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# A Mechanism for SQS Avalanche

Chen Jige[1], Xu Zizong, Chen Hongfang and Ma Wengan

Modern Physics Department, University of Science and Technology of China, Hefei, Anhui, China
[1]Permanent address: Institute of Modern Physics, P. O. Box 69, Lanzhou, Gansu, China

**Based on a large amount of experiment information, it is assumed that SQS avalanche is developed when the electric field around the anode wire is heavily distorted by the space charge accumulated in the primary avalanche. Following this assumption calculations are performed. The dependence of charge output on the high voltage of the counter is presented. Some key quantities, such as SQS transition voltage $V_{tr}$ and charge output $Q_{pt}$ and $Q_{st}$, are calculated. Their dependence on gas composition is also presented.**

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## 1. INTRODUCTION

The observations and studies on self quenching streamer have lasted for more than 10 years. There are several explanations on its mechanism. One of them is that SQS avalanche is mainly caused by photons [1,2]. Another explanation is that SQS avalanche is fired as soon as the concentration of meta-stable state of argon reaches a critical value [3]. They can qualitatively explain some experiment observations, but some ambiguities remain [4,5]. A mechanism for SQS which is based on the electric field distortion caused by space charge is described here and some characteristic parameters have been calculated.

## 2. BASIC ASSUMPTIONS

1) On SQS avalanche: When Townsend avalanche induced by primary electrons develops to a given scale, the space charge of positive ions accumulated near the anode wire makes the electric field distorted. The longitudinal component $E_y$ (perpendicular to the anode) of the resultant field on the anode surface will drop considerably, and the transverse component $E_x$ will increase. When $E_x$

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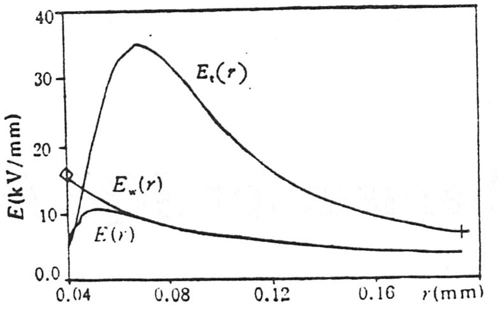


**Fig. 1**

Field distribution in the counter. $E_W$: external field; $E_W(r) = V_0/r\ln(b/a)$; $E(r)$: instant resultant field; $E_t(r)$: total field along the axis of space charge ring.

>> $E_y$, a small amount of electrons in this region will scatter randomly instead of drifting toward anode wire. The SQS avalanche will grow in this region where the $E_x > E_s$ (critical field for electron multiplication). When SQS avalanche develops to such a level that the electron density in this region reaches $\rho_e \sim 10^{-6}$ C/cm$^3$ [6], the plasma-like conductivity will make the space charge distribution change ($\tau \sim 10^{-10}$ s), the center of space charge will move away from the anode wire, the field around the anode wire will recover accordingly and electrons will be collected by the anode. Then the streamer is quenched.

2) On the distribution of space charge: Space charge accumulated in primary avalanche is assumed on a positive ion cone [7] which consists of many charged rings with different diameters determined by diffusion of drifting electrons. Following the law of static electricity, the resultant field around the anode is calculated. The results are demonstrated in Fig. 1 for a coaxial counter with the cathode diameter $2b$ = 36 mm and anode diameter $2a$ = 0.08 mm, the working high voltage $V_0$ = 3.9 kV.

## 3. PROCEDURES FOR CALCULATING THE SQS PARAMETERS

After selecting an initial working voltage $V$ in the proportional or limited proportional, we did the following: 1) according to $\int_b^s \alpha(r)dr \geq 1$, we searched for the start point of primary avalanche $s$, $\alpha(r)$-Townsend coefficient corresponding to $E(r)$; 2) we determined the position of the $i$th positive charge ring according to $\exp\left[\int_s^{p_i} \alpha(r)dr\right] \geq 2^i$, $\alpha$ being determined by the instant resultant field $E(r)$ at position $r$. $\vec{E}(r) = \vec{E}_W(r) + \vec{E}_+(r)$. $E_W$ is external field and $E_+$ is the field produced by 1 – ($i$ – 1)th rings of space charge. The charge quantity of the $i$th ring $Q_i = 2^{i-1}n_0$, $n_0$ being the number of primary ionization. The radius of the $i$th ring $r_i = (4D_e t_i)^{1/2}$. $D_e$ is the electron diffusion coefficient and $t_i$ is the electron drift time from $s$ to $p_i$. For various gas composition $D_e$ and the electron drift

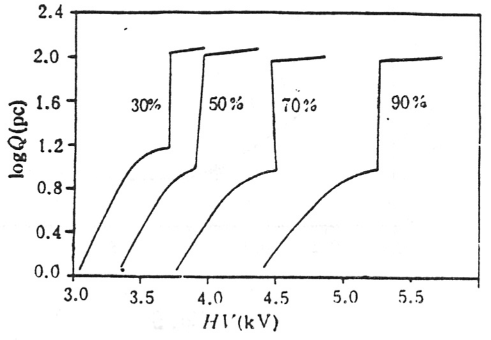


**Fig. 2**
$HV$-dependence of output charge and $CO_2$ percentage on the curves.

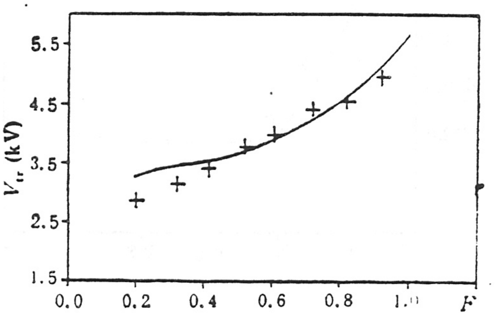


**Fig. 3**
$F$-dependence of $V_{tr}$.

velocities $V_e$ can be calculated by using the program WIRCHA, the output charge $Q = n_0 \exp\left[\int_s^a \alpha(r)\mathrm{d}r\right]$; and 3) we compared $E_y(a)$ with $E_s$. If $E_y > E_s$ and $V > V_B$ (the breakdown voltage of the counter determined experimentally), the calculation came to an end and no SQS conclusion can be drawn; if $E_y > E_s$ and $V < V_B$, let $V = V + \Delta V$, the above calculation was repeated until the condition of $E_y < E_s$ and $V < V_B$ were satisfied. $V$, which satisfies the condition mentioned above, is defined as SQS transition voltage $V_{tr}$, and the corresponding output charge $Q$ defined as $Q_{pt}$.

Under the conditions $V_{tr}$ and $V_{tr} + \Delta V$, we calculated the total field $E_t(r)$ distribution induced by the whole positive charge cone added with external field (Fig. 1). We found the region with sizes of $l_s \times R$ where $E_t > E_s$, $l_s$ is defined as the length of streamer. $V_s = (1/3)\pi R^2 l_s$ is the developing volume of streamer and $Q_{st} = \rho_e V_s$ is the output charge of SQS.

## 4. RESULT AND DISCUSSION

For various gas compositions, the working voltage dependence of output charge is shown in Fig. 2. The model predicts the typical $Q$-$HV$ properties of proportional, limited proportional and SQS avalanche. For Ar + $CO_2$ system, ($F = CO_2/(Ar + CO_2)$) dependence (solid cures) of $V_{tr}$, $Q_{pt}$ and $Q_{st}$ is demonstrated in Figs. 3, 4 and 5, respectively. The experimental data fit with the model prediction quite well.

Assuming that the co-existence of limited proportional mode with the SQS mode is determined by the fluctuation of primary ionization, the $F$-dependence of the width of co-existence region can be calculated [8].

For Ar + $CH_4$ (+Methylal) system and Xe + $CO_2$ (or $CH_4$) system, the model prediction also follows the tendency of experimental data.

Based on our model, we also studied the gas pressure dependence for 75%Ar + 25%$CO_2$ system with $2a = 0.08$ mm and $2b = 16$ mm, and anode diameter dependence for 50%Ar + 50%$CO_2$ system with $2b = 36$ mm.

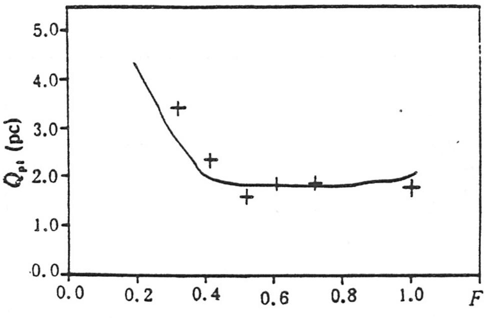


**Fig. 4**
$F$-dependence of $Q_{pt}$ at $V_{tr}$.

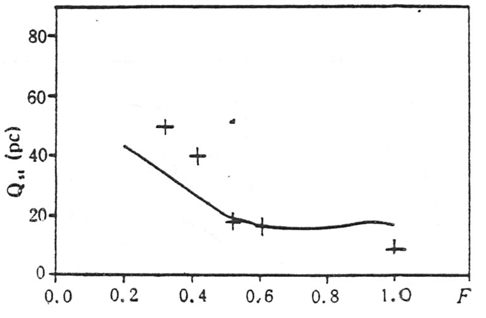


**Fig. 5**
$F$-dependence of $Q_{st}$ at $V_{tr}$.

The results indicate that the consistency between the calculation and the experimental data is satisfactory. The deviation at small $F$ values is mainly due to the photon contribution. The effects of photon could make $V_{tr}$ lower, $Q_{pt}$ and $Q_{st}$ higher, the SQS avalanche less local and less stable, and the multi-streamer appear more easily. When the photon contribution plays the main role in avalanche, the GM mode will take the place of SQS mode.

The process of gas discharge is very complex. If more effects are taken into account in this simple mode, the consistency between the model prediction and the experimental data will be improved. Further studies are underway.

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