

5

## *Supplemental material*

### **MEMS-based condensation particle growth chip for optically measuring airborne nanoparticle concentration**

10

**Hong-Beom Kwon<sup>a</sup>, Seong-Jae Yoo<sup>a</sup>, Hong-Lae Kim<sup>a</sup>, Kyungtae Kim<sup>a</sup>, Jang-Sup Han<sup>a</sup>, Min-Ki Kim<sup>a</sup>, Dong-Hyun Kang<sup>b</sup> and Yong-Jun Kim<sup>a\*</sup>**

<sup>a</sup> School of Mechanical Engineering, Yonsei University, Republic of Korea

15

<sup>b</sup> Micro Nano Fab Center, Korea Institute of Science and Technology, Republic of Korea.

\* To whom correspondence should be addressed: [yjk@yonsei.ac.kr](mailto:yjk@yonsei.ac.kr)

## [Experimental setup]

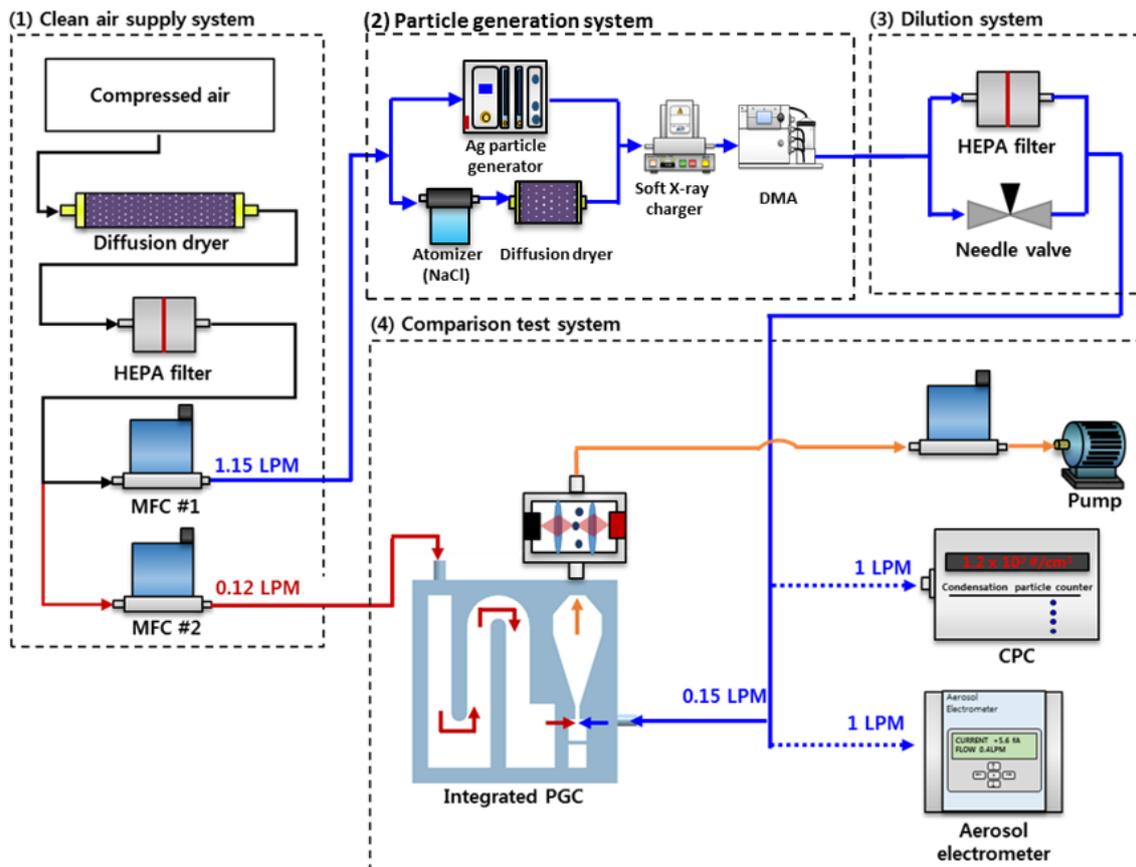


Fig. S1 The experimental setup for the characterization and performance evaluation of our system.

5 Fig. S1 shows a schematic diagram of the experimental setup for performance evaluation of our system. The experimental setup included four sections: (1) clean air supply system, (2) monodisperse particle generating system, (3) dilution system, and (4) comparison test system. In the first section, compressed air, carrier gas, was dried and filtered using a diffusion dryer and a high efficiency particulate air (HEPA) filter. The clean air was then supplied at a precise flow rate by mass flow controllers (MFC; VIC-D200, MKP Co., KR). In the second section, Ag and NaCl particles were generated from a nanoparticle generator (EP-NGS20, EcoPictures Co., KR) and an atomizer (model 9302, TSI Inc., USA) with a diffusion drier, respectively. They were electrically charged by soft X-ray charger (XRC-05, HCT Co., KR). The particles then became monodisperse to a specific diameter in a differential mobility analyzer (DMA; model 3081A, TSI Co. Ltd., USA) adjusting the applied voltage. When polydisperse particles were needed, the voltage and sheath flow rate of the DMA was set to zero to keep their size distributions. Next, the particles were diluted to a specific concentration in the dilution system by adjusting the needle valve. Our system was quantitatively characterized by the aerosol electrometer (Model 3068B, TSI Inc., USA) and CPC (Model 3772, TSI Inc., USA) to evaluate its minimum detectable particle size, detectable number concentration range, accuracy, and sensitivity.

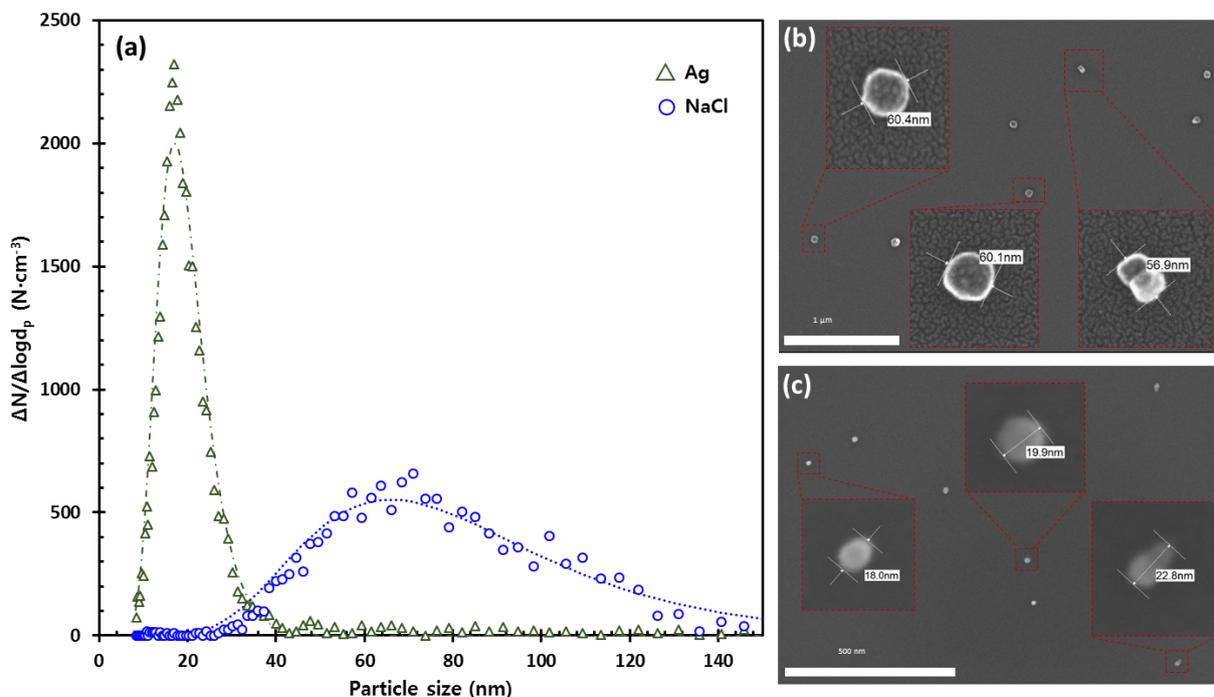
## [Reference number concentration]

The reference concentration was obtained from the aerosol electrometer, because most of the nanoparticles were singly charged before they were classified. to a specific diameter. The relationship between the current ( $I$ ) carried by the particles and the reference concentration ( $N_{ref}$ ) can be expressed as

$$I = N_{ref} \cdot ne \cdot Q, \quad (S1)$$

where  $n$  is the charge number (+1) on a single particle,  $e$  is the elementary charge ( $1.6 \times 10^{-19}$  C), and  $Q$  is the volumetric flow rate entering an aerosol electrometer.

[Information about test aerosols]



**Fig. S2** (a) Size distributions of test aerosols; SEM images of (b) 60 nm-sized NaCl particles and (c) 20 nm-sized Ag particles.

5 Figure S2 (a) shows the size distributions of the generated Ag and NaCl particles, which were measured using a scanning mobility particle sizer (SMPS; model 3936, TSI Inc., USA). A log-normal fit was then applied to each distribution, and the corresponding peak diameters from the fitted curves were 18 nm for Ag and 66 nm for NaCl, respectively. Microscopic characterizations using SEM were performed to evaluate the morphologies of Ag and NaCl particles. The generated Ag and NaCl nanoparticles were highly spherical, indicating that they were appropriate for being used as test aerosol. Furthermore, it was demonstrated that after passing through the DMA (particle-size classifier), the nanoparticles become highly monodisperse and their sizes were almost the same as the target diameters input to the DMA.

Ag nanoparticles were used for characterizing the minimum detectable particle size, detectable number concentration range, accuracy and sensitivity of our system, while NaCl particles were used for evaluating the system response when particles with a wide size distribution were introduced.

[Generation of droplets using nanoparticles as condensational nuclei]

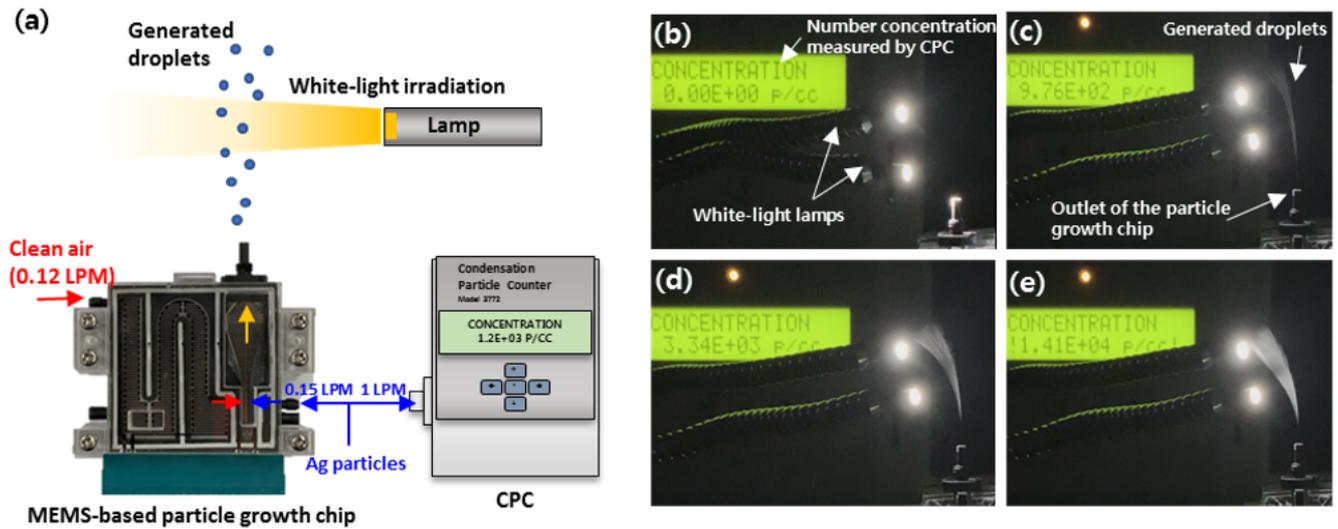


Fig. S3 (a) The experimental setup for visualizing the droplet generation using nanoparticles as nuclei; Optical images of generated droplets coming out from the outlet of the particle growth chip, in case of (b) filtering Ag nanoparticles and (c)-(e) increasing their number concentration.

Our system utilizes the principle of heterogeneous nucleation: under the controlled supersaturated condition, nanoparticles act as condensational nuclei and grow to micrometer-sized droplets. However, where the saturation ratio exceeds the saturation ratio, droplets may form as vapor condenses by itself without nanoparticles (homogeneous nucleation), which leads false counts (measuring concentration higher than actual concentration). Therefore, it is important to identify whether homogeneous nucleation occurs in the MEMS-based particle growth chip.

To evaluate and visualize this phenomenon, white-light lamps were irradiated just above the outlet of the MEMS-based condensation particle growth chip in operation (Fig. S3 (a)). The concentration of Ag nanoparticles entering the chip was controlled by the needle valve of the dilution system and monitored by the reference CPC. As shown in Fig. S3 (b), when filtering nanoparticles, any scattered light from droplets was not detected, indicating that droplets were not grown in the chip without condensational nuclei. On the contrary, with the increment of the nanoparticle number concentration, the scattered light intensity increased and thereby the path of the generated droplets coming out from the outlet of the chip was clearly visible (Fig. S3 (c) - (e)). These results demonstrate that the MEMS-based particle growth chip is capable of growing nanoparticles to droplets.

