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RAPID COMMUNICATION

Self-powered cleaning of air pollution by wind driven triboelectric nanogenerator

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Abstract
Air pollution is one of the major challenges faced by the human kind, but cleaning of air is a horrendous task and hugely expensive, because of its large scope and the cost of energy. Up to now, all of the air cleaning systems are generally driven by external power, making it rather expensive and infeasible. Here, we introduce the first self-powered air cleaning system focusing on sulfur dioxide (SO_2) and dust removal as driven by the electricity generated by natural wind, with the use of rotating triboelectric nanogenerator (R-TENG). Distinguished from traditional approach of electrostatic precipitation by applying a voltage of thousand volt, our technology takes the advantages of high output voltage of R-TENG, typically in the order of a few hundreds volt. This self-powered air cleaning system not only adsorbs dust particles in air, but also oxidizes SO_2 without producing byproducts. Therefore, it could be potential for easing the haze–fog situation, which is one of the most important directions in self-powered electrochemistry.

Introduction

With the growing threat of air pollution and the crisis of energy, the search for cost-effective, renewable and green methods to clean air is one of the most urgent challenges. Especially in China that is experiencing a fast development, people have long been tormented by polluted air, which is

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mainly due to particulate matter (PM), sulfur dioxide and nitrogen oxide (NO_X). In Beijing, during 2000–2014, the annual average concentration of PM10 was never lower than 100 μg/cm^3. Various health problems are believed to be associated with long-term exposure to polluted air [1], such as respiratory diseases, rise in numbers of deaths from cardiovascular and respiratory disease among older people [2], and increase of lung cancer and cardiopulmonary mortality[3]. Therefore, it is essential to find a cost-effective way to resolve this issue in order to improve the quality of people's life.

Multiple approaches have been extensively demonstrated to remove dust and SO_2. For dust removal, methods such as simple filtration, adsorption with solid sorbents [4,5] pulsed electron beam, reaction with negative ion [6] and electrostatic precipitation [7] have been reported. Among these de-dusting approaches, electrostatic precipitation has been widely used in industries and indoors [8]. But a major drawback of this approach is that it requires an external power even at a high voltage, making it expensive and not adequate for large-scale outdoor usage. Moreover, some of the methods rely on corona effect for electrically charging particulates, which could generate ozone and NO_2 as byproduct [9]. The filtration is very simple and effective, but it could be easily clogged by submicron solid aerosol particles [10]. As for SO_2 removal, there are also many methods such as electro-catalytic and metal catalytic oxidation [11]. However, electro-catalytic oxidation needs external power, and the metal catalytic oxidation relies on novel metals which are very expensive and are rather limited.

Currently, many self-powered electronics or electrochemical applications have been achieved through triboelectric nanogenerators or piezoelectric nanogenerators such as splitting water [12] or degrading methyl orange [13] or sensing [14]. However, air cleaning as a big issue has not been realized using this self-powered method.

Herein, we innovatively fabricated a very simple and practical system for self-powered clearing of toxic materials in the air by electrostatic precipitating of flying dust particles and oxidizing SO_2. Instead of utilizing an external electricity power, we utilize the electricity generated from natural wind with the use of R-TENG. The output voltage of the R-TENG is about 300 V, which is not too high to generate byproducts such as ozone and NO_X [15], as produced in traditional electrostatic precipitation by using high voltage discharge. In addition, no noble metals are needed to electrochemically oxidize SO_2, since the generated current is high enough to electro-catalyze the oxidation of SO_2. Last but not the least, the self-powered SO_2 and flying dust removal system is cost-effective, versatile in size and easy to be applied, making it feasible for environmental cleaning and indoor air purification. It is also worth mentioning that the method of oxidizing SO_2 may have a great influence on sulfuric acid production, and this principle could be used in many other electrochemical reduction or oxidation applications.

Fabrication and characterization of R-TENG

The multi-layered R-TENG is mainly composed of a rotator and a stator, as shown in sketch diagram Figure 1a and optical image Supplementary Figure S1. The key components of the stator and rotator are top grating and bottom grating electrodes which are fabricated by the print circuit board (PCB) technology [16]. Both of the electrodes are clusters of radially arrayed segments, made of copper, with radius of 70 mm and a central angle of 1°. The difference is that the top electrode has 180 sector units separated by an interval of 1°; while the bottom electrode is composed of two complementary patterned electrode networks which are separated by fine trenches in between. Each group of patterned electrode networks is respectively connected at one end. The rotator rotates under the driving force from wind blowing; while the stator is fixed on a bracket. For the fabrication of rotator, as depicted in Figure 1b, the top grating was just needed to be immobilized onto the top substrate (made of PMMA). As to the stator, the bottom grating was firstly immobilized onto the bottom substrate, and then adhered with a Kapton film (thickness of 30 μm) (Figure 1c).

The working principle of this kind of R-TENG has been reported previously [17,18]. Because of the PCB technology, the tribo-electrification units are miniaturized, and the output current is increased remarkably, yet the volume has not been enlarged. Moreover, the rotating design is very convenient for the exploitation of wind energy. Because of the light weight of the materials for making the rotator, the R-TENG could be easily driven by wind.

To characterize the optimized performance, the fabricated R-TENG was mechanically driven by a rotary motor with a rotating speed of 600 rpm. The open-circuit voltage (V_{oc}) was measured by a low-noise voltage preamplifier (Keithley 6514 System Electrometer) and the short-circuit current (I_{sc}) of the R-TENG was measured by a low-noise current preamplifier (Stanford Research SR570). As illustrated in Figure 1d and e, the measured I_{sc} and V_{oc} are 3.4 mA and 320 V respectively. For supplying the air cleaning system, the alternating current (AC) output of the R-TENG should be rectified into direct current (DC) output (supplementary Figure S2a–S2b). To indicate the capability of the R-TENG as a power source, it was connected to conventional light bulbs after rectification. With the wind gusting up to 8.5 m/s (5 BF in Beaufort wind force scale), the spot lights on the panel were all lightened up, as illustrated in Supplementary Movie S1.

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Experiments of self-powered SO_2 removing and de-dusting

To drive the two systems using electricity harvested from wind energy, the R-TENG was connected to a miniaturized wind cup structure that was driven by air blower at a wind speed of 15.1 m/s (7 BF). The oxidation of SO_2 and adsorption of flying dust were all performed in a closed transparent cubic chamber of 125 L with an air inlet, an air outlet and two needle-like copper wires across the wall at ambient temperature. Through wires, the R-TENG outside the chamber was connected to two paralleled copper meshes inside. For the experiment of SO_2 oxidation, the chamber was filled with SO_2 beforehand. Then the copper meshes were connected through a sink of saturated $NaHSO_3$ solution (Figure 3a). At given time intervals, the SO_2