AEROSOL PARTICLE SIZE SPECTROMETER USING A MICROMACHINED CASCADE IMPACTOR

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ABSTRACT

This paper reports a MEMS-based particle size spectrometer using a micromachined cascade impactor. While a MEMS-based particle counter presented in our previous research was developed for measuring the total number concentration of particles within certain size range, the proposed particle size spectrometer is developed for measuring airborne particle size distribution. To the best of our knowledge, MEMS device for measuring aerodynamic particle size distribution is a first attempt. The overall performance of the MEMS-based particle size spectrometer was evaluated by comparing size distribution measurements with commercial instrument.

INTRODUCTION

Measurement of the particle size distribution is an important tool for research and development in many industries including pharmaceutical, automotive, etc. However, commercially available particle size analyzers are large and expensive [1]. In these days, several studies are reported for the compact, portable, and inexpensive particle detection instruments. [2,3]. Among these studies, a MEMS-based particle counter was presented in our previous research [4,5]. However, it is not suitable for measuring the particle size distribution because it can only measure the total number concentration of particles within certain size range. In this paper, a low cost and compact particle size spectrometer using a micromachined cascade impactor is proposed for measuring the particle size distribution. The overall performance of the particle size spectrometer was evaluated by comparing size distribution measurements with commercial instrument.

DESIGN AND FABIRICATION

As shown in Figure 1, the proposed MEMS-based particle size spectrometer is composed of a micromachined corona charger and a micromachined cascade impactor. The working principle of the particle size spectrometer is quite simple. The micro corona charger is used for electrical charging of aerosol particles. If a high voltage is applied between a discharging electrode and a ground electrode, corona discharge occurs, and gaseous ions are generated. The particles are charged due to collision of the particles with migrated ions. And then charged aerosol particles are introduced into the micromachined cascade impactor. Electrically charged aerosol-containing working fluid is directed by a nozzle toward a flat particle collection plate, and the working fluid is deflected around the edges of the plate toward an outlet. Particles larger than the certain threshold (cut-off diameter) have sufficient inertia to hurdle across the working fluid streamlines and impinge on the particle collection plate. Particles smaller than the cut-off diameter (the particle diameter corresponding to 50% collection efficiency) follow the streamline more closely and remain suspended in the working fluid.

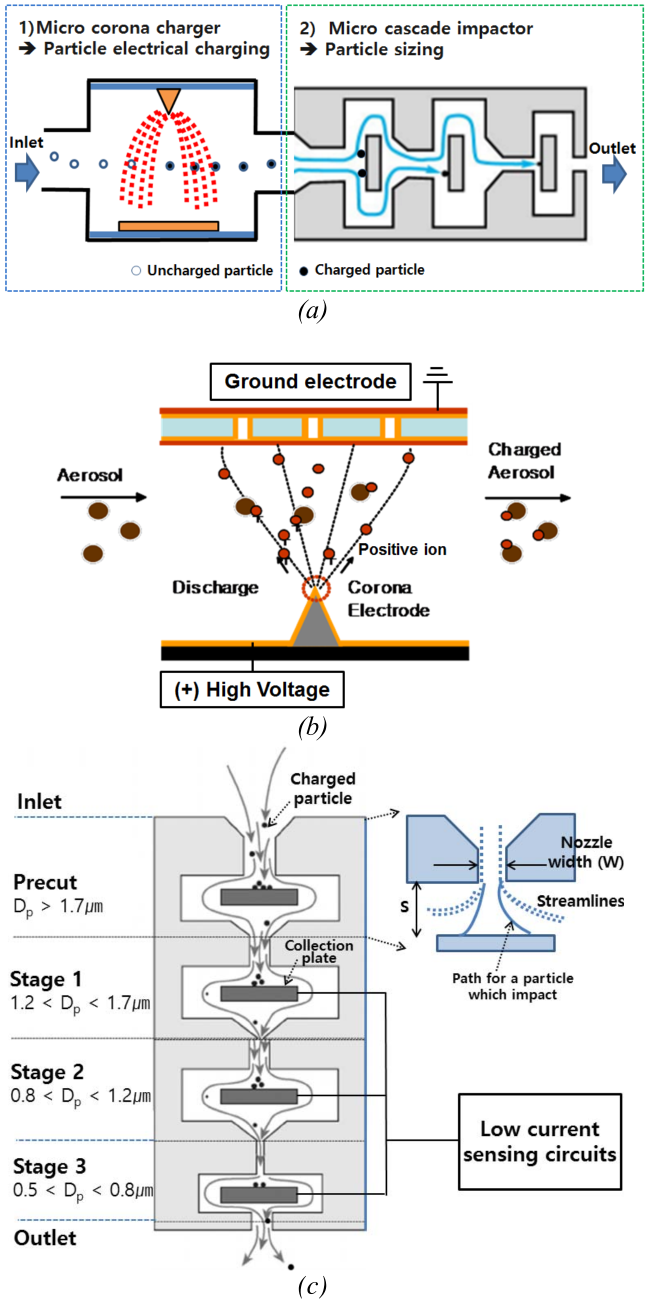


Figure 1: (a) Microfluidic layout of the MEMS-based particle size spectrometer, (b) particle charging and (c) sizing process.

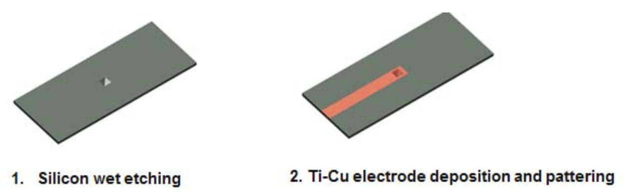
The micromachined cascade impactor consists of four collection stage in a microchannel. The cut-off diameter of the each stages are numerically calculated to be 500, 800, 1200, and 1700 nm. The low current sensing circuit is used to simultaneously measure the charges carried by the collected particles from each stage. The measured current signals are then converted to the number concentration of particles. The particle size distribution can be obtained by measuring the number concentration of collected particles from each stage. Table 1 summarizes the design and operating parameters of the cascade impactor for a sample flow rate of 0.3 L/min.

Table 1: Design parameters and experimental results for the micromachined cascade impactor operated at a flow rate of 0.3 L/min.

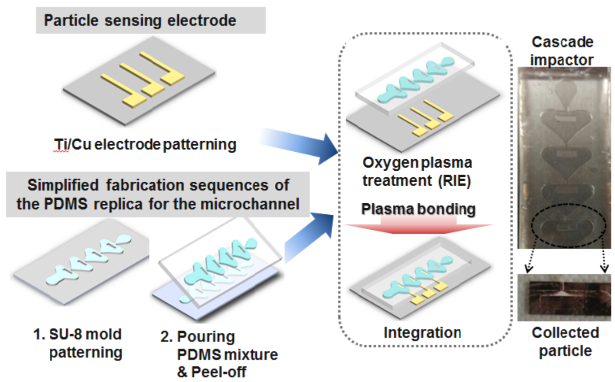
Stage	Cut-off diameter (nm)		Nozzle width (µm)	Micro channel thickness (µm)
	Designed	Measured		
Precut	1700	1630	890	500
1	1200	1110	660	500
2	800	820	460	500
3	500	480	300	500

Figure 2 shows a simplified fabrication process of the micromachined corona charger and cascade impactor. The fabrication of the micro corona charger began with patterning the silicon dioxide layer on a four inch silicon wafer. The sharp silicon tip was realized by anisotropic wet etching of the silicon wafer using a 20%wt potassium hydroxide and water (KOH, J.T. Baker) aqueous solution. The fabricated silicon tip was 35µm in height and 50µm in width on average. Subsequently, a fresh 1 µm-thick silicon dioxide layer for insulation was thermally grown on the sharp silicon tip. After this step, a 1 µm-thick titanium-copper layer was deposited and patterned.

The micromachined cascade impactor consists of particle sensing electrodes patterned on a glass substrate and a polydimethylsiloxane (PDMS) replica of the microfluidic channels. To form particle sensing electrodes, a 1 µm-thick titanium-copper electrode was deposited and patterned using a conventional photolithography method. To form a PDMS replica of the microfluidic channels, SUEX sheets (SUEX D500, DJ DevCorp) was patterned on a silicon wafer at a thickness of 500 µm for the microchannel and particle collection palates. Then, a mixture of PDMS pre-polymer and curing agent (Sylgard 184, Dow Corning, MI) was poured onto the patterned SUEX sheets and cured. To define the microfluidic channel, both the PDMS replica and particle sensing electrodes on a glass substrate were aligned and bonded after treatment with oxygen plasma.



(a)



(b)

Figure 2: Simplified fabrication process of the (a) micro corona charger and (b) cascade impactor

EXPERIMENT AND RESULTS

Figure 3 shows a schematic diagram of the experimental setup for evaluating overall performance of the MEMS-based particle spectrometer. Compressed air was used as a carrier gas, after oil droplets, moisture, and contamination particles were removed by a clean air supply system. Polystyrene latex (PSL) particles ranging from 100 to 2000 nm were used as test particles and were generated from an atomizer. The PSL particles were supplied to the proposed particle spectrometer. The particles were charged by corona charger and then the current by charged particles was measured by signal processing circuits [5]. The overall performance of the MEMS-based particle spectrometer was evaluated by comparing size distribution measurements with APS (Aerodynamic Particle Sizer, TSI Inc.)

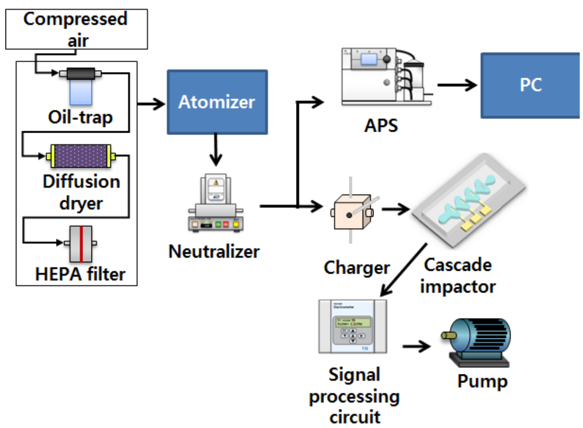


Figure 3: Schematic diagram of the experimental setup for evaluating performance of the MEMS-based particle spectrometer.

Figure 4 shows schematic view of signal processing circuits for measuring the current carried by charged particles. Signal processing circuits are composed of a low current amplifying circuit and a MCU (micro controller unit). The low current amplifying circuit transforms *fA* level currents, carried by charged particles, into voltages. In order to minimize an effect of the outside electrical noise, a high integrity PCB design, shielding, and electronic packaging method was utilized. The MCU converts analog signal into digital signal.

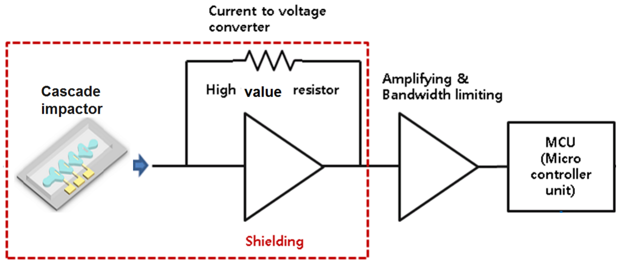


Figure 4: Schematic view of signal processing circuits for measuring the current carried by charged particles.

Figure 5 shows the particle collection efficiency at each stage of the micromachined cascade impactor. The collection efficiency of a given particle size was calculated using the current carried by collected particles from each stage. The measured cut-off diameters were found to be 1630, 1110, 820, and 480 nm, respectively. The experimental values were within 10% of the theoretical values.

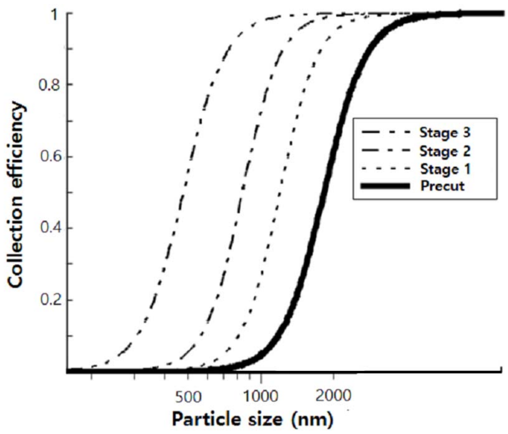


Figure 5: Collection efficiencies at each particle collection stage of the micromachined cascade impactor

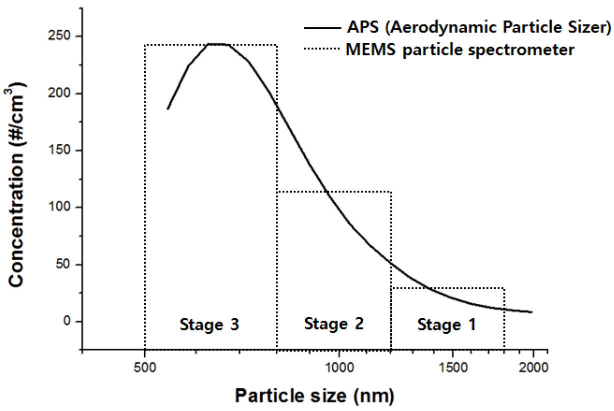


Figure 6: Comparison between the MEMS-based particle size spectrometer and the APS

The overall performance of the MEMS-based particle spectrometer was evaluated by comparing size distribution measurements with APS (Aerodynamic Particle Sizer, TSI Inc.). Polydispersed PSL particles were used as test particles. The current carried by charged particles was measured by a low current sensing electrometer. By using the measured current, the number concentration of particles can be calculated.

$$N = I / PneQ \qquad (1)$$

where, N is the number concentration of particles, I the current by charged particles, P the particle penetration, n the number of charges, e the elementary charge, Q the flow rate. Figure 6 shows the measured particle size distributions using the proposed particle size spectrometer and APS. The good agreement between the two distributions shows that the MEMS-based particle size spectrometer performs well an can be used for cost-effective and real-time particle size distribution measurements.

CONCLUSION

The MEMS-based aerosol particle size spectrometer has been proposed for cost-effective and real-time particle size distribution measurements. The particle spectrometer is composed of a micro corona charger and a cascade impactor. While a MEMS-based particle counter presented in our previous research was developed for measuring the total number concentration of particles within certain size range, the proposed particle size spectrometer is developed for measuring airborne particle size distribution. The proposed particle size spectrometer demonstrates successful measurement of particle size distribution. Future work will focus on the high-resolution particle size analysis and measurement of nanoparticle size distribution.

ACKNOWLEDGEMENTS

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REFERENCES

[1] M. Marjamaki, J. Keskinen, D.-R. chen and D.Y.H. Pui, “Performance evaluation of the Electrical Low-Pressure Impactor (ELPI)”, *J. Aerosol Sci.*, vol. 31, pp. 249-261, 2000

[2] C. Qi, D. Chen, and Greenberg, “Performance study of a unipolar aerosol mini-charger for a personal nanoparticle sizer”, *J. Aerosol Sci.*, vol. 39, pp. 450-459, 2008

[3] D. Xu, L. Sheng, H. Wang, Y. Sun, X. Zhang and J. Mi, “Study of magnetically enhanced corona pre-charger”, *J. Electrostatics*, vol. 65, pp. 101-106, 2007.

[4] Y. H. Kim, D. H. Park, J. H. Hwang and Y. J. Kim, “Integrated particle detection chip for environmental monitoring”, *Lab on a chip*, vol. 8, pp. 1950-1956, 2008

[5] H. L. Kim, J. S. Han, S. M. Lee, H. B. Kwon, J. H. Hwang and Y. J. Kim, “Ultrafine particle counter using a MEMS-based particle processing chip”, *Proc. MEMS 2015*, pp. 559-562, 2015

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