material between the cathode lines. The copper reflects the laser light and thus screens the spacer material. Finally the groove has to be cleaned to remove material evaporated during the laser treatment and deposited at the electrodes or the side walls of the groove. The desmearing has been performed with a KMnO$_4$ solution but could also be done by plasma etching.

There are no obvious limitations on the size of the detectors from the production technique. In order to be able to perform a large number of tests we have produced many small detectors which we cut from plates of 40 cm x 40 cm.

Figure 3a shows a cross section of a groove structure$^2$. The spacers carrying the cathode strips have a trapezoidal shape. The aramid fibers embedded in the expoxy matrix are well seen. Figure 3b is a top view showing the regular grid formed by the anode and the cathode lines.

$^2$ To produce the cut through the detector the empty space had been filled with epoxy.
Fig. 2. Sequence of production steps of a groove structure.

Table 1
Geometric constants of detectors

| detector | cathode width | pitch | spacer height |
|----------|---------------|-------|---------------|
| I        | 160           | 140   | 220           |
| II       | 80            | 120   | 170           |
| III      | 70            | 130   | 100           |
To reduce the number of readout channels we always combined ten cathode strips and ten anode strips to one readout channel except for ten adjacent anodes which were readout individually. The sensitive area of the detectors were 31.8 x 28.5 mm$^2$. The anode structure is identical in all three chambers. It is shown in Figure 1 (anode width: 200$\mu$m, pitch: 80$\mu$m). The three different cathode configurations which were produced are summarized in Table 1.

We used a standard gas mixture of 82% CO and 18% Ar. The gas gap was 8 mm and the drift field was about 2 kV/cm. Figure 4 shows the result of a field simulation. The field is rather insensitive to the dielectric constant of the spacer material. In reality, it will be distorted by positive ions deposited
at the side walls of the groove.

We used standard readout amplifiers with a shaping time of $\approx 20\, \text{ns}$ and identical timing for the anode and the cathode channels.

The detector II was operated with GEM pre-amplification. The GEM was produced at the CERN workshop and consisted of a 50 $\mu$m thick polyimid foil cladded on both sides by 10 $\mu$m thick copper layers. The holes were arranged in form of a hexagonal grid, the distance between neighboring holes being 125 $\mu$m. Hole diameters were 40 $\mu$m at the centre and 85 $\mu$m at the copper sides. The foil was stretched 3 mm above the groove structure and 5.5 mm below the drift electrode. The GEM was operated at a maximum voltage of 440 V, corresponding to a gas amplification of about 40. Drift and transfer fields were around 2 kV/cm and 2.2 kV/cm, respectively.

![Fig. 5. Anode pulse height distribution of an Fe-55 source.](image)

### 3 Results

Figure 5 shows Fe-55 spectra with an energy resolution of about 27%, very similar to that of MSGCs or GEMs. The gas amplification is very sensitive to the gap height. Thus we expected rather large gain variations across the chambers. Even though our chambers were quite small, the observed variation reached almost 20%.

The cathode signals are very similar to the anode signals and show a similar energy resolution. Figure 6 is a scatter plot of anode pulse height versus cathode pulse height. It shows the expected strong correlation which could be a useful tool in the analysis of overlapping signals.
The average anode multiplicity (anodes fired per primary photon) is about 2.2 for a threshold of 1% of the total energy. In the pulse height spectrum for the 18% of cases where three anodes fire the escape peak is almost completely absent indicating that a large fraction of these events is due to an escape photon converting at a small distance from its origin. Correspondingly, the escape peak is very pronounced in the 9% of cases where only a single anode shows a signal.

The cathode multiplicity must be at least two. Experimentally, it can be deduced only indirectly because of the cathode grouping. We find a mean value of 2.7±0.7.

We have gauged the gas amplification using the chamber with GEM. Raising
the GEM voltage from zero to 440 V at fixed groove voltage we could determine the GEM amplification and the ADC channel-to-amplitude relation.

Figure 7 compares the gas amplifications of chambers I and II. The discharge limits occurred at a gain of 2000 for chamber I and at 1000 for chamber II. The chambers are not affected by spurious discharges, however continuous sparking of course prevent measurements. Since the spacer of chamber I is much higher than that of chamber II, naively, we could expect a much higher gain for the former. In fact only a moderate improvement factor of two was achieved. The discharge limit is most likely given by the non-uniformity of the electric field caused by surface currents at the groove walls.

Fig. 8. Gas amplification of a groove chamber with GEM pre-amplification.

With the groove chamber with the GEM pre-amplification, gas amplifications in excess of $5 \times 10^4$ were reached. At this regime no sizable deviation of the exponential increase of the gain with the applied voltages was observed (see Figure 8). The relatively large errors in Figure 8 stem from the combination of the various gain factors and the necessity to use voltage dividers to access the full amplification range with a single amplifier.

Results from a similar device to ours have been presented in ref. [5].

4 Possible improvements and conclusions

We are convinced that the present limitations of the groove chamber are related to the ill defined electric properties of the plastic spacer which does not lead to an uniform potential drop between cathode and anode. Ideally, the material should have electronic conductivity independent of the irradiation.
Since large currents have to be avoided for large detectors a large surface conductivity combined with a low bulk conductivity were desirable. Coating the insulator with polycrystalline carbon which was successful for MSGCs and partially also for GEMs [6] is not possible because the CVD process is hampered by the metal electrodes.

We have investigated different prepreg materials and bakelite which has a rather good conductivity. We also tried the famous linseed oil coating which successfully reduces discharges in resistive plate chambers. All these efforts were unsuccessful. Nevertheless we are convinced that there exist technological solutions which would solve the problem and provide gas amplifications of grove chambers of $10^5$. The necessary developments however are expensive as long as there is no interest and engagement from industry.

The results obtained so far indicate that large detectors with an additional single GEM could be a solution superior to triple GEM detectors in many applications. It is mechanically and electronically much simpler. To demonstrate this, large scale detectors have to be produced and tested in hadron beams.

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