Letter to the Editor

Comparison between large discharges of a gas counter in pure CH₄ and in a CH₄–Ar mixture

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Comparison between large discharges of a gas counter in pure CH$_4$ and in a CH$_4$–Ar mixture

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Abstract

Gas discharge characteristics in pure CH$_4$ have been studied in the high gas-multiplication region by using a gas counter with a thick anode wire (50 µm in diameter) and compared with those of the self-quenching streamer (SQS) mode in a CH$_4$–Ar mixture. The results of the first optical observation indicate that the large pulses observed in CH$_4$, whose pulse amplitudes are comparable to those of the SQS mode, are not due to streamer discharges. Instead, a luminous region is observed near the anode wire ($r \leq 0.7$ mm) where the electric field is higher than the threshold value for gas multiplication, 10$^4$ V/cm.

The generation of self-quenching streamer (SQS) discharges in gas counters with rare-gas-free mixtures, including pure quenching gases, is an important subject for understanding the SQS formation mechanism. The gas mixtures usually used for the SQS mode operation contain a certain proportion of rare gases; it has been assumed that such rare gases play significant roles in some proposed mechanisms of SQS formation [1,2]. Until now many researchers have investigated the SQS discharges with rare-gas-free mixtures. Some have observed the SQS transition in the avalanche-size curves with pure CO$_2$ or CH$_4$ [3–5]; however, others could not identify the transition [6–10]. Koori et al. obtained the SQS mode operation by use of $^{210}$Po α-rays in pure hydrocarbon gases or CO$_2$, but clear evidence of the SQS transition did not appear on $^{55}$Fe X-ray irradiation in such gases [7].

Direct observation of discharge images, in addition to the avalanche-size measurement, is an effective and informative means to identify streamer formation [1,11–14]. But such an observation in pure quenching gases has not yet been attempted for X-ray irradiation. In the present article, the first observation of discharge images in pure CH$_4$, triggered by X-rays is described and compared with those in a CH$_4$–Ar mixture.

The gas counter used is made of a 150 mm long square brass pipe whose inner cross section is 19.5×19.5 mm$^2$; a gold-plated tungsten wire of 50 µm diameter is stretched along the axis. The effective length of the anode wire is about 130 mm. A part of the cathode wall was removed and a transparent LiF window was attached for optical observations. Therefore, observation of the counter inside from the direction perpendicular to the anode axis is possible, as shown in Fig. 1. Such modification of the gas counter may distort the electric field from that desirable near the optical observation region. In order to avoid distortion, the cathode wires (50 µm in diameter) were stretched every 1 mm instead of the removed cathode wall. A charge sensitive preamplifier was connected to the anode wire to measure the pulse height. Through an aluminized mylar window, the counter was irradiated with collimated $^{55}$Fe X-rays whose spreading width is less than 2 mm inside the gas counter. The counting gas was CH$_4$ (100%) or CH$_4$ (90%) + Ar (10%), which flowed in the counter at atmospheric pressure. The purities of gases were higher than 99.9% for Ar and higher than 99% for CH$_4$. An image intensifier (Night Viewer, Hamamatsu, model C2100) was used to obtain clear images. Observed images were recorded on photographic films or on video tapes.

Fig. 2 shows mean avalanche sizes measured as a function of the applied high voltage. In the plots, discontinuous transition from the proportional mode...
to the SQS mode is clearly identified for the CH₄(90%)+Ar(10%) mixture. On the other hand, there is no obvious transition in the avalanche-size curve for CH₄(100%); nevertheless, the signal charges around 4.5 kV are the same as the streamer charges seen in the CH₄−Ar mixture. For CH₄(100%) the counter operation seemed to be unstable when HV = 4.6 kV, while no indication of a discontinuous transition appeared in the pulse height spectra.

Optical images of large discharges observed in the CH₄(90%)+Ar(10%) mixture and CH₄(100%) are

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Fig. 1. A schematic view of the experimental apparatus used.

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Fig. 2. Avalanche sizes as a function of applied voltage for CH₄(90%)+Ar(10%) and CH₄(100%). The arrows indicate avalanche sizes which correspond to discharges in photographs of Fig. 3.

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Fig. 3. Discharge images observed in (a) CH₄(90%)+Ar(10%), and (b) CH₄(100%). About 1500 discharges are exposed in each photograph. The arrows indicate the anode wire position.
shown in Fig. 3. About 1500 discharges are exposed in each photograph. For CH\(_4\)(90\%) + Ar(10\%), Fig. 3a, a luminous region limited to along the anode-wire direction is observed, which gradually extends towards the cathode with increasing applied voltage. The luminosity distribution is well explained by the integrated radiation of the streamers increasing from the anode towards the cathode. The optical images in Fig. 3a are very similar to the photographs of SQSs taken by Alekseev et al. (Fig. 6 in Ref. [11]). On the other hand, for CH\(_4\)(100\%), luminosity spreading towards the cathode is not evident, as shown in Fig. 3b, though the charge density seems to be high around the position where primary electrons arrive. The glowing region is limited to near the anode wire (r<0.7 mm) where the electric field is higher than the threshold value for gas multiplication, 10\(\text{V/cm}\). Therefore, the discharge may be attributed to the conventional Townsend-avalanche process.

The results of the present optical observation can be summarized as follows. The large pulses observed in pure CH\(_4\), whose pulse amplitudes are comparable to those of the SQS mode, are not due to streamer discharges. Instead, very intensive Townsend avalanches are generated near the anode wire prior to the breakdown. Consequently, the avalanche size reaches about 8\times10^9 electrons without leaping to the SQS mode. The addition of Ar(10\%) to the pure CH\(_4\) gas effectively changes the gas-discharge form and SQS discharges are obtained. This proves the significant contribution of Ar to SQS transitions.

According to streamer theories in a uniformly high electric field [15], for streamer development, additional electrons must be supplied to primary avalanches through some process. With respect to the discharge in a gas counter, a photo-ionization process by energetic photons emitted from rare gases has been considered as the most dominant process for the production of such additional electrons. Therefore, in the present case, a small amount of Ar may work well as the source of energetic photons and lead to a SQS transition in the CH\(_4\)-Ar mixture. On the other hand, in pure CH\(_4\), a SQS transition is not induced due to the lack of available sources of energetic photons; the cross section for such photons from CH\(_4\) is estimated to be about 1/50 of that from Ar atoms [7].

References