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Application of Columnar Cesium Iodide (CsI) as a Secondary-Electron Emission Source to Gas Avalanche Detectors

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A columnar cesium iodide (CsI) layer as a secondary-electron emission (SEE) source was applied to conventional gas avalanche detectors to improve their operating characteristics. The concentration of the primary electrons to a small interaction region allows gas avalanche detectors to have better spatial and timing resolutions. In this study, the signal enhancement and timing resolution of a microstrip gas chamber (MSGC) coupled with the columnar CsI layer were investigated. A large amount of electron amplification occurred within the columnar CsI layer when it was activated, greatly enhancing the signal pulse amplitude over that coming from the ionization in the gas drift region alone. The measured timing resolution of the MSGC detector having an anode width of 5 μm, a cathode width of 95 μm, and a pitch of 200 μm was about 5.5 ns rms at a reduced gas pressure to 30 torr. The SEE efficiency of the columnar CsI layer was also investigated and estimated with about 6%.

KEYWORDS: Radiation detector, cesium iodide, secondary-electron emission, gas avalanche detector

I. Introduction

In our previous works, it has been reported that the performance of gas avalanche detectors is degraded when radiation particles are not incident nearly perpendicular to detector plane [1,2]. The spread of the primary electrons along particle track in the gas drift region makes detector performance poor, such as detection efficiency, spatial resolution, and timing resolution. In order to improve such detector performance, the mechanism of secondary-electron emission (SEE) has been proposed to use as a primary electron source in gas avalanche detectors. With this approach using a '*planar*' SEE layer, the timing resolution was improved by more than one order of magnitude, compared with a conventional microstrip gas chamber (MSGC), and no angular dependence of the detection efficiency was observed [3]. However, the SEE efficiency was very low (only a few percent for most materials). On the other hand, alkali-halide '*porous*' materials such as CsI and KCl have much larger SEE efficiency, compare with the planar one. The efficiency of a single porous CsI layer was measured to be about 55% by Chianelli *et al.* [4]. This result suggests that many surface crossings of each incident particle should provide a higher SEE efficiency.

A '*columnar*' CsI layer, which has been extensively used for X-ray imaging due to the advantage of light channeling, can also allow many surface crossings by an incident particle. Therefore, we initially thought that a columnar structure of pure CsI might improve the SEE efficiency. However, as we shall see, subsequent tests and simulations indicate that SEE is limited to only the top surface of the CsI layer, and the SEE efficiency was estimated with about 6% only.

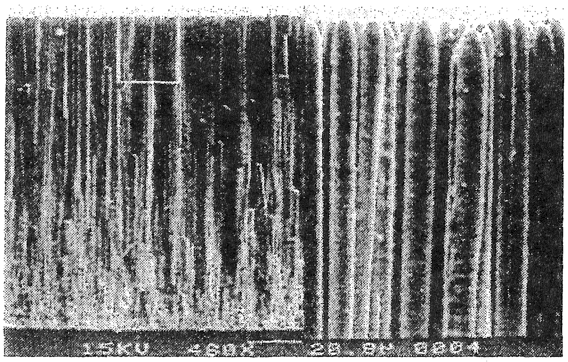

Fig. 1 A scanning electron microscope (SEM) photograph of a columnar CsI layer of a 100 μm thickness.

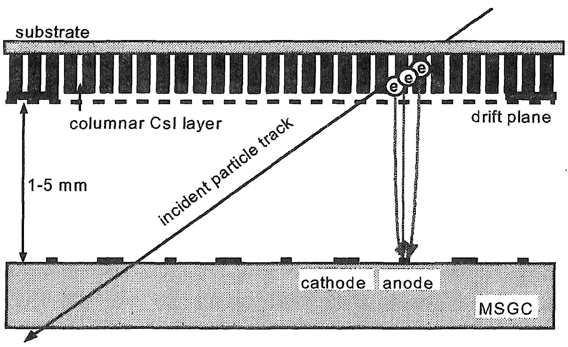

Fig. 2 A conventional MSGC detector coupled with a 300 μm thick columnar CsI layer added to the drift plane.

In this paper, a columnar CsI layer was initially coupled to a conventional MSGC detector to compare the signal enhancement, the timing resolution, and the SEE efficiency

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with a bare MSGC. **Figure 1** shows a scanning electron microscope (SEM) photograph of a columnar CsI layer. The measured diameter and the wall spacing of the CsI columns were about 5 μm and 3-5 μm, respectively.

II. Characteristics of Detector Performance

1. Signal Enhancement

In order to investigate the utilization of a columnar CsI layer for a conventional gas avalanche detector, we initially mounted a 300 μm thick columnar CsI layer on a drift plane of a MSGC detector which has an anode width of 5 μm, a cathode width of 95 μm, and a pitch of 200 μm (**Fig. 2**). This method uses the same fundamental idea as in the previous approaches: an incident particle provides the source of primary electrons by the SEE process, predominantly from a very small region, or '*point*' on the drift plane. For an inclined track the concentration of electron production allows primary electrons to be focused on a fewer anode strips, which leads directly to the improvements in spatial resolution and timing resolution. A collimated ^{90}Sr β-source was used for the measurements. The chamber was filled with a gas mixture of Ar/Ethane (50%/50%). Kapton pieces of a 125 μm thickness were placed between the columnar CsI layer and the drift plane as an insulating spacer. **Figure 3 (a)** shows pulse-height spectra of the ^{90}Sr β-source, for $\triangle V_{csi}=0$ and –1600 V, where $\triangle V_{csi}$ is the voltage applied across the CsI layer. The applied voltage to the MSGC detector was 500 V, and the measured gas gain was about 2100. **Figure 3(b)** shows measurements of relative signal enhancement as a function of $\triangle V_{csi}$. Here the relative signal enhancement is defined as the ratio of signal-pulse amplitude produced when V_{csi} is turned on to that produced when V_{csi} is turned off. As shown in **Fig. 3**, a large amount of electron amplification occurs within the CsI layer when it is activated, greatly enhancing the signal pulse amplitude over that coming from the ionization in the gas drift region alone. This remarkable signal enhancement may be due to combining effects of primary electrons initialized from the CsI surface and a gas avalanching in the gas gap between the columnar layer and the drift plane.

2. Timing Resolution

In a large number of detector applications, information of precise arrival time of a radiation particle is of particular interest. In a conventional MSGC detector, the timing resolution has been measured about 20 ns rms [3]. The timing resolution of a gas avalanche detector significantly depends on the length of drift gap because the primary electrons are distributed along incident particle track in the gas gap. However, the use of a secondary electron emitter in a gas avalanche detector can provide a good timing resolution due to the "*point-like*" source of primary electrons. A timing measurement system is shown in **Fig. 4**. A P-10 gas mixture and a ^{90}Sr β-source were used in this measurement. This experiment was performed at a reduced

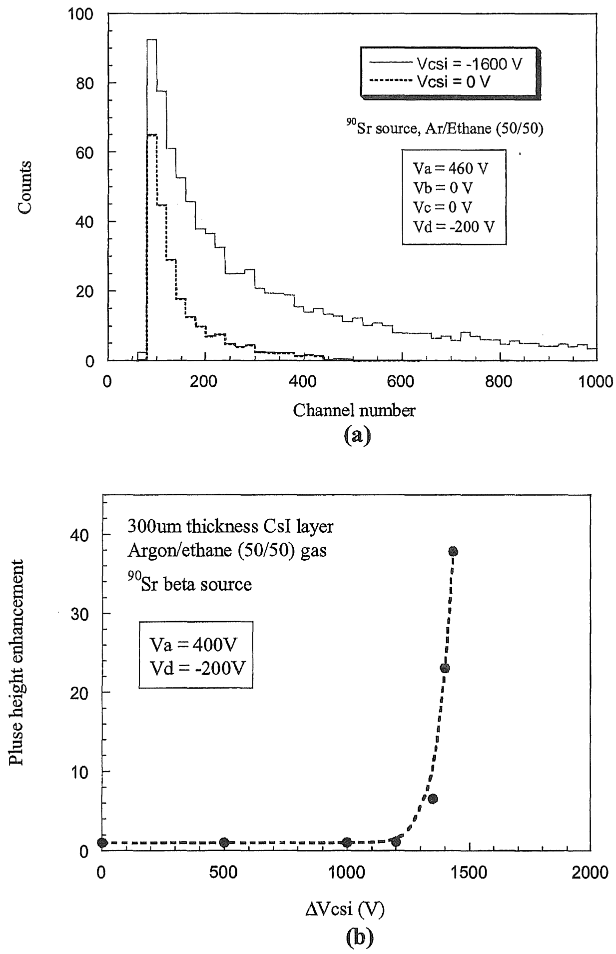


Fig. 3 **(a)** Pulse height spectra of a ^{90}Sr β-source, using a conventional MSGC detector coupled with a columnar CsI layer, and **(b)** relative signal enhancement as a function of the applied CsI voltages ($\triangle V_{csi}$).

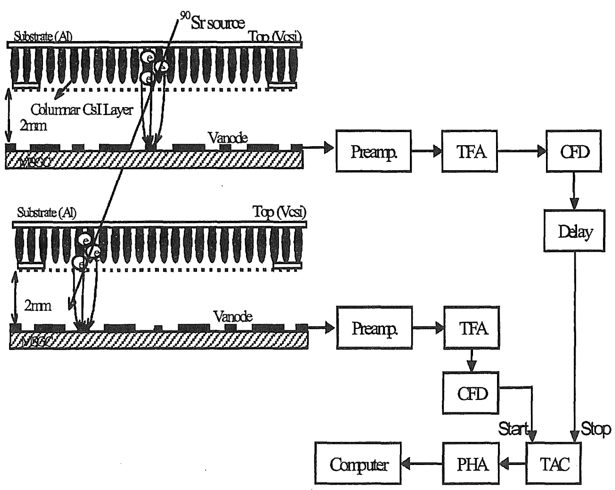


Fig. 4 A timing measurement system for a MSGC detector when a columnar CsI layer was used as a drift plane.

gas pressure to 30 torr to eliminate the possible primary source in the drift gas gap. In this system, a timing filter amplifier (TFA) was used for fast shaping time. The signal from each TFA was fed to a constant fraction discriminator (CFD) for accurate timing, and the CFD signals were used as the start and stop signals in a time-to-amplitude converter (TAC). The test result is shown in **Fig. 5**. The timing resolution for the MSGC coupled with a columnar CsI layer was determined to 5.5 ns rms at a reduced gas pressure to 30 torr.

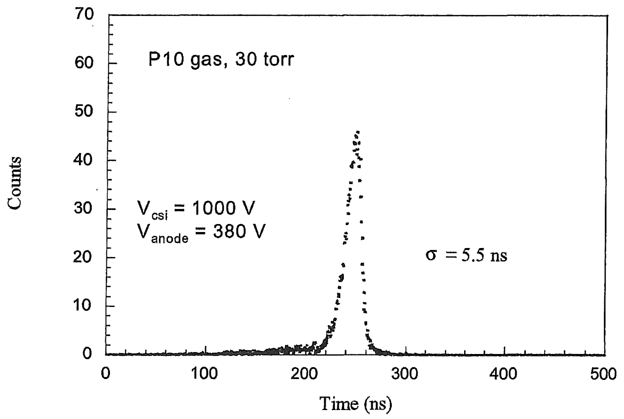


Fig. 5 Timing spectrum at a reduced gas pressure to 30 torr.

3. Secondary-Electron Emission (SEE) Efficiency

To investigate SEE efficiency of a columnar CsI layer, a parallel plane structure consisting of a columnar CsI layer as the cathode plane and a metal coated glass plate as the anode plane were used, as shown in **Fig. 6**. The primary electrons produced in the columnar CsI detector arise from two different mechanisms: one is gas ionization due to the β-ray in the gas gap between the anode and the CsI layer, and the other is the production of secondary electrons from the CsI surface by bombardment of the β-rays. After the primary electrons are emitted, electron avalanching starts at the emitting position. **Figure 7** shows the experimental system used for SEE efficiency measurements. Beta-rays from the ^{90}Sr source were directed onto the CsI layer. A MSGC detector was used as a trigger to count only the high energy (> 1 MeV) tail of the β-source spectrum. Here, the SEE efficiency is defined as the count rate of coincidence divided by the count rate of the bottom MSGC detector. The average number of the collected electrons as a function of applied

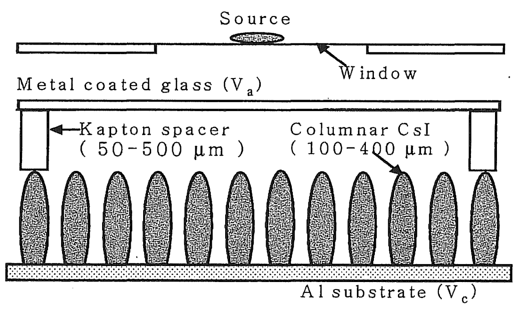


Fig. 6 A schematic of a columnar CsI layer and a metallic anode. Here V_a is a voltage on the metallic anode, and V_c is a voltage on the CsI cathode layer.

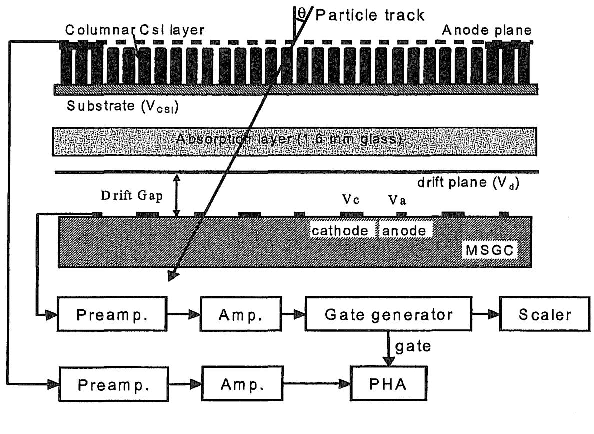


Fig. 7 Coincidence measurement system of a columnar CsI layer for SEE efficiency.

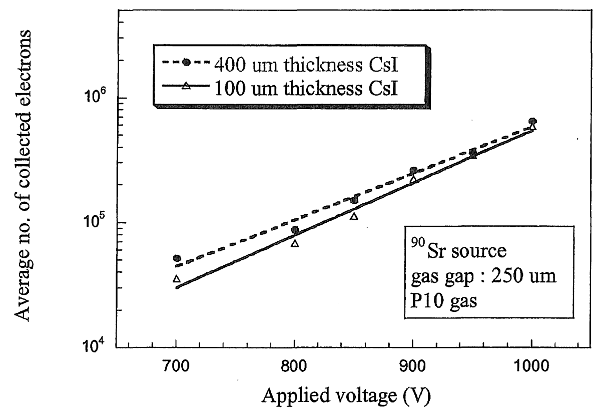


Fig. 8 Average number of collected electrons from the columnar CsI-coupled detector for two different layer thicknesses.

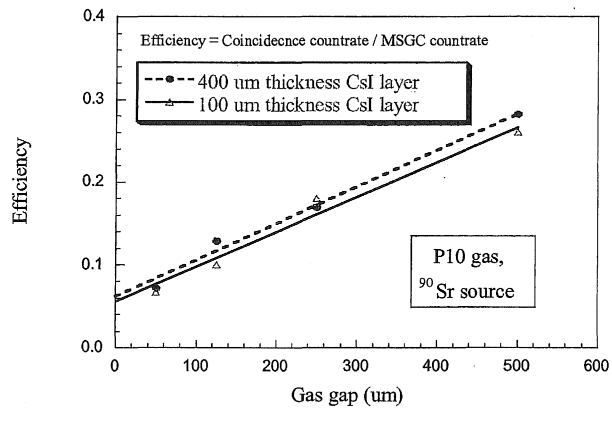
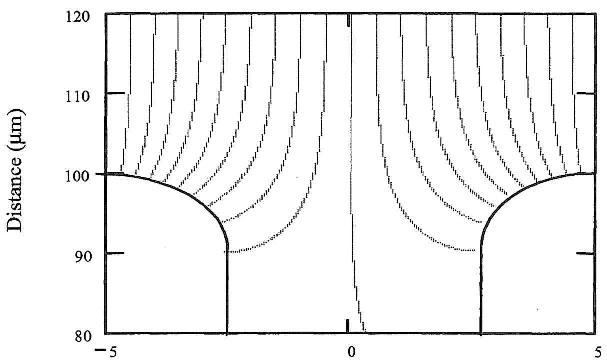


Fig. 9 SEE efficiency measured for 100 μm and 400 μm thick columnar CsI layers as a function of gas gap.

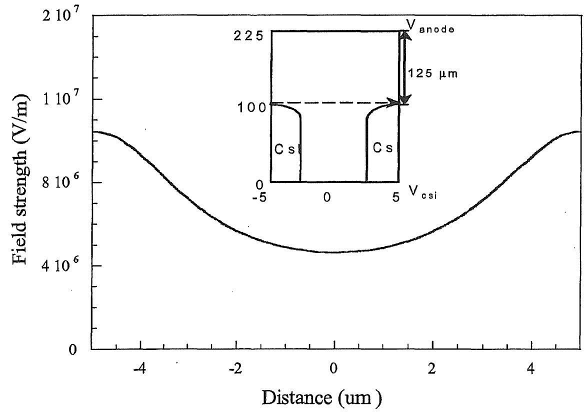
voltages for 100 μm and 400 μm thick CsI layers is shown in **Fig. 8**. The gas gap was 250 μm. The maximum average number of the electrons collected before breakdown was about 6×10^5 for either CsI layer. The SEE efficiency for the 100 μm and the 400 μm thick columnar CsI layers as a function of gas gap is shown in **Fig. 9**. The β-particles enter the detector with 5° dip angle. The SEE efficiency values were measured in the plateau region found by varying V_{csi}. As shown in **Fig. 9**, there is no noticeable difference in the SEE efficiencies measured between for the 100 μm and for the 400 μm thick CsI layers, indicating that the signal does not come from within the bulk of CsI layer. Rather, the SEE efficiency increases with the gas gap, and for all except the smallest gap, the direct ionization of the gas becomes predominant. However, a contribution from the CsI secondary electron emission is seen to exist as the gap size is extrapolated to zero. From this result, we estimated that the SEE efficiency of the columnar CsI layer alone was about 6 % for layers of either thickness.

4. Electric Field Simulations

In order to understand the result of the SEE efficiency measurements, electric field simulations were performed using the MAXWELL program [5]. The simulations were performed for a columnar CsI layer of a 100 μm thickness, with a 125 μm thick gas gap between the top of the CsI and the anode. A resistivity of CsI is 10^{11} Ωcm, which is essentially small relative to that of the gas media. Therefore, we can assume that the columnar CsI layer has everywhere the same potential. Using this assumption, we calculated the map of the electric field lines, which is shown in **Fig. 10**.



(a)



(b)

Fig. 10 (a) Electric field line near the top of the CsI layer, and **(b)** field strengths along the dashed line, 1 μm above the top of the CsI layer.

The corresponding field strength at the surface of the anode plane was about 6×10^6 V/m. The field strength on the tip of the columns was about 1.5 times higher than uniform value of the field near the anode. Therefore, in the presence of an incident charged particle, the gas avalanching is most intense near the top of CsI layer. However, the gap between the columns does not have a field enough for gas avalanching to occur, and the field strength is much too small even for drift electrons to come out from between columns of the CsI layer. This result indicates that only the secondary electrons ejected from near the tip of columnar layer can contribute to the signal. Thus, this simulation result explains the reason that the SEE efficiency of the columnar CsI layer is much smaller than we expected.

III. Summary

To investigate utilization of a thin columnar CsI layer for a gas avalanche detector, a columnar CsI layer was mounted on the drift plane of a MSGC detector. As expected, the columnar CsI layer improves timing of the MSGC detector by a large factor at a reduced gas pressure to 30 torr, and a remarkable signal enhancement was achieved due to combining effects of the primary electrons initialized from the CsI surface and the gas avalanching in the gas gap between the columnar layer and the drift plane. However, the initial idea that the columnar CsI layer might have a much higher SEE efficiency than a planer one turned out erroneous assumption from the result of the SEE efficiency measurements and the electric field simulations. We measured about 6% SEE efficiency for the columnar CsI layer.

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