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सत्यमेव जयते

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भारत सरकार
GOVERNMENT OF INDIA

पेटेंट कार्यालय
THE PATENT OFFICE

पेटेंट प्रमाणपत्र
PATENT CERTIFICATE
(Rule 74 Of The Patents Rules)

पेटेंट सं. / Patent No. : 351038
आवेदन सं. / Application No. : 201741007433
फाइल करने की तारीख / Date of Filing : 02/03/2017
पेटेंटी / Patentee : INDIAN INSTITUTE OF TECHNOLOGY MADRAS (IIT Madras)

प्रमाणित किया जाता है कि पेटेंटी को उपरोक्त आवेदन में यथाप्रकटित MULTILAYER MULTIFUNCTIONAL NASAL FILTER नामक आविष्कार के लिए, पेटेंट अधिनियम, १९७० के उपबंधों के अनुसार आज तारीख 2nd day of March 2017 से बीस वर्ष की अवधि के लिए पेटेंट अनुदत्त किया गया है।

It is hereby certified that a patent has been granted to the patentee for an invention entitled MULTILAYER MULTIFUNCTIONAL NASAL FILTER as disclosed in the above mentioned application for the term of 20 years from the 2nd day of March 2017 in accordance with the provisions of the Patents Act, 1970.



अनुदान की तारीख : 06/11/2020
Date of Grant :

पेटेंट नियंत्रक
Controller of Patent

Okrajla

टिप्पणी - इस पेटेंट के नवीकरण के लिए फीस, यदि इसे बनाए रखा जाना है, 2nd day of March 2019 को और उसके पश्चात प्रत्येक वर्ष में उसी दिन देय होगी।

Note. - The fees for renewal of this patent, if it is to be maintained will fall / has fallen due on 2nd day of March 2019 and on the same day in every year thereafter.

FORM 2
THE PATENTS ACT, 1970
(39 OF 1970)
&
The Patents Rules, 2003
COMPLETESPECIFICATION
(Refer section 10 and rule 13)

TITLE OF THE INVENTION:

MULTILAYER MULTIFUNCTIONAL NASAL FILTER

2. APPLICANT:

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3. Preamble to the Description

COMPLETESPECIFICATION

The following specification particularly describes the invention and the manner in which is to be performed.

COMPLETE SPECIFICATION

TITLE OF THE INVENTION

5 MULTILAYER MULTIFUNCTIONAL NASAL FILTER

FIELD OF THE INVENTION

The present invention relates to the field of nasal filters as a particulate filtration (PM_{2.5})
10 device and particularly to the method and design of multilayered functional nanofibres made by
electrospinning of polymers and soft chemical treatment of the said polymers to attain controlled
charge, enabling enhanced filtration of particulate matter.

BACKGROUND OF THE INVENTION

15 Air pollution is one of the major environmental risks resulting in respiratory and
cardiovascular diseases (Liu et al., 2015). Numbers of people exposed to dust (PM_{2.5}) may
increase exponentially in the near future. Nanotechnology has made it possible to design new
and improved products to reduce effects of pollution. Inhalation is one of the direct pathways for
the aerosol exposure; some studies reveal that aerosol particles enter the human body through the
20 skin(Liu et al., 2015; Kirchner et al., 2005). Applying filters in the nasal area is one of the
practical ways to reduce risks of inhalation (Khajvi et al., 2013). Textile fabrics constitute the
most important and widely accepted materials as filter media amongst several other groups of
materials. Among the woven and nonwoven filter media, nonwovens (fibrous filter) are
potentially better filters than woven ones as they are versatile, offer wide range of functionalities
25 like smaller pore size, higher air permeability, improved cake separation and higher filtration
efficiency especially in the submicron range and aerosol regimes as well as being economical
compared to woven media(Sutherland, 2004).

There are two ways to improve the quality of a filter. The first is to make it more efficient
in filtering out dust, which enhances the filtration efficiency. The second is to make it more
30 permeable to reduce the pressure drop. In practical scenarios, it is difficult to improve both the
filtration efficiency and air permeability at the same time (Hung et al., 2011; Zhang et al., 2017).
Most researchers suggest that the nonwoven filters composed of nanofibres possess greatly

enhanced filtration efficiency, but increased pressure drop is a trade-off. Hence, the amount of nanofibres in a filter medium has to be carefully adjusted to prevent excess pressure drop (Leung et al., 2010; Podgórski et al., 2006; Hung et al., 2011). It is desirable to use an extremely permeable nonwoven filter with high filtration efficiency as the substrate, so that the filtration efficiency and pressure drop measured across the composite can be approximated to those of the nanofiber layers (Wang et al., 2008). Nanofibres can be produced by electrospinning, melt-blown processes, multi-component fiber spinning, force spinning, and centrifugal spinning, of which electrospinning process is widely desirable due to the reduced diameter of the fibre (Park et al., 2005; Zhang et al., 2010).

An investigation on Indian urban environments concluded that the dusts which are smaller in size are negatively charged and the bigger particles are positively charged (Kok et al., 2009), hence development of charged filter mats with multiple layers of differently charged surfaces will possess enhanced dust filtration efficiency, which is particularly relevant to India and countries of similar urban air quality.

The present invention relates to the fabrication of a nasal air filter which can segregate dust and capture it based on its charge. By placing the positively charged fibres close to the nonwoven mats, negatively charged particles are captured. Any positively charged particle present gets trapped by the second layer of oppositely charged filters. Finally neutral particles which may be present get trapped by the non-woven mats which sandwiches the electrospun mat. Size-dependent trapping will happen in all the mats. The membrane offers triple stage filtering when compared to the commercial HEPA filters.

In the process of filtering particles, the filter is also exposed to constituents of breath, especially humidity. This can change the properties of the filter and a measurement of the same can be used for the characterization of the breath.

SUMMARY OF THE INVENTION

The present invention relates to the field of nasal filter for particulate filtration from air and more particularly to the method and design of multilayered functional nanofibres made from polymers with multiple charges.

In one embodiment, the present invention describes the preparation of functional nanofibres made from polymers such as polyacrylonitrile (PAN) and polystyrene (PS) by

electrospinning process and subsequently incorporating charges in them by chemical functionalization. The positively and negatively charged nanofibre mats are responsible for filtering negatively and positively charged particulate matter, respectively from air.

In another preferred modification, the present invention relates to a method of constructing the multilayer nanofibre nasal filter, composed of from the outside primarily an external substrate layer made of spun-bonded polypropylene nonwoven filter mat, secondly the first intermediate layer made of nanofibres with positive charge, thirdly the second intermediate layer made of nanofibres with negative charge and finally an internal substrate layer made of spun-bonded polypropylene nonwoven filter mat.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 Plot of charge vs time of certain dust collected from (A) Location 1 and (B) Location 2. Scanning electron micrographs of the dust collected from (C) Location 1 and (D) Location 2.

Figure 2 Schematic diagram of the arrangement of the functionalized nanofibres which capture particulate matter to obtain clean air.

Figure 3 Scanning electron micrograph of the electrospun PAN fibres (A,B) as-spun, (C,D) choline chloride treated, at different magnifications.

Figure 4 Infrared spectral features of the electrospun PAN fibres, as-synthesized in comparison with the chemically treated fibres.

Figure 5 Scanning electron micrograph of the electrospun PS fibres (A,B) as-spun, (C,D) sulfuric acid treated, at different magnifications.

Figure 6 Infrared spectral features of the electrospun PS fibres, as-synthesized in comparison with the chemically treated fibres.

Figure 7 Filtration efficiencies of bare electrospun mat and their chemically treated analogues. The expanded region is in the inset.

Figure 8 Scanning electron micrographs of sulfonated polystyrene fibres (A) with captured NaCl aerosol and (B) EDS for the boxed region in A.

Figure 9 (A) Schematic representation of the humidity sensor which can be incorporated within the nasal filter. Only the time window of 725 to 900 s is shown to see the features clearly. (B)

Plot of current vs time in the presence of humidity.

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Figure 10 (A) Plot of current vs time in the process of breathing. The different periods of response are marked. (B) Enlarged view of rise in current vs time during exhalation. (C) Enlarged view of fall in current vs time during inhalation.

Referring to the drawings, the embodiments of the present invention are further described. The figures are not necessarily drawn to scale, and in some instances the drawings have been exaggerated or simplified for illustrative purposes only. One of ordinary skill in the art may appreciate the many possible applications and variations of the present invention based on the following examples of possible embodiments of the present invention.

10 DETAILED DESCRIPTION OF THE INVENTION

The following description is presented to enable any person skilled in the art to make and use the embodiments, and is provided in the context of a particular application and its requirements. Various modifications to the disclosed embodiments will be readily apparent to those skilled in the art, and the general principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the present disclosure. Thus, the present invention is not limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

The present invention relates to the development of multilayer multifunctional polymer nanofibre nasal filter for the removal of particulate matter (PM_{2.5}) from air. To understand the physical properties of dust, passive monitoring of dust was carried out at two different locations, both within the residential area of Indian Institute of Technology Madras campus. Dust, which was deposited on plant leaves was scooped and analysed. These particles were first washed and dried in water and ethanol to remove any organic content as per standard protocol (Ram et al., 2014) the samples were dried and these dry powders were used for measuring the charge on them. To measure the charges on the particles, a home fabricated Faraday cup was connected to a Keithley 6514 electrometer. The plot of charge vs time is shown in Figure 1. Once the measurement was started, the first 300 s were left for the instrument to stabilize and later 500 mg of the collected dust was added to the sample compartment. The dust particles collected from location 1 had a positive charge and the rise in charge was steep as seen in the Figure 1 (A). A maximum value of 1.4×10^{-10} μC was reached and it was stabilized at 1.0×10^{-10} μC . The dust collected from location 2 had an overall negative charge of -1.8×10^{-9} μC as seen from Figure 1

(B). The charge on particles were measured in the dry condition unlike zeta potential measurements, providing the accurate charges on particles in solution. SEM images of the collected dust from location 1 and location 2 are shown in Figure 1 (C and D), respectively. The particles were non-uniform and irregular in shape. The average particle size of dust collected from location 1 was 2.3 μm . The average charge per particle was $\sim 1.0 \cdot 10^{-10}$ μC . The average particle size of dust collected from location 2 was 1.8 μm , having charge of $\sim -1.8 \cdot 10^{-9}$ μC . We therefore conclude that particles with larger average size possess positive charge when compared to smaller particles, which negative charge.

Figure 2 shows the schematic diagram of the multifunctional nanofilter. According to the invention, the first, second and third intermediate functional nanofilter mats are introduced to carry out effective filtration of particulate matter based on their charge transfer mechanism which makes it plausible to filter fine positive, negative, and neutral particles at reduced pressure drop (with the normal breathing capacity).

The first intermediate layer is made of polyacrylonitrile (PAN) nanofibre mat which is molecularly charged to be positive. The PAN nanofibrous membrane was prepared by the electrospinning technique. PAN was dissolved in dimethylformamide (DMF) (14% by weight/volume) at ambient temperature by magnetic stirring for 8 h. The polymer solution was electrospun at a positive voltage of 20 kV with a working distance of 15 cm, and the flow rate was set as 0.5 mL/h ESPIN-NANO electrospinning apparatus. These fibres were collected onto a non-woven mat which was placed over the drum collector. Then the PAN nanofibrous membrane was functionalised by treating with aqueous choline chloride at 30 $^{\circ}\text{C}$ for 24 h (Pfaff et al., 2013) in such a way that positive charges are created on PAN nanofibres to carry out effective filtration of negatively charged particles.

The second intermediate layer is made of negatively charged polystyrene (PS) nanofibre mat. The PS nanofibrous membrane was prepared by the electrospinning technique. PS was dissolved in DMF (20% weight/volume) at ambient temperature by magnetic stirring for 5 h. The polymer solution was electrospun at a positive voltage of 20 kV with a working distance of 12 cm, and the flow rate was set as 1 mL/h using ESPIN-NANO electrospinning apparatus. Thus formed PS nanofibrous membrane was further functionalised by treating with 3 M H_2SO_4 for 24 h at 100 $^{\circ}\text{C}$ to anchor the sulfonate groups. After that, the obtained S-PS fibre mats were rinsed in deionized water 6 times and dried in a vacuum oven at 60 $^{\circ}\text{C}$ for 8 h (Yao et al., 2011) in such

a way that negative charges are created on the PS nanofibres to carry out effective filtration of positively charged particles.

Figure 2 shows the schematic of the nasal filter. Chemically treated PAN and PS fibres are sandwiched between non-woven mats. The non-woven mats not only provide mechanical strength to the composite but also act as a substrate for holding the electrospun fibres.

Figure 3 SEM images of as-spun (A, B) PAN fibres and choline-PAN (C, D) fibres at different magnifications are shown. From these images, it is evident that there are visible physical changes to the chemically treated fibres. The amination reaction conditions were modified so as to retain the fibre diameter after amination. The diameter of the choline treated fibres haven't changed but a visible bridging between the fibres is observed. The fibres were immersed in 6 M hydrochloric acid containing 0.6 g choline chloride. The solution was left at room temperature for 24 h later the fibres were washed repeatedly with deionized water and subsequently dried for 12 h to remove moisture. These fibres were later analyzed using FTIR.

Figure 4 depicts comparison of FT-IR spectra of as-spun PAN and aminated PAN. FT-IR spectra of PAN fibres have many peaks which relate to the existence of C-H, C≡N, C=O and C-O bond and associated groups. The absorption peaks in the range of 2926-2935 cm^{-1} are related to C-H bonds in CH, CH₂ and CH₃. The peaks at 1700-1780 cm^{-1} indicate the presence of C-O and C=O, these could be because of the presence of monomers such as methacrylate (Shimada et al., 1986). The precursor used was commercial grade PAN. The presence of C=O peak in the choline chloride treated PAN confirms the addition of choline to PAN. Peaks at 1650 cm^{-1} represents the N-H bending frequency.

Figure 5 show SEM images of the as-spun (A, B) PS fibres and sulfonated-PS fibres (C, D) at different magnification are shown. From these images, it is evident that the fibres do not show any physical damage or reduction in diameter post sulfonation. For incorporating the negative charge, slight modification in the reaction condition has been followed. The temperature of sulfonation was kept at room temperature and the concentration was restricted to 3 M sulphuric acid. These fibres were immersed in sulphuric acid for 24 h and they were dried for 24 h to remove any moisture, after washing. These dried fibres were later analyzed using FT-IR to confirm the presence of sulfonate peaks on the fibres.

Figure 6 shows FT-IR data of the as-spun and sulfonated PS fibres. The presence of a peak in the region of 1195-1168 cm⁻¹ represents the presence of S=O sulfonate stretching. These fingerprint regions indicate the anchoring of sulfonate group onto PS.

To estimate the filtration efficiency of the fibres, an in-house Dust Filtration Efficiency Tester (DFET) was assembled based on ASTM F2299. For performing experiments, the required amount of clean air was obtained from a compressor with pre-filters. This pressurized air was used to aerosolize salt solution (10 % NaCl by wt). These particles flow upstream into a laser particle counter for obtaining a quantitative value of input particles. To estimate the resistance for the air flow offered due to the presence of the mat, a pressure gauge is placed across the mat. Fibre mat which is used as a nasal filter must not offer a resistance greater than 245.1 Pa (Jung-Hyun Kim et al., 2015). Similarly, the particles which pass through the filter are also measured to obtain the output value. The filtration efficiency is obtained as follows:

$$\text{Filtration Efficiency (\%)} = \left(\frac{\text{Input particulate count} - \text{Output particulate count}}{\text{Input particulate count}} \right) * 100$$

Figure 7 shows the filtration efficiencies of the untreated electrospun mat and the chemically treated mat. To create the synthetic dust, 10 wt % brine solution was aerosolized, and this particulate matter was trapped by the nasal filter. PAN and PS were electrospun for 30 min onto 2 different non-woven mat, respectively and these mats were sandwiched between 2 additional non-woven mats as shown in Figure1. Similarly, the choline treated PAN and sulfonated PS mats were also sandwiched between 2 additional non-woven mats. From Figure 7 it is evident that 99% of the particles whose size is greater than 1 µm were trapped in both treated and untreated samples. The untreated (bare filter) showed a filtration efficiency (trapping of particles in the 0.3 micron range) of ~90 ±0.55%, while the treated sample showed an enhanced efficiency of 93 ± 0.98% in filtering out 0.3 micron sized particles. The chemically treated fibres can filter out ~93 % of PM0.3 without any increase in the resistance offered to the air flow. To visually observe the particles trapped on the fibres, NaCl concentration was increased to 60 % by wt and this solution was aerosolized. The fibres were placed within the DFET under the air stream for 25 min. Later the fibres were dried and analyzed under SEM as shown in Figure 8. In Figure 8 shows NaCl crystals which were trapped by the sulfonated PS fibres are seen. The chemical composition of the crystal was determined by spot EDS. The semi-

quantitative view of the elemental composition in both atomic % and weight % is shown. During the generation of NaCl aerosols, Na⁺ excess and Cl⁻ excess leads to charged droplets. Due to the molecular charges present on the fibres, there is an enhancement in the entrapment of charged species which is evident from the filtration efficiency. Based on the filtration efficiency, the chemically treated fibres showed an enhanced efficiency compared to the chemically untreated samples. The enhancement in the filtration efficiency may be due to the fibre entanglement during the chemical treatment as well as due to the presence of charges due to the chemical modification. Note that slight Na excess is seen in EDS which is expected for sulfonated fibres. Such fibres which are negative in charge attract positively charged (Na⁺ excess) droplets.

Schematic of a humidity sensor, which can be embedded along with the nasal filter, is shown in Figure 9 (A). Electrospun polyvinylidene fluoride (PVDF) – polyethylene oxide (PEO)/ polyaniline (PANI) composites are embedded along with the nasal filter to act as humidity sensors. Such PVDF-PEO/PANI composites may be inserted in the filters shown in Figure 2 in-between the existing filters or may be added at the end of the filter. For fabricating the composite, 10 wt % of PVDF along with 1 wt % of PEO was added to 10 mL DMF. This solution was left for stirring at room temperature for 12 h to obtain a uniform solution. This solution was loaded into a 5 mL disposable syringe and was placed in an ESPIN NANO electropinning apparatus. The voltage was set to 10 kV and flow rate used was 1 mLph. The distance between the needle and the collector plate was 10 cm and the fibres were collected onto a glass slide for 20 min. PANI was grown on these fibres via Successive Ionic Layer Adsorption and Reaction (SILAR) (Pathan et al., 2004)) method. Initially the glass slide was immersed into a beaker containing 40 mL of 1 M HCl with 10 % of aniline for 1 min. Later, the slide was immersed into another beaker containing 40 mL of 1 M HCl with 2 g of ammonium persulphate (APS) for 2 min. This cycle was repeated 5 times to see a greenish coloration of the fibres. Silver paste was applied on these fibres which act as electrical contacts to provide zones for measuring the change in current, in presence of humidity. The distance between the two leads was 1 cm. The terminals from the silver paste were connected to the Source meter for collecting the change in current with respect to time. A constant voltage of 2 mV was applied between the two terminals. This set-up was used to collect the changes in humidity, while a volunteer inhaled and exhaled air through the fibres. Exhaled air has a humidity ~ 85 % and under this condition, due to the presence of conducting polymer (PANI), conductivity of the fibres increases. This change

in conductivity can be used to measure the humidity. Change in current in presence of humidity is shown in Figure 9 (B). The rise in current when humidity increases from ~63 % to ~85 % is 2.8 μA , with a rise time of ~3 s. Upon reducing the humidity, the current drops from 5.2 μA to 3.8 μA over a longer time window. It takes ~ 19.8 s for the adsorbed water molecules to desorb which decrease the current. As the current dropped to a stationary value, the fibres were placed near the volunteer's nose to sense the exhaled air. These cycles of exhalation and inhalation are depicted in Figure 9. The rise in current while exhalation is depicted as exhalation zone, while during inhalation, the adsorbed moisture desorbs. The current decreases as the species desorb. To attain a constant value, the mat was removed from the volunteer's nose and this zone is represented as the relaxation zone. The rate of desorption is not linear compared to the rate of adsorption, which could be due to the multiple adsorption sites. By varying the chemical and physical aspects of the fibres, the adsorption and desorption timescales and change in current can be modified. Temperature of the fibre mat may also be changed to effect this change.

For enhancing the rate of adsorption and rate of desorption of humidity, beta-cyclodextrin (βCD) was incorporated into the PVDF-PEO/PANI composite. For the preparation of these fibres, 10 wt % PVDF along with 1 wt % of PEO (wt% of the solution) was added into 10 mL of DMF. To this solution, 25 mg of (βCD) was added and this solution was stirred for 12 h to obtain a uniform solution. This solution was later transferred into a disposable syringe and loaded onto an electrospinning apparatus. The voltage was set to 10 kV and flow rate used was 1 mL per hour. The distance between the needle and the collector plate was 10 cm and the fibres were collected onto a glass slide for 20 min. PANI was grown on these fibres by following the procedure mentioned earlier. Silver paste was applied onto the fibre mat which acted as the terminals. The distance between the terminals was 1 cm, the wires were later connected to a source meter. A constant voltage of 2 mV was applied between the terminals and current vs time was measured in presence of humidity as shown in Figure 10. A volunteer exhaled and inhaled air through the fibres continuously for 1000 s with a time for relaxation in-between. Change in current with respect to time under varying humidity is shown in Figure 10 (A). A consistent rise and fall in current is observed as the humidity rises from 65 % RH (ambient) to 85 % RH (nasal breath). As the volunteer exhaled into the fibres, the humidity increased from 65 % to 85 %, this caused the current to rise as seen in Figure 10 (B). The current stabilized at the end of exhalation, if the fibres were kept exposed to ambient air, the current decreased slowly due to desorption.

This is enhanced during inhalation as the humidity exposed in that of the ambient air. Due to the presence of β CD, there is a prominent decrease in the rise and fall time as shown in Figure 10 (B) and (C). Current rose from 4.2 μ A to 10 μ A as the humidity increased from 65-85 % RH. The rate of increase is approximately 10 s, while the fall is 4 s, the latter happened during inhalation. The water molecules desorbed faster (4 s) due to the presence of β CD when compared to the bare fibres (~19.8 s). We observed a linear rate of adsorption and desorption in current under the influence of humidity.

EXAMPLES

10 **Use of multi-layered functional nanofibres as nasal plug filters:**

The invention proposed to use the electrospun mat, cut into proper dimensions, embedded inside hollow silicone nasal plugs to trap particulate matter from entering the human body. These filters function as use and throw devices.

Use of multi-layered functional nanofibres as face masks:

15 Even though our predominant uses of these filters are as nasal plugs, we propose to use the electrospun mat as stand-alone face masks. The non-woven mats are bio-inert and they can be in contact with the skin for long periods of time.

Use of fibres as a humidity sensor within the nasal filter:

20 The invention proposed to use the electrospun PVDF-PEO-PANI embedded mat within the nasal filter to measure humidity during respiration.

Use of conducting fibres for the deposition of metallic nanobrushes:

The invention used electrospun conducting fibres as substrates for the deposition of metallic nanobrushes via nano electrospray ionization (n-ESI) (Sarkar et al., 2016). These fibres can also be incorporated in the nasal filter for further efficient capture of PM.

25 **Use of functional materials embedded within fibres:**

Embedded the functional materials such as, alumina, silica, magnesia, Fe_2O_3 , etc., into the fibres while spinning. The presence of these materials could embed charges on the fibres, which could enhance the filtration efficiency.

30 It may be appreciated by those skilled in the art that the drawings, examples and detailed description herein are to be regarded in an illustrative rather than a restrictive manner.

We claim:

1. A multilayer nasal filter for particulate filtration comprising an external and internal substrate layer made of spun-bonded nonwoven filter mat and a network of chemically modified intermediate polymeric nanofibers layer sandwiched between the substrate with one or more charges, wherein the filter improves the quality of inhaled air with a filtration efficiency of 99 % for PM_{2.5}.
2. The multilayer nasal filter as claimed in claim 1, wherein at least one chemically modified intermediate polymeric nanofiber layer is positively charged.
3. The multilayer nasal filter as claimed in claim 2, wherein the positive charge is incorporated by functionalizing the said polymeric nanofiber with aqueous choline chloride at 30 °C for 24 h
4. The multilayer nasal filter as claimed in claim 2, wherein the positively charged polymer is polyacrylonitrile.
5. The multilayer nasal filter as claimed in claim 1, wherein at least one chemically modified intermediate polymeric nanofiber layer is negatively charged.
6. The multilayer nasal filter as claimed in claim 5, wherein the negative charge is incorporated by functionalizing the said polymeric nanofiber with 3 M H₂SO₄ for 24 h at 100 °C to anchor the sulfonate groups
7. The multilayer nasal filter as claimed in claim 5, wherein the negatively charged polymer is polystyrene.
8. The multilayer nasal filter as claimed in claim 1, wherein the spun-bonded nonwoven filter mat of external and internal substrate layer act as mechanical support for the charged intermediate layers.
9. The multilayer nasal filter as claimed in claim 1, wherein the polymers of the intermediate layers is selected from the group of functionalizable polymers including cellulose, polysulphone, polyaniline, nylon, polyvinyl acetate, polycaprolactone, cyclodextrine, chitosan, amino clay and alginate.
10. The multilayer nasal filter as claimed in claim 1, wherein the filter traps positively charged, negatively charged and neutral particulate matter in ≥ 0.3 micron range against inhalation.

11. The multilayer nasal filter as claimed in claim 1, wherein the filter fits to the shape of the nose nostrils to filter the air inhaled by the user.

12. The multilayer nasal filter as claimed in claim 1 and 10, wherein the external layer placed to the outer periphery of the nostrils and inner layer placed inside the nostrils.

5 13. The multilayer nasal filter as claimed in claim 1, wherein electrospun PVDF – PEO/ PANI composites are embedded along with the nasal filter, to act as humidity sensors during respiration.

10 14. The multilayer nasal filter as claimed in claim 1, wherein the nasal filter enhances filtration of particulate matter with filtration efficiency >99.99% and with a pressure drop of less than 130 Pa.

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Dated at Chennai this February 26, 2018

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Signature:



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IN/PA — 369

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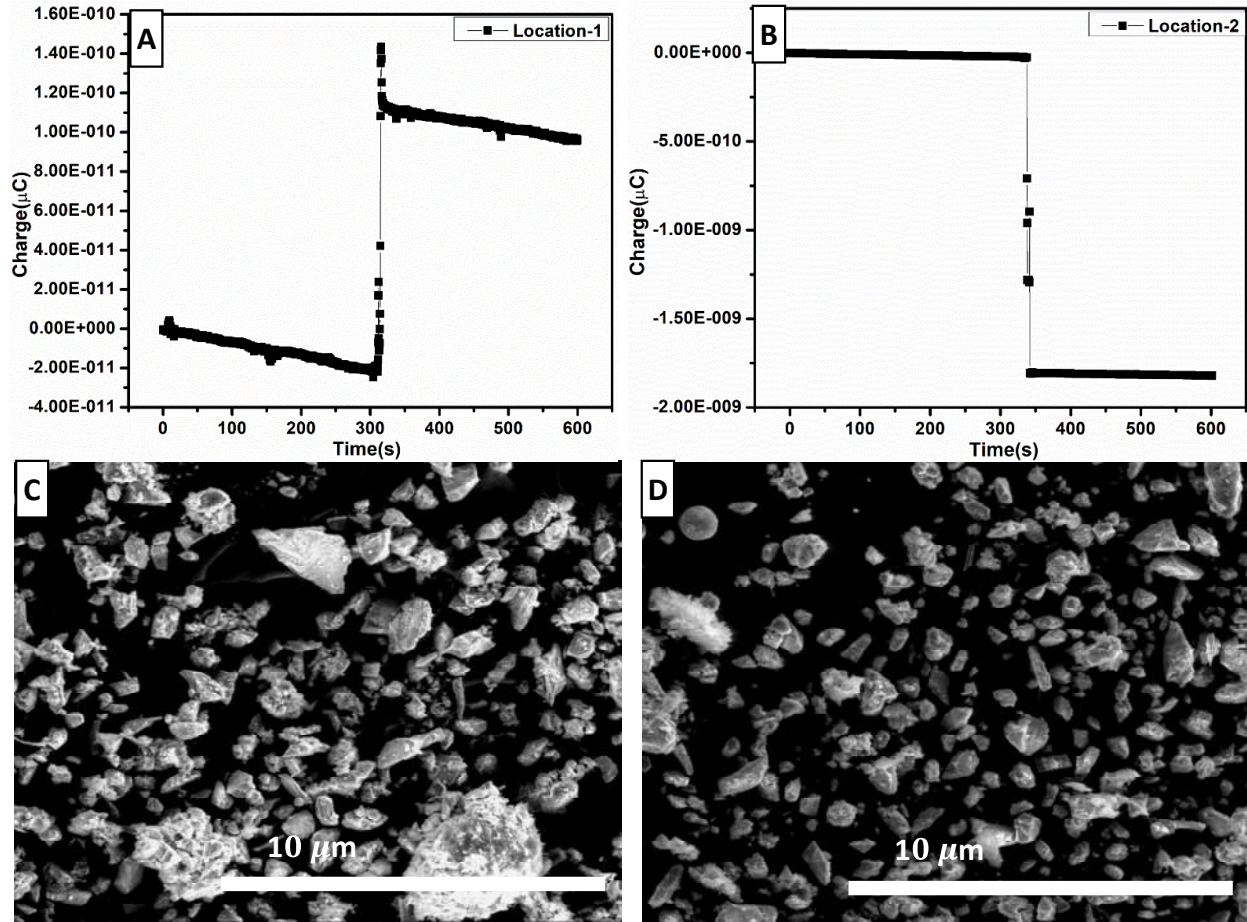
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MULTILAYER MULTIFUNCTIONAL NASAL FILTER

ABSTRACT

5 An improved nasal filter to remove particles below 10 μm in size has been fabricated by
utilizing multilayered molecularly functionalized nanofibres. The nasal filter described here
comprises of a substrate and two layers of surface functionalized nanofibres deposited on the
substrate. Multilayer nasal filter composition comprises, in the direction of flow, a) an external
substrate layer made of spun-bonded nonwoven polymer mat which faces outside of nose, b) the
10 first intermediate layer made of nanofibres with molecularly induced positive charge, c) the
second intermediate layer made of nanofibres with molecularly induced negative charge and d)
an internal substrate layer made of spun-bonded nonwoven polymer mat which faces inside the
nose. The multilayer nasal filter improves the quality of inhaled air with a filtration efficiency of
99 % for $\text{PM}_{2.5}$, wherein the filter provides comfortable and customized fit. The filter with
15 appropriate functionalities also retains molecular contaminants of air. Modified filters acts also
as a humidity sensors during respiration.

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FIGURE 1

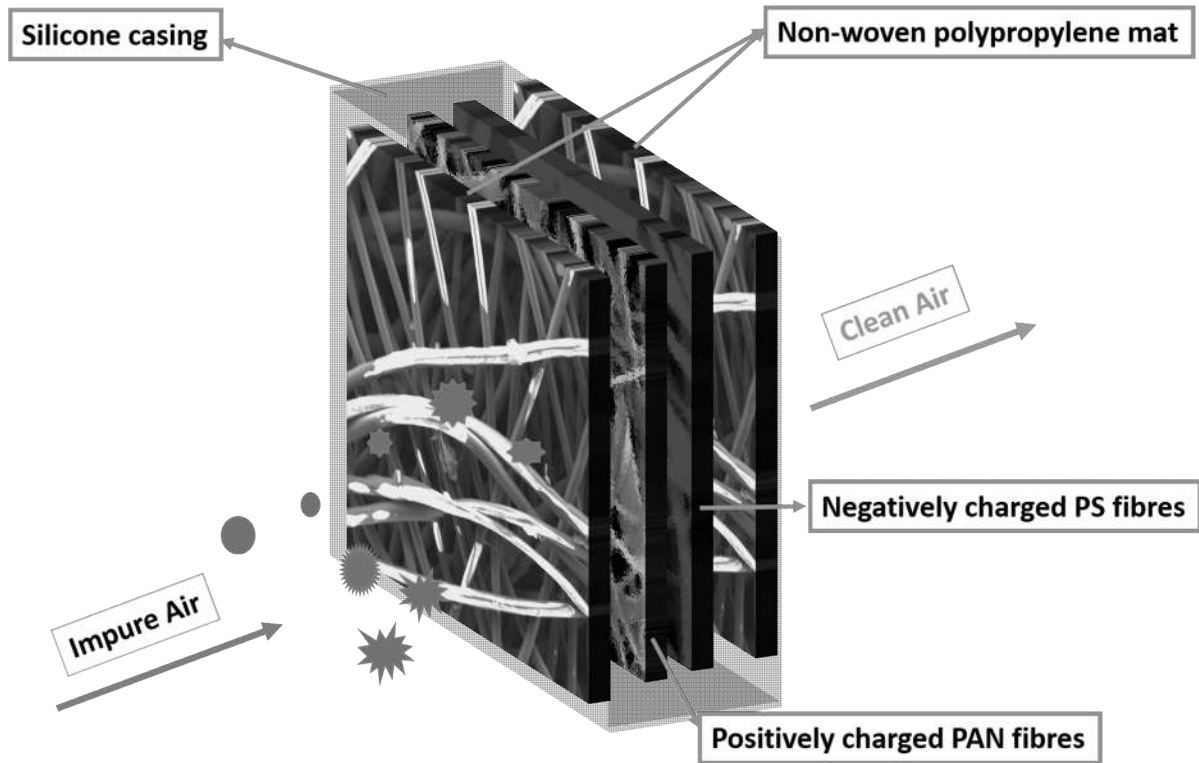
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Signature: 

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FIGURE 2

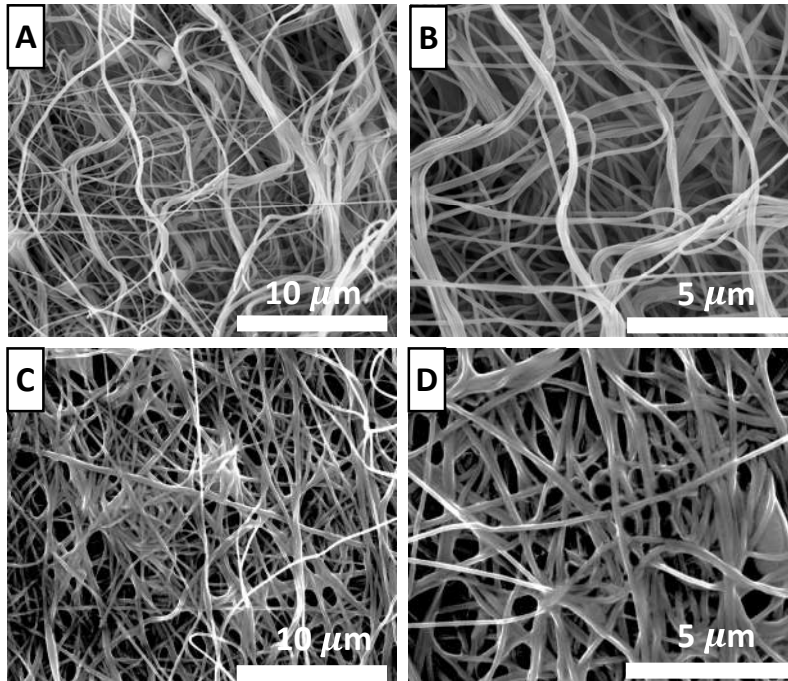
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FIGURE 3

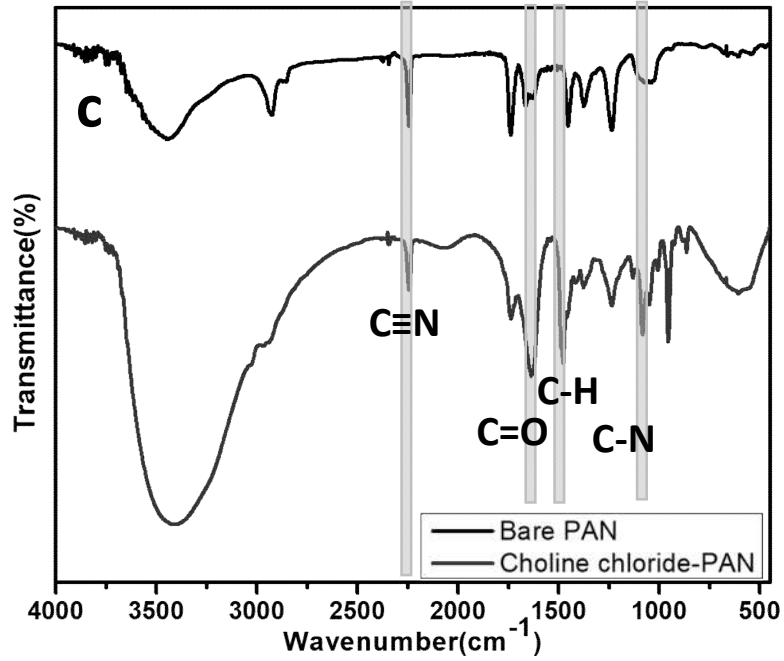
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FIGURE 4

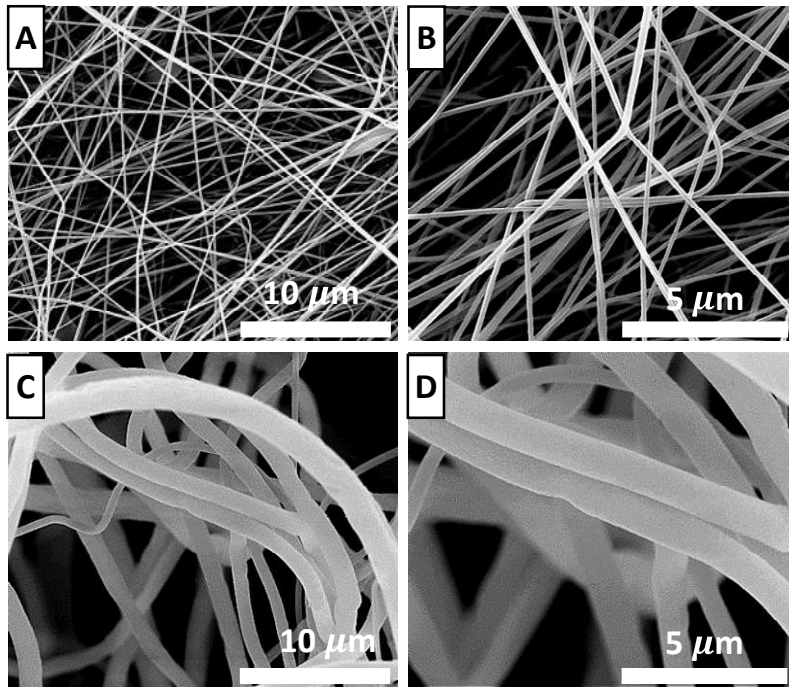
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FIGURE 5

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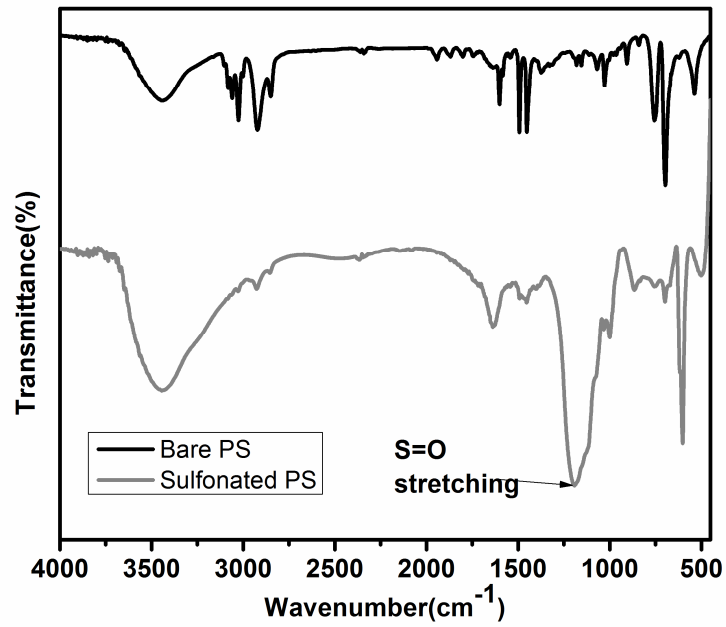
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FIGURE 6

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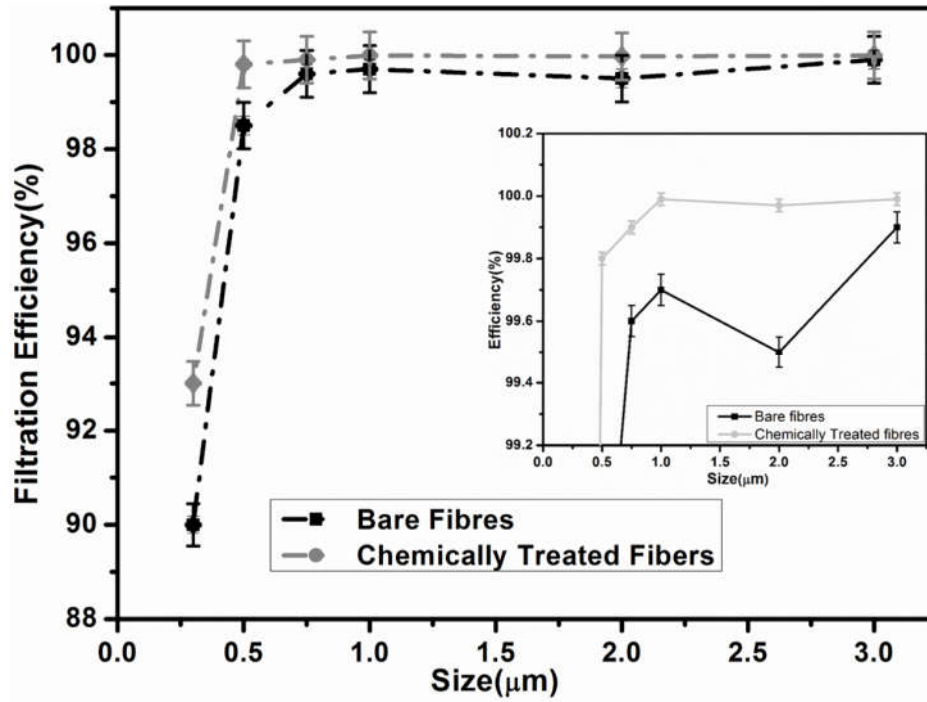
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FIGURE 7

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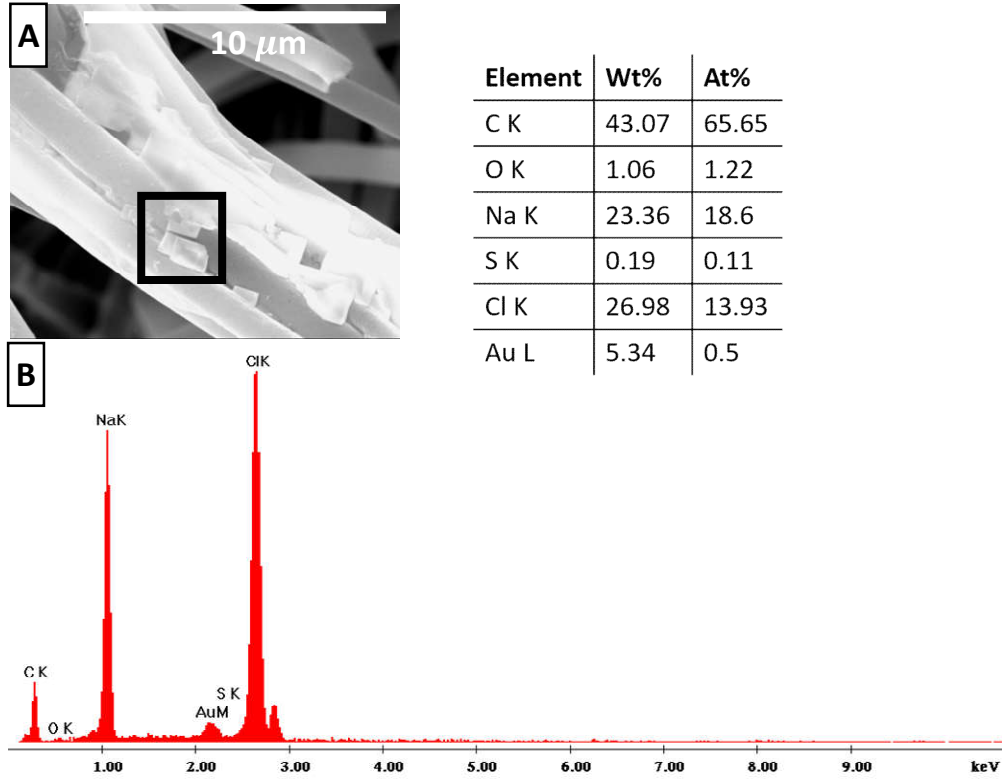
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FIGURE 8

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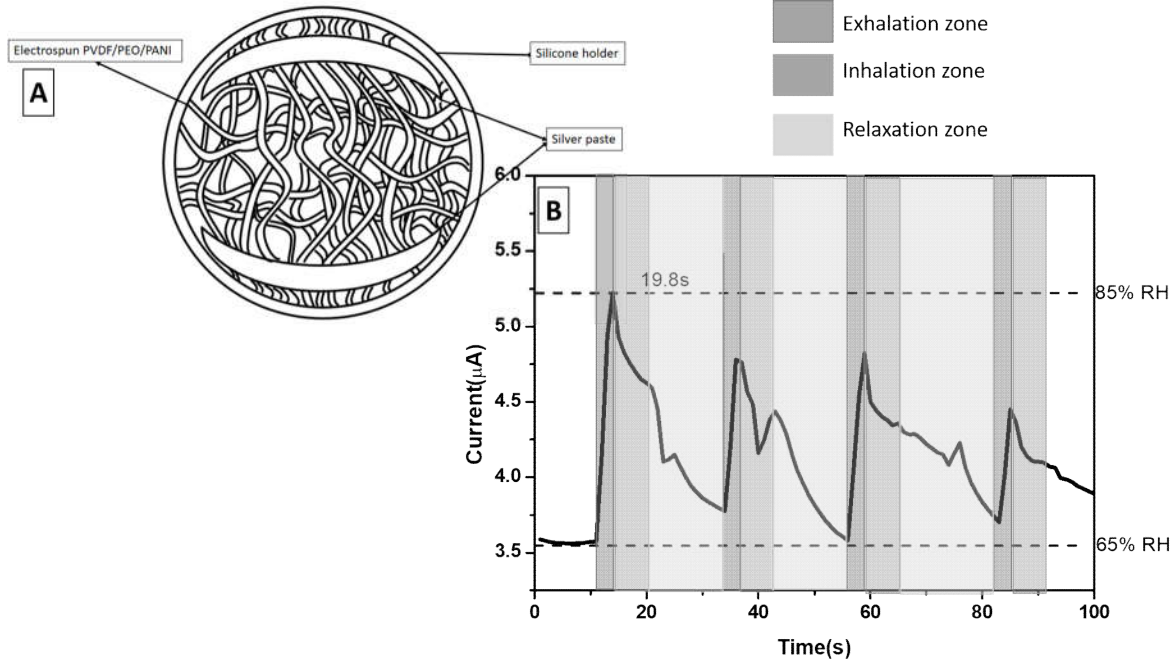
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FIGURE 9

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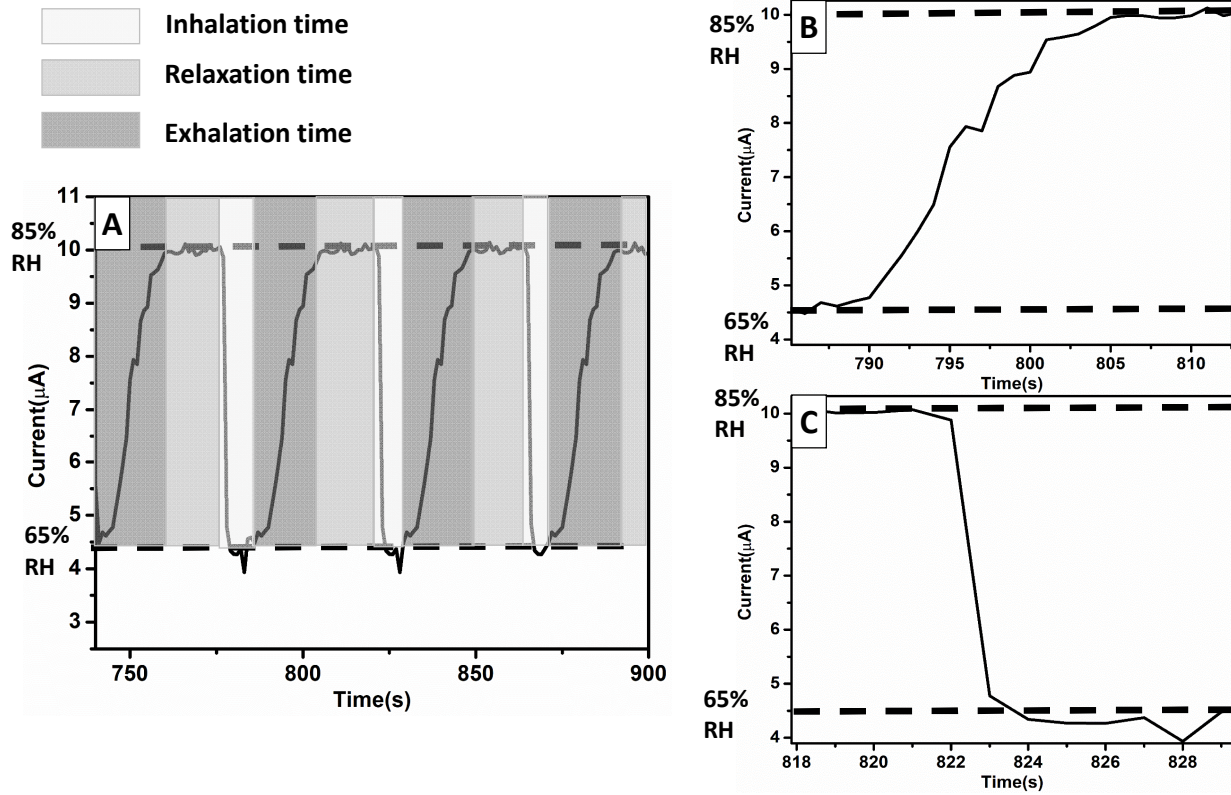
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FIGURE 10

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