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Resolution of Read-out Patterns for Position-Sensitive Proportional Counter

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A simple apparatus has been fabricated to measure the resolution of backgammon patterns, which are usually used to produce position signals with the charge-division method and often employed as a read-out system of position-sensitive proportional counter (PSPC). The present method is available to estimate the position resolution of practical PSPCs.

KEY WORDS: Position-Sensitive Proportional Counter/PSPC/Position Resolution/Charge Division/Backgammon.

1. INTRODUCTION

In the high-resolution X-ray crystal spectrometer, gas-filled proportional counters are often employed to measure precisely the position of X rays detected. Several methods were proposed for determining the position of ionizing events in the proportional counter[1-4]. In one of the simplest methods, so-called "backgammon" pattern is used for one-dimensional position sensing, which consists of two adequate geometrically shaped electrodes[2]. The Wedge and Strip pattern, which were naturally developed from backgammon[5-7], are used for two-dimensional position sensing. To obtain position signals, a part of cathode of proportional counters is formed by electrodes of backgammon or Wedge and Strip pattern printed on the insulating substrate. The partition of charges induced on the electrodes is available for determining the gravity center of the charges produced during the electron avalanche around the wire (charge-division method).

The position resolution depends on performances of proportional counter itself, read-out electrodes described above and electronics employed. For design of position-sensitive proportional counter (PSPC), it is important to examine the performance of read-out electrodes. The intrinsic resolution of read-out electrodes with the printed patterns can be easily determined by the charge inductive method, in which the electron avalanche in the proportional counter is simulated by a charged needle. We here describe our recent measurements on the intrinsic resolution of read-out elec-

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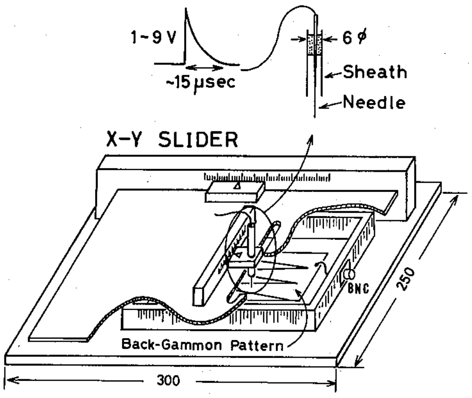

Fig. 1. An apparatus for measuring the position-resolution of backgammon patterns. The present apparatus mainly consists of a needle to generate strong electric field and a X-Y slider to move the needle. Electric pulses are applied to the needle to generate strong field and induce charges on the backgammon pattern as a cathode. The part of needle and the pulse shape applied are also shown in the figure.

trodes with the charge inductive method.

2. APPARATUS

The present apparatus for the charge inductive method is shown in Fig. 1, which consists of an needle, an X-Y slider to move it and a box to mount the read-out electrodes. Two boxes are prepared, $17\times13\times2$ cm^2 and $17\times13\times3$ cm^2. The read-out electrode is set at the bottom of the box. The movable length of the slider is 10 cm in X-direction and 6 cm in Y-direction. Voltage pulses of 1~9 V is applied to the needle. The strong electric field at the top of the needle results in inducing electric charges on the read-out electrodes to be examined. The needle is mounted in a metal sheath of 6 mm diameter. The total charges induced on the electrode are adjusted by changing the part of needle outside the sheath. The sheath can be moved up and down to change the distance between the top of needle and the cathode. The signal from the electrodes are fed to preamplifiers through BNC connectors on the side faces of the box. For electric shielding, the top of the slider is covered with a metal plate.

The charge induced on the read-out electrodes strongly depends on the length of

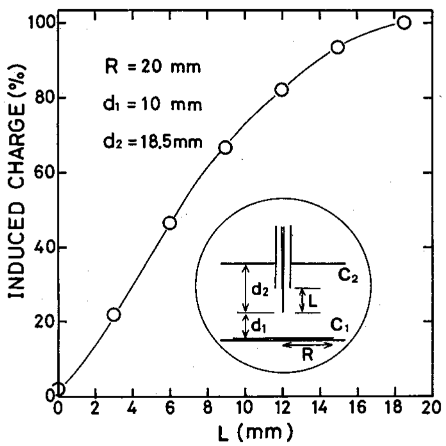

Fig. 2. The charge Q induced in the circular region with a radius $R=20$ mm on the electrode, which was measured as a function of the length of needle, L; the sheath was slided to adjust the length of needle. The charge Q is normalized by the value at $L=18.5$ mm.

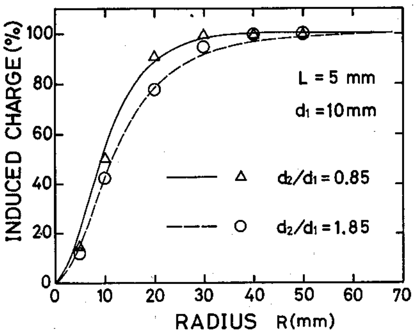

Fig. 3. The charge induced in the circular region on a plate electrode: solid curve, $d_2/d_1=0.85$; dashed curve, $d_2/d_1=1.85$. Other parameters L *and* d_1 (shown in Fig. 2) are fixed at 5 mm and 10 mm in the measurements. The measured charge is plotted as a function of the radius R of the circular region, where the charge is normalized by the value at $R=20$ mm. Solid and dashed curves indicate theoretical values estimated with Eq. (A1).

the needle (L as defined in Fig. 2). We measured the charge induced in the circular region with a radius of 20 mm as a function of the length L. The results are given by open circles in Fig. 2; the induced charges increase as the length L increases. From practical reasons, the length L was set at 5 mm in the present measurements described below.

In gas-filled proportional counters, electrons produced by the primary ionization process, i. e., the ionization of filled gas by incident radiations, are attracted to the anode wire at the center of the counter. Since the electric field becomes steeply stronger near the center, those electrons successively ionize the filled gas near the anode wire. A lot of electrons and positive ions are produced in this secondary ionization process, which is usually called electron avalanche. The mobility of positive ions in the gas is much slower than that of electrons. The positive ions do not part so much from the anode wire when the electrons arrive at the anode. The charge induced on the cathode is caused by the removal of the positive ions from the region quite near the anode wire. When the cathodes of the counter can be approximated by parallel plates with infinite areas, the charge induced on such cathodes can be easily estimated from a simple theoretical model given in Appendix A.

The charges of positive ions produced in the electron avalanches are simulated by the charges on the needle in the present apparatus. We measured the charge induced in the circular region on the read-out electrode as a function of the radius of the region R. Results are shown by open circles for $d_2/d_1=0.85$ and triangles for $d_2/d_1=1.85$. Theoretical estimates according to Appendix A are given by solid and dashed curves. The agreement between measured and calculated data are fairly good. This result indicates that the present method with the charge induced on the top of the needle can be used for simulating the cahrge induction in the proportional counter.

3. MEASUREMENTS

In Fig. 4 are shown the read-out electrodes with backgammon pattern. The pattern (I) was used in the counter with a cylindrical shape (30 mm diam. ×150 mm)[8], while the pattern (II) was used in the counter with a thin rectangular shape (20 mm× 100mm×8 mm)[9]. The block diagram of the electronics for the measurement of the position resolution of the backgammon patterns is given by Fig 5. Signals from both

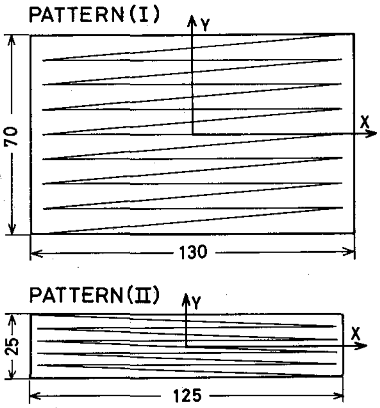

Fig. 4. Backgammon patterns used in the present measurtements: (I), X=70 mm and Y=130 mm; (II), X=25 mm and Y=125 mm.

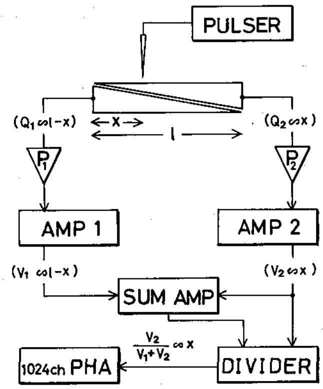

Fig. 5. Block diagram of electronics for determining the position resolution of backgammon patterns.

electrodes on the backgammon pattern are used for the position measurements with the charge division method. The electric charges Q_1 and Q_2 induced on two electrodes are given by

$$Q_1 = Q \cdot (l\text{-}x)/l, \tag{1}$$

$$Q_2 = Q \cdot X/l, \tag{2}$$

where l is the length of electrode in X-direction and $Q(=Q_1+Q_2)$ is the total charge induced on both electrodes. Therefore, the position of the needle can be determined by the ratio of Q_1 or Q_2 to the total charge Q. Outputs of preamplifiers (P1 and P2) are processed with spectroscopy amplifiers (AMP1 and AMP2); the output voltage from AMP1, V_1, is proportional to the length $(l\text{-}x)$, while that from AMP2, V_2, is proportional to the length x. To produce signals proportional to the sum of (Q_1+Q_2), outputs from the amplifiers are fed to to a sum amplifier. The divider is used to perform the division of $Q_1/(Q_1+Q_2)$ with the signals from SUM-AMP and AMP2; the output from the divider is then proportional to the length x. In the present work, we employed commercially available electronics of low noise preamplifiers designed for surface-barrier semiconductor detectors (Canberra 2003T) and a analog divider (Ortec 464).

The position linearities of both patterns (I) and (II) were examined with the present apparatus. Results for X-direction are given by Fig. 6. For the design of PSPC, we should always be careful to the distortion at the end of electrodes, which cannot be avoided as long as the printed patterns are employed as read-out electrodes. The only way to make the distortion smaller is to bring the needle closer to the cathode; the distance between the anode wire and cathode should be reduced for the proportional counter of rectangular shape. Results for the position linearity in Y-direction are given by Fig. 7, which also show the distortion near the end of electrodes. This distortion for

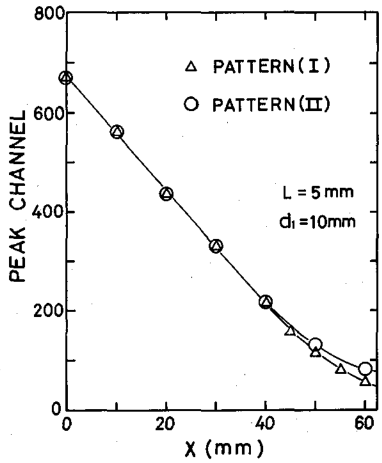

Fig. 6. Position linearity in the direction X; triangles and open circles correspond to data obtained with backgammon patterns (I) and (II), respectively. Parameters L and d_1 (shown in Fig. 2) are fixed at 5 mm and 10 mm in the measurements, respectively.

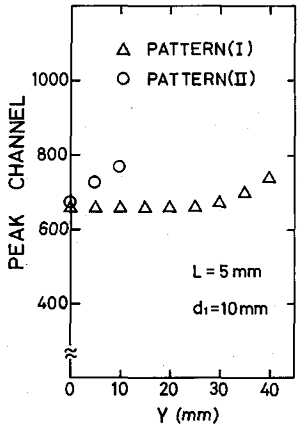

Fig. 7. Position linearity in the direction Y; triangles and open circles correspond to data obtained with backgammon patterns (I) and (II), respectively. Parameters L and d_1 (shown in Fig. 2) are fixed at 5 mm and 10 mm in the measurements.

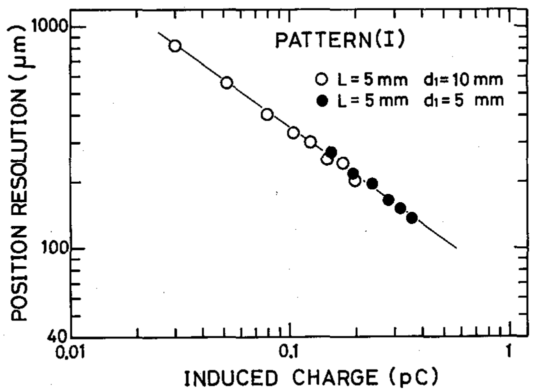

Fig. 8. Position resolution as a function of the charges induced on the needle: open circles, $L=5$ mm and $d_1=10$ mm; closed circles, $L=5$ mm and $d_1=5$ mm. Backgammon pattern (I) given in Fig. 5 was employed in this measurement.

pattern (II) is more serious than that for pattern (I); this is caused by the length in Y-direction much shorter than that of pattern (I). However, the distortion in Y-direction does not affect so much the linearity in X-direction.

In Fig. 8, the position resolution measured for the pattern (I) are plotted as a function of the total charges induced on the pattern; open circles were obtained with conditions of $d_1=10$ mm, while closed circles were obtained with $d_1=5$ mm. The resolution is clearly more improved as the total induced charge is increased.

4. DISCUSSIONS

According to previous works[6,7,10-15], some relations between position resolution and noise sources are discussed is Appendix B. When it can be assumed that the broading in position sensing is caused by the electronic noise from preamplifiers, a theoretical expression for the position resolution is given by Eq. (B1) in Appendix B. This equation suggests that the position resolution p is proportional to the signal to noise (S/N) ratio of output signals from preamplifiers:

$$P \alpha (Q/N)^{-1}. \quad (3)$$

Assuming that the electric noise does not depend on the total charge induced on electrodes in the present work, we obtain a relation of

$$P \propto (Q/N)^{-0.71} \quad (4)$$

from Fig. 8. The resolution presently measured deviates from the simple theoretical model given by Eq. (B1). The origin of this deviation has not been revealed in the present work. The performance of the analog divider employed (Ortec 464) is now examined in detail.

The present result given by Fig. 8 can be applied to roughly estimate the practical resolution of PSPCs with the same electrodes and the same electronics. The total charges of positive ions produced in electron avalanches are given by

$$Q_T = e \cdot E \cdot G/W, \quad (5)$$

where e is the electric charge of an electron, E is the energy of incident radiations, G is the gas multiplication factor and W is an average of energies to ionize atoms and molecules in the filled gas. The charge induced on read-out electrodes is formally given by

$$Q = \varepsilon \cdot Q_T, \quad (6)$$

where ε is a geometrical factor to express the ratio of the induced charge to the total charge, which is a complicated function of the position on the electrodes.

The position resolution was $R = \sim 100$ μm in our separate measurements with the read-out pattern (II)[8], where 8.0-keV Cu KX rays were detected by a cylindrical proportional counter filled with 7-atm Ar+10%CH_4. Since W for Ar+10%CH_4 is 26. 5 eV, M is 2×10^4 and ε is ~75% in this case, the induced charge is estimated to 0.72 pC. It is seen from Fig. 8 that this value corresponds to the resolution of ~90 μm. Thus, the present charge inductive method to measure the resolution of read-out electrodes are useful to predict the position resolution of PSPCs.

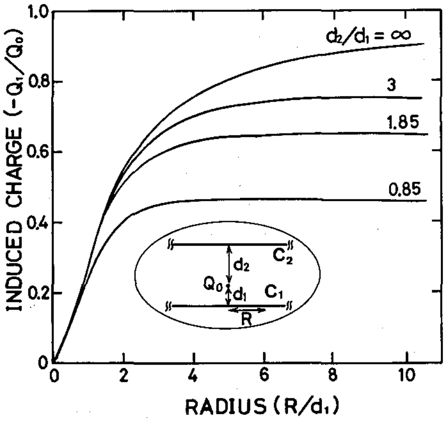

Fig. 9. Theoretical estimate of the charge induced on infinite parallel plate electrodes; Q_0 is the supplied charge, d_1 and d_2 are distances from the supplied charge and plate electrodes C_1 and C_2, respectively, and Q_1 is the charge induced in the circular region with a radius R on the electrode C_1. In this figure, ratios $(-Q_1/Q_0)$ estimated with $d_2/d_1=0.85$, 1.85, 3.0, ∞ are plotted as a function of (R/d_1).

APPENDIX A.

ELECTRIC CHARGES INDUCED ON PARALLEL PLATE ELECTRODES

When electric charges are produced in the space between infinite parallel plate electrodes as shown in Fig. 2, the same amount of charges with opposite sign are induced on the electrodes. The charge induced on the lower plate C_1 is given by

$$Q_1=-\frac{Q}{2}\sum_{n=-\infty}^{\infty}\left\{\frac{d_1+2n(d_1+d_2)}{\sqrt{\{d_1+2n(d_1+d_2)\}^2+R^2}}-\frac{d_1+2n(d_1+d_2)+2d_2}{\sqrt{\{d_1+2n(d_1+d_2)+2d_2\}^2+R^2}}\right\}, \tag{A1}$$

where Q_0 is the supplied charge, d_1 and d_2 are distances from the supplied charge and plate electrodes C_1 and C_2, respectively, and Q_1 is the charge induced in the circular region with a radius R on the electrode C_1. A part of results estimated for the induced charge are given by curves in Fig. 9.

APPENDIX B.

THEORETICAL EXPRESSIONS OF POSITION RESOLUTION

There are two noise sources which contribute to the position resolution obtained with read-out electrodes such as backgammon and wedge and Strip patterns[6,7,10–15]. One is electronic noise mainly caused by preamplifiers. The other is partition noise, which is a fundamental limit to the resolution due to the statistical fluctuations in the distribution of discrete charges among electrodes. The FWHM resolution components caused by electronic noise and partition noise, i. e., P_E and P_P, are given by

$$P_E=\frac{2.36\cdot L}{f_{\max}-f_{\min}}\frac{N}{Q}\sqrt{(1-f)^2+f^2}, \tag{B1}$$

$$P_p = \frac{2.36 \cdot L}{f_{max} - f_{min}} \sqrt{\frac{f \cdot (1-f)}{Q}} , \tag{B2}$$

where Q is the total charges induced on electrodes, N is the rms noise of preamplifiers, L is the length on a side of the read-out, f is the fractional area of an electrode and $f_{max} - f_{min}$ are the upper and lower limits on f.

As discussed by Thornton[15], the partition noise is important when read-out electrodes are used as anodes of multichannel plate device (MCP) or parallel plate proportional counter (PPAC). Since electrons are collected by read-out electrodes in both cases, the signal amplitudes from the electrodes are proportional to the number of electrons collected. This number of electrons is subject to chance; the statistical distribution is binomial because an electron can be collected in two ways, by one electrode or the other one. On the other hand, read-out electrodes are used as cathodes in the present charge inductive method or ordinary PSPCs. The signal amplitude from electrodes depends on induced charges which are not subject to chance. Thus, the partition noise can be neglected in the present work.

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