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Optical Observation of Self-Quenching Streamers by α- and β-Rays

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Abstract

Optical images of self-quenching streamers (SQSs) in a gas counter have been observed for α- and β-ray, incident charged particles. Individual images of the streamers were obtained by using an image-intensifier system with a gating function. The observation was performed from the axial direction of the gas counter used.

For α-ray irradiation, streamers develop only in two specific directions orienting primary-ionization tracks formed by α-rays. On the other hand, for β-ray, streamers grow in various directions; obtained images are similar to those for X-ray. On the basis of the observation, SQS-formation mechanisms by different sorts of ionizing radiation are discussed. A possible mechanism of "PRimary-Ionization Track ORiented (PRITOR) type SQS" induced by α-ray is proposed.

I. Introduction

Today the gas filled detectors based on the self-quenching streamer (SQS) mode are widely used on high-energy physics experiments [1]. Several models have been proposed to explain the SQS phenomena. But the complete interpretation of the phenomena has not been obtained yet [2, 3, 4, 5, 6].

Optical images of SQSs in gas counters give us useful information to consider the formation mechanism. So far optical observations of SQSs have been performed by X-ray irradiation [2, 7]. Referring to the obtained images, Atac et al. proposed a model of X-ray induced SQS which is based on an electron-feeding mechanism through a photo-ionization process by energetic photons from molecular excited states of Ar [2]. The Atac's model seems to be adequate to interpret the discontinuous transition from the proportional mode. In this model, existence of rare gas, such as Ar, in the counting gas mixture is essential. The importance of rare gas for SQS transition has been shown also experimentally; in a gas filling without rare gas, there was no obvious evidence of SQS transition in avalanche-size curves by X-ray irradiation [8].

On the other hand, for α-ray irradiation, rather different properties of SQS transition have been reported. The first study on α-ray induced SQSs has been performed by Koori et al. [8, 9]. They observed clear SQS transitions in some sorts of sole quenching gas filling such as CH_4. This result can not be explained by the mechanism based on the photo-ionization process. The mechanism of SQS formation by charged particles, such as α- or β-ray, may be different from that by X-ray because such charged particles form ionization tracks in gas counters [8, 9, 10]. There is, however, no article reporting optical images of SQSs induced by α- or β-ray.

In the present work, by using an image-intensifier system, optical observations of SQSs by α-, β- and X-ray have been performed from the axial direction of a gas counter. Shapes and directions of the streamers developing around the anode wire are studied by the analysis of obtained images. SQS-formation mechanisms for different ionizing radiations are discussed.

II. Experimental Procedure

We used a gas counter made of 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 in diameter is stretched along the axis as an anode. A transparent quartz-window is arranged to obtain an inside view of the counter from the axial direction. The counter was irradiated by collimated ^{210}Po α-rays, ^{90}Sr β-rays or ^{55}Fe X-rays through a 7 μm thick aluminized mylar window. Gas mixture was Ne(70%)+CH_4(30%), Ar(70%)+CH_4(30%) or CH_4(100%); the gas flowed in the counter at atmospheric pressure.

Arrangement of observation apparatus is illustrated in Fig.1. In order to obtain individual images of streamers, we used two different types of image-intensifiers, Hamamatsu Model-C2100 (Night Viewer) and Hamamatsu Model-C4273, optically connecting with each other in tandem. Images are stored at a phosphor plate built in the first stage image-intensifier, Model-C2100; gating is accomplished by gate-pulse input to the second stage image-intensifier, Model-C4273. The gate pulses are triggered by the signals obtained from the anode wire of the gas counter. In order to avoid overlapping of images of different events occurring successively in short time intervals, a one-shot gate generator was used successfully. Sometimes we used merely Model-C2100 (Night Viewer) for the purpose of having properly-integrated images. Obtained images were recorded on photographic films with a camera or on video tapes with a CCD camera.

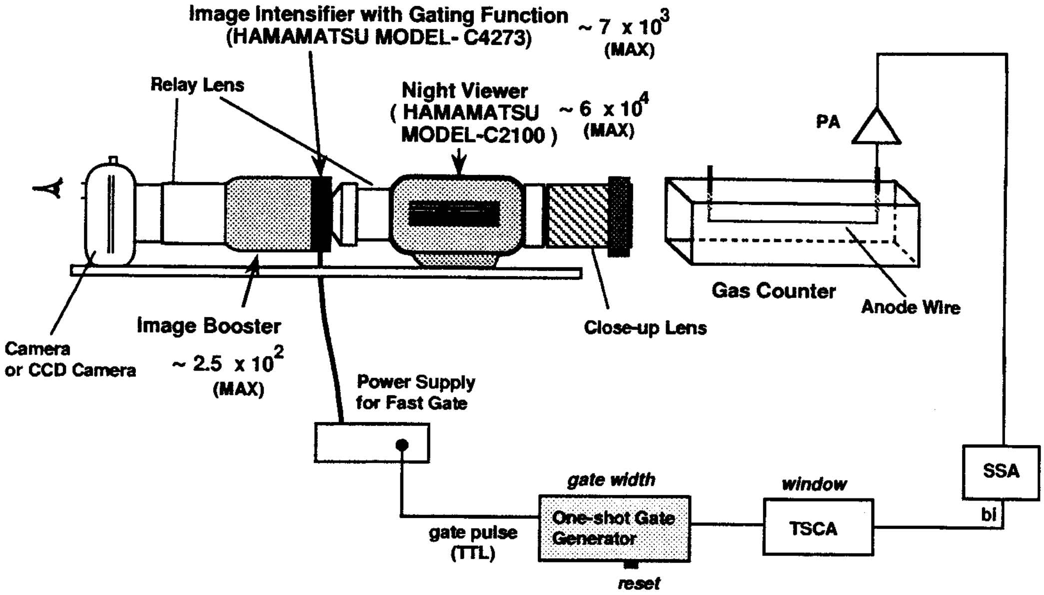

Fig.1 Arrangement of the observation apparatus.

III. Results and Discussion

A. *Primary-Ionization Track Oriented SQSs by α-rays*

Figure 2 shows photographs of SQS discharges obtained in a Ne(70%)+CH_4(30%) mixture by α-ray irradiation [10]. The α-ray source was put at different distance *d* from the mylar window of the counter and a fixed incident height *h* = 6 mm from the anode wire. About 60 streamers were exposed on each photograph. As shown in the figures, streamers develop, from the anode wire towards the cathode, only in the specific directions orienting primary-ionization tracks formed by α-rays; they are mono-directional for *d* = 14 mm (a) and bi-directional for *d* = 9 mm (b) and 4 mm (c).

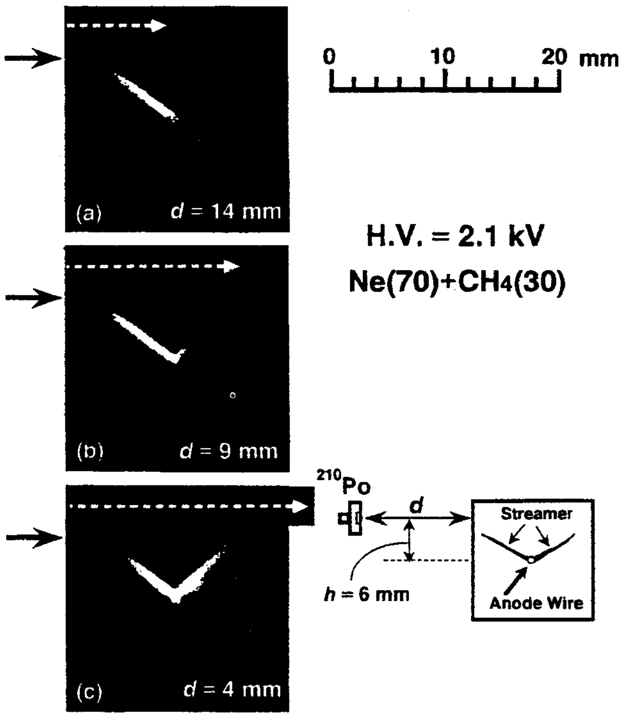

Fig.2 Integrated images of SQSs in a Ne(70%)+CH_4(30%) mixture by α-ray irradiation. Left-side arrows indicate the incident positions and directions of α-rays. The ranges of α-rays are shown by white broken-lines.

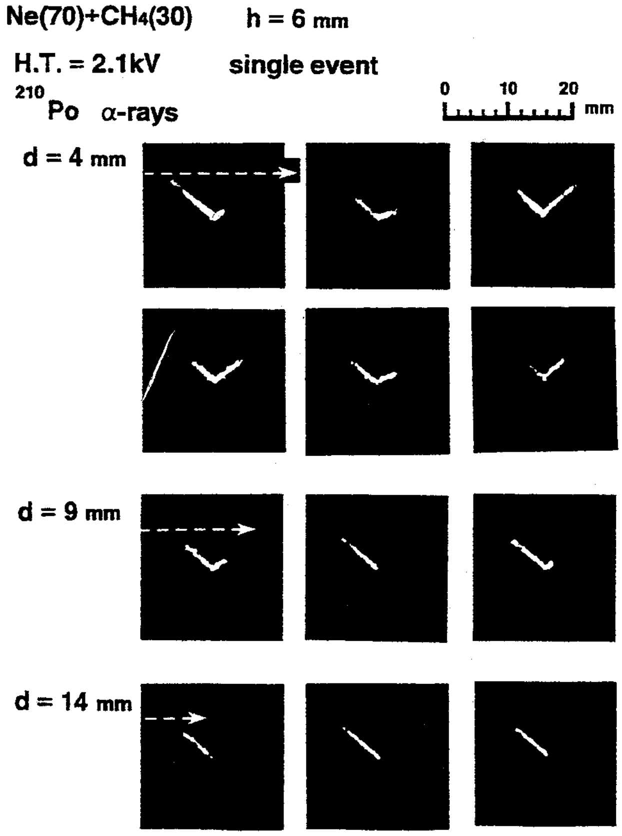

Fig.3 Individual images of SQSs in a Ne(70%)+CH_4(30%) mixture by α-ray irradiation. The ranges of α-rays are indicated by white broken-lines.

According to an estimation of α-ray ranges in the gas counter, those reach a distance of 9 mm from the mylar window for d = 14 mm, 16 mm for d = 9 mm and 23 mm for d = 4 mm (α-rays reach the opposite side cathode for d = 4 mm); the bi-directional streamers were observed when α-rays reach over the anode wire position. The same tendency was observed in individual images as shown in Fig. 3.

Variation of streamer shapes was investigated by changing the position of ionization track formed by α-ray. Streamers develop in the specific directions depending on the position of ionization tracks as shown in Fig.4.

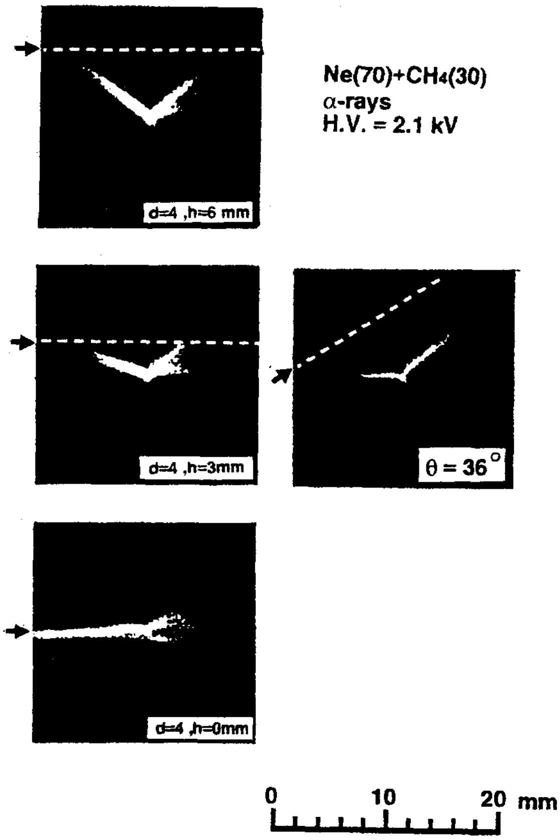

Fig.4 Integrated images of SQSs in a Ne(70%)+CH_4(30%) mixture for different positions of ionization track formed by α-rays.

Moreover we observed SQS formation by α-ray in a sole quenching gas of CH_4 [10]. As shown in Fig.5, the obtained image is similar to those of SQSs generated in rare-gas based mixtures (Ne(70%)+CH_4(30%) and Ar(70%)+CH_4(30%)). It should be noted again this phenomenon can not be explained by the Atac's model.

These results obtained for α-ray suggest the existence of an SQS-formation mechanism that is different from another one based on the photo-ionization process. Large number of electrons formed along ionization tracks of α-rays may be important. For example, in the case of d = 4 mm in Figs. 2, 3 and 4, it is estimated that about 57000 electrons are generated along the ionization tracks by the energy deposition of 2.1 MeV to the counting gas, with an assumption that the W-value of Ne(70%)+CH_4(30%) mixture approximates that of Ne gas (36.6 eV) [11].

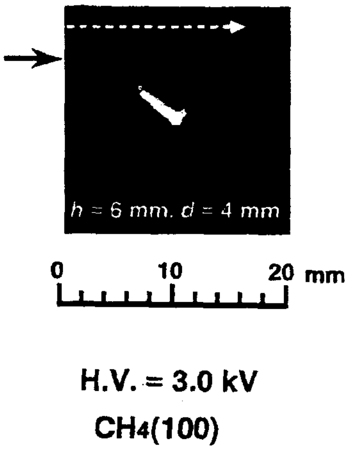

Fig.5 Integrated image of SQSs in a CH_4(100%) by α-ray irradiation. A left-side arrow indicates the incident positions and directions of α-rays. The range of α-rays is shown by a white broken-line.

When an α particle passes through the entrance mylar window, secondary electrons are emitted from the surface of the mylar foil into the counting-gas volume. However, the number of such electrons may be far smaller than that produced along the ionization track of α-ray.#

Figure 6 shows drifting of electrons formed along an α-ray ionization track; the drifting was calculated on the basis of electron drift-velocity measured in Ne(70%) + CH_4(30%) mixture [12]. The nearest electron arrives at the anode wire in 104 ns and is followed by other delayed electrons. So it may be quite natural to think that large number of free electrons are fed into an initial avalanche from the directions limited by the ionization track. Such delayed electrons can multiply around the high field tip of positive ion cone successively and must assist the SQS development in the specific directions such as bi-directional discharges shown in Figs.2, 3, 4 and 5. An artist's view of the phenomenon is shown in Fig.7. Since α-ray induced streamers are so strongly primary-ionization track oriented, not only on the streamer directions but also on the formation mechanism, we refer to them as "PRimary-Ionization Track ORiented (PRITOR) type SQSs" in this article.

#Though we have not confirmed the fact experimentally, a calculation based on the formula of knock-on electrons production-rate (VII-7, [13]) shows that the number of secondary-emitted electrons does not exceed 8.5 for the passing of a 3 MeV α-particle through 7 μm thick mylar foil.

Electron-emission characteristics from Ti foil (2 μm thick) were measured by using 250 keV deuteron beam [14]. The preliminary estimation shows that the number of emitted electrons was less than 10 with single deuteron passing.

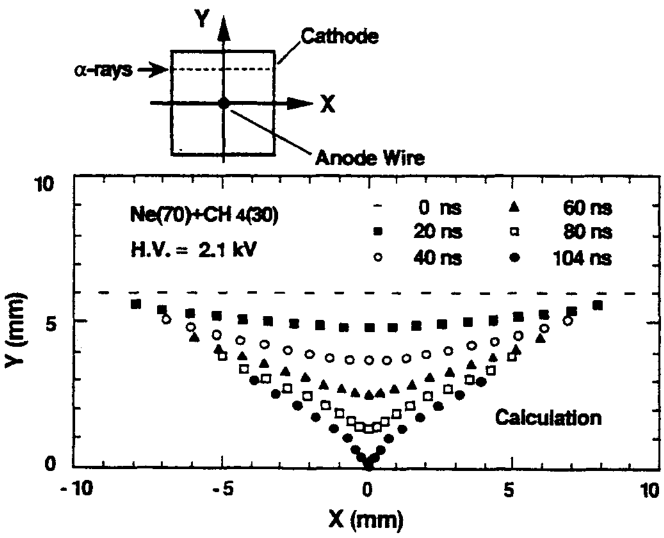

Fig.6 Calculated electrons drifting from an ionization track formed by α-ray to the anode wire.

B. Distribution of X-ray Induced SQSs Developing Around The Anode Wire

For X-ray ionization, typically a few hundred electrons are generated just near the point where the primary interaction (photoelectric absorption) occurs. Until now some optical images of SQSs by X-ray have been reported as mentioned already. Those images were, however, taken from the direction perpendicular to anode wire axis. We observed X-ray induced streamers developing around the anode wire from the axial direction, as shown in Fig. 8. Streamers induced by X-ray grow to various directions apparently differing from those by α-rays, though the streamers seem to grow more frequently to the side of the incident X-ray ionization.

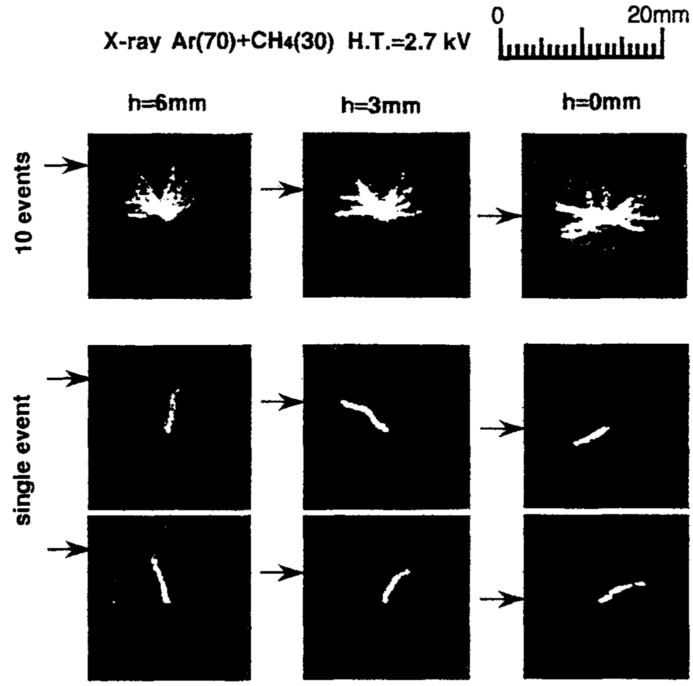

Fig.8 Optical images of SQSs induced by X-rays in an $Ar(70\%)+CH_4(30\%)$ mixture.

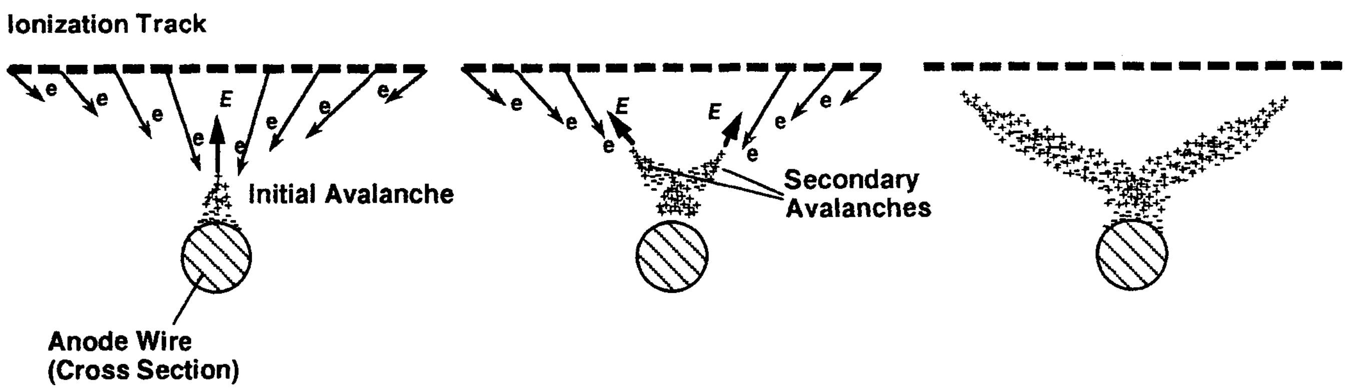

Fig.7 An artist's description of the self-quenching streamer formation induced by an α-ray ionization track.

In order to understand the streamer directions for X-ray ionization, the angular distribution of streamers developing around the anode wire was investigated. The inside space of the counter around the anode wire was divided into 9 imaginary regions (A-H, Z) as shown in Fig.9 and the number of streamers growing to each region was counted out. About 500 events were sampled respectively for X-ray incident height of h = 0, 3 and 6 mm; obtained data were converted to frequency distributions normalized by the number of total events for each h (solid lines in Fig.9). Broken lines in the same figures indicate the calculated probability that incident X-rays interact with the counting gas in each region when X-rays pass through the inside of gas counter. In this calculation, the mean free path of 5.9 keV X-rays in an Ar(70%)+CH_4(30%) mixture is 3.0 cm and spreading of X-ray beam (± 1°), that is deduced from the collimation geometry, is taken account. As shown in Fig.9, the results of this estimation show rather good agreement with the observed angular distributions. This means the streamer remembers the arrival direction of the primary electron cluster [15 ,16].

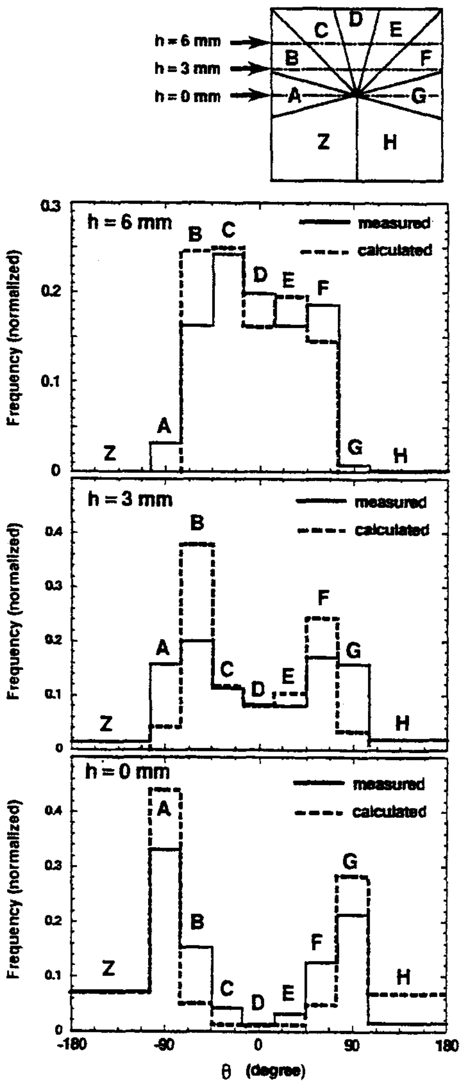

Fig.9 Angular distribution of directions of SQSs developing around the anode wire for X-ray irradiation.

C. Self-Quenching Streamers Induced by β-rays

Though β-ray is a charged particle, obtained images for β-ray incident (Fig.10) are similar to those for X-rays; strong contribution of ionization track is not observed. This is probably because the charge density of ionization tracks by β-ray is far lower than that by α-ray. Only 6 keV, on average, is deposited in the gas along the ionization track when a β-ray passes through the counter. Consequently the number of electrons fed to the initial avalanche may not be enough to promote the PRITOR-type streamers. Instead the photo-ionization process becomes dominant, the same as in the case of X-ray induced streamers. Therefore, in this case, only the first electron cluster to arrive at the anode is important to generate the initial avalanche while other delayed electrons do not contribute to the streamer formation.

Almost all streamers seem to grow to the side of the incident β-ray track. But it is difficult to explain the streamer direction distribution accurately because the β-ray energy continuously spreads from zero to the maximum(2.27 MeV); the energy loss inside the gas counter varies depending on the β-ray energy. In addition to this, the energy-loss distribution itself has rather large fluctuation along an ionization track.

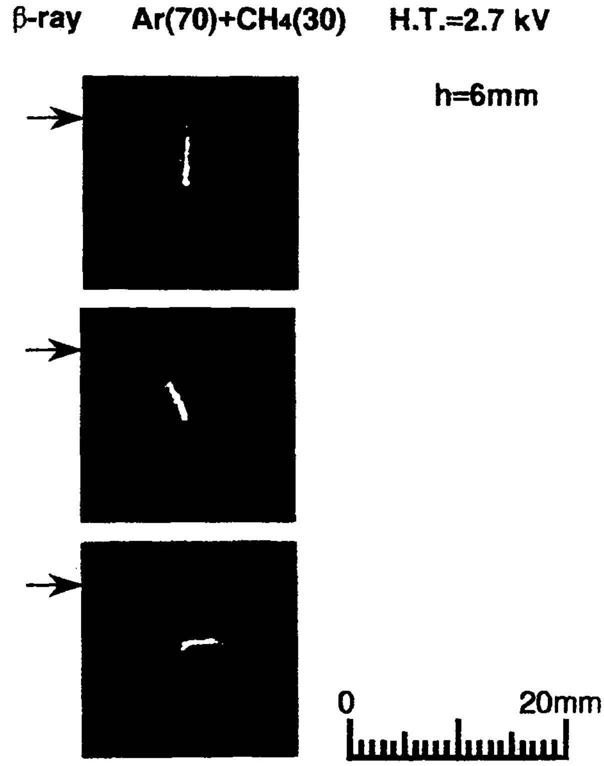

Fig.10 Individual images of SQSs induced by β-rays in an Ar(70%)+CH_4(30%) mixture.

IV. SUMMARY

Large numbers of electrons generated along the primary-ionization track play a significant role for the SQS formation induced by α-ray. From this point of view, a possible mechanism of PRimary-Ionization Track ORiented (PRITOR) type SQS is proposed. An exact quantitative interpretation of the PRITOR-type SQS will be made by carrying out a computer simulation. For X-ray irradiation, distribution of SQSs developing around the anode wire is explained by considering drifting path of electrons from the primary-ionization point to the anode wire. Obtained images for β-ray are similar to those for X-ray because the charge density of ionization tracks formed by β-ray is too low to promote PRITOR type SQSs.

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