Dead Zone Characteristics of SQS and GM Tubes

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Abstract

Characteristics of the dead zone of a gas counter have been studied at gas pressures of 760-150 Torr of Ar(75)+isoC4H10(25) mixture, and compared with those of a commercially available GM tube. The counter operated in the SQS mode at pressures higher than 350 Torr, and in the GM mode at the lower pressures; the operation mode changed around 350 Torr, where the mean free path of VUV photons is about 50 μm. The dead zone of the counter used was evaluated to be 290 μs·cm for the SQS mode (at 760 Torr) and 2450 μs·cm for the GM mode (at 150 Torr). The counting rate capability of the SQS tube is more than one order of magnitude larger than that of the GM tube.

II. EXPERIMENTAL PROCEDURE

We have studied the dead zone characteristics of a gas counter, changing the pressure of Ar(75)+isoC4H10(25) gas filling between 760 and 150 Torr. The gas counter was made of a stainless steel pipe whose inner diameter was 14 mm; a gold plated tungsten wire of 50 μm in diameter was stretched along the axis as an anode. The effective length of the counter was 105 mm. The counter filled with Ar-isoc4H10 mixture was irradiated by 55Fe X-rays or 90Sr β-rays through a 10 μm thick mylar window, or by 60Co γ-rays. Gas multiplication properties, pulse shape of current signals, and dead zone were measured at several gas pressures equal to and less than one atmospheric pressure.

The pulse height, which was measured with a charge sensitive preamplifier, was converted to the avalanche size corresponding to the number of electrons or ions produced in an avalanche. Pulse shapes of signal current flowing through a 200 Ω resistor were recorded on photographs. In order to determine the dead zone of SQS and GM tubes, the counting losses at time intervals between pulses were measured with a time-interval to amplitude converter; this was a better method for the measurement than the delayed self-coincidence method[1].

III. RESULTS AND DISCUSSION

A. Gas Multiplication Properties

Figure 1 shows avalanche sizes measured as a function of applied voltage at several gas pressures. The transition probability is shown for the SQS transition in the figure. The SQS transition, which is indicated by a large leap in the avalanche size curve, is clearly shown for the pressures of 760-300 Torr. At the pressures of 350 and 300 Torr, the mode can be identified as the SQS mode from this observation, but as described later in this pressure region SQSs are formed simultaneously with a GM discharge. The SQS transition does not occur at pressures less than 250 Torr; the avalanche size increases continuously as the applied voltage increases. This feature is attributed to the GM mode, because the avalanche size of a typical GM tube (Aloka 2008) indicates similar feature, as shown in the figure. It should be noted that either the SQS or GM mode can be alternatively obtained by changing the pressure of the gas mixture.
Fig. 1. (a) Avalanche size curves as a function of applied voltage at several gas pressures. (b) The transition probability for the SQS mode.

The SQS transition can be characterized by the transition voltage $V_1$, which is defined as the voltage where the transition probability is 50%. As shown in Fig. 2(a), the transition voltage indicates a linear dependence on the pressure. As discussed in our previous paper[4], the transition condition may also be represented by the quantity of $Q_p/E_a$, which corresponds to the positive charge cancelling the applied electric field on the anode surface ($E_a$). Since the transition should occur at almost the same value of $Q_p/E_a$ for the same spread of positive ions near the anode, Fig. 2(b) suggests avalanches spread more at lower pressure.

Fig. 2. The transition voltages $V_1$ for the SQS mode (a), and the quantity $Q_p/E_a$, which corresponds to the number of ions cancelling the electric field on the anode surface (b), are plotted as a function of the gas pressure.

B. Pulse Shapes

In the SQS mode, an electron avalanche initiated by radiation develops to an SQS formed normal to the anode wire. On the other hand, the development of an electron avalanche spreads over the entire anode wire in the GM mode (the GM discharge). This difference in the avalanche development, therefore, may appear in the pulse shape of signals, especially of current signals induced by electrons. Figure 3 shows the pulse shape of electron induced current signals formed by $^{90}$Sr $\beta$-rays at the pressures of 760, 300, and 150 Torr, where the SQS, intermediate, and GM modes are obtained, respectively. Difference in the avalanche development is evident.

In the SQS mode (obtained at 760 Torr), the signals rise very fast and decay exponentially. Furthermore the signals are doubled with a delay of about 0.4 $\mu$s at higher voltages; the doubled signals correspond to the double SQS. The width of the SQS signals is about 0.2 $\mu$s fwhm. The GM signals observed at 150 Torr rise more slowly than the SQS signals and form an approximately flat-top shape having about 0.5 $\mu$s fwhm. This pulse width corresponds to a time for an avalanche, initially formed at the half way of the anode in this case, that develops and reaches to the ends of the anode wire.
The counting losses are partial, while the counter in the GM mode is completely insensitive during a dead time. Concerning the intermediate mode obtained at 300 Torr, whose operation mode could not be determined yet, the mode at this pressure can now be attributed to the GM mode, because counts are completely lost during the dead time of about 200 µs.

C. Dead Zone

Since the streamer develops normal to the axis of the counter, the spatial dead length along the anode is very small and the sensitivity of the counter is kept except for the dead region. On the other hand, the GM tube is completely insensitive during the dead time, because an avalanche spreads over along the anode wire. It is, therefore, important to compare the dead zone characteristics of the SQS and GM modes.

The dead zone is defined as the product of dead length and dead time by Alekseev et al. It can be evaluated by measuring counting losses at different time intervals between signals. Figure 4 shows the counting losses at time intervals for the SQS (at 760 Torr), GM (at 150 Torr), and intermediate (at 300 Torr) modes. The straight lines present the expected counts at time intervals when there is no dead zone. In the SQS mode the counting losses are partial, while the counter in the GM mode is completely insensitive during a dead time. Concerning the intermediate mode obtained at 300 Torr, whose operation mode could not be determined yet, the mode at this pressure can now be attributed to the GM mode, because counts are completely lost during the dead time of about 200 µs.
According to the definition of the dead zone, given by Alekseev et al. [1], the dead length $\delta(t)$ was obtained as a function of time interval. Figure 5 shows a comparison of the dead zone characteristics of the SQS and GM modes. The maximum dead time is almost the same in the SQS and GM modes for an identical counter, because the dead time is determined from the sweep-out time of positive ions. The obtained dead zone of the counter was 290 $\mu$s-cm for the SQS mode and 2450 $\mu$s-cm for the GM mode. On the other hand, a GM tube (Aloka 2008) has a typical dead zone of about 4000 $\mu$s-cm. The dead zone of the GM tube was found to be very sensitive to applied voltage: for example, a slight increase of 40 V in the applied voltage in its plateau provided a very large dead zone of 8000 $\mu$s-cm.

![Fig. 5 The dead zone as a function of time interval for the SQS and GM modes.](image)

The dead zone depends on the gas pressure, as shown in Fig.6. Around 300 Torr, the operation mode is changed. At lower pressures than 300 Torr, the dead zone of the GM mode decreases as the pressure decreases. This can be explained by estimated ion drift time from the anode to the cathode, if the GM discharge is assumed to spread over the anode length. For the SQS mode the dead zone does not vary so much; slight decrease is indicated with increase in the pressure. The spatial spread of SQS would decrease as the pressure increases, because the calculated drift time for the pressure cannot explain the feature.

According to the above measurements, the critical pressure for changing the mode is 300-350 Torr for this gas mixture. Alekseev et al. have suggested that the GM mode can be obtained if the mean free path of photons emitted from avalanches is larger than the spread of avalanches, and the SQS mode for an equivalent or smaller mean free path of the photons. The estimated critical mean free path is about 50 $\mu$m in the mixture used, if the photons are due to the de-excitation of molecular excited states of Ar.

![Fig.6. Pressure dependence of the dead zone.](image)

**D. Counting Rate Capability**

In order to confirm the superiority of the SQS tube to the GM tube, output counting rates were measured as a function of the exposure dose rate of $^{60}$Co $\gamma$-rays. As shown in Fig.7, the counting rates follow the exposure dose rate up to about 100 mR/h. Above this rate the counting rate indicates drastic difference from the expected rate for the GM mode. For the SQS mode, the measured counting rates follow the exposure rate with some counting loss and indicate saturation above 700 mR/h. The counting rate capability of the SQS tube is more than one order of magnitude larger than that of the GM tube. Hence, SQS tubes are suitable as monitoring devices in high counting rate condition.

![Fig.7. Counting rates measured as a function of the exposure dose rate. A and B contained in the legend mean different conditions in the measurements.](image)
IV. SUMMARY

Either the SQS or GM mode can be obtained by changing the gas pressure with a cylindrical gas counter. The operation mode of the counter could be correctly determined from the dead zone measurement. The measured results show that the SQS and GM modes are exclusive, even though SQSs can simultaneously be formed with a GM discharge. The counting rate capability of the SQS mode is much superior to the GM mode by about one order of magnitude. Hence, SQS tubes are suitable in high flux radiation fields instead of GM tubes.

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