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Supplementary Information

Nano-dry-salt deposition on electret nonwoven confers anticoronaviral effect while retaining aerosol filtration performance

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CHARACTERIZATION

Surface potential of treated electret nonwoven

To simulate commonly accessible disinfections or aging of filters, meltblown polypropylene electret nonwoven sheets (HNMB040, Hana Filter, Korea) were used as the base material to obtain surface potentials from exposure to alcohol (isopropyl alcohol; W292907, Sigma-Aldrich, USA), surfactant (6058985, Aekyung Industrial, Korea), or artificial saliva (Xerova, Kolmar Korea, Korea). To simulate the disinfections, the pristine electret nonwoven sheet was immersed in the alcohol or surfactant solution for 2 h, and subsequently dried for 24 h in ambient conditions after washing with deionized water (18.2 mΩ cm^{-1}; Milli-Q Plus System, Millipore, France). In the case of saliva exposure, the artificial saliva solution was sprayed to generate droplets using a Collison-type atomizer (9302, TSI, USA) in the presence of filtered air flow, and this droplet-laden flow entered into a straight duct containing an electret nonwoven sheet placed perpendicular to the direction of air flow. The sheet was constantly exposed to the droplets for a predetermined period of time and dried in ambient conditions. Changes in NDS shape from the saliva exposure were monitored using a FESEM (JSM-7610F-Plus, JEOL, Japan). Surface potentials of the nontreated and treated electret nonwovens were obtained using a commercial electrostatic fieldmeter (ARS-H002ZA, Dong Il Technology, Korea).

Pressure drop of NDS deposited nonwoven

To identify the changes in air permeability after NDS deposition, pressure drops of NDS deposited (1.0 to 14.5×10^9 particles cm^{-2}) electret nonwovens for different face velocities of air from 1.00 to 1.50 m s^{-1} were measured using a differential pressure gauge (Magnehelic 2000, Dwyer Instruments, USA). In addition, the deposition of NDS particles on the nonwoven material was examined using FESEM. The experimental data were validated through comparison with theoretical plots obtained using the following equation:

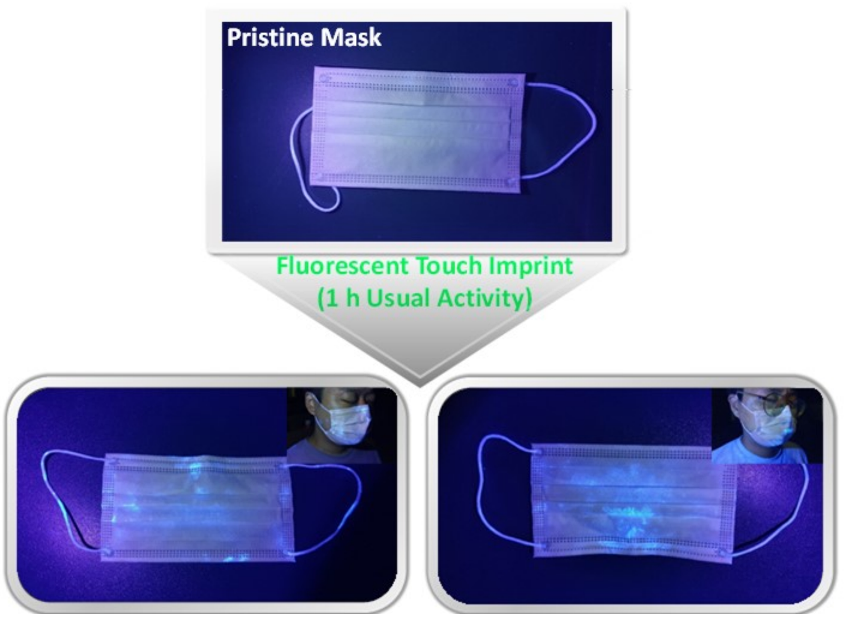
$$\Delta P = \frac{4\mu\alpha Lu(1 + 1.996Kn)}{0.25d_f^2\left\{ - 0.5ln\alpha - 0.75 + \alpha - \frac{\alpha^2}{4} + 1.996Kn\left(- 0.5ln\alpha - 0.25 + \frac{\alpha^2}{4}\right)\right\}}$$

where, μ, α, L, u, Kn, and d_f are the dynamic viscosity of air, nonwoven solidity, depth of nonwoven sheet, face velocity, Knudsen number, and fiber diameter, respectively.

Anticoronaviral stability of NDS treated nonwoven

To simulate the long-term use of NDS treated electret nonwovens, Arizona road dust (12713F, Powder Technology, USA) was used for aging the NDS treated nonwovens, given that the dust has been standardized (ISO 12103-1) as simulated airborne particles for the performance tests of air cleaning devices and cabin air filters in automobile heating, ventilating, and air conditioning systems. These dusts were aerosolized using a lab-made dust feeder consisting of an Erlenmeyer flask, magnetic stirrer, and filtered air supply (2 L min^{-1}). The mass concentration of aerosolized dust particles was monitored using an aerodynamic particle sizer (3321, TSI, USA) to obtain the required dust exposure time. We simultaneously weighed the treated (NDS only and NDS+dust) nonwovens using a microbalance (AR2140, Ohaus, USA); thereby, the desired dust deposition densities (1 to 3 mg cm^{-2}) were obtained. These nonwovens were then exposed to the aerosolized HcoV particles (OC43 and 229E) to examine anticoronaviral stabilities through the test protocol described in the Method section of the main text.

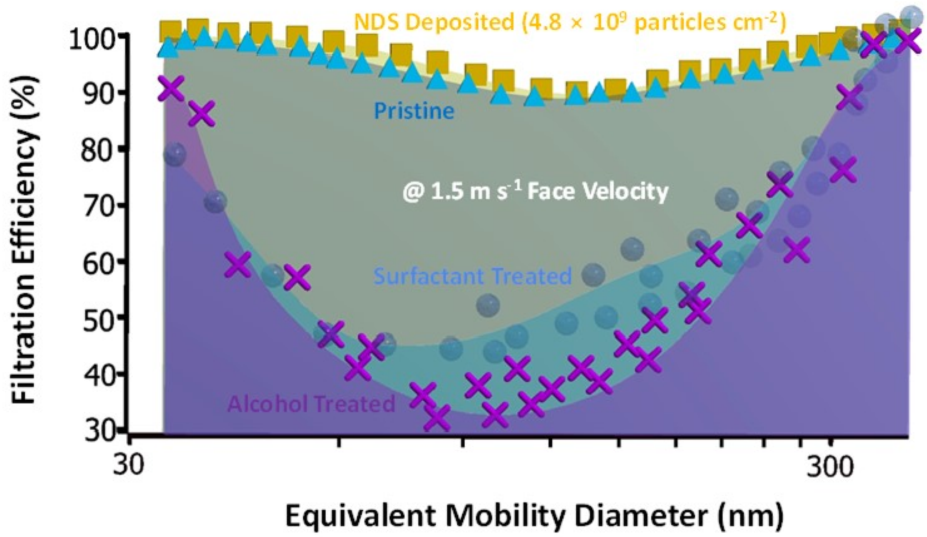
Fig. S1



Digital images of fluorescent touch imprint on face masks collected after wear with usual activity for 1 h.

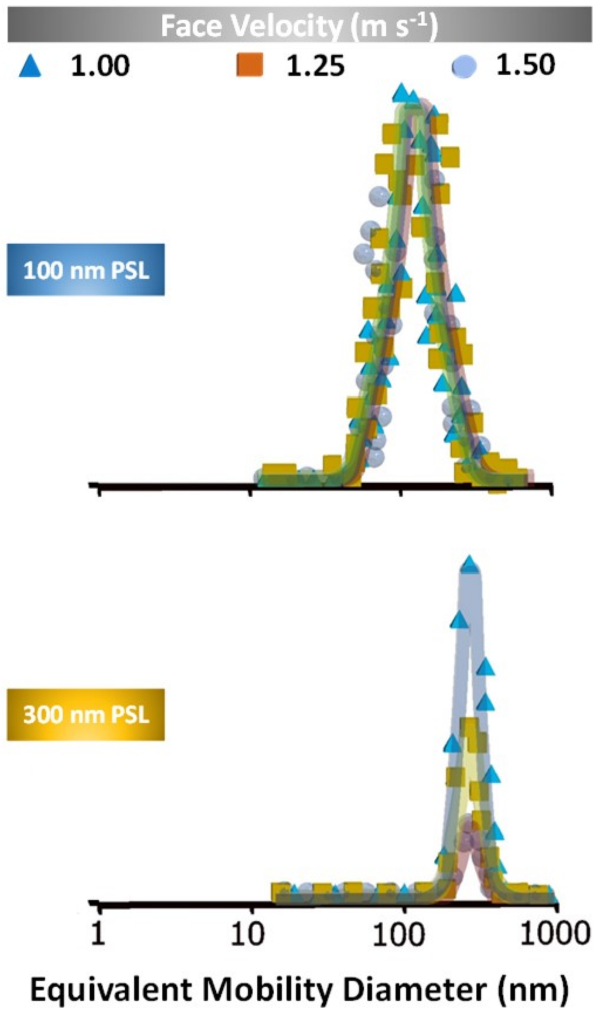
The fluorescent images were obtained under UV-365 nm irradiation.

Fig. S2



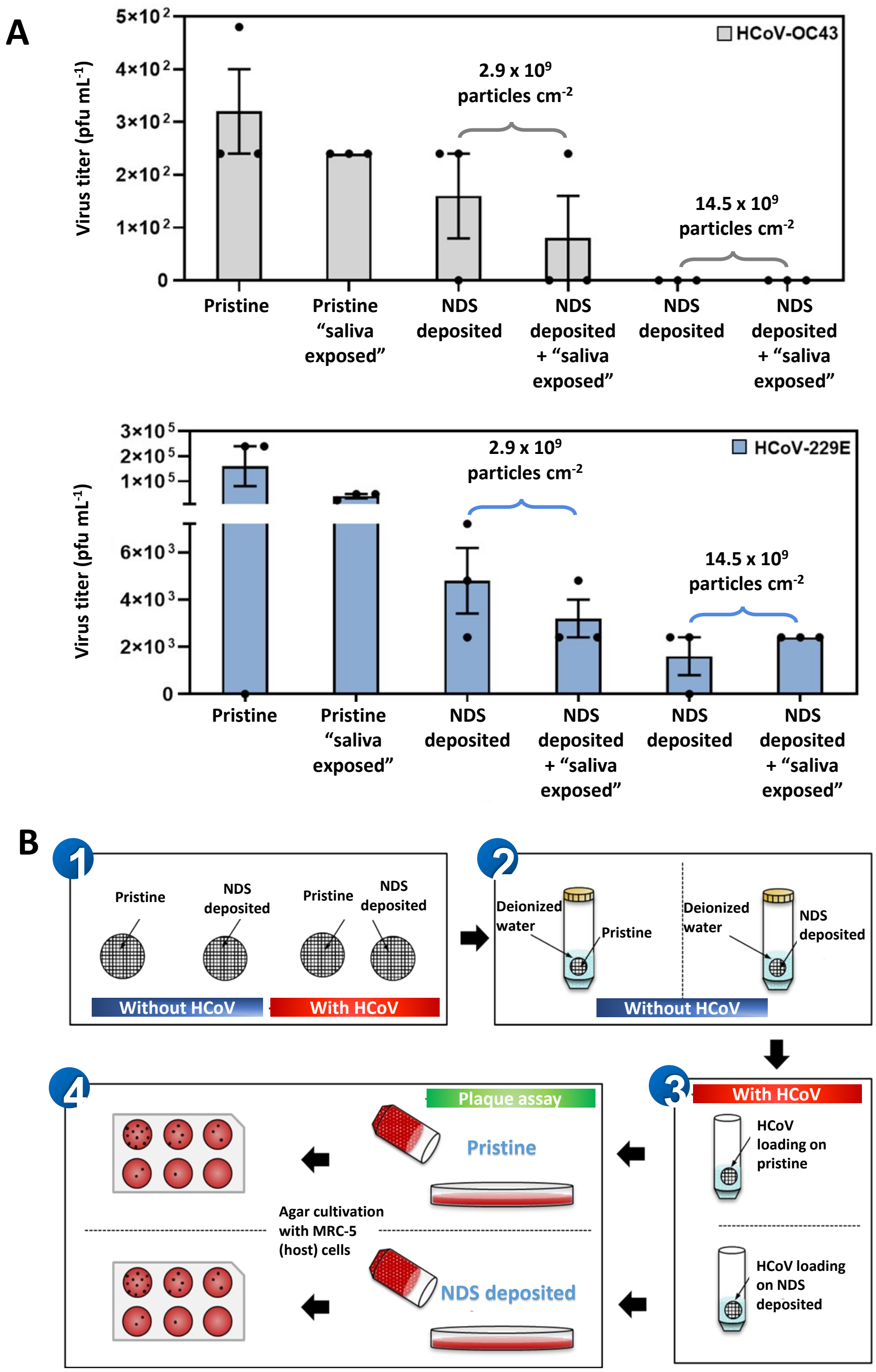
Filtration efficiencies of electret nonwoven sheets as a function of particle size after NDS deposition and simulated disinfection (alcohol or surfactant treated). The efficiency values were compared with the results from a nontreated electret nonwoven at a fixed face velocity of air (1.5 m s^{-1}) while polydispersed KCl particles (30–400 nm) from Collison atomization were adopted to this test.

Fig. S3



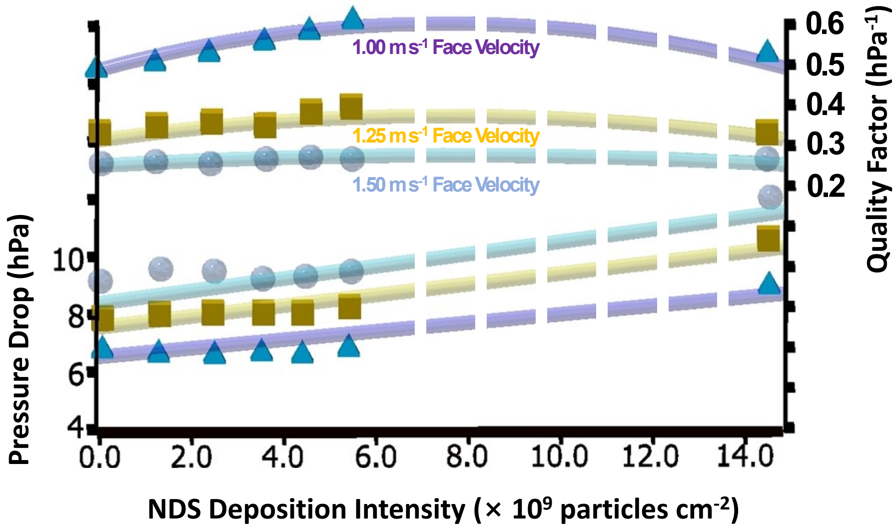
Particle size distributions of aerosolized monodisperse (100 and 300 nm) PSL particles under different air flow rates (represented as 1.00 to 1.50 m s^{-1}). In order to assess the filtration performance at the range of MPPS, commercial PSL beads were dispersed in deionized water for Collison atomization, providing the desired aerosol monodisperse particles. The particle-laden flow was then directed to an electret nonwoven sheet to determine the filtration efficiency.

Fig. S4



Plaque titration assays to examine coronaviral inactivation upon HCoV exposure to NDS particles or dissolved NDS from NDS treated nonwovens. (A) Inactivation activity of NDS for HCoV-OC43 and -229E strains with different deposition intensities in the absence and presence of artificial saliva droplet exposure. (B) Protocol to examine HCoV inactivation from NDS dissolution from NDS treated nonwovens.

Fig. S5

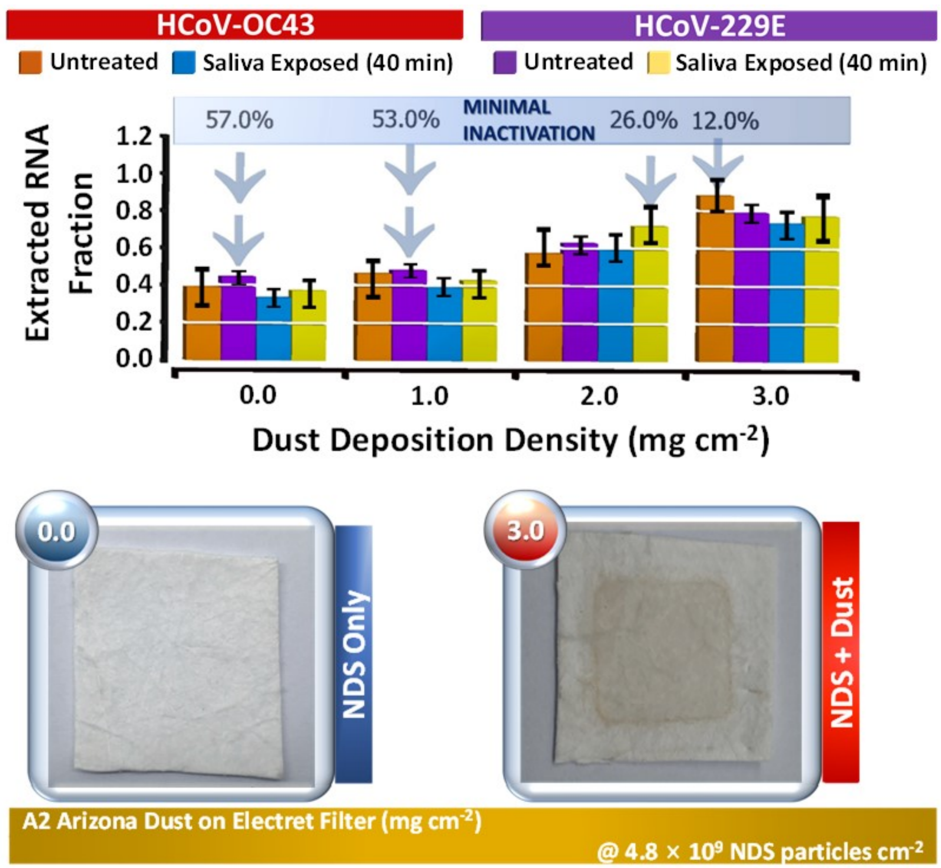


Changes in pressure drop (lower) and quality factor (upper) of electret nonwovens from varying NDS deposition densities (1.0 to 14.5 × 10^9 particles cm^{-2}). The highest deposition intensity (14.5 × 10^9 particles cm^{-2}) was selected to obtain >99.9% anticoronaviral efficiency. The experimental data were compared with theoretical plots obtained from the relevant equations. The quality factor was determined using the following equation:

$$QF = \frac{-\ln(1-\eta)}{\Delta P}$$

where, η and ΔP are the total filtration efficiency and pressure drop of nonwoven sheet for air flow, respectively.

Fig. S6

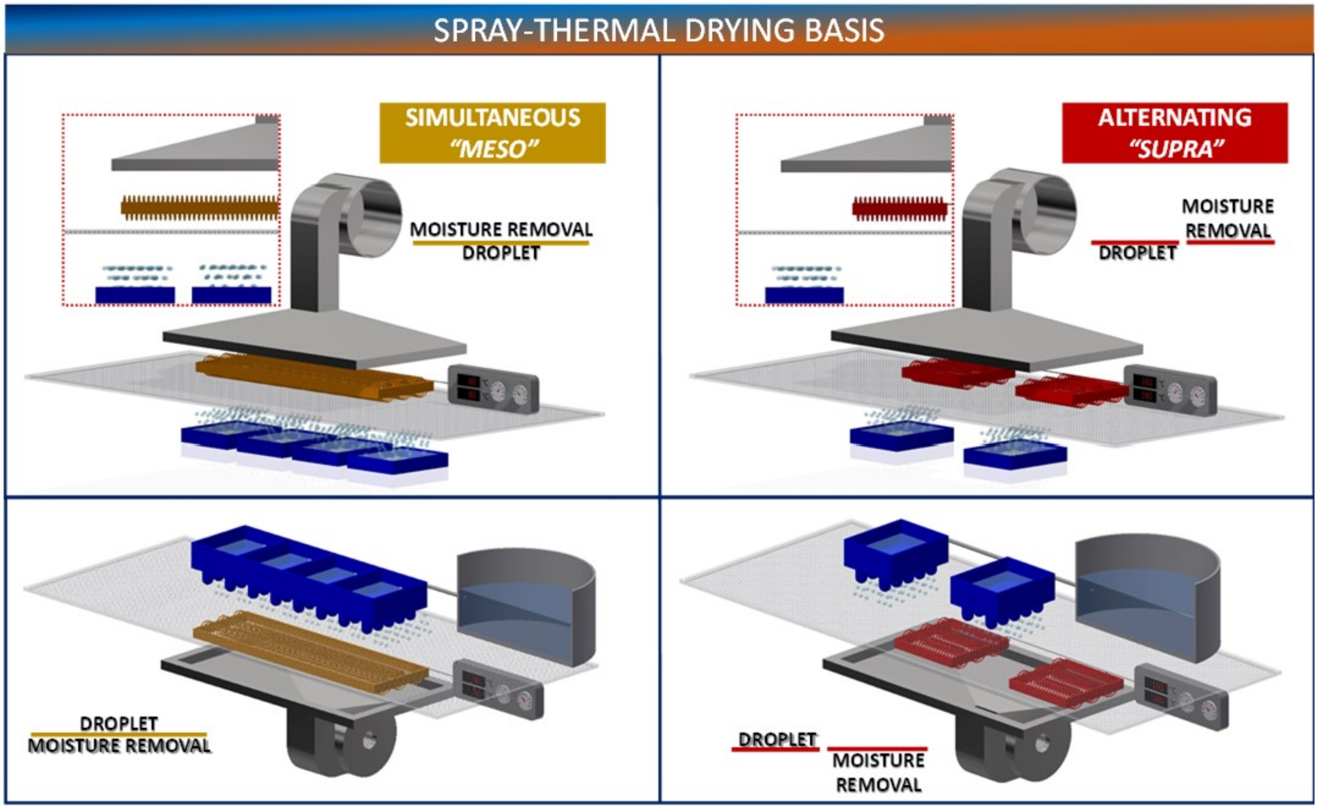


Changes in anticoronaviral activity from Arizona dust loading (1.0 to 3.0 mg cm^{-2}) on NDS treated electret nonwoven sheets (4.8×10^9 particles cm^{-2}, exhibiting <5% increases in pressure drop compared to the untreated nonwovens) in the absence and presence of saliva droplet exposure (40 min) to identify anticoronaviral breakthrough of NDS treated electret nonwovens under harsh conditions. 1.0 mg cm^{-2} represents the periods of sheet use (P_{su}) as >40 d (based on WHO TSP guideline: 0.12 mg m^{-3}) and >100 d (based on WHO PM_{10} guideline: 0.05 mg m^{-3}) on an all-day use basis with the following formula:

$$P_{su} = \frac{D_d EA_s \eta_f}{V_r C_m}$$

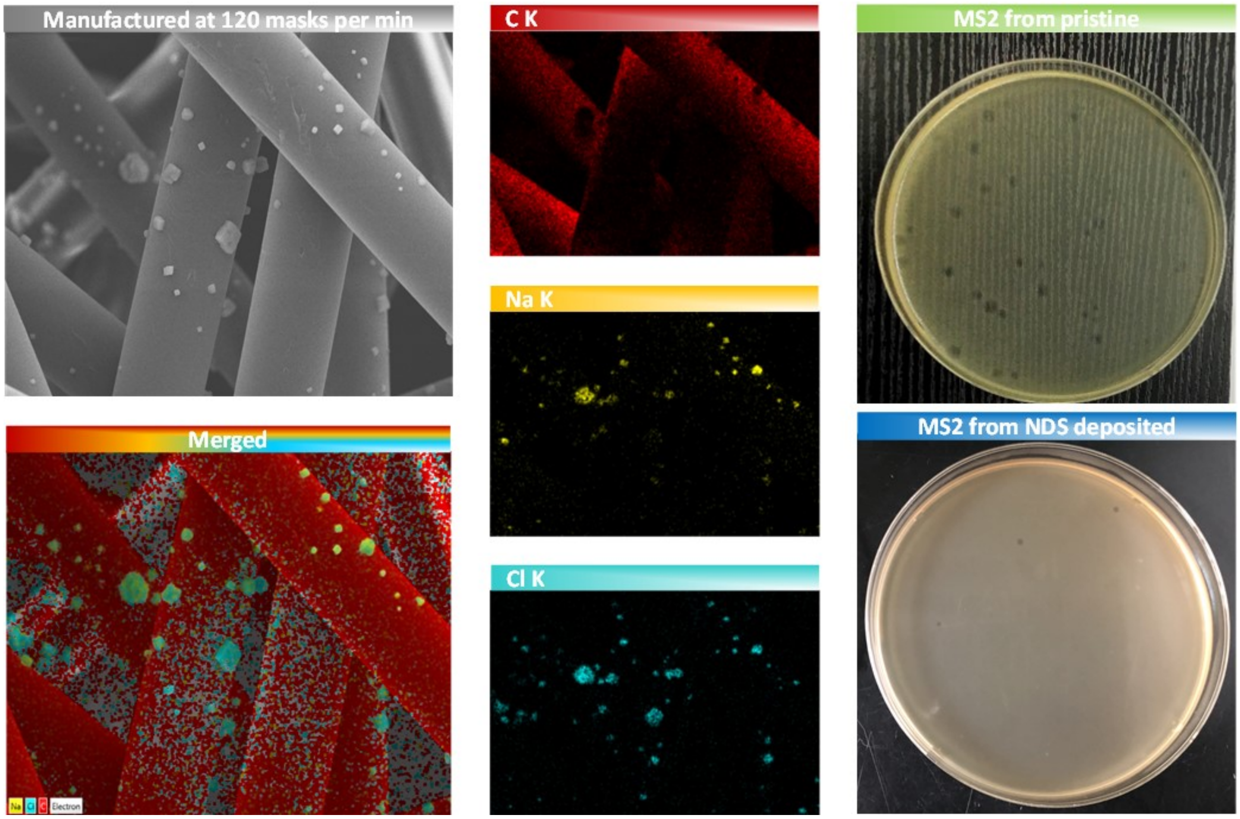
where, D_d, EA_s, η_f, V_r, and C_m are the dust deposition density (mg cm^{-2}), effective area of nonwoven sheet (60 cm^2, based on a face mask), filtration efficiency (0.95), treatment volume (11 m^3 d^{-1}, daily respiration volume), and particle mass concentration (mg m^{-3}, TSP or PM_{10}), respectively. The upper image depicts the minimal antiviral activity for each dust deposition density; the lower digital images exhibit representative appearances of electret nonwoven sheets with NDS and NDS+dust particles.

Fig. S7



Several possible concepts for adopting thermal drying into high-throughput manufacturing of NDS treated electret nonwoven sheets. Upper left: simultaneous processing of droplet supply and moisture removal at mesothermal conditions (50^{o}C to 150^{o}C wall temperatures of heating source). Upper right: alteration of the supply and removal at suprathermal conditions (100^{o}C to 250^{o}C). Lower images: switching of the position of droplet supply and moisture removal at meso- and suprathermal conditions, including connection between a multi-nozzle spray and NaCl solution reservoir. The thermal range of the moisture removal may be changeable by modulating process speed, nonwoven material, and other material and process conditions.

Fig. S8



SEM and energy dispersive X-ray (EDX) maps, including digital images before and after NDS exposure to aerosolized MS2 bacteriophage. The SEM and EDX results are acquired from NDS deposited masks manufactured at a yield of 120 masks per min. More than 90% of inactivation efficiencies are maintained even longer than 3 h MS2 exposure to NDS deposited nonwovens.