Title: NANOSTRUCTURES AND METHOD FOR MAKING THEM

Abstract: The present invention relates to nanostructures comprising nanosized filamentary material based on carbon and to a method of fabricating it. The inventive method improves the adhesion of nanosized filamentary carbon-based materials, like carbon nanotubes, to substrates. It was found that the presence of at least one carbide-forming material can improve the adhesion of a nanosized filamentary carbon-based material to a substrate. Therefore, in another aspect, a method for firmly attaching a nanosized filamentary carbon-based material to a substrate is provided, wherein a layer is formed over the substrate, the layer comprising at least one carbide-forming material and at least one catalytically active material, and the nanosized filamentary carbon-based material is grown on the catalytically active material.
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The present invention relates to nanostructures comprising nanosized filamentary material based on carbon and to a method of fabricating same. The inventive method improves the adhesion of nanosized filamentary carbon-based materials, like carbon nanotubes, to substrates.

BACKGROUND OF THE INVENTION

Nanomaterials or nanosized filamentary materials such as nanowires and nanotubes have drawn considerable attention in numerous fields of application. Nanowires and nanotubes efficiently carry charge and excitons, and therefore are interesting building blocks for nanoscale electronics or optoelectronics. Carbon nanotubes, for example, have already been exploited for energy storage, sensor elements, nanoelectronic components such as diodes, transistors or capacitors, or field-emission devices such as electron source for use in x-ray tubes or cold electron sources for electron microscopy. Furthermore, carbon nanotubes can be used, e.g., as substrates or matrix materials in desorption-ionization analytics or in biomedical applications.

In many of the above-mentioned applications it is a prerequisite that the nanosized filamentary material, like carbon nanotubes, is firmly attached to a substrate. Only firm attachment allows, e.g., to process the samples for functionalization, to load the sample with a variety of liquids for biochemical analysis or to transport high current across the interface between a substrate and nanosized filamentary material attached thereto.

Currently, carbon nanotubes and other nanomaterials are produced by a variety of different techniques such as arc-discharge, laser ablation or by catalyst-supported chemical vapor deposition (CVD) processes, e.g. thermal CVD or plasma CVD processes. In particular, microwave plasma CVD provides an efficient technique
for preparing carbon nanotubes. Plasma-grown carbon nanotubes can be grown vertically aligned from gas mixtures that contain a carbon carrier (methane, acetylene or other carbon sources), hydrogen, and other gases (ammonia, nitrogen). Usually, the catalyst is provided as a continuous metal layer deposited on a substrate. In the course of grow the catalyst layer is heated and breaks up into catalyst particles which define the carbon nanotube characteristics such as diameter, number of walls, etc.

A method for the manufacture of nanosized filamentary materials being connected to two solid substrates is described in EP 1 751 055. According to EP 1 751 055, the catalytic layer is sandwiched between a first and a second layer and the nanosized material is grown in between the first and the second layer.

OBJECTS AND SUMMARY OF THE INVENTION

Nanosized filamentary materials based on carbon, which are directly deposited onto a substrate by means of e.g. a chemical vapour deposition (CVD) method tend to adhere rather poorly to the substrate. However, for use of such materials as substrates or matrix materials in methods for detection of analytes on a sample, e.g. in desorption-ionization analytics such as mass spectrometry analyses, it is of utmost importance to attach the nanosized filamentary material to a substrate surface such that delamination of the nanosized filamentary material is prevented, e.g., during functionalization of said material, application of biological samples onto the nanosized filamentary material attached to the substrate, or subsequent measurement procedures. The same is true for the use of nanosized filamentary materials attached to a substrate in biomedical applications that require array formats. Good adhesion of the nanosized filamentary material to a substrate is also required to transport high currents across the interface between a substrate and a nanosized filamentary material, like carbon nanotubes, attached thereto. Firm conductive attachment of the nanosized filamentary material to a substrate is also needed for the use of said materials as, e.g., building blocks on electronic devices or as a field emission source for use in x-ray tubes.

Therefore, it would be advantageous to provide a nanosized filamentary carbon-based material being firmly attached to a substrate. Furthermore, it would be advantageous if the material is attached a way that allows to transport high electric currents across the interface between a substrate and said filamentary material.
The techniques and materials currently used for growing surface-attached nanosized filamentary material on a substrate create layers of nanosized filamentary material with poor or limited adhesion to the substrate, which can lead to delamination of the nanosized filamentary material. For example, the nanosized filamentary material attached to a substrate may easily be removed from the substrate by simply blowing across the sample surface with a stream of air, by wiping across the surface with a paper towel or by pipetting a liquid onto the layer of said material.

To better address these disadvantages, according to the present invention a fabrication method for attaching nanosized filamentary carbon-based materials to a substrate is provided that improves the adhesion of the nanosized filamentary material to the substrate. It was found that the presence of at least one carbide-forming material can significantly improve the adhesion of a nanosized filamentary carbon-based material to a substrate.

According to one aspect of the present invention, a method for firmly attaching a nanosized filamentary carbon-based material to a substrate is provided, wherein a layer is formed over the substrate, the layer comprising at least one carbide-forming material and at least one catalytically active material, and wherein the nanosized filamentary carbon-based material is grown on the catalytically active material. For growing the nanosized filamentary carbon-based material on a substrate, according to the present invention, it is preferred to use a catalyst-supported CVD process.

The term "nanosized filamentary carbon-based material" as used herein encompasses carbon nanotubes, carbon nanowires as well as nanotubes or nanowires formed out of other compounds of carbon such as silicon carbide, boron carbide, or CVD diamond.

The term "layer" is defined for the purposes of the invention as the collectivity of all materials formed over the substrate prior to the growing of the nanosized filamentary carbon-based material. The layer comprises at least one carbide-forming material and at least one catalytically active material. Optionally, the layer may comprise further materials such as conductive materials and barrier materials. The layer can have a "stack structure", wherein the respective materials form individual "sub-layers". Accordingly, the inventive layer situated on the substrate may be composed of several, essentially continuous sub-layers of the materials contemplated according to the
The present invention. Alternatively, the layer can have a "island-like structure", wherein the respective materials form a randomly distributed or ordered island-like structure, wherein the individual materials do not form continuous sub-layers, but "islands", i.e. localized areas within the inventive layer or the one or more sub-layers. The layer according to the present invention may have partly a continuous structure and partly an island-like structure.

The term "conductive material" as used herein refers to materials that readily conduct electric current. This includes but is not limited to inert as well as other metals.

The term "barrier material" as used herein refers to a material that prevents or reduces diffusion or migration of the catalytically active material in horizontal and/or vertical direction. Preferably, horizontal diffusion i.e. diffusion parallel to the substrate surface is reduced or prevented.

According to further advantageous aspects of the present invention, the layer formed over the substrate comprises further materials such as conductive materials and/or barrier materials.

In a further aspect of the invention a nanosized filamentary carbon-based material attached to a substrate is provided that can be used in desorption-ionization analytics, e.g. as substrate or matrix material.

In another aspect of the invention a nanosized filamentary carbon-based material attached to a substrate is provided that can be used in biomedical applications, especially biomedical applications that require an array format.

In still another aspect of the invention a nanosized filamentary carbon-based material attached to a substrate is provided that enables the transport of high currents across the substrate nanosized filamentary material interface.

These and other aspects of the present invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a cross sectional view of a microwave plasma CVD set up used for growing nanosized filamentary carbon-based material which may be useful according to the present invention.
Fig. 2a shows SEM micrographs of delamination of carbon nanotubes from a substrate induced by mechanical impact such as wiping with a paper towel or forced air flow.

Fig. 2b shows SEM micrographs of delamination induced by pipetting aqueous solutions onto carbon nanotubes that are not grown according to the present invention.

Fig. 3 illustrates that carbon nanotubes grown on silicon substrates can be rinsed with water and thus possess improved adhesion if the manufacturing method according to the invention is used.

Fig. 4 illustrates that carbon nanotubes grown on silicon dioxide substrates can be rinsed with water and thus possess improved adhesion if the manufacturing method according to the invention is used.

Fig. 5 shows SEM micrographs of possible carbon nanotube array formats with different sizes and pitches which will be useful according to the present invention.

Fig. 6 visualizes the processing steps required for the fabrication of carbon nanotube array structures.

Fig. 7 shows SEM micrographs of 3 μm x 3 μm carbon nanotube array structures on silicon substrates manufactured using the process described in Fig. 6.

DETAILED DESCRIPTION OF EMBODIMENTS

According to one embodiment of the present invention a method for attaching a nanosized filamentary carbon-based material to a substrate is provided, the method comprising the steps of providing a substrate, forming a layer over the substrate, the layer comprising at least one carbide-forming material and at least one catalytically active material, and growing nanosized filamentary carbon-based material on the catalytically active material. The inventive method allows for firmly attaching a nanosized filamentary carbon-based material, like carbon nanotubes, to a substrate.

According to another embodiment of the present invention, the layer formed over the substrate further comprises at least one conductive material.
In another embodiment of the present invention, the layer formed over the substrate further comprises at least one barrier material to prevent diffusion of material, especially to prevent diffusion of the catalyst material. The barrier material especially prevents the diffusion in the horizontal direction, i.e. in parallel to the surface of the substrate.

The provided substrate may be any material that is able to resist the temperatures employed in the technique used for growing the nanosized filamentary carbon-based material. Furthermore, the substrate material should be non-catalytic with respect to the growth of the nanosized filamentary carbon-based material. Suitable substrates, for example, can be made from silicon dioxide such as, e.g. glass or quartz, or ceramics. The substrates can also be made from silicon, such as amorphous silicon, polycrystalline silicon, single crystal silicon and the like. Other suitable materials are, for example, metals such as, e.g. copper, silver or gold. Another class of materials that, for example, can be used as a substrate includes flexible metal foils or polymers. The substrate may have thickness of between 1 μm and several millimeters.

The layer over the substrate may be formed by any conventional deposition technique, such as e.g. evaporation, sputtering, CVD, wet chemical methods, etc. According to the present invention, the same or different deposition techniques may be used for applying the respective materials contemplated according to the present invention. Preferably, the individual materials are deposited separately and subsequently. However, according to another embodiment two or more materials may be deposited at the same time. The individual materials of the layer formed over the substrate may be deposited in any order. Preferably, the at least one carbide-forming material is deposited primarily and the at least one catalytically active material finally. If the layer formed over the substrate further comprises at least one conductive material and at least one barrier material, it may be preferred that the at least one conductive material is deposited or applied previous to the at least one barrier material. According to one preferred aspect of the invention, the materials are deposited on the substrate in the following order: carbide-forming material, barrier material, catalytically active material. Another preferred order is: carbide-forming material, conductive material, barrier material, catalytically active material.

The at least one carbide-forming material may comprise any element that
is capable of forming carbides in the presence of carbon-based materials to be used for manufacturing nanosized filamentary materials based on carbon. For example, the carbide-forming material may comprise metals or semimetals, e.g., Si, Ti, V, Cr, Zr, Nb, Mo, Hf, Ta, W or mixtures and compounds thereof. Alternatively or additionally the carbide-forming material may comprise nitrides, e.g. nitrides of Si, Ti, V, Cr, Zr, Nb, Mo, Hf, Ta, or W. According to one embodiment of the present invention, the at least one carbide-forming material comprises Ti. According to another embodiment, the at least one carbide-forming material is simultaneously deposited with nitrogen, partially forming nitrides of the carbide-forming material. This procedure preferably is performed in absence of oxygen, since in the presence of oxygen unwanted oxides of the carbide-forming material will be generated. This is especially true if Ti is used.

Furthermore, it should be noted that the simultaneous deposition of a carbide-forming material and nitrogen in many cases will not lead to a stoichiometric nitride compound, but rather to a mixture of the nitride-forming metal or semimetal, crystalline nitride structures and amorphous structures of the formed nitride compound, like e.g. TiN. In an exemplary embodiment the carbide-forming material comprises titanium nitride. In another exemplary embodiment titanium nitride acts additionally as effective diffusion barrier between the at least one catalytically active material and the substrate (i.e. in the vertical direction).

The at least one catalytically active material may comprise any suitable material with appropriate catalytic properties such as transition metals, e.g. Fe, Ni, Co or alloys and compounds thereof. This includes but is not limited to oxides of said materials. This also includes composite materials of several catalytically active materials as well as composites of catalytically active and catalytically inert materials. In one exemplary embodiment the at least one catalytically active material comprises Fe or iron oxide. In another embodiment the at least one catalytically active material comprises Ni.

The at least one conductive material may comprise any material that readily conducts electric current such as, e.g., Cu, Ag or Au or mixtures thereof. In one exemplary embodiment the at least one conductive material comprises Cu.

The at least one barrier material may comprise any material that can prevent or reduce the diffusion and/or clustering of the nanoparticles of the catalytic active material at the temperature employed in the technique used for growing the
nanosized filamentary carbon-based material. Suitable barrier materials may include, e.g., oxidized aluminum or titanium nitride. In one exemplary embodiment the at least one barrier material comprises Al or Al-oxide.

In one exemplary embodiment the layer formed over the substrate comprises TiN, Al/Al-oxide and Fe/Fe-oxide. In another exemplary embodiment of the present invention, the layer formed over the substrate comprises Ti, Cu, fully or partially oxidized aluminum and fully or partially oxidized Fe.

The individual materials of the layer may be deposited, e.g. as sub-layers or areas in a thickness of a few nanometers to a few hundred nanometers. For example, the carbide-forming material may be deposited in a thickness between 1 nm and 100 nm, or in a thickness between 5 nm and 50 nm, or in a thickness of about 20 nm. The conductive material may be deposited, e.g., in a thickness between 1 nm and 1000 nm, or in a thickness between 50 nm and 200 nm, or in a thickness of about 150 nm. For example, the barrier material is deposited in a thickness between 1 nm and 50 nm, or in a thickness of between 3 nm and 20 nm or in a thickness of about 5 nm.

The thickness of the catalytic active material will later determine the size of the nanosized filamentary carbon-based material as the catalytic material will, during the catalyst preparation step described below, convert into nanoparticles whose size will determine the size of the nanosized filamentary carbon-based material, like carbon nanotubes. Conversion in this context includes chemical modification, e.g. reduction of oxidic layers. For example, the catalytic material is deposited in a thickness between 1 and 20 nm, or in a thickness of about 5 nm.

According to one embodiment of the present invention, the layer formed over the substrate has a stack structure, the stack structure comprising sub-layers of at least one carbide-forming material, at least one catalytically active material and, optionally further materials.

According to another embodiment of the present invention, the layer formed over the substrate has an island-like structure, comprising islands or areas of at least one carbide-forming material, at least one catalytically active material and, optionally further materials.

Growing of the nanosized filamentary carbon-based material may comprise two steps: a catalytic nanoparticle forming step, and a nanomaterial growing step.
During the catalytic nanoparticle forming step, the substrate and the layer formed over the substrate are heated. The heating may be performed, for example, by a plasma, e.g. a carbon containing plasma which may be also used for growth of carbon nanotubes. Alternatively, heating may also be performed by any other suitable heat source, e.g. a resistance heater or a radio-frequency heater provided underneath the substrate. Temperatures may be elevated to higher than 100°C, preferably higher than 300°C. During this step the deposited catalytic active material is converted into catalyst nanoparticles.

In the nanomaterial growing step the nanosized filamentary carbon-based material is grown by catalyst-supported chemical vapor deposition (CVD) processes, e.g. thermal CVD, plasma CVD processes such as microwave plasma enhanced CVD, or any other suitable technique. In one embodiment, microwave plasma enhanced CVD is used for growing the nanosized filamentary carbon-based material according to the invention. A cross sectional view of a microwave plasma CVD set up suitable for growing nanosized filamentary carbon-based material is shown in Fig. 1.

In one exemplary embodiment of the present invention, the "sandwich growth" technology is used, wherein the layer formed over the substrate is covered by a second layer comprising a material which is non-catalytic with respect to the growing of the nanosized filamentary carbon-based material and the nanosized material is grown in between the substrate and the second layer. For example, the second layer may comprise a material which would also be suitable as substrate material.

In an exemplary embodiment of the present invention, the nanosized filamentary carbon-based material is a carbon nanotube material.

According to another embodiment of the present invention, a microwave plasma CVD process is performed to attach carbon nanotubes to a substrate. The substrate to be used for this process already comprises a layer formed over the substrate, the layer comprising at least one carbide-forming material and at least one catalytically active material. Preferably, the process is carried out at a reactor pressure between 1 and 500 mbar, more preferably between 5 and 50 mbar or even more preferably between 25 and 30 mbar. Suitable processing or substrate temperatures are in the range between 400 and 900°C, preferably between 550 and 750°C and even more preferably between 620 and 680°C. The substrate may be mounted on a substrate heating stage inside a
microwave cavity of a reactor. Hydrogen is preferably introduced into the reactor at a flow rate of between 150 seem and 250 seem, more preferably at 180 seem. The atomic ratio of carbon to hydrogen (C/H) in the gas phase is between 0.5% C/H and 40% C/H, preferably between 15%-25% C/H. The term "seem" means standard cubic centimeters per minute and refers to the gas quantity flow under standard conditions. For performing the process, a 2.54 GHz microwave plasma may be ignited. Methane or another carbons source material is then added to the gas phase inside the reactor, e.g. at a flow rate of e.g. 20 seem while the pressure is kept constant. By using this method, after 1 min. of grow time about 5 µm long carbon nanotubes may be obtained.

While carbon nanotubes grown on a substrate using conventional techniques may be detached from the substrate surface by, e.g., application of water, forced air or even using a paper towel (see Figs. 2a and 2b), Fig. 3 and 4 demonstrate that carbon nanotubes grown on silicon or quartz substrates according to the method of the present invention will possess stronger adhesion to the substrate. Neither rinsing with water nor a subsequent ultrasound treatment led to delamination of the carbon nanotubes.

According to one embodiment of the present invention, the nanosized filamentary carbon-based material covers the substrate continuously, i.e. the nanosized filamentary carbon-based material forms an essentially continuous layer.

According to another embodiment of the present invention, the nanosized filamentary carbon-based material covers the substrate in a patterned fashion. Array formats of any kind may be accessible by structuring the layer formed over the substrate by using e.g. a lithography process. Alternatively, any other suitable technique, e.g. the use of a contact mask during deposition of the layer, maybe employed to create patterned structures of the nanosized filamentary carbon-based material attached to the substrate.

In an exemplary embodiment of the present invention, array formats with carbon nanotube-covered dots possessing a certain diameter are achieved by patterning at the least the catalytically active material, wherein a mechanical mask may be used for the deposition of the catalytically active material. Fig. 5 shows SEM micrograph examples of dot structures having a diameter of 2 mm (left), 70 µm (middle) and 25 µm (right). Array formats with a 2 mm dot structure may be suitable as substrates, e.g., for desorption-ionization analytics such as surface-enhanced laser desorption ionisation-mass spectroscopy (SELDI-MS).
In another exemplary embodiment of the present invention, a lithography process is provided, to generate small-sized, high density carbon nanotube arrays, the process comprising (1) cleaning of a silicon substrate, (2) spinning-on of a UV-curing lacquer (photoresist), (3) illuminating the photoresist using a suitable designed shadow mask, e.g. on a lithography stepper, (4) removing the photoresist from areas that were not illuminated by UV-light, (5) forming a layer over the substrate comprising at least one carbide-forming material and at least one catalytic active material, (6) removing (lift-off process) the photoresist together with the layer formed over the photoresist, and (7) growing nanosized filamentary carbon-based material on the catalytic material using e.g. the "sandwich growth" technology. The described lithography processing steps are illustrated in Fig. 6. Carbon nanotube array structures having a size of 3 μm x 3μm obtained by a lithography process according to one exemplary embodiment of the invention are shown in Fig. 7.

The adhesion of the nanosized filamentary carbon-based material to the substrate can be evaluated by using the Scotch Tape test, wherein an adhesive tape is applied to an area of the nanosized filamentary carbon-based material attached to a substrate. Adhesion is considered to be adequate if the nanosized material is not pulled off by the tape when it is removed. The adhesion can also be evaluated by an ultrasound treatment in water with e.g. 1-100 W for 1-60 sec depending on the application requirements. For the applications envisioned and described here, carbon nanotubes that stay attached to the substrate after 60 W ultrasound treatment in water for more than 1 sec is considered to be adequate (cf. Figures 3 and 4).

The nanosized filamentary carbon-based material attached to a substrate according to the embodiments of the invention may be employed in any application, where firm attachment of the nanosized material to the substrate is required or advantageous. For example, said material can be used for desorption-ionization analytics, e.g., in SELDI-TOF mass spectrometry to replace laser-absorbing matrix material, especially as substrate or matrix material. The materials according to the present invention may also be used as a building block for an electronic device.

Furthermore, the material according to the embodiments of the invention may also be used as functionalized substrate for chromatographic and bioseparation purposes.

While the present invention has been described with respect to specific
embodiments thereof, it will be recognized by those of ordinary skill in the art that many modifications, enhancements, and/or changes can be achieved without departing from the spirit and scope of the invention. Therefore, it is manifestly intended that the invention be limited only by the scope of the claims and equivalents thereof. The word "comprising" does not exclude the presence of elements or steps other than those listed in a claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. In the following, the invention is illustrated in view of certain examples. These examples are however in no way meant to limit the invention as to its scope, but rather serve to illustrate the invention by way of some of its exemplary embodiments.

EXAMPLES

Four different examples of carbon nanotubes attached to a substrate using four different layer compositions were prepared:

Examples 1, 2 and 4 are comparative examples, while examples 3 and 5 represent examples according to the invention.

In all examples a silicon substrate was used. The layer comprising at least one carbide-forming material and at least one catalytically active material was formed over the substrate by depositing every material separately and subsequently using thermal evaporation of the corresponding metals in a vacuum system at approx. 10⁻⁶ mbar. In all examples Fe was initially evaporated onto the sample for use as catalytically active material. In the course of the experiments this catalytically active material might convert into its oxide. The "sandwich growth" technology was employed for growing carbon nanotubes on the catalytically active material. The conditions used during the growing step were a H₂ flow rate of 180 seem, a CH₄ flow rate of 20 seem, a reactor pressure of 28-30 mbar, a substrate temperature of 630-650°C (heating provided by an radio frequency heater), and a 2.54 GHz microwave plasma power of 1000 W.

Furthermore, the substrate was pre-heated for about 15 min prior to the carbon carrier injection into the plasma.

The adhesion of the carbon nanotubes to the substrate was evaluated using the Scotch Tape test as well as by an ultrasound treatment in water with 60 W for 5 sec. Adhesion is considered to be adequate if the nanosized material is not delaminated
from the substrate. Figure 3 confirms the positive outcome of this test.

The table below summarizes the materials used to form a layer over the substrate. Layer materials are given in the order of their deposition. The thickness of every deposited material is given in brackets. Furthermore, it is indicated if the nanotubes grown on the catalytically active material of the respective layers passed the adhesion tests.

<table>
<thead>
<tr>
<th>Example</th>
<th>Layer materials in the order of their deposition. The thickness of every deposited material is given in brackets.</th>
<th>Adhesion tests passed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fe (6 nm)</td>
<td>no</td>
</tr>
<tr>
<td>2</td>
<td>Al (6 nm)/Fe (6 nm)</td>
<td>no</td>
</tr>
<tr>
<td>3</td>
<td>TiN (10 nm)/Al (6 nm)/Fe (6 nm)</td>
<td>yes</td>
</tr>
<tr>
<td>4</td>
<td>Cu (150 nm)/Al (6 nm)/Fe (6 nm)</td>
<td>no</td>
</tr>
<tr>
<td>5</td>
<td>Ti (20 nm)/Cu (150 nm)/Al (6 nm)/Fe (6 nm)</td>
<td>yes</td>
</tr>
</tbody>
</table>
5

1. A method for attaching a nanosized filamentary carbon-based material to a substrate, the method comprising the steps of:
   providing a substrate,
   forming a layer over the substrate, the layer comprising at least one carbide-forming material and at least one catalytically active material, and
   growing nanosized filamentary carbon-based material on the catalytically active material.

2. The method according to claim 1, wherein the layer formed over the substrate further comprises at least one conductive material.

3. The method according to claim 1 or 2, wherein the layer formed over the substrate further comprises at least one barrier material to prevent or reduce diffusion of the catalyst material.

4. The method according to any of the preceding claims, wherein the substrate comprises silicon or silicon dioxide or both.

5. The method according to any of the preceding claims, wherein the nanosized filamentary carbon-based material is a carbon nanotube material.

6. The method according to any of the preceding claims, wherein the carbide-forming material comprises titanium.
7. A nanosized filamentary carbon-based material attached to a substrate comprising:
   a substrate,
   a layer formed over the substrate, the layer comprising at least one carbide-forming material and at least one catalytically active material, and
   a nanosized filamentary carbon-based material grown on the catalytically active material.

8. The material according to claim 7, wherein the layer formed over the substrate further comprises at least one conductive material.

9. The material according to claim 7 or 8, wherein the layer formed over the substrate further comprises at least one barrier material to prevent or reduce diffusion of the catalytically active material.

10. The material according to any of claims 7 to 9, wherein the substrate comprises silicon or silicon dioxide or both.

11. The material according to any of claims 7 to 10, wherein the nanosized filamentary carbon-based material covers the substrate continuously.

12. The material according to any of claims 7 to 11, wherein the nanosized filamentary carbon-based material covers the substrate in a patterned fashion.

13. The material according to any of claims 7 to 12, wherein the layer formed over the substrate comprises a stack structure, comprising sub-layers of at least one carbide-forming material, at least one catalytically active material and, optionally, further materials.

14. The material according to any of claims 7 to 12, wherein the layer comprises an island-like structure, comprising areas of at least one carbide-forming material, areas of at least one catalytically active material and, optionally, areas of further materials.
15. The material according to any of claims 7 to 14, wherein the nanosized filamentary carbon-based material is a carbon nanotube material.

16. The material according to any of claims 7 to 15, wherein the carbide-forming material comprises titanium.

17. Use of the material according to any of claims 7 to 16 for desorption-ionization analytics.

18. Use of the material according to any of claims 7 to 16 as a building block for an electronic device.
FIG. 1
FIG. 3

FIG. 4

FIG. 5
FIG. 7