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Review

Triboelectric nanogenerator as a new technology for effective $PM_{2.5}$ removing with zero ozone emission[☆]

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A R T I C L E I N F O

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A B S T R A C T

Particles matters (PMs) have raised serious concerns due to their great impact on human health. Coupling triboelectric effect and electrostatic induction, triboelectric nanogenerator (TENG) has demonstrated as a practical sustainable power source for portable devices. The characteristics of TENG, such as high electric field and high output power, make it a promising technology in air cleaning applications. Here, the mechanism of the TENG and its application in self-powered air cleaning technologies are reviewed. Using the TENG as a voltage source, a self-powered air cleaning system for removing SO_2 and PMs is developed; and the removal efficiency of nanofiber filters is greatly enhanced due to electrostatic attraction. More importantly, the technology is not only most effective for removing nano-scale particles that cannot be effectively filtered using conventional fiber-film filters, but also produces no ozone emission. Besides being an independent power supply, a vibration TENG based triboelectric filter is designed to effectively capture the PMs from automobile exhaust fumes. Hence, the TENG demonstrates its great potential in self-powered air cleaning applications.

1. Introduction

In parallel with human activity, air pollution has been one of the most predominant environmental concerns over the past decades [1,2]. At 1970, the Clean Air Act declared in the United States has addressed six "criteria air pollutants": particulate matter (PM), ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and lead (Pb) [1]. Recently, airborne PMs have attracted much attention due to its outburst in developing countries and its hazardous threat to human health.[3,4] Typically, PMs are categorized according to the diameter of the particles, which determines their lifetime, transportation distance, and impact on the respiratory system [2]. As the most important parameter, the diameter of the PMs ranges from several nm to tens of microns. For PMs with an aerodynamic diameter less than 10 µm (PM_{10}), they are inhalable and may reach the upper part of the airways and lung, and a statistically significant association between risk for lung cancer and PM_{10} is found [5]. Fine particles with an aerodynamic diameter less than 2.5 µm ($PM_{2.5}$) may penetrate deeply into the lungs and even reach the alveoli. An increase of 10 µg/m^3 in $PM_{2.5}$ was associated with a nearly doubling of the risk of postneonatal death, a 14% increase in nonfatal cardiovascular events, and a 32% increase in fatal cardiovascular events [6]. Moreover, ultrafine particles with an aerodynamic diameter less than 0.1 µm ($PM_{.1}$) are also a major concern due to its greatest impact on human health [2]. Generally, the ultrafine particles come from combustion-related sources [7] and have a relatively short lifetime because they will form complex aggregates of a larger size within several hours [8]. However, in spite of the short lifetime, the ultrafine particles are capable of penetrating into the bloodstream and translocating to other parts of the body, hence induce a greater damage [9]. The size comparison of PMs against fine beach sand and human hair is schematically illustrated in Fig. 1(a).

Removal of PMs is one of the major objectives for air cleaning technology. Based on different mechanisms, various technologies have been developed for this purpose. The most common types are electrostatic precipitator (ESP) [10] and fibrous filter [11]. The ESP has been widely applied in industry for its high collection efficiency and low-pressure drop. The system consists of a sharp discharge electrode and smooth collecting electrodes. When a high-voltage direct current is applied, ions and electrons are produced at the corona point, hence the particles are charged before they moved to the collecting electrodes. Then, subjected to a Coulomb force, the charged particles are attracted the electrode plates [10]. However, the production of ozone limits its

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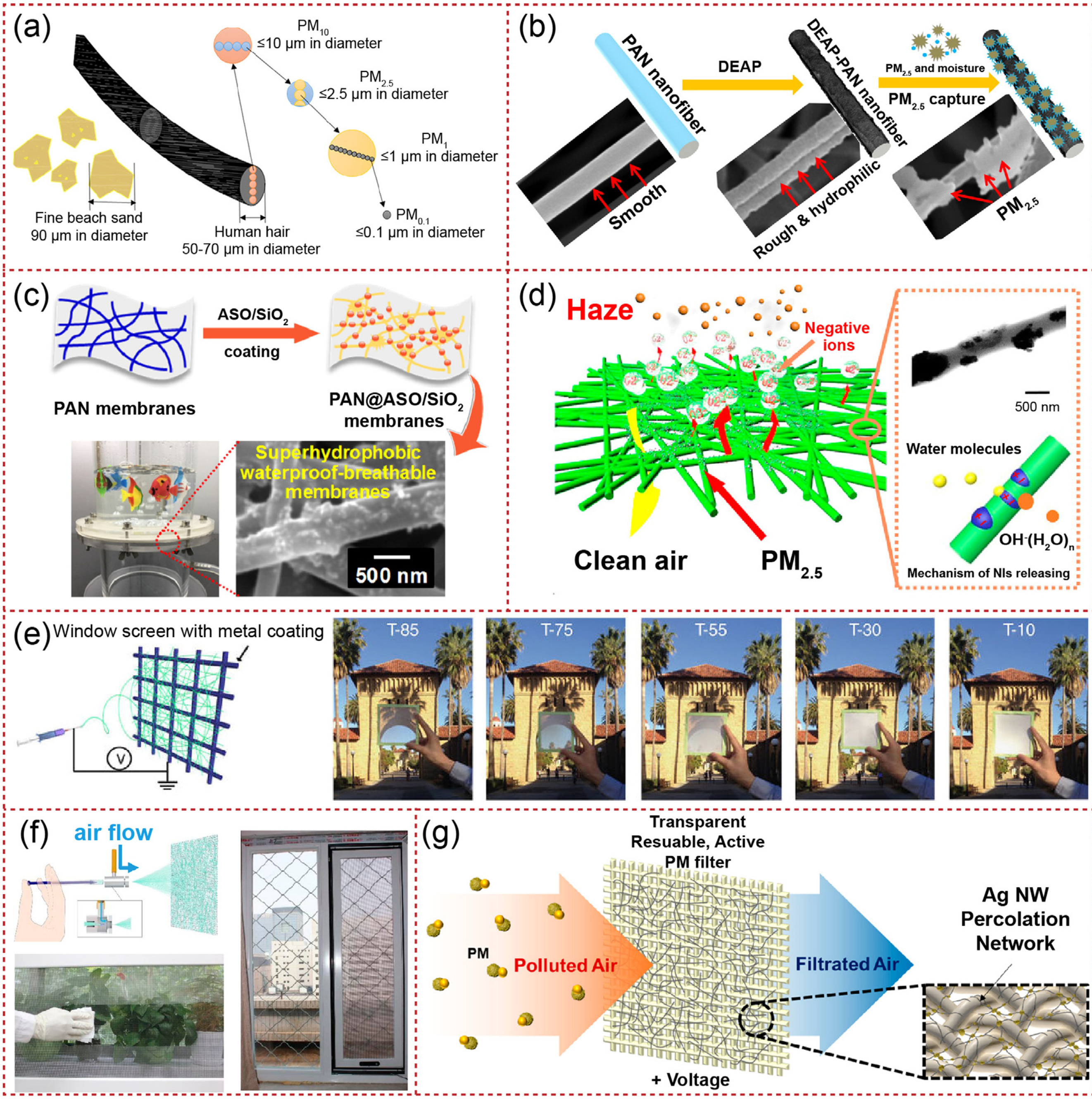

Fig. 1. (a) Size comparison of PMs against the average diameter of a human hair (~ 70 μm) and fine beach sand (~ 90 μm). Reproduced with permission from American Chemical Society [14]. (b) Diethylammonium dihydrogen phosphate (DEAP) modified polyacrylonitrile (PAN) nanofibers. Reproduced with permission from American Chemical Society [15]. (c) Superhydrophobic microporous membranes. Reproduced with permission from American Chemical Society [16]. (d) Low-resistance nanofibrous membranes capable of releasing negative ions. Reproduced with permission from American Chemical Society [17]. (e) Photographs of PAN transparent air filters at different transparency [17]. (f) Direct blow-spinning of nanofibers. Reproduced with permission from Macmillan Publishers Ltd [18]. (g) Transparent, Reusable and Active PM (TRAP) filter using hierarchical Ag nanowire percolation network. Reproduced with permission from American Chemical Society [31].

application for indoor air cleaning. Filtration of PMs from air stream is another main type of particulate air cleaning devices. As an essential component, the fibrous filter is multilayered randomly organized fibers that separate PMs from the air stream with minimum energy consumption. Thus, the removal efficiency and pressure drop are two major parameters that characterize the performance of a fibrous filter. The mechanisms for removing the PMs from the air stream by filtration are Brownian diffusion, interception, diffusion, inertial impaction, and gravitational settling. For the particles with a diameter smaller than 0.5 μm, the Brownian motion greatly increased the probability of their collision with fibers and contributes to the capture of the particles [12]. The particles with diameters of tens of microns have sufficient inertia, thus inertial impaction and gravitational settling will become dominant, where the particles will not follow the rapidly changing streamline around the fibers and collide with the fibers [13]. As for the particles on the order of submicrons to several microns, the particles possessing negligible Brownian motion and inertia will follow the air streamline and then be intercepted by coming into direct contact with