STUDY ON A GAS-FILLED CAPILLARY WAVEGUIDE FOR LASER WAKEFIELD ACCELERATION*

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Abstract

In gas-filled capillary waveguide for laser wakefield accelerators the gas flows through the two gas feed lines used to sustain constant pressure. Compared to the supersonic gas-jet system operated under high pressure, the gas at low pressure (<1atm) is injected inside capillary waveguide, so that this waveguide has experimental limit to the measurement of the neutral density. In order to investigate the gas pressure in capillary system we used computational fluid dynamics (CFD) simulation. In this paper, we presented the gas pressure changed by a variety of parameters, such as length and sizes of gas feed lines, and the method to decrease the turbulence effect at the ends of capillary.

INTRODUCTION

The conventional particle accelerators are difficult to obtain beyond acceleration gradients on the order ~100MV/m because of breakdown problem. In order to overcome this problem laser-plasma acceleration methods, which have acceleration gradients ~100GV/m, have been studied by using two key system, supersonic gas-jet and capillary system. In the initial stage the electron acceleration research with gas-jet system have been widely performed and have attained a few hundred of MeV electron beams. However, GeV scale electron generation using this method is limited because of laser diffraction of in a short range. A gas-filled capillary waveguide can be used to guide the intense laser beam over several Rayleigh lengths (~cm), and thereby 1GeV electron beam generation with a gas-filled capillary discharge plasma was accomplished in 2006 [1]. In addition, the electron acceleration experiment with the gas cell system was carried out in 2008 [2]. For such gas-filled systems the gas is injected through feed lines fabricated by micromachining laser and is filled through the capillary. Thus, the gas flow inside capillary channel, including turbulence effect, must be investigated using fluid simulation for stable experimental conditions. For this purpose, we performed a CFD simulation for variable structures and described a structure for turbulence decrease.

SIMULATION SETUP

Figure 1 shows the gas-filled capillary scheme with each two gas inlets and outlets. The capillary used for experiments in Fig. 1 is made by putting two machined sapphires together. For the CFD simulation, we used

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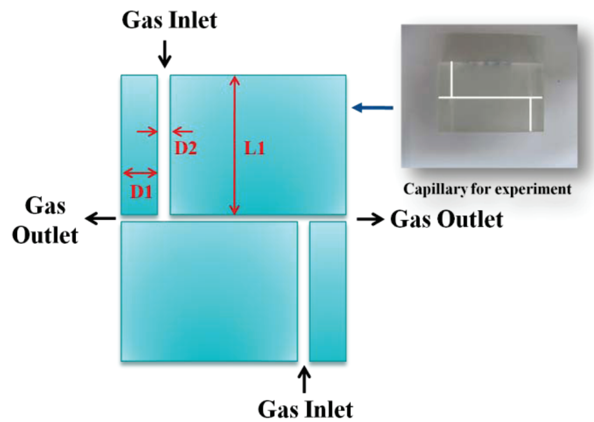

Figure 1: A gas-filled capillary waveguide for simulation.

Ansys CFX (vers. 11.0) based on Navier-Stokes equations, and steady state simulation type and κ-ε turbulence model are used. The capillary length and diameter are fixed 15mm and 0.2mm, respectively. A kind of gas is selected to the air at 25℃. To give pressure difference between inlet and outlet, the pressure of two outlets is set to vacuum and the pressure of 150Torr is introduced to two gas inlets.

SIMULATION RESULTS

A Laser beam is focused to the entrance of capillary during the gas goes out at the ends of capillary. Although the gas pressure is low, the interaction between laser pulse and outgoing gas may give rise to minor effect. The initial capillary waveguides have right angle corners to send a gas for filling in the capillary. The severe turbulence, therefore, can occur at the intersections and at the ends of capillary from this structure. To decrease this effect we changed from right angle structure to fillet shape as in Fig. 2. The distance between edge of capillary and gas inlet (D1) is 1.5mm and fillet radius of capillary scheme in Fig. 2(b) is 1.4mm. The magnified regions in Fig. 2 show the pressure distributions at each corner. The gas flow of revised capillary, as seen in Fig. 2(b), comes nearer to laminar flow compared to that of initial capillary in Fig. 2(a). In addition, as the fillet radius is high, the turbulence is decreased because the gas flows with lower angle compared to the capillary in Fig. 2(a).

Figure 3 shows the pressure along the centre of longitudinal direction (top) and radial pressure near the

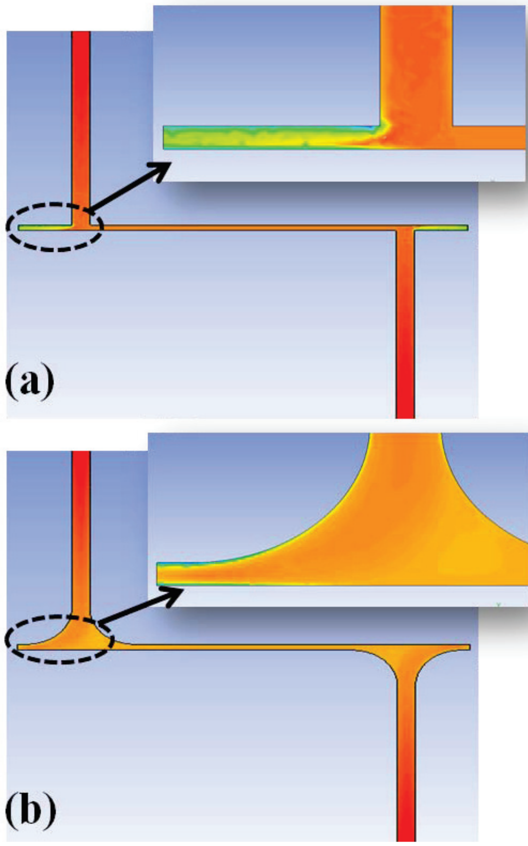

Figure 2: Turbulence level of capillaries with and without fillet.

edge of capillary (bottom) for the capillary with and without fillet. In the capillary without fillet as top figure of Fig. 3 the high pressure difference between the edge and centre of capillary is clearly produced, but the capillary with rounded line obtained nearly constant pressure. Furthermore bottom figures of Fig. 3 show the pressure distribution along radial direction of capillary is different at two cases and the capillary with fillet (large figure) is more symmetry than that without fillet (small figure). This structure may be effectively used to achieve stable status of gas discharge plasmas or interaction of laser beam and output gas.

When the gas is injected through gas feed lines, the size of lines flowing the gas is very critical parameter than capillary length. Figure 4 shows the pressure change along the capillary length direction under a variety of inlet lengths, L1, (top) and inlet widths, D3, (bottom) for the capillary with fillet line. The inlet length and width of capillary used for experiment performed at GIST are 10mm and 0.7mm, respectively. As seen in Fig. 4 the pressure difference between centre and end of capillary is not high enough and similar at each condition. When the inlet length is increased as top figure of Fig. 4, total pressure is reduced. Compared to the result about the change of inlet length, as the inlet width is increased from 0.1mm to 2mm, the total pressure is measured 10Torr to

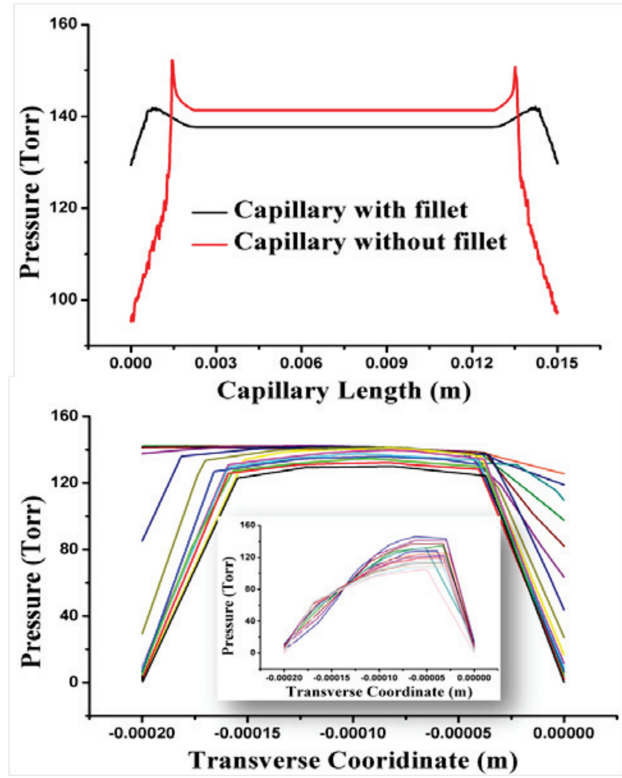

Figure 3: Comparison of pressures along the longitudinal direction (top) and radial pressures near the end of capillary (bottom) for capillary with and without fillet.

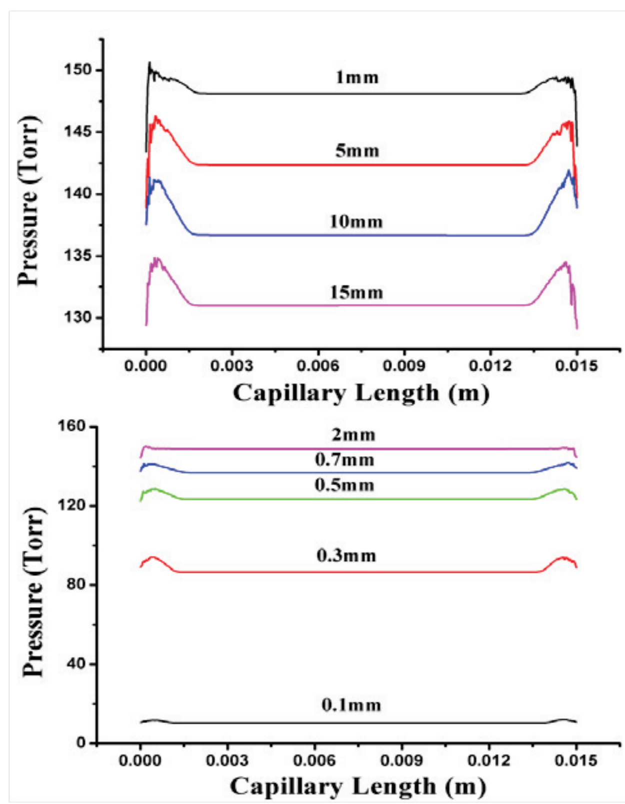

Figure 4: Pressures under various inlet lengths (top) and inlet widths (bottom).

150Torr with a wide variation.

SUMMARY

We carried out the CFD simulation for understanding of gas flow inside the capillary before electron acceleration experiments. We suggested the method to decrease the turbulence effect at the intersection in a gas-filled capillary waveguide and showed nearly stable laminar flow at the corner. The symmetry at the regions of ends of capillary was obtained. The total pressure under various conditions, such as inlet lengths and inlet widths, was measured and the pressure distributions were shown along the longitudinal direction. In addition, the simulation at more variable conditions and experiments to prove simulation results are under way.

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REFERENCES

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