NUMERICAL ANALYSIS ON THE GAIN-REDUCTION CHARACTERISTICS OF MULTI-WIRE PROPORTIONAL CHAMBERS

Ken Katagiri, Takuji Furukawa, and Koji Noda,
Dept. of Accelerator and Medical Physics, National Institute of Radiological Sciences, Chiba, Japan

Abstract

In order to investigate the gain-reduction characteristics of the multi-wire proportional chamber (MWPC) for different geometric parameters, we performed numerical simulations using a numerical code. The numerical code was developed using a two-dimensional drift-diffusion model to evaluate the gas gain taking into account the reduction effect caused by the space charge effect of the moving positive ions. We investigated the gain-reduction rate for several parameters of the anode-anode distance when beam intensity was increased. We found that the gain reduction could be improved by decreasing the anode-anode distance, owing to the sharing of the initial-ion pairs among the anode wires. From these results, we discuss a desirable distance between the anode wires to improve the gain reduction.

INTRODUCTION

Several tens of MWPCs have been installed in the beam transport line at HIMAC (Heavy Ion Medical Accelerator in Chiba) to diagnose the beam profiles [1]. Also in the scanning irradiation system, which was started to be operated for the cancer treatment in 2011, the MWPCs are used to evaluate the beam position and to construct 2-D fluence maps [2]. In normal operation for treatments, the MWPCs are operated in the current mode and irradiated by high-rate incident particles of $\sim 10^8 - 10^9$ particles per second (pps). Under such a beam condition, gain reduction of the output signal is observed. The gain reduction is due to the distorted electric field, which originates from the space charge of the accumulated ions. If the gain reduction is large, the measured beam profiles may differ from the actual profiles. Therefore, modification of the MWPCs to suppress the gain reduction is an important issue.

In the treatment operation at HIMAC, the irradiation period of ~1 s is much longer than that required by ions to travel from the anodes to the cathodes. Therefore, the gain reduction process cannot be explained only by the remaining ions around the anodes, and it is expected to be transient during the beam irradiation. Information on the relations between the gas-gain variation and the ion-density distribution is necessary for modification of the MWPC parameters, such as anode radius and distance between electrodes. For those reasons, we developed a 2-D simulation code to evaluate the gas gain taking into account the gain-reduction effect [3].

Using the numerical code, we performed analyses on the dynamics of ions/electrons in a helium-filled MWPC to improve the gain reduction. In this paper, we report the simulation results of the gas gain for several parameters of the anode-anode distance. Also we discuss the transient dynamics of the ions, which leads to the variation of the output signal.

SIMULATION METHOD

The 2-dimentional drift-diffusion model was employed to analyse the dynamics of the ions and electrons. In order to simplify the analysis, electrons (e^-) and positive ions (He^+) were only taken into account. The two advection-diffusion equations and the Poisson equation were coupled and solved numerically. The pressure and the temperature inside the MWPC were assumed to be 10^5 Pa and 300 K, respectively. Figure 1(a) – (c) show schematic diagrams of the MWPC in a discrete space. Three types of MWPC with different anode-anode distance were considered for comparison. The 6×6 mm region of the MWPC were discretized by rectangular grids. The anode-anode distance d was altered by changing the number of the anode wires in 6-mm region: 1 wire for $d = 6$ mm (Fig. 1(a)), 2 wires for $d = 3$ mm (Fig. 1(b)), and 3 wires for $d = 2$ mm (Fig. 1(c)). The periodic boundary condition was applied to the boundaries at $x = -3$ mm and 3 mm. The outlet boundary condition was applied to the surface of the two cathodes at $y = -3$ mm and 3 mm, and to the surface of the anodes. Incident projectiles were injected with constant rate of $I = 5 \times 10^8$ pps from $t = 0$. The beam profile formed by all the projectiles was determined to be a Gaussian distribution of $2\sigma = 3.0$ mm, as shown Fig. 1(d). The beam profile along the z-axis was assumed to be homogeneous in the depth direction of 3 mm. The number of the ion-pairs was determined by W-value and energy deposition of 350-MeV/u projectiles in 1-atm He gas [3].

RESULTS AND DISCUSSION

Conditions for Comparisons of the Gain-reduction Characteristics

Figure 2 shows the calculation results of the gas gain without the gain reduction. In order to calculate the no-reduction regime, the space-charge effect was excluded by considering the low rate beams. In order to compare the gain-reduction characteristics, the applied voltages of three types of MWPC need to be determined to obtain same gas gain in the no-reduction regime. For that reason, the applied voltages were determined to obtain the gas gain of $M = 30$: $V = 847$ V for $d = 2$ mm, $V = 751$ V for $d = 3$ mm, $V = 674$ V for $d = 6$ mm.

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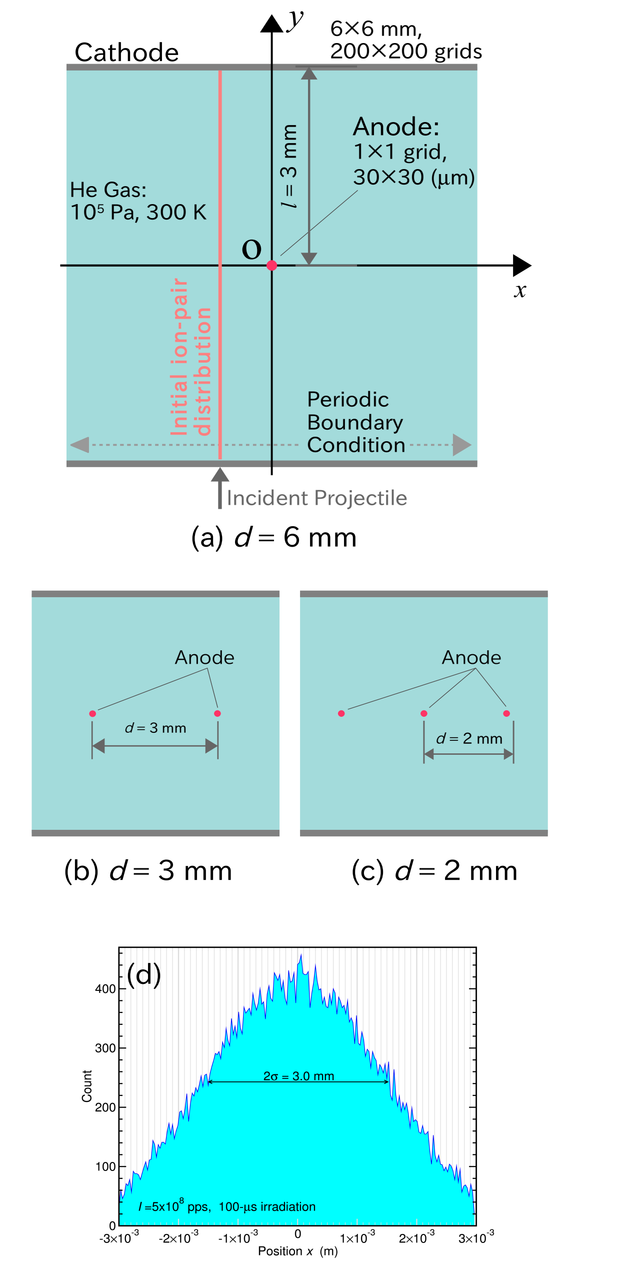

Figure1: Schematic diagram of the MWPC of (a) d = 6 mm, (b) d = 3 mm, and (c) d = 6 mm. (d) The initial distribution of ion-pairs.

Gain-reduction Characteristics

In order to compare the gain-reduction characteristics for three types of MWPC, we calculated the variation of the gas gain from t = 0 to t = 25 μs. Figure 3 shows the temporal evolutions of the gas gain for three types of MWPC. Although each of three curves reached the gas gain of M = 30 at t = 0, they drastically decreased during 25 μs. In order to evaluate the gas gain after the transient decay, each of curves was fitted by a function of y = const. using t = 20 – 25 μs region, as shown in the Fig. 3.

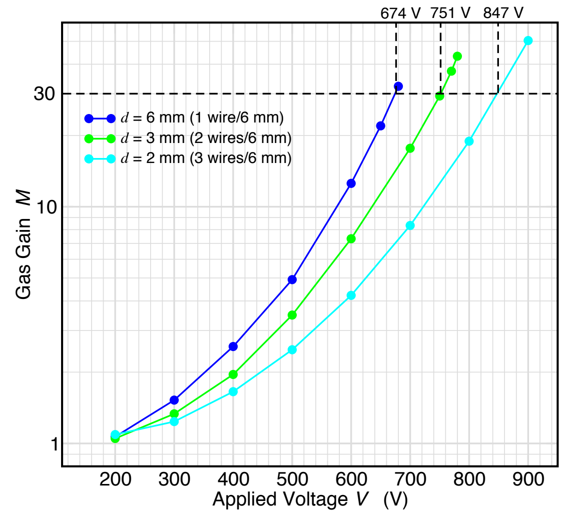

Figure 2: Gain curves without the space-charge effect.

The results of reduction rate are 30% for d = 2 mm, 35% for d = 3 mm, and 48% for d = 6 mm. From those results, we confirmed that the gain reduction could be improved by reducing the anode-anode distance.

We evaluated the total number of ions in MWPC, which were produced by electron-multiplication processes

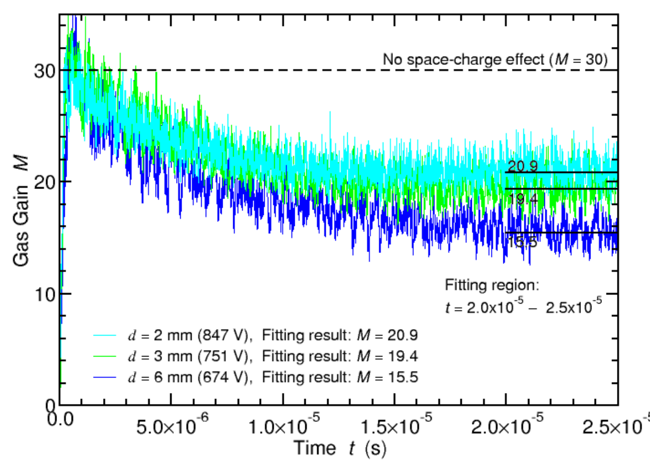

Figure 3: Temporal evolution of gas gain.

(avalanche), to consider the reason of the improvement on the gain reduction. Figure 4 shows the temporal evolutions of the total number of the ions in MWPC. The ion dynamics in the 6-mm-distance MWPC did not reach the quasi-stationary state [3] during 25 μs, as we can see the transient variation in the curve. On the other hand, the gas-gain variation for the 6-mm-distance shown in Fig. 3 was in the end of the transient process and nearly constant. Also, for example at t = 15 μs, we can see the least number of ions in the 6-mm-distance MWPC, however its gain-reduction rate was most intense for three types of the MWPC. This is due to fact that the gain variation was strongly affected by the ions around the anodes.

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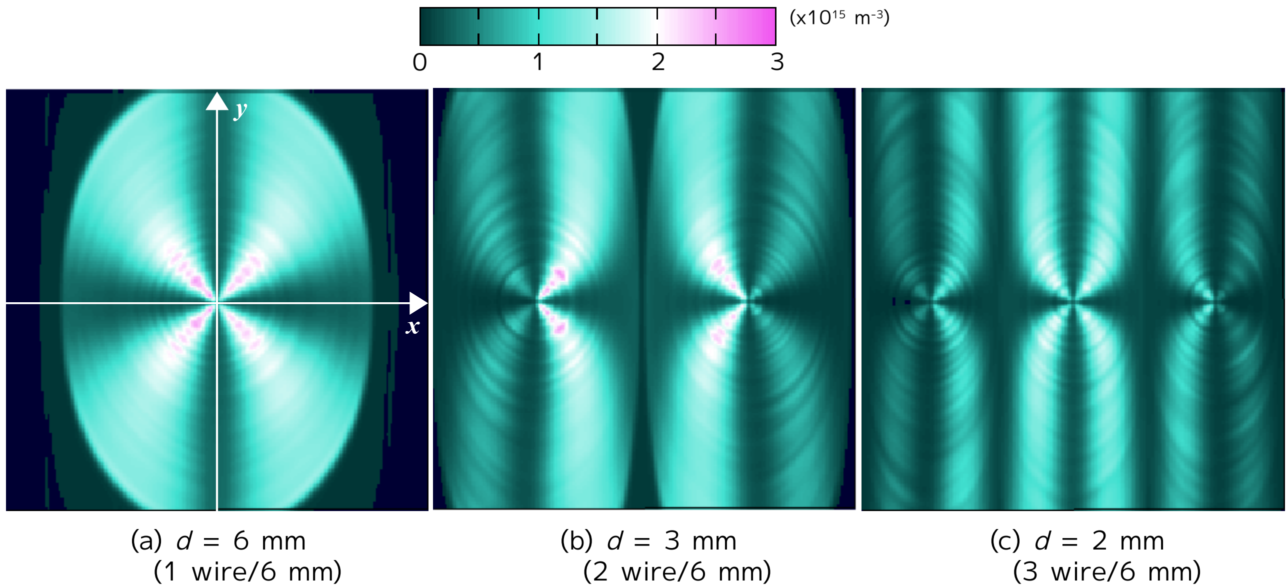

Figure 5: Ion density distribution at $t = 25$ μs.

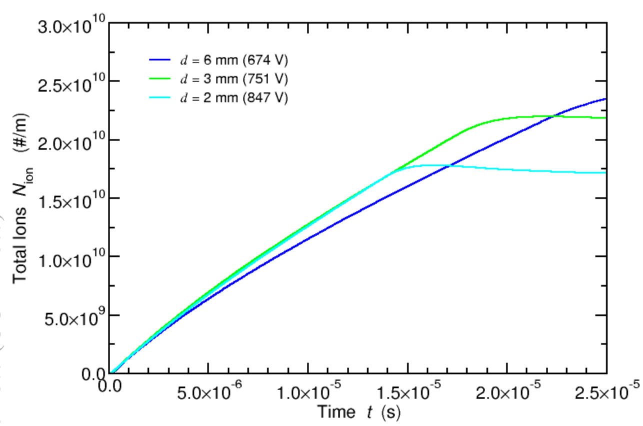

Figure 4: Temporal evolutions of the number of ions.

Figure 5 shows the ion density distribution for (a) $d = 6$ mm, (b) $d = 3$ mm, and (c) $d = 2$ mm. We see that the ions drifted from the anodes to the cathodes along the electrical flux lines. By comparing the results from three types of the MWPC, we confirmed that the ion density around the anodes decreased as reducing the anode-anode distance. When the fluence distribution of the incident beams is same condition for three types of MWPC, the anode wires existing in the irradiation region share the initial-ion pairs; The avalanche events around each anode, which are caused by the initial-ion pairs, can be reduced by increasing the number of anode wires. Therefore, we could decrease the ion density around each anode. Owing to the low-ion density around the anode wires, the field distortion of the electric field was weakened. As a result, we could improve the gain-reduction rate by increasing the number of the anode wires.

CONCLUSION

Using a 2-D simulation code based on the drift-diffusion model, we performed analyses on the dynamics of ions/electrons in a helium-filled MWPC to improve the gain reduction. From the simulation results, we found that the gain reduction caused by high-intensity incident beams could be relaxed by the sharing of the initial-ion pairs among the anode wires. In order to further optimize the MWPCs used for beam profile monitor in the HIMAC facility, we are going to investigate the dependence of other parameters, such as the anode-wire radius and the anode-cathode distance, on gain-reduction rate.

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