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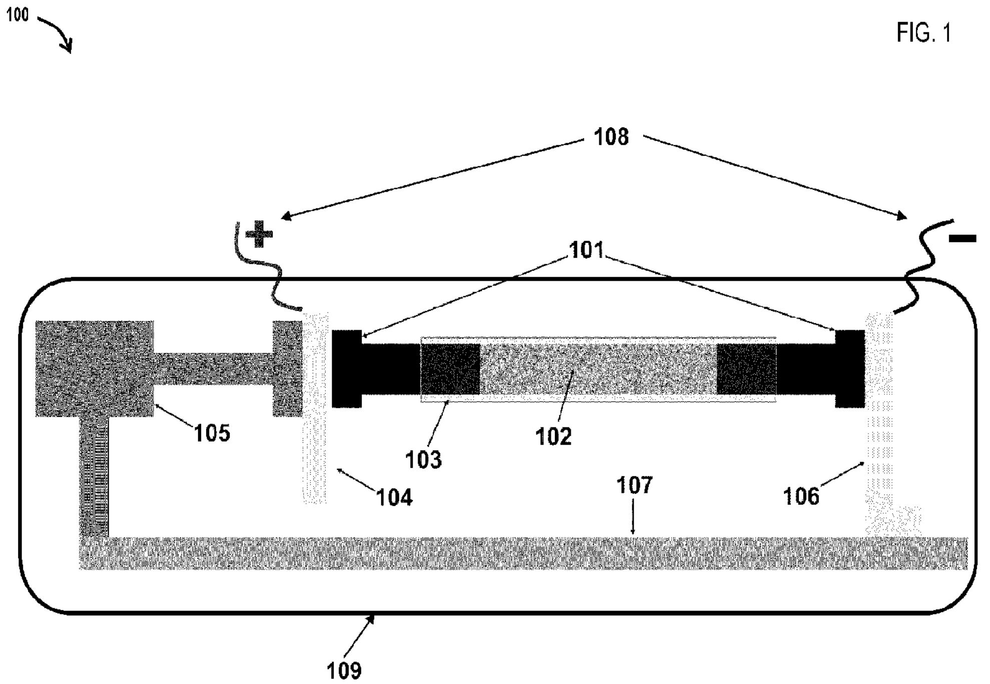

(57) **Abstract:** A system and method for a conversion of plastic and carbon feedstock resulting in a hybrid morphology of carbon nanotubes is provided herein. The system includes a feedstock containing a plastic, a conductive carbon, and a metal-based catalyst. The system further includes a plurality of graphite electrodes configured to conduct a current through the feedstock. The system further includes a reservoir configured to contain the feedstock while allowing outgassing during the conversion. The system further includes a chamber configured to contain combustible volatile substances. The system further includes a power source configured to provide electrical power for the conversion. The system further includes an electrical controller configured to use a feedback mechanism for controlling the conversion and growth of the carbon nanotubes.

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COMPOSITIONS, SYSTEMS AND METHODS FOR FLASH JOULE HEATING CARBON NANOTUBES

Technical Field

[0001] The following relates generally to the synthesis of carbon nanotubes, and more particularly to systems and methods for hybrid morphology synthesis of flash graphene and carbon nanotubes in Flash Joule Heating production.

Introduction

[0002] Graphene, a single layer of carbon atoms arranged in a hexagonal lattice, has garnered immense attention due to its exceptional properties, including high electrical conductivity, thermal conductivity, mechanical strength, and optical transparency. However, conventional methods for producing graphene, such as chemical vapor deposition and mechanical exfoliation, often suffer from scalability issues, high costs, and environmental concerns.

[0003] Accordingly, there is a need for an improved system and method for producing graphene that overcomes at least some of the disadvantages of existing systems and methods.

[0004] This background information is provided to reveal information believed by the applicant to be of possible relevance to the present disclosure. No admission is necessarily intended, nor should be construed, that any of the preceding information constitutes prior art against the present disclosure.

Summary

[0005] A system for a conversion of plastic and carbon feedstock resulting in a hybrid morphology of carbon nanotubes is provided. The system includes a feedstock containing a plastic, a conductive carbon, and a metal-based catalyst. The system further includes a plurality of graphite electrodes configured to conduct a current through the feedstock. The system further includes a reservoir configured to contain the feedstock while allowing outgassing during the conversion. The system further includes a chamber configured to contain combustible volatile substances. The system further includes a power source configured to provide electrical power for the conversion. The system further includes an electrical controller configured to use a feedback mechanism for controlling the conversion and growth of the carbon nanotubes.

[0006] In an embodiment, the plastic includes at least one of: polypropylene; polyethylene; polystyrene; nylon; polyethylene terephthalate; polyimide; Polyvinyl Chloride; Polycarbonate; Acrylic; Epoxy Resins; Polyurethanes; Phenolic Resins; Bioplastics; and Elastomers.

[0007] In an embodiment, the conductive carbon includes at least one of: carbon black; metallurgy coke; calcine petroleum coke; biochar; flashed polyhedral graphene; flashed flake graphene; pyrolyzed cotton fiber; and carbon fiber.

[0008] In an embodiment, the metal-based catalyst includes at least one of: transitional metals; salts; compositions of iron; nickel; copper; aluminum; and silicon.

[0009] In an embodiment, the reservoir is composed of at least one of: quartz tubes; and confined troughs, wherein the quartz tubes and confined troughs are composed of a combination of quartz tiles and graphite plates.

[0010] In an embodiment, a compression force is regulated to provide a high pressure during low current, and a low pressure during high current.

[0011] In an embodiment, outgassing of the reservoir is via apertures in the reservoir.

[0012] In an embodiment, the electrical controller is further configured to vary the electrical power between 1 kW/kg and 1000 kW/kg during the conversion.

[0013] In an embodiment, the electrical controller is further configured to receive temperature feedback from the conversion to allow variance of a temperature of the conversion between 600°C and 2000°C.

[0014] In an embodiment, a carbon yield of the conversion of plastic to carbon nanotubes is between 5% and 40%.

[0015] In an embodiment, a product of the conversion includes hybrid morphology between Polyhedral Graphene and carbon nanotubes.

[0016] In an embodiment, the Polyhedral Graphene has particle size of 2 nm to 200 nm.

[0017] In an embodiment, a product of the conversion includes hybrid morphology between flake graphene and carbon nanotubes.

[0018] In an embodiment, a product of the conversion includes hybrid morphology between carbon fiber and carbon nanotubes.

[0019] In an embodiment, carbon nanotubes from a hybrid morphology have a diameter of 5 nm to 200 nm.

[0020] In an embodiment, carbon nanotubes from a hybrid morphology have length of 10 nm to 10000 nm.

[0021] In an embodiment, carbon nanotubes from a hybrid morphology are tunable in length and diameter by varying the catalyst concentration between 0.001% to 10%.

[0022] In an embodiment, the reservoir contains between 1g and 100000g of the feedstock.

[0023] A method for a conversion of plastic and carbon feedstock resulting in a hybrid morphology of carbon nanotubes is provided. The method includes providing a feedstock containing a plastic, a conductive carbon, and a metal-based catalyst. The method further includes conducting a current through the feedstock. The method further includes containing the feedstock in a reservoir while allowing outgassing during the conversion. The method further includes containing combustible volatile substances. The method further includes providing electrical power for the conversion. The method further includes controlling the conversion and growth of the carbon nanotubes.

[0024] In an embodiment, the plastic includes at least one of: polypropylene; polyethylene; polystyrene; nylon; polyethylene terephthalate; polyimide; Polyvinyl Chloride; Polycarbonate; Acrylic; Epoxy Resins; Polyurethanes; Phenolic Resins; Bioplastics; and Elastomers.

[0025] In an embodiment, the conductive carbon includes at least one of: carbon black; metallurgy coke; calcine petroleum coke; biochar; flashed polyhedral graphene; flashed flake graphene; pyrolyzed cotton fiber; and carbon fiber.

[0026] In an embodiment, the metal-based catalyst includes at least one of: transitional metals; salts; compositions of iron; nickel; copper; aluminum; and silicon.

[0027] In an embodiment, the reservoir is composed of at least one of: quartz tubes; and confined troughs, wherein the quartz tubes and confined troughs are composed of a combination of quartz tiles and graphite plates.

[0028] In an embodiment, a compression force is regulated to provide a high pressure during low current, and a low pressure during high current.

[0029] In an embodiment, outgassing of the reservoir is via apertures in the reservoir.

[0030] In an embodiment, an electrical controller is further configured to vary the electrical power between 1 kW/kg and 1000 kW/kg during the conversion.

[0031] In an embodiment, an electrical controller is further configured to receive temperature feedback from the conversion to allow variance of a temperature of the conversion between 600°C and 2000°C.

[0032] In an embodiment, a carbon yield of the conversion of plastic to carbon nanotubes is between 5% and 40%.

[0033] In an embodiment, a product of the conversion includes hybrid morphology between Polyhedral Graphene and carbon nanotubes.

[0034] In an embodiment, the Polyhedral Graphene has particle size of 2 nm to 200 nm.

[0035] In an embodiment, a product of the conversion includes hybrid morphology between flake graphene and carbon nanotubes.

[0036] In an embodiment, a product of the conversion includes hybrid morphology between carbon fiber and carbon nanotubes.

[0037] In an embodiment, carbon nanotubes from a hybrid morphology have a diameter of 5 nm to 200 nm.

[0038] In an embodiment, carbon nanotubes from a hybrid morphology have length of 10 nm to 10000 nm.

[0039] In an embodiment, carbon nanotubes from a hybrid morphology are tunable in length and diameter by varying the catalyst concentration between 0.001% to 10%.

[0040] In an embodiment, the reservoir contains between 1g and 100000g of the feedstock.

[0041] Other aspects and features will become apparent, to those ordinarily skilled in the art, upon review of the following description of some exemplary embodiments.

Brief Description of the Drawings

[0042] The drawings included herewith are for illustrating various examples of articles, methods, and apparatuses of the present specification. In the drawings:

[0043] Figure 1 is a schematic diagram of a system for a conversion of plastic and carbon feedstock resulting in a hybrid morphology of carbon nanotubes, according to an embodiment;

[0044] Figure 2 is a schematic diagram of a system of an automated version of a batch-to-batch hybrid flash graphene carbon nanotubes (HFGCNTs) synthesis based on the system of Figure 1, according to an embodiment;

[0045] Figure 3 is a schematic diagram of a system for handling volatile substances that contains the system of Figure 1, according to an embodiment;

[0046] Figure 4 is a schematic diagram of a system for a lab scale Flash Joule Heating synthesis of HFGCNTs, according to an embodiment;

[0047] Figure 5 is a collection of images of HFGCNTs characterized by Scanning Electron Microscopes (SEM) and Raman imaging, according to an embodiment;

[0048] Figure 6 is a schematic of an exemplary production of HCFCNTs in the system of Figure 1, according to an embodiment;

[0049] Figure 7 is a collection of images of pyrolyzed cotton fiber mixed with polyethylene powder and iron sulfonate used in the system of Figure 1, according to an embodiment;

[0050] Figure 8 is a collection of images of commercial carbon fibers with different sizes and lengths are mixed with polyethylene powder and iron sulfonate and flashed in the system of Figure 1, according to an embodiment;

[0051] Figure 9 is a collection of images of different catalyst loadings results in different carbon nanotubes morphologies used in the system of Figure 1, according to an embodiment; and

[0052] Figure 10 is a flowchart of a method of for a conversion of plastic and carbon feedstock resulting in a hybrid morphology of carbon nanotubes, according to an embodiment.

Detailed Description

[0053] Various apparatuses or processes will be described below to provide an example of each claimed embodiment. No embodiment described below limits any claimed embodiment and any claimed embodiment may cover processes or apparatuses that differ from those described below. The claimed embodiments are not limited to apparatuses or processes having all of the features of any one apparatus or process described below or to features common to multiple or all of the apparatuses described below.

[0054] As used herein, the term “about” should be read as including variation from the nominal value, for example, a +/-10% variation from the nominal value. It is to be understood that such a variation is always included in a given value provided herein, whether or not it is specifically referred to.

[0055] A description of an embodiment with several components in communication with each other does not imply that all such components are required. On the contrary, a variety of optional components are described to illustrate the wide variety of possible embodiments of the present disclosure.

[0056] Further, although process steps, method steps, algorithms or the like may be described (in the disclosure and / or in the claims) in a sequential order, such processes, methods and algorithms may be configured to work in alternate orders. In other words, any sequence or order of steps that may be described does not necessarily indicate a requirement that the steps be performed in that order. The steps of processes described herein may be performed in any order that is practical. Further, some steps may be performed simultaneously.

[0057] When a single device or article is described herein, it will be readily apparent that more than one device / article (whether or not they cooperate) may be used in place of a single device / article. Similarly, where more than one device or article is described herein (whether or not they cooperate), it will be readily apparent that a single device / article may be used in place of the more than one device or article.

[0058] The following relates generally to the synthesis of carbon nanotubes, and more particularly to systems and methods for hybrid morphology synthesis of flash graphene and carbon nanotubes in Flash Joule Heating production.

[0059] In recent years, a novel technique known as "flash graphene" has emerged as a promising alternative to conventional methods for producing graphene. This method, Flash Joule Heating (FJH), involves the rapid Joule heating of carbon-containing precursors, such as coal, biomass, or plastic waste, to temperatures exceeding 3000 K for a fraction of a second. This intense heating process leads to the exfoliation and rearrangement of carbon atoms, resulting in the formation of high-quality graphene flakes.

[0060] Provided herein are systems and methods for synthesizing hybrid morphology of flash graphene and carbon nanotubes utilizing the Flash Joule Heating (FJH) method. The hybrid flash graphene carbon nanotubes (HFGCNTs) morphology is enabled by using feedstock that contains plastic or hydrocarbon mixed with flash graphene feedstock. Catalysts containing iron, nickel, copper can be used to increase the yield of the carbon nanotubes (CNTs).

[0061] To facilitate the CNTs growth, lower voltage is used for a longer heat treatment comparing the FJH method of graphene synthesis. The heat treatment is controlled with feedback from temperature for homogeneous and high-yield CNTs growth.

[0062] The process of synthesizing HFGCNTs can be scaled up with various flashing apparatuses. For safe industrial scale up system, the flash apparatus must be contained inside a controlled environment system to prevent contact with atmospheric oxygen, and collect the byproducts from feedstock decomposition.

[0063] The flash graphene synthesis offers several advantages, including scalability, low cost, and the ability to utilize a wide range of readily available carbon sources, including waste materials. This technique holds tremendous potential for revolutionizing the production of graphene and enabling its widespread application in various fields, such as electronics, energy storage, composites, and environmental remediation.

[0064] Referring now to Figure 1, shown therein is a system 100 for a conversion of plastic and carbon feedstock resulting in a hybrid morphology of carbon nanotubes, according to an embodiment.

[0065] For example, the system 100 may be a scaled-up batch-to-batch flash Joule heating apparatus for the synthesis of HFGCNTs.

[0066] The system 100 includes a feedstock 102 containing a plastic, a conductive carbon, and a metal-based catalyst.

[0067] In various embodiments, feedstock 102 may be a mixture of ground plastic with carbon black and a catalyst.

[0068] The system 100 further includes a plurality of graphite electrodes 101 configured to conduct a current through the feedstock 102.

[0069] In various embodiments, graphite plugs 101 may be used to contain and conduct electricity to the feedstock 102.

[0070] The system 100 further includes a reservoir 103 configured to contain the feedstock while allowing outgassing during the conversion.

[0071] In various embodiments, the reservoir 103 may be a quartz tube used for the containment of about 0.1-10 kg of feedstock 102.

[0072] The system 100 further includes a chamber 109 configured to contain combustible volatile substances.

[0073] The system 100 further includes a power source 108 configured to provide electrical power for the conversion.

[0074] The system 100 further includes an electrical controller (depicted as an example circuit created by brass electrode 106, platform 107, pneumatic actuator 105, and counter electrode 104) configured to use a feedback mechanism for controlling the conversion and growth of the carbon nanotubes.

[0075] One brass electrode 106 may be permanently attached to but electrically isolated from a platform 107. A counter electrode 104 may be attached to but electrically isolated from a pneumatic actuator 105 that is attached to platform 107.

[0076] During a conversion, 60-80% of the plastic becomes volatile and the rest carbonizes to carbon nanotubes under the aid of the catalyst. The volatile compound creates positive pressure inside the quartz tube 103 and comes out through the two sides of the quartz tube 103.

[0077] The pneumatic actuator 105 prevents the positive pressure creating void inside the feedstock 102 that disrupts the current. It also allows a constant compression to the feedstock 102 throughout the conversion to maintain an electrical connection.

[0078] In an embodiment, the plastic includes at least one of: polypropylene; polyethylene; polystyrene; nylon; polyethylene terephthalate; polyimide; Polyvinyl Chloride; Polycarbonate; Acrylic; Epoxy Resins; Polyurethanes; Phenolic Resins; Bioplastics; and Elastomers.

[0079] In an embodiment, the conductive carbon includes at least one of: carbon black; metallurgy coke; calcine petroleum coke; biochar; flashed polyhedral graphene; flashed flake graphene; pyrolyzed cotton fiber; and carbon fiber.

[0080] In an embodiment, the metal-based catalyst includes at least one of: transitional metals; salts; compositions of iron; nickel; copper; aluminum; and silicon.

[0081] In an embodiment, the reservoir 103 is composed of at least one of quartz tubes, and confined troughs. The quartz tubes and confined troughs are composed of a combination of quartz tiles and graphite plates.

[0082] In an embodiment, a compression force is regulated to provide a high pressure during low current, and a low pressure during high current.

[0083] In an embodiment, outgassing of the reservoir 103 is via apertures in the reservoir.

[0084] In an embodiment, the electrical controller is further configured to vary the electrical power between 1 kW/kg and 1000 kW/kg during the conversion.

[0085] In an embodiment, the electrical controller is further configured to receive temperature feedback from the conversion to allow variance of a temperature of the conversion between 600°C and 2000°C.

[0086] In an embodiment, a carbon yield of the conversion of plastic to carbon nanotubes is between 5% and 40%.

[0087] In an embodiment, a product of the conversion includes hybrid morphology between Polyhedral Graphene and carbon nanotubes.

[0088] In an embodiment, the Polyhedral Graphene has particle size of 2 nm to 200 nm.

[0089] In an embodiment, a product of the conversion includes hybrid morphology between flake graphene and carbon nanotubes.

[0090] In an embodiment, a product of the conversion includes hybrid morphology between carbon fiber and carbon nanotubes.

[0091] In an embodiment, carbon nanotubes from a hybrid morphology have a diameter of 5 nm to 200 nm.

[0092] In an embodiment, carbon nanotubes from a hybrid morphology have length of 10 nm to 10000 nm.

[0093] In an embodiment, carbon nanotubes from a hybrid morphology are tunable in length and diameter by varying the catalyst concentration between 0.001% to 10%.

[0094] In an embodiment, the reservoir contains between 1g and 100000g of the feedstock.

[0095] Referring now to Figure 2, shown therein is a system 200 of an automated version of a batch-to-batch hybrid flash graphene carbon nanotubes (HFGCNTs) synthesis based on the system 100 of Figure 1, according to an embodiment.

[0096] In the system 200, instead of the quartz tube, an insulated trough 203 is used to contain feedstock 204.

[0097] Electrodes 201 are bolted to the trough 203 by insulated bolts 202.

[0098] Top brick 205 completes the containment of the feedstock and provides pressure for compression.

[0099] The design of the trough 203 may be automated using robotics with ease of product collection and trough reusability.

[0100] Referring now to Figure 3, shown therein is a system 300 for handling volatile substances that contains the system 100 of Figure 1, according to an embodiment.

[0101] Conversion of feedstock into HFCNTs produces high amounts of volatile substances that pose explosion hazard if not well contained. The flashing apparatus (e.g., the system 100 of Figure 1) is contained inside chamber 301 (e.g., chamber 109 of Figure 1) that is purged with an inert gas such as Nitrogen or Argon.

[0102] The gas in the chamber 301 is circulated out of the chamber 301 through the gas output duct 302 to a condenser 303.

[0103] Volatile substances are collected as a condensed liquid through a liquid collection hose 304.

[0104] The remaining gas is circulated back to the chamber 301 through a gas input hose 305.

[0105] Advantageously, this design keeps oxygen out of the conversion system while also recovering volatile substances as another potential petroleum byproduct.

[0106] Referring now to Figure 4, shown therein is a system 400 for a lab scale Flash Joule Heating synthesis of HFGCNTs, according to an embodiment.

[0107] The Flash Joule Heating power system 400 has different requirements compared to previous graphene synthesis flashing system. Since the temperature required for CNTs growth is much less than flash graphene synthesis, a lower power but continuous flashing system is desired.

[0108] Three-phase power supply from cutoff switch 401 is directed to the commercial DC power supply 402 to be rectified to low voltage high current DC.

[0109] In an embodiment, the digital controller system 403 controls the power supply 402 via a constant current mode.

[0110] In an embodiment, the digital controller system 403 acquires data from current, voltage, temperature sensors 404 for the feedback loop to power the load 405.

[0111] In an embodiment, the user interfaces with the controller 403 through computer system 406.

[0112] In an embodiment, the system 400 is operated with a controlled power profile from current, voltage, power, temperature feedback loop for a desired recipe for each HFGCNTs synthesis.

[0113] Referring now to Figure 5, shown therein are images of HFGCNTs characterized by Scanning Electron Microscopes (SEM) and Raman imaging, according to an embodiment.

[0114] Images 501 and 502 show the SEM images of the Hybrid Polyhedral Graphene Carbon Nanotubes morphology. Carbon nanotubes and polyhedral graphene are seen entangled and merged.

[0115] Images 503 and 504 show images of separated HPGCNTs structures. A single CNTs string can be seen connecting several polyhedral graphene structures.

[0116] Images 505 and 506 are SEM images of Hybrid Flake Graphene Carbon Nanotubes morphology. Flake graphene is produced from flashing Metallurgy Coke and is seen covered with CNTs on the surface.

[0117] Both of the polyhedral graphene and flake graphene represents the morphology change with the flash graphene using the CNTs addition.

[0118] Image 507 shows typical Raman imaging of the HFGCNTs with a high D-peak at 1350 cm^{-1} that indicates the defective structure of the sp2 carbon. A 2D peak at 2700 cm^{-1} indicates the graphene/carbon nanotube nature of the material.

[0119] Large polyhedral graphene and carbon nanotubes hybrids may also be produced, and one exemplary morphology is shown in image 508. This indicates that CNTs can form hybrids with a wide range of PG with different sizes and structures.

[0120] Referring now to Figure 6, shown therein is a schematic of the production of HCFCNTs, according to an embodiment.

[0121] In the schematic 600, an iron-based catalyst is added to increase CNTs yield. Carbon nanotubes grow on carbon fiber to form Hybrid Carbon Fiber Carbon Nanotubes (HCFCNTs) structures.

[0122] Referring now to Figure 7, shown therein are images of pyrolyzed cotton fiber mixed with polyethylene powder and iron sulfonate (in a ratio of 50:48:2), according to an embodiment.

[0123] The mixture is flashed in quartz tube at 700 C to 1000 C.

[0124] The SEM characterization from image 701 show CNTs growth on cotton derived carbon fiber surface.

[0125] EDAX elemental analysis in images 702 and 703 shows no iron content on the fiber HCFCNTs surface.

[0126] In images 704 and 705, Raman spectra show CNT radial breathing mode peak may be detected at some locations of the sample.

[0127] Referring now to Figure 8, shown therein are images of commercial carbon fibers with different sizes and lengths are mixed with polyethylene powder and iron sulfonate (50:48:2) and flashed at 700 C to 1000 C, according to an embodiment.

[0128] In the images 801 to 806, carbon nanotubes are seen covering the carbon fiber surface. The carbon nanotubes on the surface grow in bundles with diameters of 20-100 nm.

[0129] The iron content is low or undetectable with EDAX. This indicates or suggests the iron is removed as volatile during the flash, after the growth of the carbon nanotubes.

[0130] Referring now to Figure 9, shown therein are images of different catalyst loadings results in different carbon nanotubes morphologies, according to an embodiment.

[0131] A higher iron catalyst loading results in bigger carbon nanotubes while a lower loading result in thinner carbon nanotubes.

[0132] Referring now to Figure 10, shown therein is a flowchart of a method 1000 for a conversion of plastic and carbon feedstock resulting in a hybrid morphology of carbon nanotubes, according to an embodiment.

[0133] At 1010, the method includes providing a feedstock containing a plastic, a conductive carbon, and a metal-based catalyst.

[0134] At 1020, the method further includes conducting a current through the feedstock.

[0135] At 1030, the method further includes containing the feedstock in a reservoir while allowing outgassing during the conversion.

[0136] At 1040, the method further includes containing combustible volatile substances.

[0137] At 1050, the method further includes providing electrical power for the conversion.

[0138] At 1060, the method further includes controlling the conversion and growth of the carbon nanotubes.

[0139] In an embodiment, the plastic includes at least one of: polypropylene; polyethylene; polystyrene; nylon; polyethylene terephthalate; polyimide; Polyvinyl

Chloride; Polycarbonate; Acrylic; Epoxy Resins; Polyurethanes; Phenolic Resins; Bioplastics; and Elastomers.

[0140] In an embodiment, the conductive carbon includes at least one of: carbon black; metallurgy coke; calcine petroleum coke; biochar; flashed polyhedral graphene; flashed flake graphene; pyrolyzed cotton fiber; and carbon fiber.

[0141] In an embodiment, the metal-based catalyst includes at least one of: transitional metals; salts; compositions of iron; nickel; copper; aluminum; and silicon.

[0142] In an embodiment, the reservoir is composed of at least one of quartz tubes, and confined troughs. The quartz tubes and confined troughs are composed of a combination of quartz tiles and graphite plates.

[0143] In an embodiment, a compression force is regulated to provide a high pressure during low current, and a low pressure during high current.

[0144] In an embodiment, outgassing of the reservoir is via apertures in the reservoir.

[0145] In an embodiment, an electrical controller is further configured to vary the electrical power between 1 kW/kg and 1000 kW/kg during the conversion.

[0146] In an embodiment, an electrical controller is further configured to receive temperature feedback from the conversion to allow variance of a temperature of the conversion between 600°C and 2000°C.

[0147] In an embodiment, a carbon yield of the conversion of plastic to carbon nanotubes is between 5% and 40%.

[0148] In an embodiment, a product of the conversion includes hybrid morphology between Polyhedral Graphene and carbon nanotubes.

[0149] In an embodiment, the Polyhedral Graphene has particle size of 2 nm to 200 nm.

[0150] In an embodiment, a product of the conversion includes hybrid morphology between flake graphene and carbon nanotubes.

[0151] In an embodiment, a product of the conversion includes hybrid morphology between carbon fiber and carbon nanotubes.

[0152] In an embodiment, carbon nanotubes from a hybrid morphology have a diameter of 5 nm to 200 nm.

[0153] In an embodiment, carbon nanotubes from a hybrid morphology have length of 10 nm to 10000 nm.

[0154] In an embodiment, carbon nanotubes from a hybrid morphology are tunable in length and diameter by varying the catalyst concentration between 0.001% to 10%.

[0155] In an embodiment, the reservoir contains between 1g and 100000g of the feedstock.

[0156] While the above description provides examples of one or more apparatus, methods, or systems, it will be appreciated that other apparatus, methods, or systems may be within the scope of the claims as interpreted by one of skill in the art. Elements of each embodiment may be incorporated into other embodiments, for example, configurations discussed in relation to one embodiment, may be applied to other embodiments disclosed herein. Further, it is evident that various modifications and combinations can be made without departing from the invention. The specification and drawings are, accordingly, to be regarded simply as an illustration of the invention as defined by the claims, and are contemplated to cover any and all modifications, variations, combinations or equivalents that fall within the scope of the present disclosure.

Claims:

1. A system for a conversion of plastic and carbon feedstock resulting in a hybrid morphology of carbon nanotubes, the system comprising:

   a feedstock containing a plastic, a conductive carbon, and a metal-based catalyst;

   a plurality of graphite electrodes configured to conduct a current through the feedstock;

   a reservoir configured to contain the feedstock while allowing outgassing during the conversion;

   a chamber configured to contain combustible volatile substances;

   a power source configured to provide electrical power for the conversion; and

   an electrical controller configured to use a feedback mechanism for controlling the conversion and growth of the carbon nanotubes.

2. The system of claim 1, wherein the plastic includes at least one of: polypropylene; polyethylene; polystyrene; nylon; polyethylene terephthalate; polyimide; Polyvinyl Chloride; Polycarbonate; Acrylic; Epoxy Resins; Polyurethanes; Phenolic Resins; Bioplastics; and Elastomers.

3. The system of claim 1, wherein the conductive carbon includes at least one of: carbon black; metallurgy coke; calcine petroleum coke; biochar; flashed polyhedral graphene; flashed flake graphene; pyrolyzed cotton fiber; and carbon fiber.

4. The system of claim 1, wherein the metal-based catalyst includes at least one of: transitional metals; salts; compositions of iron; nickel; copper; aluminum; and silicon.

5. The system of claim 1, wherein the reservoir is composed of at least one of: quartz tubes; and confined troughs, wherein the quartz tubes and confined troughs are composed of a combination of quartz tiles and graphite plates.

6. The system of claim 1, wherein a compression force is regulated to provide a high pressure during low current, and a low pressure during high current.

7. The system of claim 1, wherein outgassing of the reservoir is via apertures in the reservoir.

8. The system of claim 1, wherein the electrical controller is further configured to vary the electrical power between 1 kW/kg and 1000 kW/kg during the conversion.

9. The system of claim 1, wherein the electrical controller is further configured to receive temperature feedback from the conversion to allow variance of a temperature of the conversion between 600°C and 2000°C.

10. The system of claim 1, wherein a carbon yield of the conversion of plastic to carbon nanotubes is between 5% and 40%.

11. The system of claim 1, wherein a product of the conversion includes hybrid morphology between Polyhedral Graphene and carbon nanotubes.

12. The system of claim 11, wherein the Polyhedral Graphene has particle size of 2 nm to 200 nm.

13. The system of claim 1, wherein a product of the conversion includes hybrid morphology between flake graphene and carbon nanotubes.

14. The system of claim 1, wherein a product of the conversion includes hybrid morphology between carbon fiber and carbon nanotubes.

15. The system of claim 1, wherein carbon nanotubes from a hybrid morphology have a diameter of 5 nm to 200 nm.

16. The system of claim 1, wherein carbon nanotubes from a hybrid morphology have length of 10 nm to 10000 nm.

17. The system of claim 1, wherein carbon nanotubes from a hybrid morphology are tunable in length and diameter by varying the catalyst concentration between 0.001% to 10%.

18. The system of claim 1, wherein the reservoir contains between 1g and 100000g of the feedstock.

19. A method for a conversion of plastic and carbon feedstock resulting in a hybrid morphology of carbon nanotubes, the method comprising:

providing a feedstock containing a plastic, a conductive carbon, and a metal-based catalyst;

conducting a current through the feedstock;

containing the feedstock in a reservoir while allowing outgassing during the conversion;

containing combustible volatile substances;

providing electrical power for the conversion; and

controlling the conversion and growth of the carbon nanotubes.

20. The method of claim 19, wherein the plastic includes at least one of: polypropylene; polyethylene; polystyrene; nylon; polyethylene terephthalate; polyimide; Polyvinyl

Chloride; Polycarbonate; Acrylic; Epoxy Resins; Polyurethanes; Phenolic Resins; Bioplastics; and Elastomers.

21. The method of claim 1, wherein the conductive carbon includes at least one of: carbon black; metallurgy coke; calcine petroleum coke; biochar; flashed polyhedral graphene; flashed flake graphene; pyrolyzed cotton fiber; and carbon fiber.

22. The method of claim 1, wherein the metal-based catalyst includes at least one of: transitional metals; salts; compositions of iron; nickel; copper; aluminum; and silicon.

23. The method of claim 1, wherein the reservoir is composed of at least one of: quartz tubes; and confined troughs, wherein the quartz tubes and confined troughs are composed of a combination of quartz tiles and graphite plates.

24. The method of claim 1, wherein a compression force is regulated to provide a high pressure during low current, and a low pressure during high current.

25. The method of claim 1, wherein outgassing of the reservoir is via apertures in the reservoir.

26. The method of claim 1, wherein an electrical controller is configured to vary the electrical power between 1 kW/kg and 1000 kW/kg during the conversion.

27. The method of claim 1, wherein the electrical controller is further configured to receive temperature feedback from the conversion to allow variance of a temperature of the conversion between 600°C and 2000°C.

28. The method of claim 1, wherein a carbon yield of the conversion of plastic to carbon nanotubes is between 5% and 40%.

29. The method of claim 1, wherein a product of the conversion includes hybrid morphology between Polyhedral Graphene and carbon nanotubes.

30. The method of claim 29, wherein the Polyhedral Graphene has particle size of 2 nm to 200 nm.

31. The method of claim 1, wherein a product of the conversion includes hybrid morphology between flake graphene and carbon nanotubes.

32. The method of claim 1, wherein a product of the conversion includes hybrid morphology between carbon fiber and carbon nanotubes.

33. The method of claim 1, wherein carbon nanotubes from a hybrid morphology have a diameter of 5 nm to 200 nm.

34. The method of claim 1, wherein carbon nanotubes from a hybrid morphology have length of 10 nm to 10000 nm.

35. The method of claim 1, wherein carbon nanotubes from a hybrid morphology are tunable in length and diameter by varying the catalyst concentration between 0.001% to 10%.

36. The method of claim 1, wherein the reservoir contains between 1g and 100000g of the feedstock.

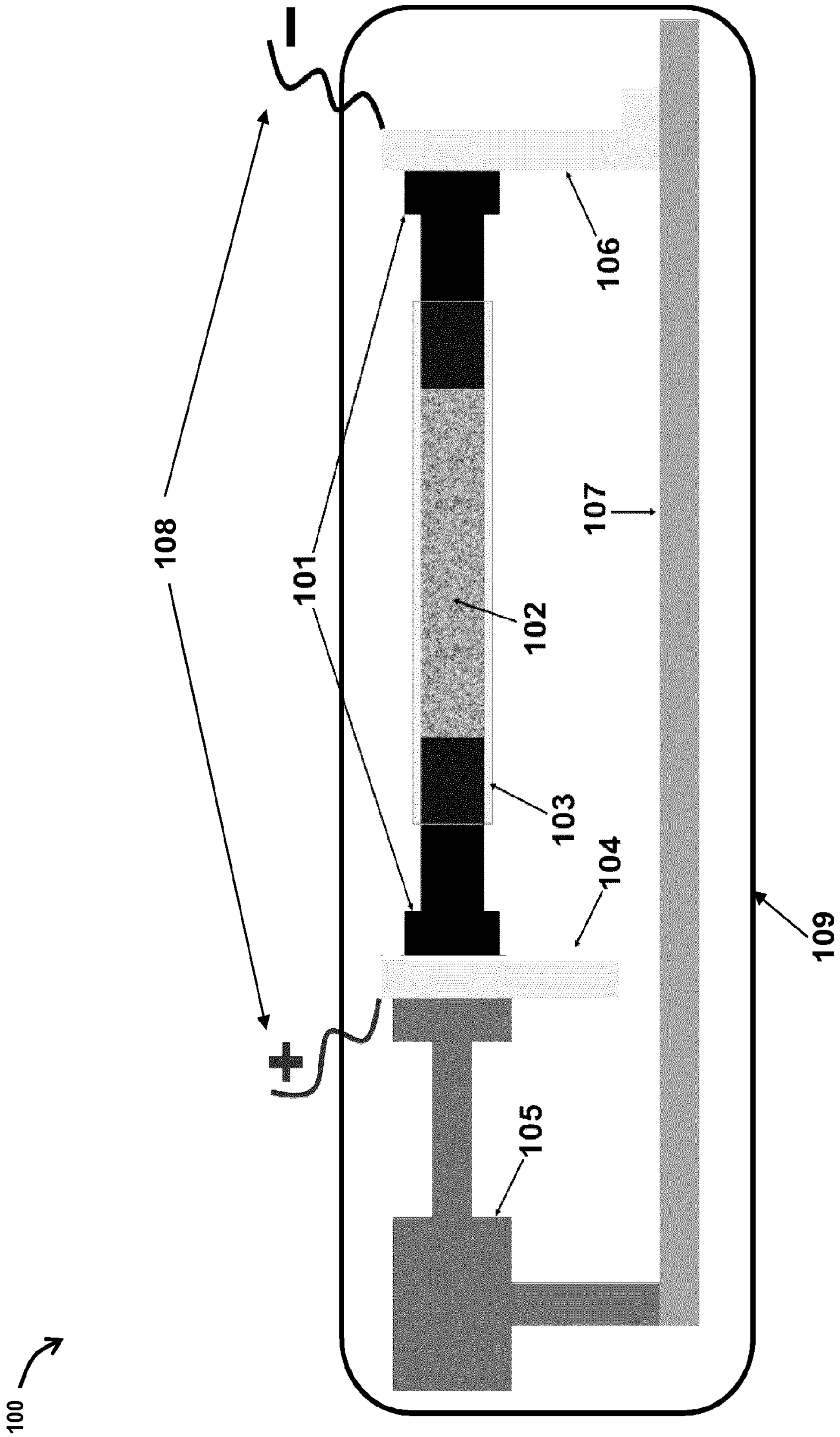


FIG. 1

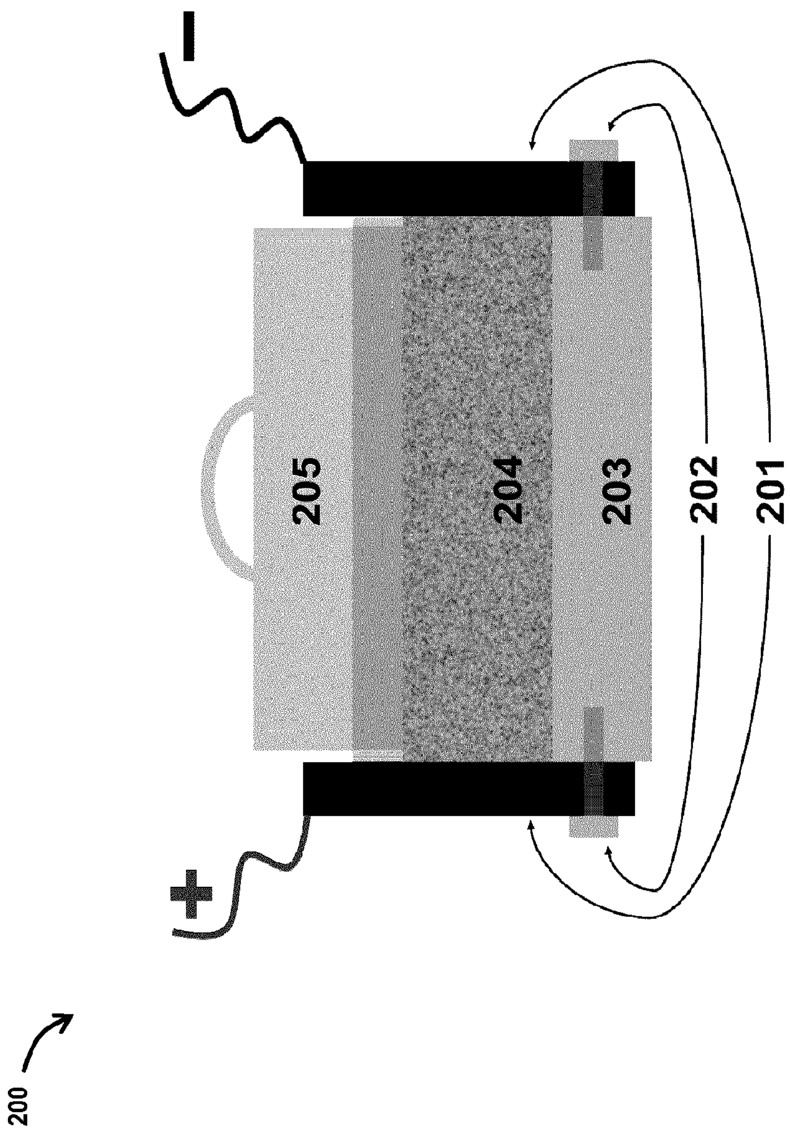


FIG. 2

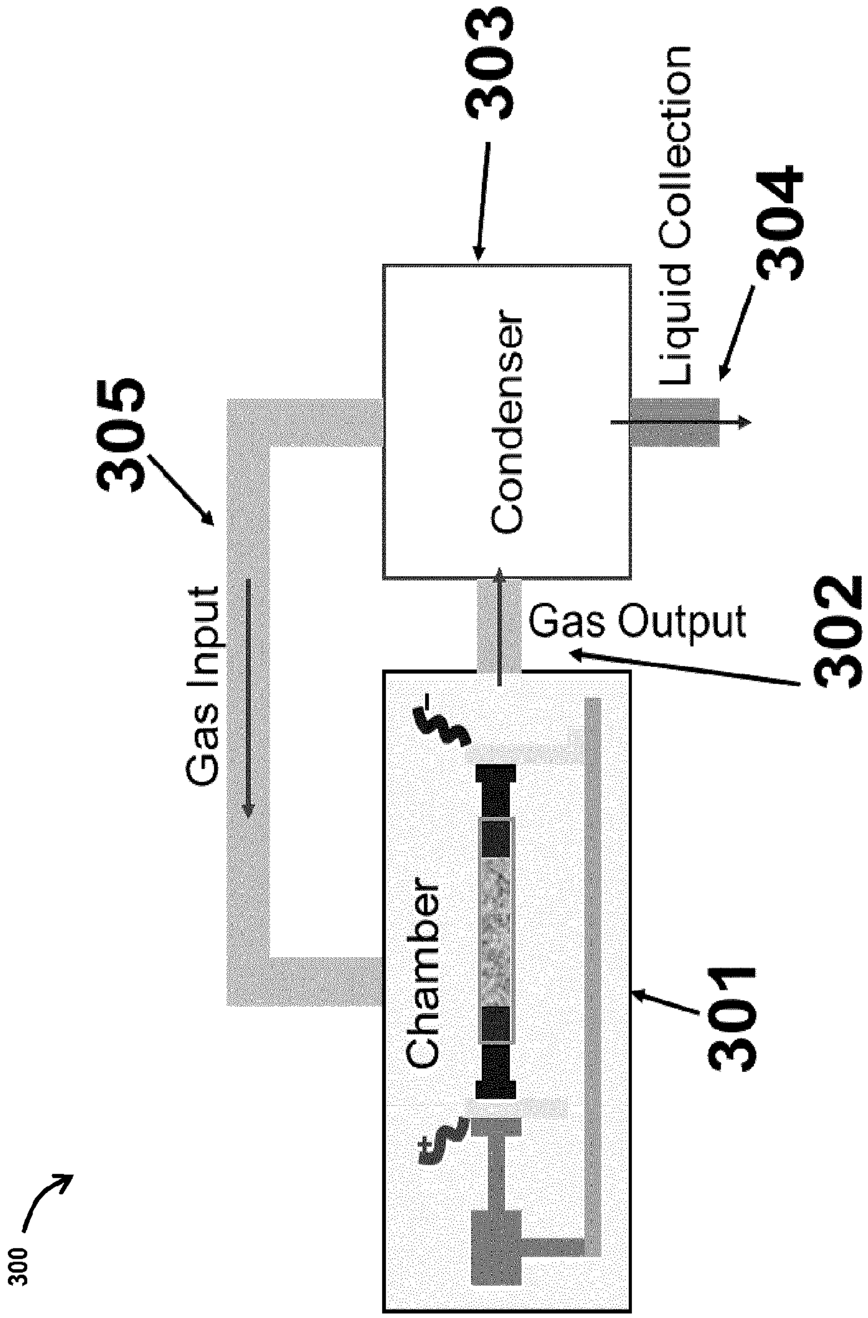

303
Liquid Collection
304
305
Condenser
Gas Input
Gas Output
302
Chamber
301
300

FIG. 3

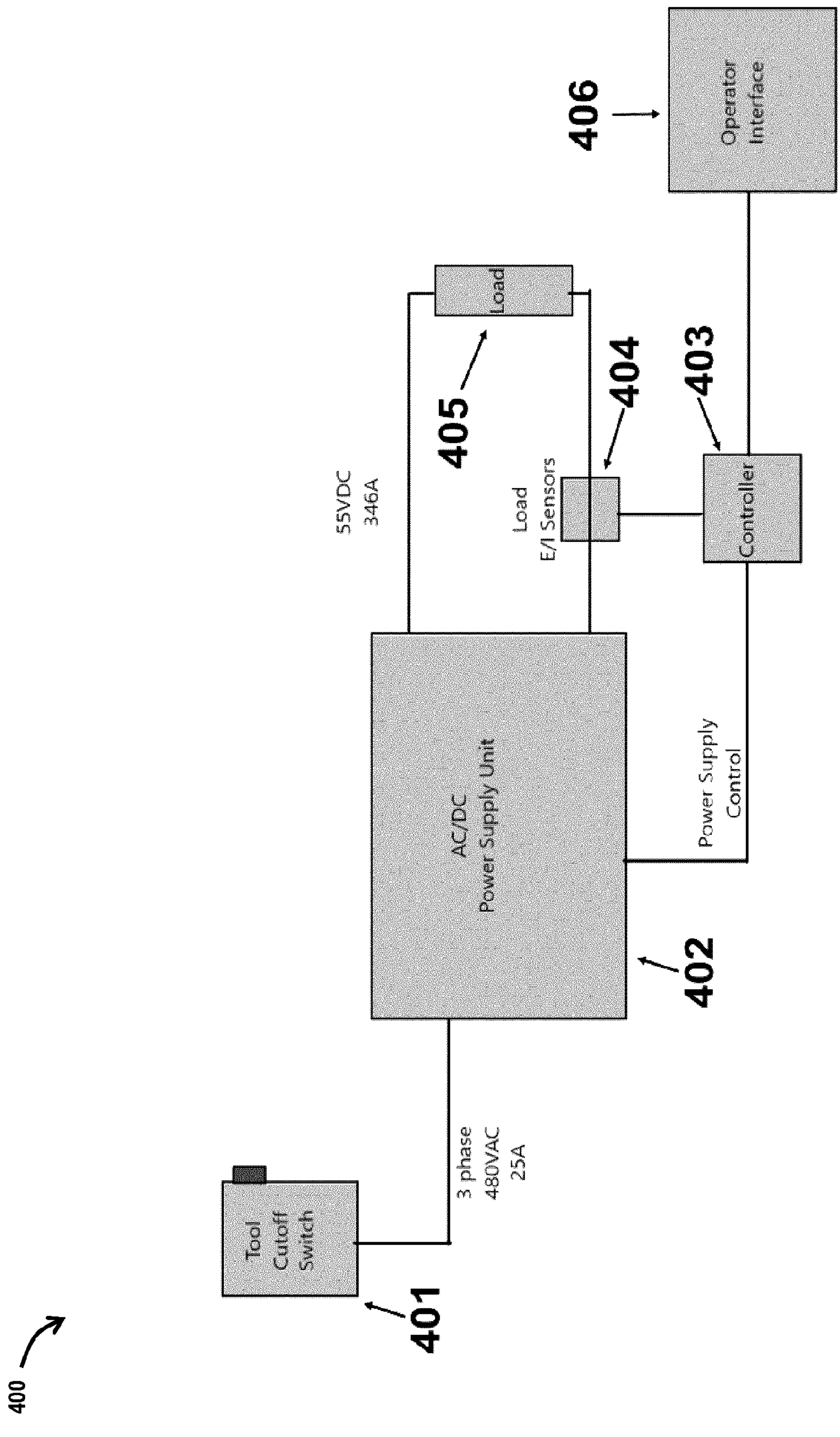

400
Tool
Cutoff
Switch
401
3 phase
480VAC
25A
AC/DC
Power Supply Unit
402
Power Supply
Control
55VDC
346A
Load
405
Load
E/I Sensors
404
Controller
403
Operator
Interface
406

FIG. 4

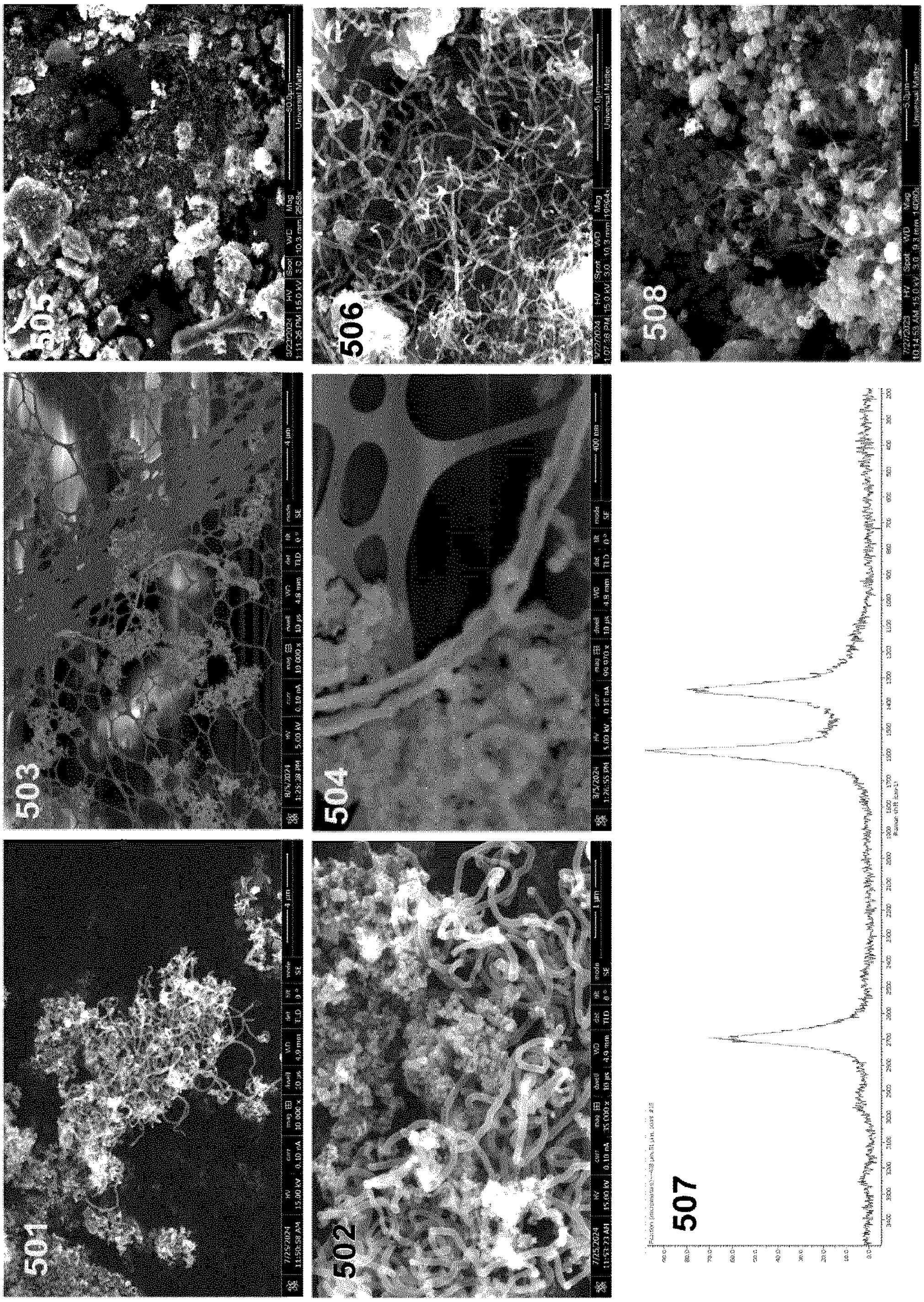


FIG. 5

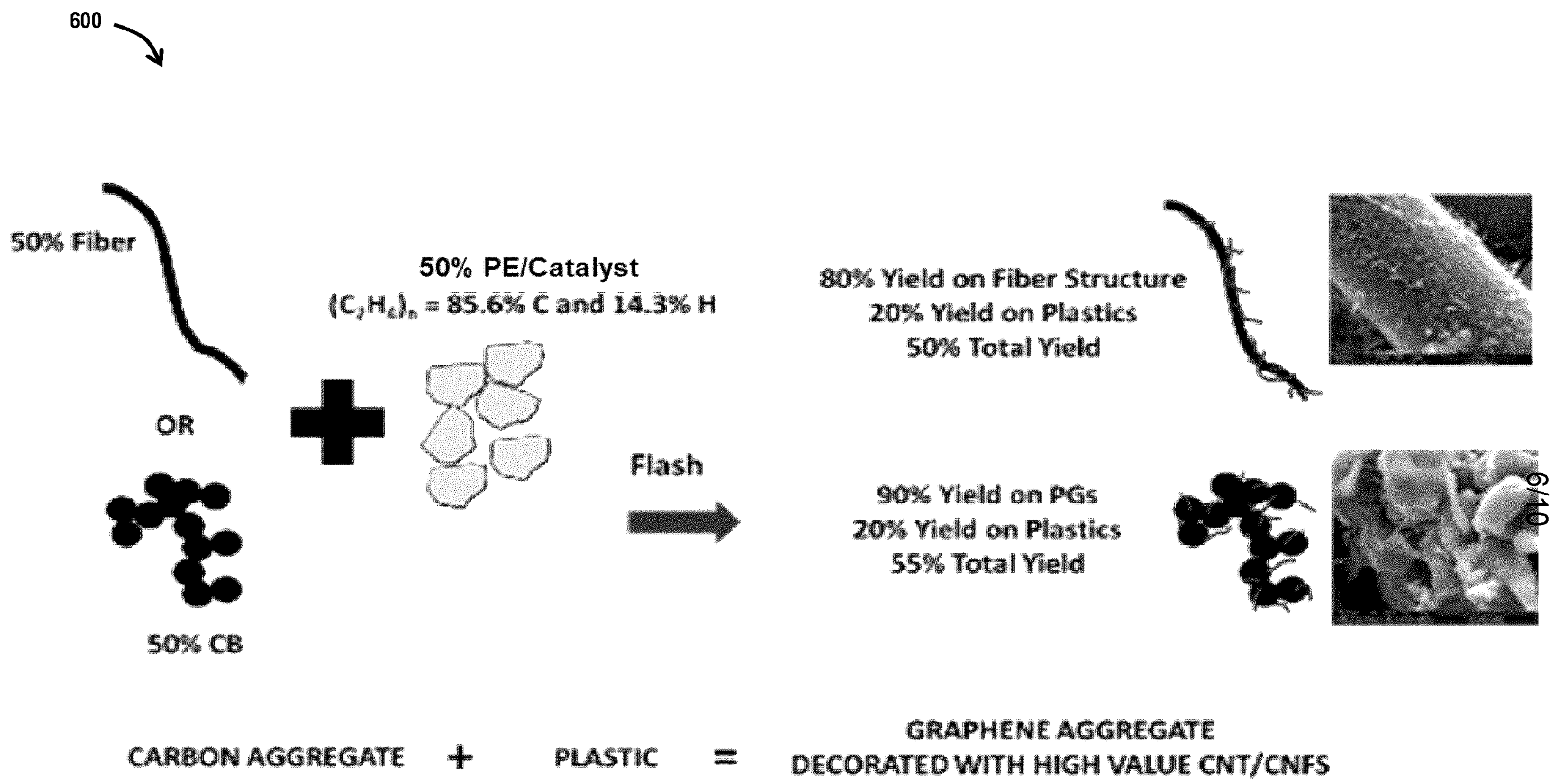

600
50% Fiber
OR
50% CB
50% PE/Catalyst
(C2H4)n = 85.6% C and 14.3% H
Flash
80% Yield on Fiber Structure
20% Yield on Plastics
50% Total Yield
90% Yield on PGs
20% Yield on Plastics
55% Total Yield
CARBON AGGREGATE + PLASTIC = GRAPHENE AGGREGATE DECORATED WITH HIGH VALUE CNT/CNFS

FIG. 6

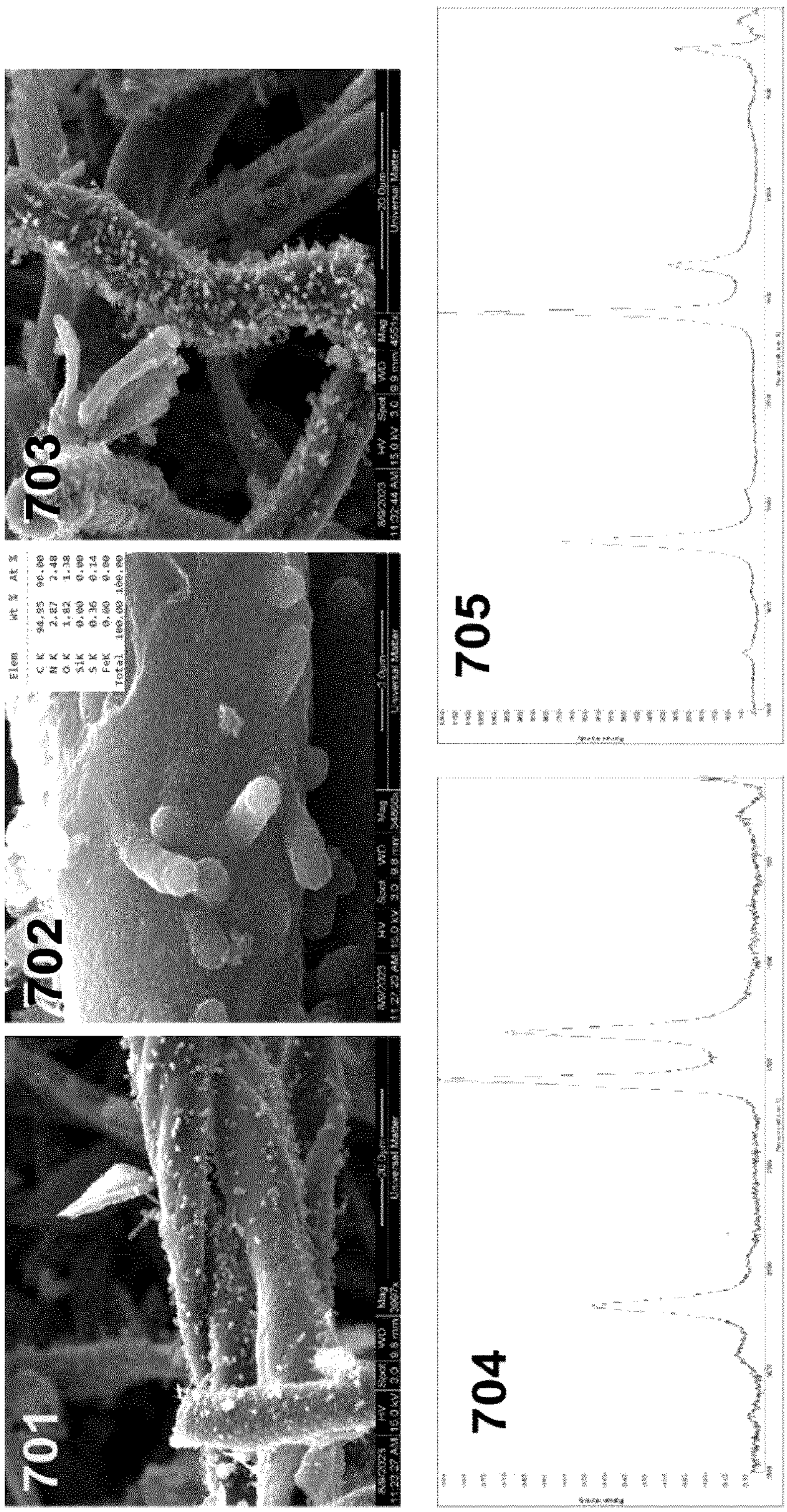

701
702
703
704
705
Elem Wt % At %
C K 94.95 96.00
N K 2.87 2.48
O K 1.82 1.38
SiK 0.00 0.00
S K 0.36 0.14
FeK 0.00 0.00
Total 100.00 100.00

FIG. 7

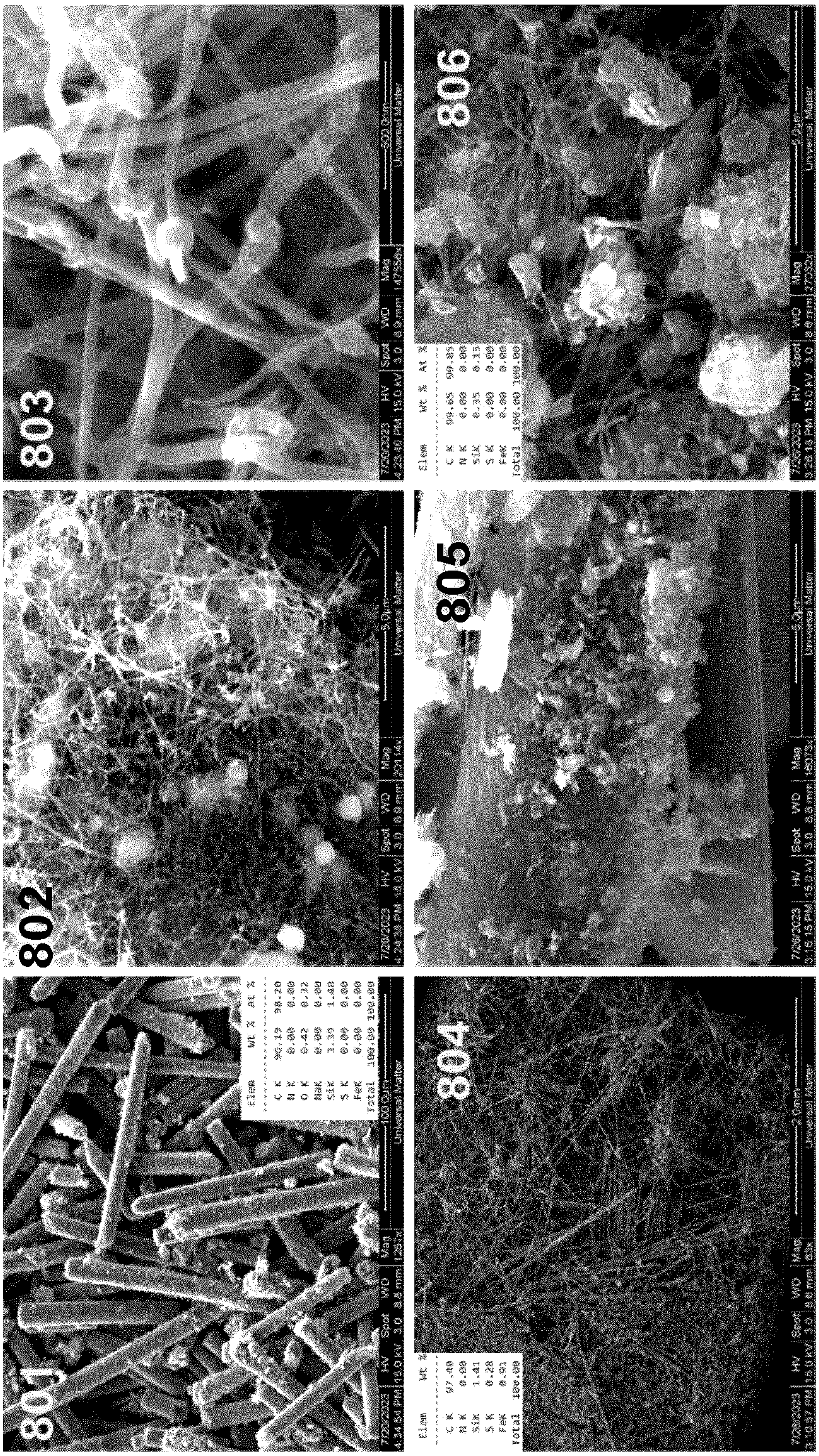
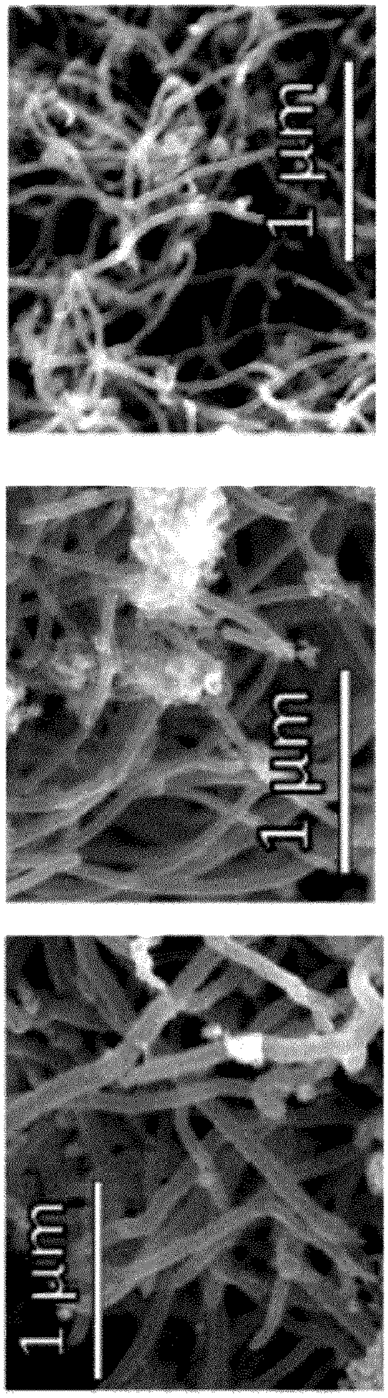


FIG. 8



0.1 g mL^{-1} loading

0.01 g mL^{-1}

0.001 g mL^{-1}

FIG. 9

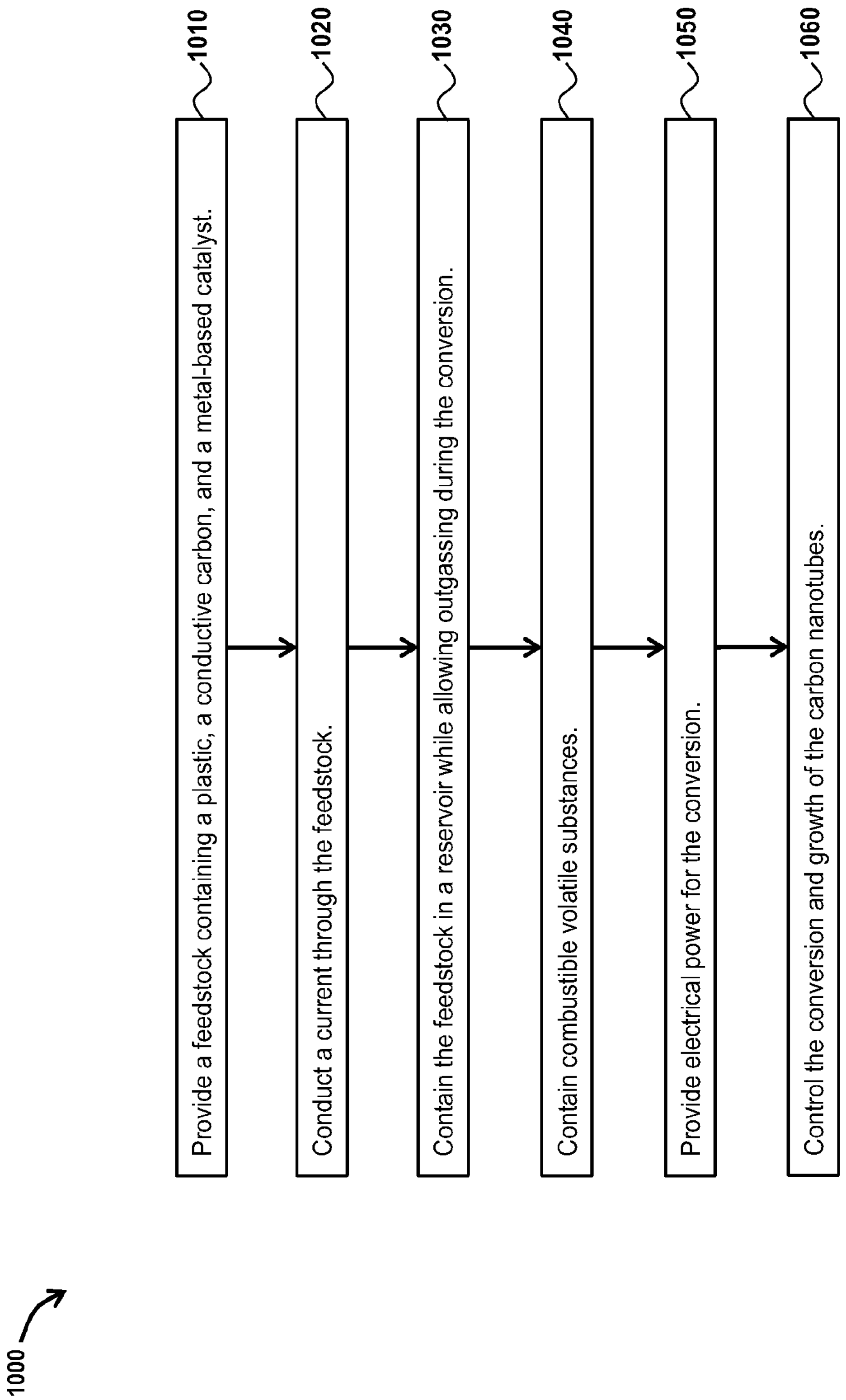

1000
1010
Provide a feedstock containing a plastic, a conductive carbon, and a metal-based catalyst.
1020
Conduct a current through the feedstock.
1030
Contain the feedstock in a reservoir while allowing outgassing during the conversion.
1040
Contain combustible volatile substances.
1050
Provide electrical power for the conversion.
1060
Control the conversion and growth of the carbon nanotubes.

FIG. 10

A. CLASSIFICATION OF SUBJECT MATTER

IPC: ***C01B 32/16*** (2017.01), ***B01J 23/70*** (2006.01), ***C01B 32/05*** (2017.01), ***C01B 32/158*** (2017.01), ***C01B 32/184*** (2017.01)

CPC: B01J 23/70 (2013.01), C01B 32/05 (2017.08), C01B 32/16 (2017.08), C01B 32/184 (2017.08)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC (2017.01): C01B 32/16, C01B 32/05, C01B 32/158, C01B 32/184
IPC (2006.01): B01J 23/70

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Keywords used across the whole IPC

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Databases: Questel Orbit, Google Scholar
Keywords: morphology, plastic, nanotubes, feedback, compression, "polyvinyl chloride", feedstock, electrodes, terephthalate, polystyrene, polyethylene, polyimide, polyvinyl, polycarbonate, acrylic, epoxy, polyurethane, resins, bioplastics, elastomers

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,Y	WYSS, K.M. et al., "Upcycling of Waste Plastic into Hybrid Carbon Nanomaterials", *Advanced Materials*, 24 January 2023 (24-01-2023), Vol. 35 (16), pp. 2209621. * Introduction; section 2.1; section 2.3; section 5.1 *	1-36
Y	WO2021/068087 A1 (MANCEVSKI) 15 April 2021 (15-04-2021) * The same applicant * * Claims; paragraph 0138; paragraph 0149 *	1-36
X,Y	WO2023/045569 A1 (MANCEVSKI et al.) 30 March 2023 (30-03-2023) * The same applicant * * Claims; paragraph 0169 *	1-36

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

*	Special categories of cited documents:
"A"	document defining the general state of the art which is not considered to be of particular relevance
"D"	document cited by the applicant in the international application
"E"	earlier application or patent but published on or after the international filing date
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O"	document referring to an oral disclosure, use, exhibition or other means
"P"	document published prior to the international filing date but later than the priority date claimed
"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&"	document member of the same patent family

Date of the actual completion of the international search
06 December 2024 (06-12-2024)

Date of mailing of the international search report
16 January 2025 (16-01-2025)

Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 819-953-2476

Authorized officer
Kevin Anderson (819) 639-8409

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JIANG, M. et al., "Upcycling Plastic Waste to Carbon Materials for Electrochemical Energy Storage and Conversion", *Chemical Engineering Journal*, 18 February 2023 (18-02-2023), Vol. 461, pp. 141962. * The whole document *	1-36
A,P	CHI, L. et al., "Upcycling Plastic Waste into Valuable Carbon Nanomaterials", *ChemNanoMat*, 16 August 2024 (16-08-2024), Vol. 10, pp. e202400409. * The whole document *	1-36

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
WO2021068087A1	15 April 2021 (15-04-2021)	CA3154453A1	15 April 2021 (15-04-2021)
		CN114787081A	22 July 2022 (22-07-2022)
		EP4041678A1	17 August 2022 (17-08-2022)
		EP4041678A4	03 January 2024 (03-01-2024)
		JP2022553921A	27 December 2022 (27-12-2022)
		KR20220088716A	28 June 2022 (28-06-2022)
		US2024092643A1	21 March 2024 (21-03-2024)
WO2023045569A1	30 March 2023 (30-03-2023)	US2023102261A1	30 March 2023 (30-03-2023)
		US11908743B2	20 February 2024 (20-02-2024)