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A new generation of GEM detectors and their applications

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ABSTRACT

We have developed a new generation of gas electron multiplier (GEM)-like detectors with double-layered electrodes instead of the commonly used metallic ones: with an inner layer consisting of thin metallic strips and an outer layer made of a resistive grid manufactured by a screen printing technology on the top of these metallic strips. The cathode of this detector has been coated with a CsI layer making it sensitive to UV light. By measuring signals induced by avalanches on the inner metallic strips one can obtain 2-D information about the position of the avalanches. The resistive grid makes the detector intrinsically spark protected: in the case of sparks the resistive layer strongly restricts their current and thus the destructive power. Results of some preliminary studies demonstrating that the new GEMs with resistive grid coating can be used in applications such as RICH counters or for the readout of noble liquid dark-matter detectors.

1. Introduction

Recently developed hole-type gaseous multipliers [1–3] have opened new possibilities in the detection of photons and charged particles. Nowadays, the most popular hole-type detector is the gas electron multiplier (GEM) [3]. Cascaded GEM structures combined with separate signal readout plates have been implemented in the layout of several large-scale high-energy physics experiments at CERN and elsewhere.

One should admit, however, that the GEM is a rather fragile detector and could easily be damaged by sparks, almost unavoidable in long-term operation. The problem becomes more severe in applications requiring single electron detection, when the detector should operate at maximum possible gain. Application examples are RICH counters and noble liquid dark-matter detectors. Moreover, the detection of single photons is necessary for adequate performance in the presence of a radioactive background (natural or created during the experiments) which may produce a great number of primary electrons. Indeed, as soon as the Raether limit [4] is reached, determining the breakdown conditions at high gains, these primary electrons produced by charged particles may trigger breakdowns. Therefore, while operating at high gain, occasional breakdowns are almost unavoidable (as a consequence of fundamental detector physics) and thus one must develop spark-proofed detectors.

In our recent paper a new approach was identified—the use of resistive electrodes manufactured using a screen printing technique instead of metallic one [5]. These detectors operate at gains as high as normal GEMs, however, the discharge energy during sparking is rather small due to the high resistivity of the electrodes. Hence, the detector, like RPCs, is intrinsically spark protected.

In this paper, our latest progress in developing resistive GEMs is described with focus on their immediate possible applications.

2. A new design of resistive GEM: S-RETGEM

The novel design of a resistive GEM, as proposed by us, is shown schematically in Fig. 1 (a more detailed description is given in Ref. [4]). Contrary to the earlier design [5] mentioned above, it has double-layered micropattern electrodes: an inner layer consisting of thin metallic strips and an outer layer comprised of a resistive grid manufactured using screen printing technology on the top of these metallic strips (see Fig. 1). We named this new design a "Strip Resistive Electrodes GEM" or S-RETGEM.

By measuring signals induced by avalanches on the inner metallic strips one can obtain 2-D information about the position of the avalanches (see some results in Ref. [4]). Thus, contrary to conventional GEMs, with this design no separate signal readout plate is needed. Moreover, owing to the high gain achievable in

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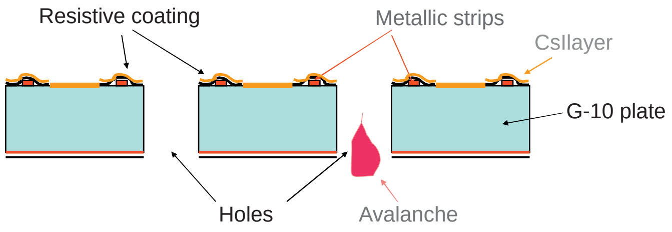

Fig. 1. A schematic drawing of photosensitive (CsI coated) a S-RETGEM cross-section.

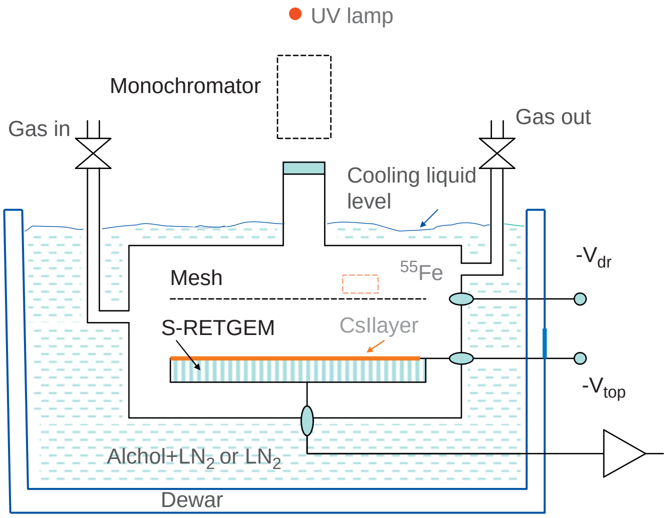

Fig. 2. A schematic drawing of the experimental setup for studies of S-RETGEMs for RICH applications and as a gas amplifier for noble liquid dark-matter detectors.

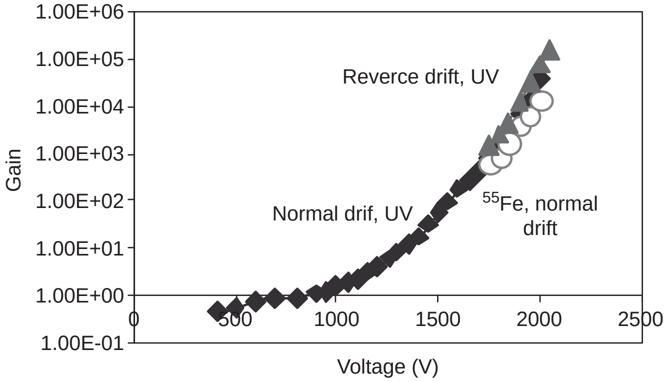

Fig. 3. Gain vs. voltage applied across a photosensitive S-RETGEM operating in Ne+25%CH$_4$. The measurements were performed with a pulsed UV light (filled symbols) and with a ^{55}Fe source (open symbols). Triangles—gain measurements performed with reversed drift field.

some gases, for example in Ne, one can detect single electrons with a single S-RETGEM and therefore, unlike with GEMs, no stack of detectors operating in cascade mode is necessary.

As shown in Ref. [4] a S-RETGEM coated with a CsI layer has a high UV detection efficiency and is stable in the long term. Position resolution measured with UV light was approximately one strip's pitch [4] of ~1 mm, sufficient for some applications.

Below are described results of some preliminary studies indicating that a single S-RETGEM can be used in RICH detectors and in noble liquid dark-matter detectors.

3. Studies oriented on S-RETGEM applications

3.1. Experimental setup

The experimental setup for studies of S-RETGEM for RICH applications and as a charge and light amplifier for noble liquid dark-matter detectors is shown schematically in Fig. 2. It consists of a gas chamber with a CaF$_2$ window inside which a S-RETGEM is installed, a monochromator combined with a Hg lamp and a gas system is provided to pump the chamber or flush it with various gases, Ne, Ar or He or mixtures with various quenchers (H$_2$, CO$_2$ or CH$_4$) at a pressure of 1 atm. S-RETGEMs of various geometries were tested: thickness 0.4–1 mm, hole diameters 0.3–0.8, pitch 0.8–1.4 mm. All detectors had an active area of $5 \times 5\,\text{cm}^2$. The cathodes of the S-RETGEMs were coated with a CsI layer 0.35 μm thick. The procedure adopted to measure the quantum efficiency (QE) is described in Ref. [6].

The gain measurements were performed with a pulsed D$_2$ lamp which enabled read-out of the signal from the S-RETGEM's strips even at a gain of one and in some measurements with 6 keV photons emitted by a ^{55}Fe radioactive source.

In the case of low-temperature tests the detector was placed inside a dewar filled with liquid nitrogen (78 K) or a mixture of alcohol with LN$_2$ (165 K).

3.2. Gas optimization for RICH applications

One of the possible applications of the S-RETGEM which is now under the consideration by the ALICE RICH group could be the upgraded ALICE RICH called VHMPID—Very High Momentum Particle Identification Detector [7]. Simulations show that the position resolution of the VHMPID should be a few mm and its QE at least 12% at 185 nm [8].

Measurements described in Refr. [4] show that CsI-coated S-RETGEM operating in Ne has exactly the QE required—12% at 185 nm. Higher QE, 14–15% at 185 nm was achieved in Ar+5%CO$_2$ gas mixture (presumably due to diminished contribution of the photoelectron back-scattering effect in quenched gases). However, the maximum achievable gas gain in this latter gas mixture (2×10^3) was insufficient for RICH applications.

In order to optimize the gas for the VHMPID photodetector we studied the maximum achievable gain and QE of various S-RETGEM geometries in all gases and gas mixtures mentioned above (the quenchers H$_2$, CO$_2$ and CH$_4$ were chosen due to their good transparency for UV Cherenkov light).

The best results obtained so far were with Ne-based mixtures. As an example Fig. 3 shows the gain curve for Ne+25%CH$_4$. One can see that a gain of 2×10^5 was achieved with single S-RETGEM operating with a reverse drift field (see [4] for explanations).

The QE of the S-RETGEM measured in this gas mixture was ~16% at 185 nm. If one takes into account the geometrical factor (~40% of the area contains holes and thus is not active) the QE of the CsI-coated surface will be ~26%, close to the maximum achievable QE with CsI photocathode. Hence, one cannot expect a better QE from the S-RETGEM. For this reason, we believe Ne+25%CH$_4$ gas mixture is optimal for RICH applications.

In contrast to results described in Ref. [9] we did not observe any clear dependence of the maximum achievable gain on the detector geometry. This indicates that the maximum achievable gain of S-RETGEM, produced by using the screen-printing technique, is basically determined by the production quality. Indeed the maximum gain achieved with a S-RETGEM is usually much below that obtained with a TGEM with the same geometry [9]. Similarly, the QE of S-RETGEMs with various hole diameters and various pitches did not reveal any strong dependence: in the

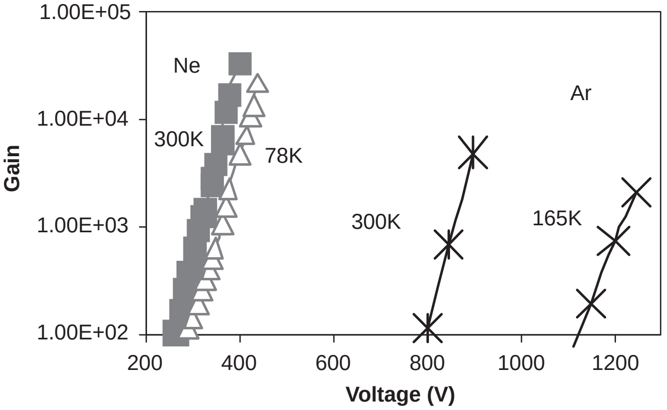

Fig. 4. Gains vs. voltage applied across S-RETGEM measured with ^{55}Fe source in Ne and Ar at 78, 165 and 300 K.

case of Ne+25%CH_4 it always remained in the range 14–16% at 185 nm.

Based on these results we are now planning a beam test in which S-RETGEM combined with a Cherenkov radiator will operate in Ne+25%CH_4.

Another possible application of S-RETGEM, which is also under the study by our group, is as the VHMPID triggering detector [10].

3.3. Tests oriented on dark matter noble liquid detectors

Nowadays, several groups are considering the use of hole-type gas multipliers for detection of the UV light and primary electrons produced by recoils in noble liquid dark-matter detectors. For example, we have earlier demonstrated that a CsI-coated thick GEM (TGEM) is a very robust detector capable of operating stably at cryogenic temperatures up to 78 K [11] (as confirmed by the Novosibirsk group [12]). This group also investigated the operation of the old version of resistive GEM (described in Ref. [5]) and fully confirmed our results obtained with this detector at room temperature. However a strong charging-up effect was observed at 78 K.

Different from the early resistive GEM design described in Ref. [5], the S-RETGEM collects the avalanche charge on the metallic strip surrounding the hole where the avalanche developed. Due to this geometrical feature the charging up effect at low temperatures is expected to be strongly diminished. Our preliminary measurements fully support this assumption. Fig. 4 shows gain curves measured in Ne and Ar at 300, 165 and 78 K and

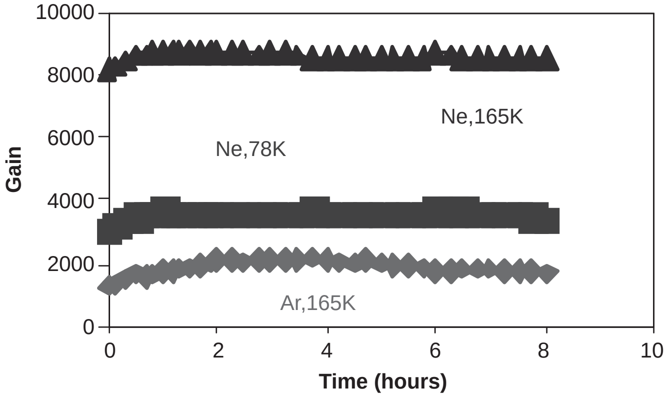

Fig. 5. Gain variations with time measured in Ne at 78 and 165 K and in Ar at 165 K.

Fig. 5 present the results of the stability measurements at these temperatures. It is evident that S-RETGEM does not exhibit any strong charging-up effect and thus could be useful as a noble liquid dark-matter detector.

4. Conclusions

The new UV photon and charged particle detector described in this work, S-RETGEM, is compact, operates at ~50 times higher gains than conventional GEMs, is intrinsically spark protected and in some cases can be used in a single-step configuration.

We believe that owing to these unique properties new GEMs will find a wide range of applications.

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