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(54) **APPARATUS FOR MAKING CARBON NANOTUBE STRUCTURE WITH CATALYST ISLAND**

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**Related U.S. Application Data**

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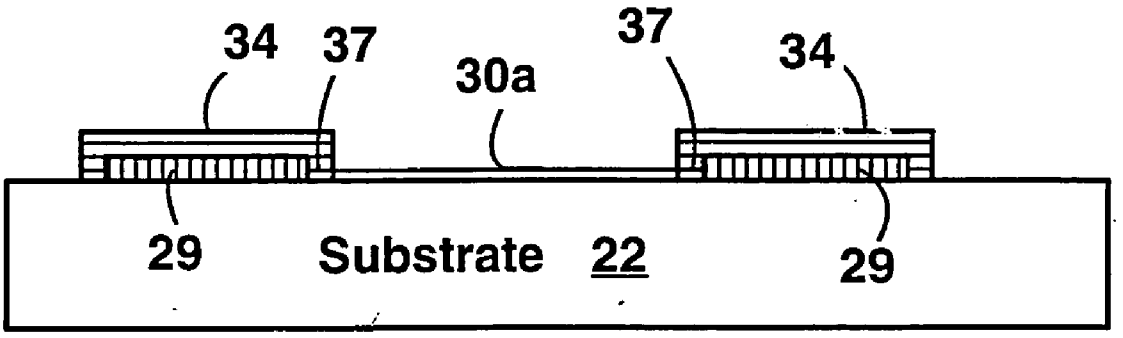
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(52) **U.S. Cl.** ..... **118/719**

(57) **ABSTRACT**

Carbon nanotube growth is achieved in a high-yield process. According to an example embodiment of the present invention, a furnace chamber is adapted to grow a carbon nanotube device via catalyst islands. The carbon nanotube device includes a catalyst island, such as $Fe_2O_3$, and a carbon nanotube extending therefrom. In one more specific implementation, the catalyst island is disposed on a top surface of a substrate. The carbon nanotube device is useful in a variety of implementations and applications, such as in an atomic force microscope (AFM), in resonators (e.g., where a free end of the carbon nanotube is adapted to vibrate) and in electronic circuits (e.g., where the carbon nanotube is electrically coupled between two nodes, such as between the catalyst island and a circuit node). In addition, growing carbon nanotubes with such a catalyst island is particularly useful in the high-yield growth of a large number of nanotubes.



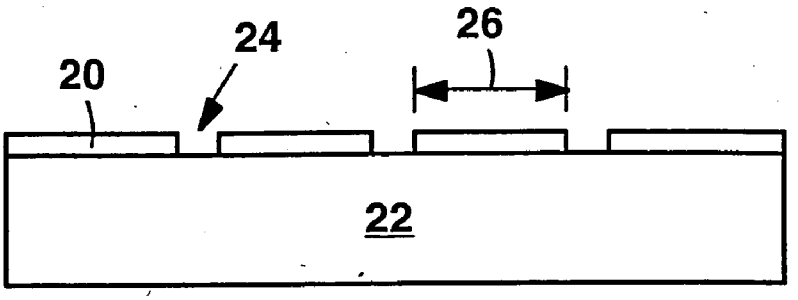



Fig. 1

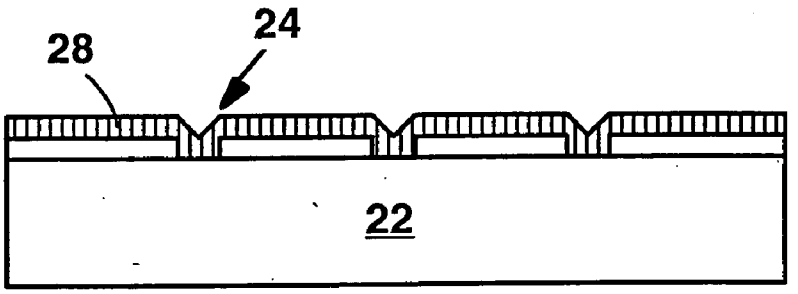



Fig. 2

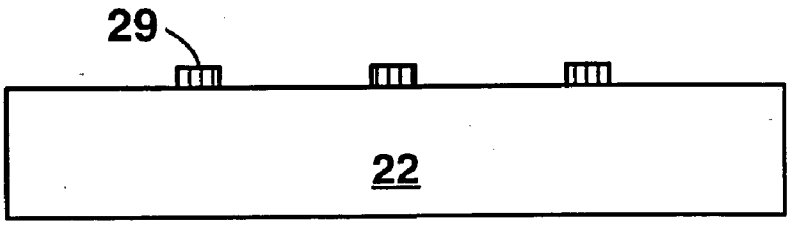



Fig. 3

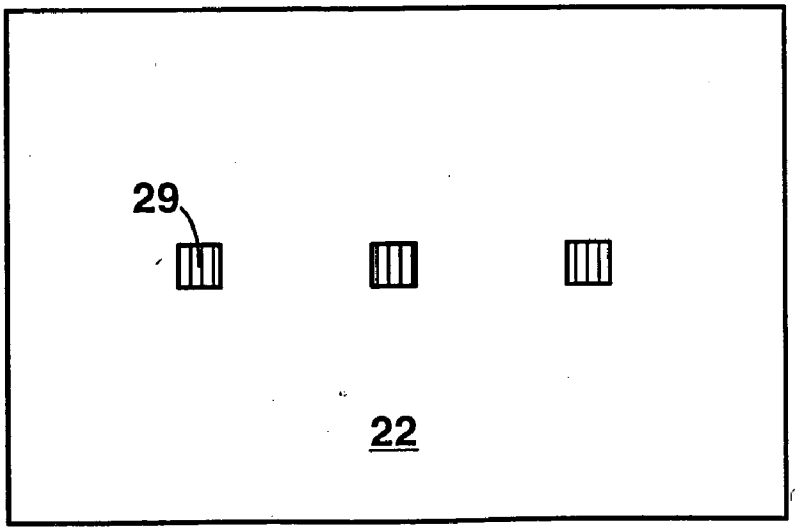



Fig. 4

Fig. 5

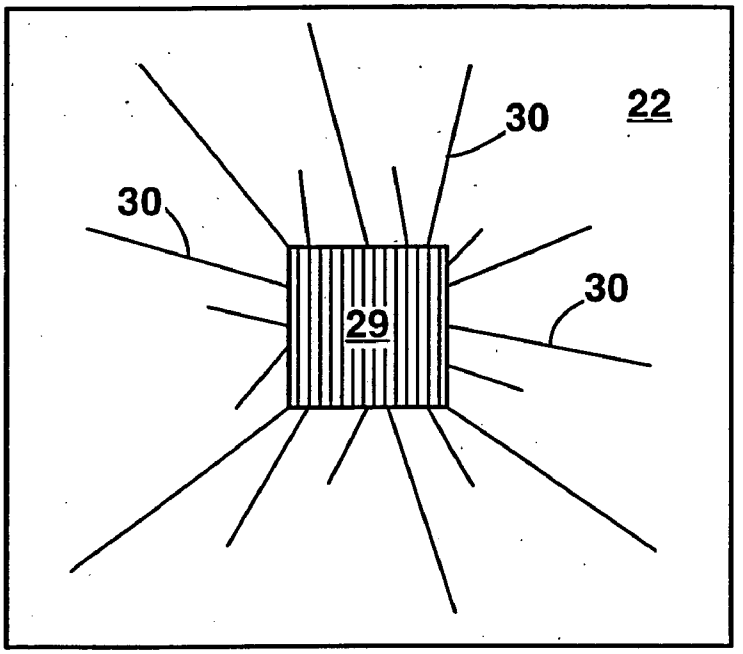
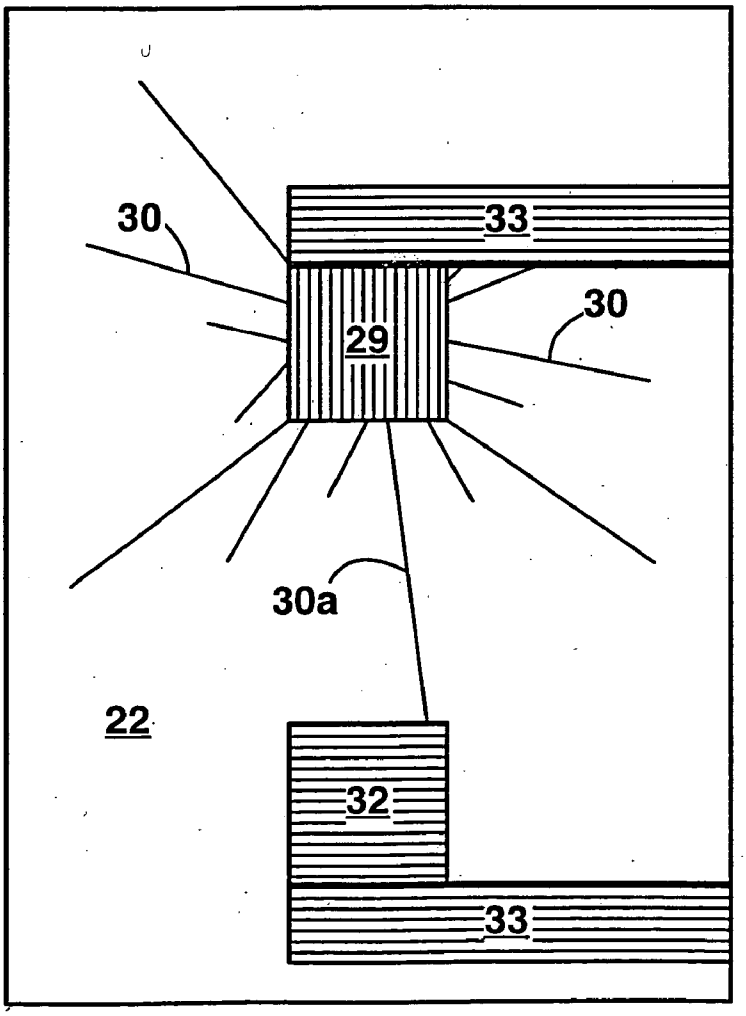



Fig. 6



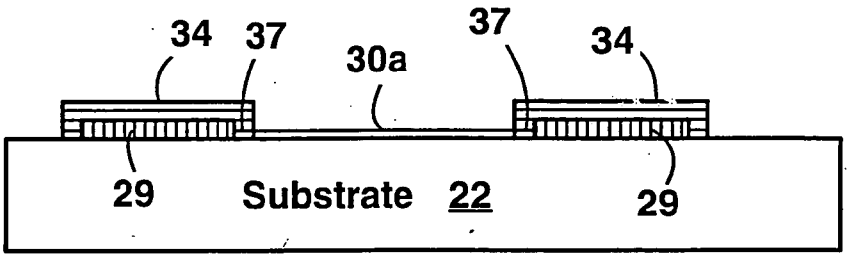



Fig. 7

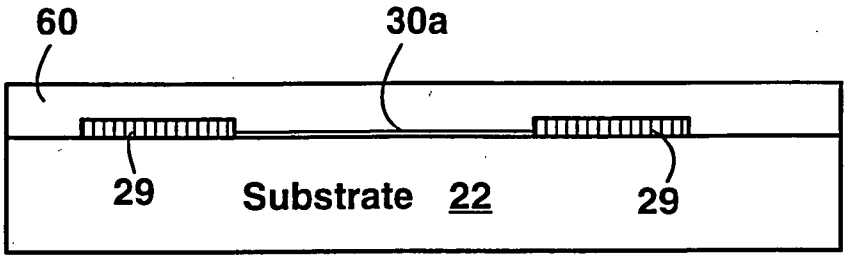



Fig. 8A

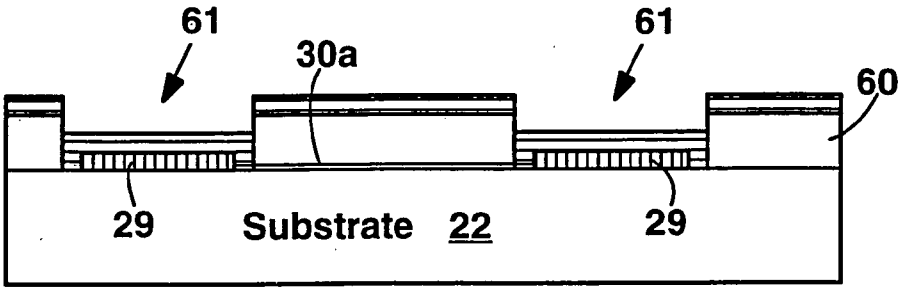



Fig. 8B

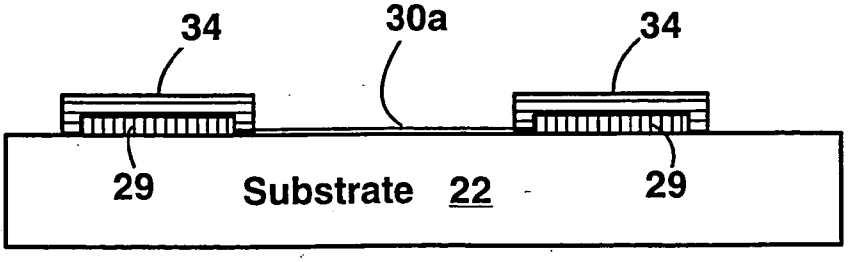



Fig. 8C

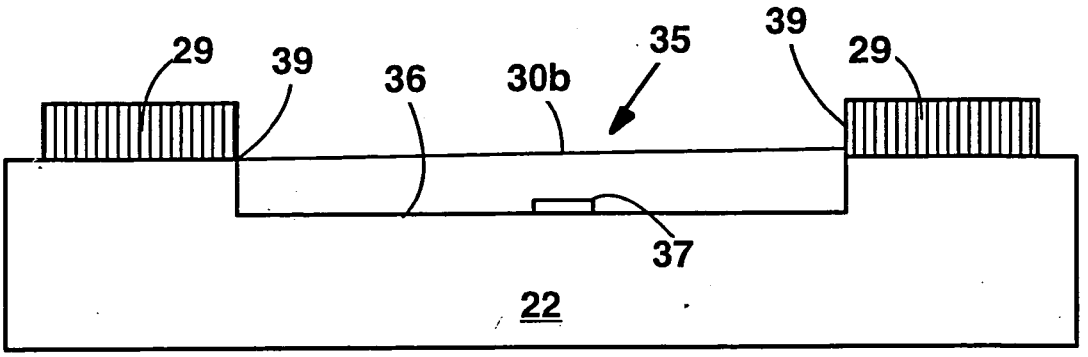
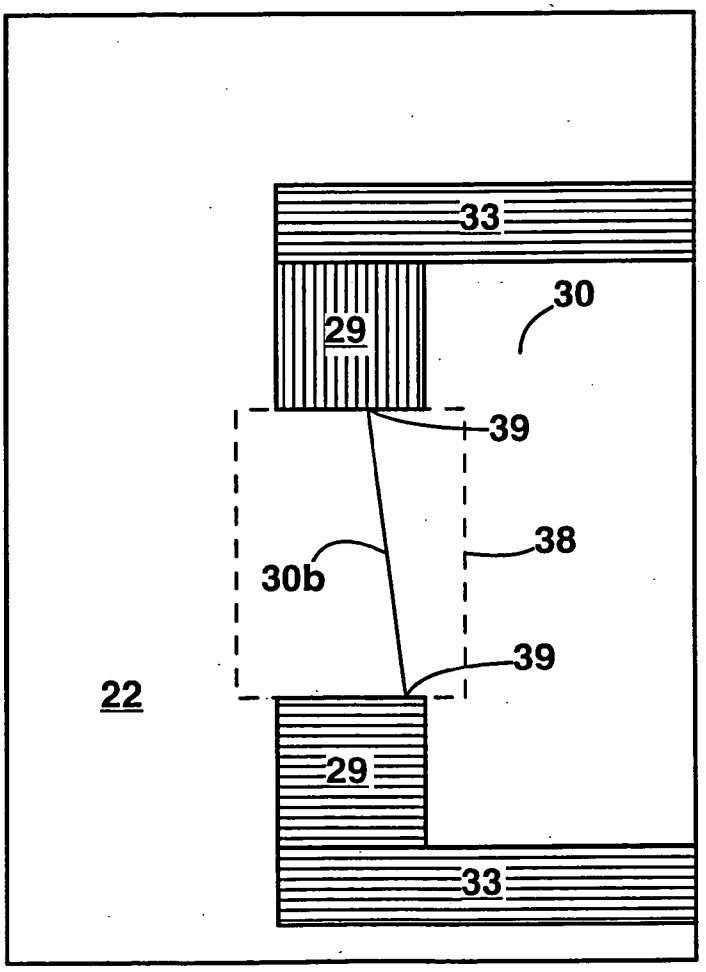



Fig. 9

Fig. 10



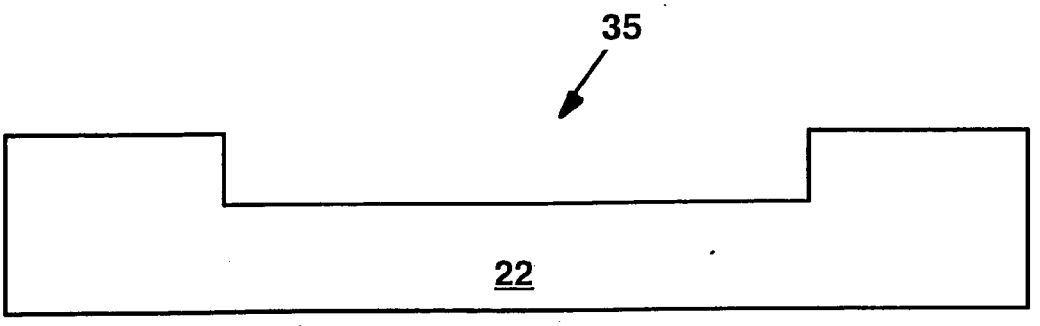



Fig. 11A

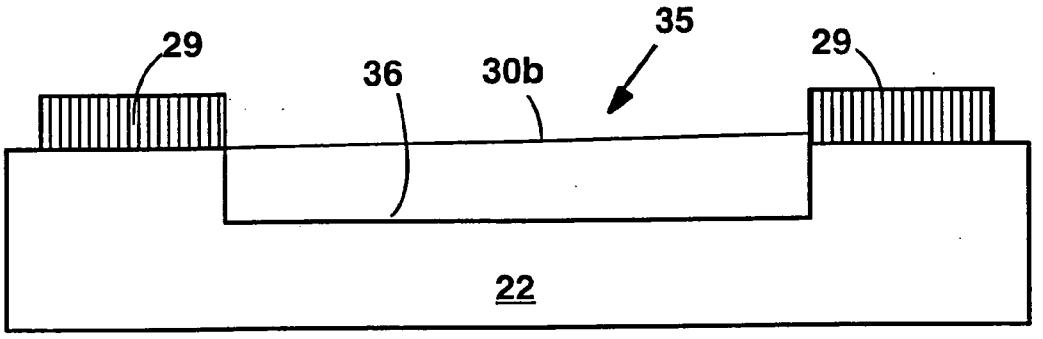



Fig. 11B

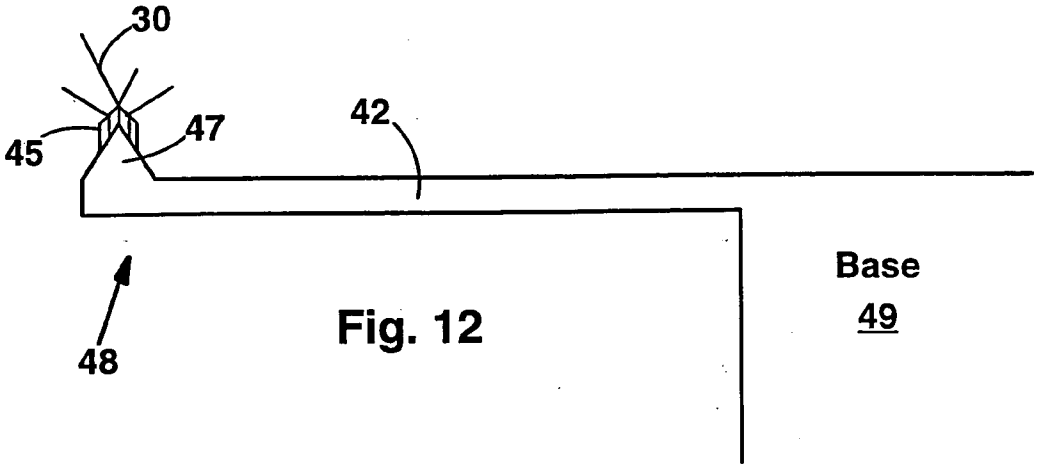



Fig. 12

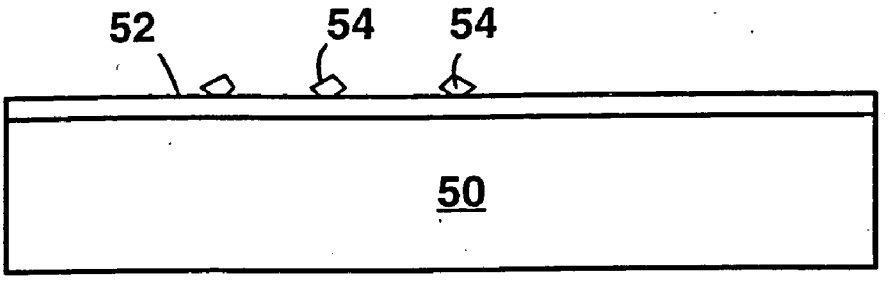



Fig. 13A

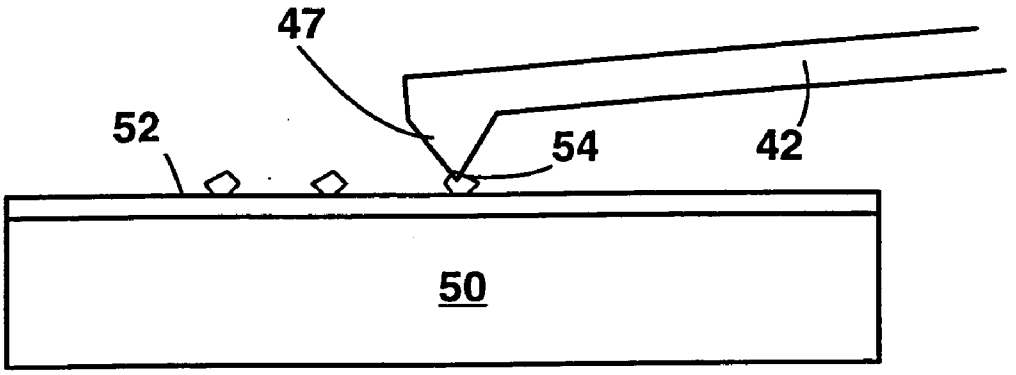



Fig. 13B

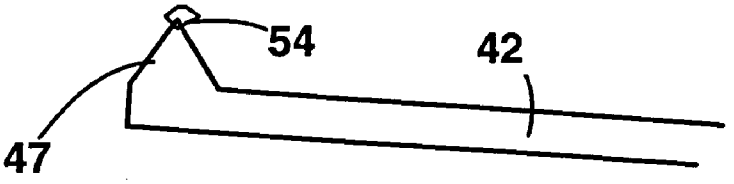



Fig. 13C

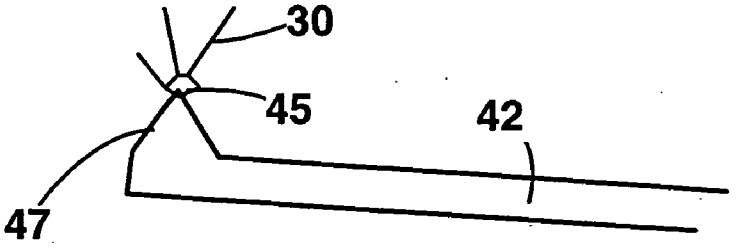



Fig. 13D

# APPARATUS FOR MAKING CARBON NANOTUBE STRUCTURE WITH CATALYST ISLAND

## RELATED PATENT DOCUMENTS

[0001] This is a divisional of U.S. patent application Ser. No. 10/042,426 (STFD.021C1) filed on Jan. 7, 2002 and entitled "Carbon Nanotube Structure Having A Catalyst Island," which is a continuation of U.S. patent application Ser. No. 09/133,948 (STFD.021PA/S98-049) filed on Aug. 14, 1998, now U.S. Pat. No. 6,346,189, and entitled "Carbon Nanotube Structures made Using Catalyst Islands," to which priority is claimed under 35 U.S.C. §120.

## FIELD OF THE INVENTION

[0002] The present invention relates generally to carbon nanotubes and more particularly to the growth of carbon nanotubes using catalyst islands.

## BACKGROUND

[0003] Carbon nanotubes including single-walled carbon nanotubes (SWNT) are ideal quantum systems for exploring basic science in one-dimension. These novel molecular-scale wires, derived by bottom-up chemical synthesis approaches are also promising as core components or interconnecting wires for electronics and other applications. Rich quantum phenomena have been revealed with SWNTs and functional electronic devices such as transistors, chemical sensors and memory devices have been built. In these and other devices, it is sometimes desirable to use individual, high quality SWNTs.

[0004] Obtaining individual, high quality, single-walled nanotubes has proven to be a difficult task, particularly when manufacturing the nanotubes in bulk quantities. Previous methods for the production of nanotubes yield bulk materials with tangled nanotubes. Nanotubes in such bulk materials are typically in a bundled form. These tangled nanotubes are difficult to purify, isolate, manipulate, and use as discrete elements for making functional devices. For example, in making functional microscopic devices, bulk tangled nanotubes are difficult to implement due to the difficulty of isolating one individual tube from the tangled nanotubes, manipulating the tube, and constructing a functional device using the isolated tube. Also, carbon nanotubes manufactured in this manner tend to exhibit molecular-level structural defects that result in weaker tubes with poor electrical characteristics. These and other difficulties have presented challenges to the manufacture of carbon nanotubes for implementation in a variety of applications, such as functional microscopic devices.

## SUMMARY OF THE INVENTION

[0005] The present invention is directed to carbon nanotubes and the fabrication thereof. The present invention is exemplified in a number of implementations and applications, some of which are summarized below.

[0006] In one example embodiment of the present invention, an individual, distinct nanotube device includes a catalyst island and a nanotube extending therefrom. In one implementation, the nanotube is a single-walled carbon nanotube. The nanotube device is adapted to be implemented in one or more semiconductor microstructures. In one implementation, a chamber arrangement is adapted as a system for manufacturing a carbon nanotube device. The arrangement includes first chamber means for forming at least one island of catalyst material, and second chamber means for contacting the catalyst island with a carbon-containing gas and forming a carbon nanotube extending from the catalyst island.

[0007] In another implementation, a chamber apparatus is configured and arranged to heat a substrate while introducing a carbon feedstock gas to an overlying catalyst material and growing an aligned carbon nanotube extending from the catalyst material and across the trench

[0008] In another implementation, the catalyst island is located on a top surface of a semiconductor substrate, which may, for example, include silicon, alumina, quartz, silicon oxide or silicon nitride. The catalyst may include $Fe_2O_3$ or other catalyst materials including molybdenum, cobalt, nickel, or zinc and oxides thereof. In one implementation, the catalyst island is between about 1 and 5 microns in size.

[0009] In another example embodiment of the present invention, individual, distinct single-walled nanotubes are grown from catalyst islands. The nanotubes are grown using a hydrocarbon gas that is introduced to the catalyst islands, where the hydrocarbon gas is reacted. The nanotube growth is confined to selected locations, and the resulting nanotubes can be easily addressed and integrated into structures to obtain functional microscopic devices.

[0010] In another example embodiment of the present invention, a nanotube-tipped atomic force microscope (AFM) device includes a nanotube extending from a catalyst island on a cantilever tip. The cantilever is adapted for use as a scanning tip in conventional AFM applications.

[0011] In another example embodiment of the present invention, a carbon nanotube device includes a substrate with two electrically conductive catalyst islands coupled to one another by a nanotube extending between the islands. The nanotube and the catalyst island are adapted for electrically coupling to other circuitry, such as via a conductive interconnect. In one implementation, the nanotube is free-standing above the substrate and adapted for use as a high frequency, high-Q resonator. In another implementation, one of the catalyst islands is replaced by a conductive metal pad.

[0012] The above summary of the present invention is not intended to describe each illustrated embodiment or every implementation of the present invention. The figures and detailed description that follow more particularly exemplify these embodiments.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The invention may be more completely understood in consideration of the detailed description of various embodiments of the invention that follows in connection with the accompanying drawings, in which:

[0014] **FIG. 1** shows a first step in making nanotubes, according to an example embodiment of the present invention;

[0015] **FIG. 2** shows a second step in making nanotubes, according to another example embodiment of the present invention;

[0016] **FIG. 3** shows a third step in making nanotubes, according to another example embodiment of the present invention;

[0017] **FIG. 4** shows a top view of a substrate with three catalyst islands, according to another example embodiment of the present invention;

[0018] **FIG. 5** shows a top view of a single catalyst island that has been used to grow nanotubes, according to another example embodiment of the present invention;

[0019] **FIG. 6** shows an apparatus that has a nanotube connected between a catalyst island and a metal pad, according to another example embodiment of the present invention;

[0020] **FIG. 7** shows metal covers disposed on top of catalyst islands and portions of nanotubes, according to another example embodiment of the present invention;

[0021] **FIGS. 8A-8C** illustrate the metal covers, such as those of **FIG. 7**, being made according to another example embodiment of the present invention;

[0022] **FIG. 9** shows a side view of a resonator made from a freestanding nanotube supported by the ends of the nanotube, according to another example embodiment of the present invention;

[0023] **FIG. 10** shows a top view illustrating a carbon nanotube device, such as that shown in **FIG. 9**, being made according to another example embodiment of the present invention;

[0024] **FIGS. 11A and 1B** illustrate a method of making a carbon nanotube device, such as that shown in **FIG. 9**, according to another example embodiment of the present invention;

[0025] **FIG. 12** shows an atomic force microscope tip undergoing manufacture, according to another example embodiment of the present invention; and

[0026] **FIGS. 13A-13D** illustrate a method of producing a carbon nanotube on a tip of an atomic force microscope cantilever, according to another example embodiment of the present invention.

[0027] While the invention is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention.

## DETAILED DESCRIPTION

[0028] The present invention is believed to be applicable to a variety of different devices and implementations, and the invention has been found to be particularly suited for manufacturing carbon nanotubes. While the present invention is not necessarily limited to such applications, various aspects of the invention may be appreciated through a discussion of various examples using this context.

[0029] According to an example embodiment of the present invention, a carbon nanotube device includes a single-walled carbon nanotube extending from a catalyst particle. The particle may, for example, be located on a surface, such as a top surface of a semiconductor substrate or on a cantilever tip of an AFM. In one implementation, the carbon nanotube device includes a plurality of catalyst islands on a top surface of a substrate, each island having a carbon nanotube extending therefrom.

[0030] **FIGS. 1-5** show individually distinct carbon nanotubes being grown, according to another example embodiment of the present invention. In **FIG. 1**, a layer of resist **20** is disposed and patterned on a top surface of a substrate **22** using, for example, electron beam (e-beam) lithography. The substrate **22** is made of material that may, for example, include one or more of silicon, alumina, quartz, silicon oxide or silicon nitride, and in one implementation, includes a metal film on the top surface. The patterning results in at least one hole **24** in the resist **20** that exposes the underlying substrate **22**. In one implementation, holes formed in the resist are about 3-5 microns in size and are spaced apart by a distance **26** of about 10 microns.

[0031] In **FIG. 2**, a catalyst layer **28** is deposited on the surfaces of the resist **20** and substrate **22**. The catalyst layer may include one or more of a variety of catalysts. In one implementation, the catalyst includes a solution of $Fe(NO_3)_3$ in methanol, mixed with alumina nanoparticles having a diameter of about 15-30 nanometers. In other implementations, the catalyst includes one or more of: elemental metals; oxides of elemental metals (e.g., iron, molybdenum and zinc oxides); a mixture of iron, molybdenum and ruthenium oxides; and iron salts such as Fe(SO4).

[0032] The nanoparticles can be made of many ceramic materials, depending upon the application and available materials. For instance, one or more of refractory oxide ceramic materials such as alumina and silica can be used. In one particular application using $Fe(NO_3)_3$, the catalyst preparation includes mixing 4.0 grams of alumina nanoparticles with 1.0 gram of $Fe(NO_3)*9H_2O$ in 30 mL methanol for 24 hours. The mixture is applied to the substrate and the methanol is evaporated, leaving a layer **28** of alumina nanoparticles coated with $Fe(NO_3)_3$ adhering to the resist and in the holes **24**. In **FIG. 3**, a lift-off process is performed, leaving isolated islands **29** of catalyst (e.g., $Fe(NO_3)_3$-coated nanoparticles) adhering in regions where holes **24** existed. **FIG. 4** shows a top view of the catalyst islands **29**.

[0033] The substrate **22** is heated and nanoparticles of the catalyst are decomposed (e.g., the $Fe(NO_3)_3$ is decomposed to $Fe_2O_3$). The substrate may be heated, for example, by placing the substrate in a furnace with an Argon atmosphere and heating to between about 100-400 degrees Celsius. The decomposed catalyst nanoparticles are an active catalyst that catalyzes the formation of carbon nanotubes when exposed to methane gas at elevated temperature.

[0034] In a more particular example embodiment of the present invention, the substrate with catalyst islands **29** is heated in a furnace at about 850-1000 degrees Celsius, and 99.99% pure methane is flowed over the catalyst islands **29** at a velocity of about 2-20 centimeters per second to grow single-walled nanotubes. In one implementation, a 1-inch diameter tube is used, wherein methane is introduced at a flow rate of about 600-6000 $cm^3$/min to achieve a velocity of about 2-20 centimeters per second. The amount of time that the methane is introduced to the catalyst island is sufficient to react the methane and grow a nanotube, and in one implementation, is about 10 minutes.

[0035] The nanotubes are formed substantially straight and without structural flaws (e.g., all the carbon rings in the

nanotubes have 6 carbon atoms instead of 5 or 7 carbon atoms). Most of the nanotubes are single-walled, with diameters in the range of about 1-5 nanometers. At a furnace temperature of about 1000 degrees Celsius, it has been discovered that about 90% of the nanotubes are single-walled when grown. At a furnace temperature of about 900 degrees Celsius, about 99% of the tubes are single-walled with most of the nanotubes having diameters in the range of about 1-2 nanometers. The nanotubes have large length to diameter aspect ratios (e.g., approaching about 10,000) and are very straight, due to the absence of structural flaws.

[0036] In another example embodiment of the present invention, nanoparticles are not used in forming the catalyst. Small quantities of Iron salts are deposited on the substrate (e.g., by dissolving the iron salts in a solvent and evaporating the solvent), and the substrate is heated to decompose the iron salts without necessarily mixing the iron salts with nanoparticles.

[0037] In another example embodiment of the present invention, a furnace chamber is configured and arranged for manufacturing carbon nanotubes. The furnace is adapted to flow a carbon feedstock gas, such as methane, and to react the carbon feedstock gas using a catalyst for growing carbon nanotubes. In one implementation, the furnace chamber is adapted to heat a substrate and catalyst to between about 850 and 1000 degrees Celsius, and to flow methane gas at a velocity of about 2-20 centimeters per second to a catalyst in the furnace. The methane may, for example, be reacted at catalyst islands on a substrate to form a carbon nanotube.

[0038] **FIG. 5** shows a top view of the catalyst island **29** having a plurality of nanotubes **30** grown therefrom in random directions. The carbon nanotubes are disposed in contact with the substrate surface and are firmly attached to the island **29**. The nanotubes are grown in a base-growth mode, where new carbon is added to the nanotubes **30** at the point where they are attached to the island **29**, such that an end of the nanotubes that is opposite the end attached to the island is free. In one implementation, the nanotubes are adapted to be used as resonators wherein the free end vibrates.

[0039] In another example embodiment of the present invention, the carbon nanotubes **30** are not tangled together, are individually separable and are spaced apart by a substantial distance. In one implementation, between about 10-50 nanotubes are grown from a catalyst island. The individually separable nanotubes are particularly useful for the manufacture of electronic and micromechanical devices, wherein individual nanotubes are incorporated into the devices by appropriately locating islands **29**. Electrical and mechanical connections are easily made to individual nanotubes if they are spatially separated and distinct.

[0040] In another example embodiment of the present invention, larger numbers of nanotubes are grown (e.g., using a more effective catalyst). The nanotubes grown in large numbers form bundles that are useful for many electrical and mechanical devices such as field effect transistors, single electron transistors, and resonators that have only one fixed end.

[0041] **FIG. 6** is a top view of an electronic device made by locating the island **29** close to a patterned metal pad **32**, according to another example embodiment of the present invention. A single nanotube **30***a* is grown extending from the island **29** to the metal pad **32** and electrically connecting the island **29** and pad **32**. The island **29** and pad **32** are spaced apart by a distance in the range of between about 100 nanometers and 5 microns, with the likelihood that the nanotube grows to the pad **32** increasing as the distance between the pad **32** and island **29** is reduced. The island **29** and pad **32** are both electrically conductive, and a patterned conductive line **33** on the substrate surface electrically connects to the nanotube **30***a* on a macroscopic scale. The nanotube **30***a* with such a macroscopic electrical connection on each end can be used in many devices including field-effect transistors, single electron transistors and low current value fuses. In one implementation, the conductive line **33** is applied to the substrate **20** before the island **29** is deposited, such that the island rests on top of the conductive line **33**. In another implementation, the conductive line **33** is disposed on top of the islands.

[0042] In another implementation (not shown), when two or more nanotubes simultaneously electrically connect the island **29** and metal pad **32**, all but one of the nanotubes is broken with an AFM tip. For instance, an AFM tip can be dragged across the substrate surface so that it bends unwanted nanotubes until they break.

[0043] In another example embodiment of the present invention, a second catalyst island is substituted for the metal pad **32**. In this implementation, the nanotube **30***a* provides electrical contact between two catalyst islands instead of between the island **29** and the metal pad **32**. Metal line **33** similarly provides electrical connection to the substituted catalyst island.

[0044] **FIG. 7** shows a side view of a substrate **22** in which a metal cover **34** is deposited on top of each catalyst island **29**, according to another example embodiment of the present invention. The metal covers **34** include one or more of a variety of metals, such as platinum or titanium-gold alloy. Each metal cover **34** covers a portion of each island **29** and covers an end portion **37** of the nanotube **30***a* and holds the nanotube **30***a* rigidly in place.

[0045] In another example embodiment of the present invention, the substrate is heated to about 300 degrees Celsius in air after the metal covers are deposited, and Ohmic electrical connection to the ends of the nanotube **30***a* are formed. Metal lines, such as line **33** in **FIG. 6**, can then be connected to the metal covers to provide macroscopic electrical connection to the nanotube **30***a*.

[0046] **FIGS. 8A-8C** show metal covers, such as those shown in **FIG. 7**, being made using lithographical patterning, according to another example embodiment of the present invention. Referring to **FIG. 8A**, a layer of spin-on resist **60** is deposited on top of catalyst islands **29** and nanotube **30***a*. In **FIG. 8B**, the resist **60** is etched in regions **61** where the metal covers **34** are to be located. A layer of metal is then deposited over the resist **60** and catalyst **29** (e.g., by physical vapor deposition or CVD). The resist **60** is removed in a lift-off process in **FIG. 8C**, leaving the metal covers **34**.

[0047] In another example embodiment of the present invention, **FIG. 9** shows a side view of a device including a freestanding nanotube **30***b* capable of acting as a high-Q resonator. The nanotube **30***b* is disposed above a surface **36**

of an etched trench region **35** in the substrate **22** between catalyst islands **29** and is supported at ends **39** of the nanotube. In one implementation, the trench **35** and metal covers **34** are combined in the same apparatus.

[**0048**] The structure in **FIG. 9** is useful in a variety of applications. In one example embodiment, the nanotube **30***b* is resonated by applying a magnetic field thereto (e.g., perpendicular to the length of the nanotube **30***b*) and passing an oscillating current through the nanotube. A conductive film **37** is capacitively coupled with the nanotube **30***b* and extracts a resonant signal from the nanotube. In another implementation, the conductive film **37** is used to electrostatically excite mechanical vibrations in the nanotube **30***b*.

[**0049**] **FIG. 10** shows a top view of a substrate **22** and islands **29**, which can be used to make a nanotube structure as shown, for example, in **FIG. 9**. First, a nanotube **30***b* that connects catalyst islands **29** is grown. Other nanotubes may also be grown from both islands, but are not shown for clarity. Then, the substrate is masked with a resist, such as a spin-on resist, leaving an unmasked region defined by a box **38**. Next, the region inside the box **38** is exposed to an etchant that removes substrate material without necessarily affecting the nanotube **30***b*. The etchant includes one or more of a variety of etchants, depending upon the composition of the substrate. For example, hydrofluoric acid can be used to etch $SiO_2$ or silicon substrates. Substrate below the nanotube **30***b* is etched, resulting in the nanotube being supported only at its ends **39** as shown in **FIG. 9**. Metal lines **33** are used to provide macroscopic electrical connections to the nanotube **30***b* via the catalyst islands **29**. Metal covers, such as covers **34** in **FIG. 8C**, can be deposited before or after etching the trench **35** to provide Ohmic electrical connections to the nanotube and improved mechanical stability for the nanotube ends **39**.

[**0050**] **FIGS. 11A and 11B** show a suspended carbon nanotube being manufactured, such as the nanotube shown in **FIG. 9**, according to another example embodiment of the present invention. In **FIG. 11A**, a substrate **22** is etched to form the trench **35** where a nanotube is to be suspended. In **FIG. 11B**, islands **29** are disposed on opposite sides of the trench **35** and a nanotube **30***b* is grown from the islands **29** and electrically connects the islands. The distance across the etched substrate, and thus between the islands **20**, is selected for the characteristics of a particular application, including manufacturing conditions and materials used. In connection with an example embodiment of the present invention, it has been discovered that using catalyst islands having a width of at least 1 micron and spacing the islands at a distance that is less than about 10 microns apart is particularly useful in forming carbon nanotubes extending between the two catalyst islands. In addition, if a number of catalyst islands are spaced at varied distances in an array, the likelihood of growing a carbon nanotube between islands is improved. As in the example embodiments above, one of the islands can be replaced with a metal pad, wherein the nanotube grows from the island **29** to the pad. In addition, metal covers, such as covers **34** in **FIG. 8C**, can be deposited on top of the nanotube **30***b* and catalyst islands **29**.

[**0051**] In another example embodiment of the present invention (not shown), the nanotube **30***b* is freestanding, such that the nanotube is supported on only one end by a catalyst island **29** (e.g., the freestanding nanotube does not extend all the way across the trench **35**). In this implementation, the nanotube is a cantilever and is adapted to be used as a resonator.

[**0052**] **FIG. 12** shows a catalyst particle **45** located on a tip **47** of an atomic force microscope (AFM) cantilever **42**, according to another example embodiment of the present invention. The cantilever **42** is supported by a base **49** and has a free end **48** opposite the base **49**. The particle **45** may be made of one or more of a variety of catalyst materials, such as $Fe_2O_3$ (decomposed from $Fe(NO_3)_3$) and others, as discussed above. The catalyst particle **45** may or may not have supporting nanoparticles (e.g., silica or alumina particles), and is firmly attached to the tip **47**. Atomically sharp nanotubes **30** are grown from the particle **45**, are firmly attached to the cantilever and are useful as probe tips for AFM. In one implementation (not shown), the cantilever does not have a tip **47** and the particle is disposed directly on the cantilever **42**.

[**0053**] **FIGS. 13A-13D** show a carbon nanotube on a tip being manufactured, according to another example embodiment of the present invention. In **FIG. 13A**, a substrate **50** is coated with a gold film **52**, and droplets of $Fe(NO_3)_3$ dissolved in methanol are deposited on the gold surface. The methanol is then evaporated, leaving only small particles **54** of $Fe(NO_3)_3$ on the gold film **52**. Next, an AFM tip **47** is brought into contact with a particle **54** of $Fe(NO_3)_3$ in **FIG. 13B**. An electric field is then applied between the tip **47** and the gold film **52**. The electric field adheres the $Fe(NO_3)_3$ particle to the tip **47**. In one implementation, the electric field also causes the $Fe(NO_3)_3$ to decompose into $Fe_2O_3$. In **FIG. 13C**, the cantilever **42** and tip **47** with the adhered $Fe(NO_3)_3$ particle **54** is removed from the gold film **52**. The cantilever **42** and tip **47** are heated to fully decompose the $Fe(NO_3)_3$ particle **54** into an $Fe_2O_3$ particle **54** in **FIG. 13D** (e.g., as shown in **FIG. 12**). Nanotubes **30** are then grown from the catalyst particle **45**.

[**0054**] While the present invention has been described with reference to several particular example embodiments, those skilled in the art will recognize that many changes may be made thereto without departing from the spirit and scope of the present invention.

What is claimed is:

**1**. A system for manufacturing a carbon nanotube device, comprising:

first chamber means for forming at least one island of catalyst material; and

second chamber means for contacting the catalyst island with a carbon-containing gas and forming a carbon nanotube extending from the catalyst island.

**2**. The system of claim 1, wherein the second chamber means is adapted to create conditions suitable for reacting the carbon-containing gas with the catalyst island for growing the carbon nanotube.

**3**. The system of claim 1, wherein the second chamber means comprises:

a chemical vapor deposition (CVD) apparatus configured and arranged for growing single wall carbon nanotubes.

**4**. The system of claim 3, wherein the CVD apparatus is configured and arranged to introduce carbon feedstock gas for growing carbon nanotubes in the second chamber means.

**5**. The system of claim 3, wherein the CVD apparatus is configured and arranged to introduce the carbon feedstock gas to a catalyst for growing carbon nanotubes in the second chamber means.

**6**. The system of claim 1, wherein the second chamber means is configured and arranged to grow carbon nanotubes from a catalyst island on a substrate in the chamber.

**7**. The system of claim 1, wherein the second chamber means is further configured and arranged to grow a carbon nanotube extending between the catalyst island and a circuit node.

**8**. The system of claim 1, wherein the second chamber means is further configured and arranged to grow a circuit including a carbon nanotube extending between two circuit nodes and adapted for conducting electricity between the two circuit nodes.

**9**. The system of claim 1, wherein the second chamber means is further configured and arranged to grow a carbon nanotube extending from a cantilever tip.

**10**. The system of claim 9, wherein the second chamber means is further configured and arranged for holding a wafer including a multitude of cantilever tips and to grow carbon nanotubes extending from a plurality of the multitude of cantilever tips.

**11**. The system of claim 1, wherein the second chamber means is further configured and arranged to grow a carbon nanotube extending between two catalyst islands.

**12**. The system of claim 1, wherein the second chamber means is further configured and arranged to grow a carbon nanotube from a catalyst island including an alumina-supported iron catalyst.

**13**. The system of claim 1, wherein the second chamber means is further configured and arranged to grow a plurality of carbon nanotubes extending from catalyst islands patterned on a substrate.

**14**. The system of claim 1, wherein a gas supply is configured and arranged for introducing the carbon feedstock gas to the second chamber means.

**15**. The system of claim 14, wherein the gas supply is configured and arranged for introducing a carbon feedstock gas including Methane to the second chamber means to grow the carbon nanotube.

**16**. The system of claim 1, wherein the second chamber means is configured and arranged to grow the carbon nanotube from catalyst particles lithographically patterned on a substrate.

**17**. The system of claim 1, wherein the carbon nanotube is grown at a temperature of less than about 1000 degrees Celsius.

**18**. The system of claim 17, wherein the carbon nanotube is grown at a temperature of between about 850 and 100 degrees Celsius.

**19**. A system for manufacturing a carbon nanotube device, the system comprising:

a chamber apparatus adapted to provide internal heat at at least one controlled level; and

a gas supply configured and arranged with the chamber apparatus for contacting a catalyst island in the chamber with a carbon-containing gas and forming, under said at least one controlled level of heat, a carbon nanotube extending from the catalyst island.

**20**. The system of claim 19, wherein the gas supply and the chamber apparatus are adapted to contact the carbon-containing gas to the catalyst island for a period of time sufficient to form carbon nanotubes.

**21**. The system of claim 19, wherein the chamber apparatus is further adapted for heating the catalyst island.

**22**. The system of claim 19, wherein the gas supply is configured and arranged for contacting the catalyst island with a carbon containing gas that has been reacted using a catalyst.

**23**. The system of claim 19, wherein the chamber apparatus is configured and arranged to heat a substrate to decompose a catalyst material to form the catalyst island.

**24**. The system of claim 19, wherein the chamber apparatus is configured and arranged to heat the substrate while introducing a carbon feedstock gas to the catalyst material and growing an aligned carbon nanotube extending from the catalyst material and across the trench.

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