Laser Formation of Graphene

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An apparatus and method is disclosed for synthesizing graphene comprising the steps of providing a substrate and focusing a laser beam in the presence of a carbon doping gas to induce photolytic decomposition of the gas to atomic carbon. The carbon is photolytically reacted with the substrate to grow graphene.

9 Claims, 11 Drawing Sheets
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FIG. 3

FIG. 4

FIG. 5

FIG. 6
FIG. 28

FIG. 29

FIG. 30

FIG. 31

FIG. 32

FIG. 33

FIG. 34

Substance | $K$ (W/mK) at 300 K
---|---
SiC | 490
Ag | 429
Cu | 401
Au | 317
BeO | 260
Al | 237
AlN | 180
Si | 150
$\text{Al}_2\text{O}_3$ | 40

Diamond (along basal planes)

Graphite (normal to basal planes)
Si atoms at the substrate surface

**FIG. 35A**

1st graphene layer

**FIG. 35B**

2nd graphene layer

**FIG. 35C**
Graphene islands and interconnects on a substrate for device fabrication.

FIG. 36
LASER FORMATION OF GRAPHENE

CROSS-REFERENCE TO RELATED APPLICATIONS


BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to solid state devices and methods and more particularly to and apparatus and method of forming graphene on a semiconductor substrates for electrical and photonic devices.

2. Description of the Related Art

Presently, silicon and gallium arsenide are the dominant conventional semiconductor materials used in the manufacture of semiconductor devices. Silicon and gallium arsenide are considered non-wide bandgap semiconductors. In contrast, wide bandgap semiconductors have superior properties including breakdown field, dielectric constant, thermal conductivity and saturated electron drift velocity. Unfortunately, wide bandgap semiconductors are expensive due to high processing costs and poor yields emanating from wafer growth through device packaging.

Ceramic substrates having wide bandgap semiconductor compositions, such as silicon carbide (SiC) and aluminum nitride (AlN), are known to exhibit electrical properties ranging from insulating electrical properties, semiconducting electrical properties and conducting electrical properties.

The wide-bandgap semiconductor phases of ceramics and other wide-bandgap semiconductors including diamond are used to create devices such as conductive tabs, interconnects, vias, wiring patterns, resistors, capacitors, semiconductor devices and the like electronic components by laser synthesis on the surfaces and within the body of such wide-bandgap semiconductors to thereby eliminate photolithography processes which require numerous steps and generate undesirable chemical pollutants when processing such traditional electronic devices, components and circuitry.

It is well known that alumina (Al₂O₃) dominates the dielectric market as an integrating substrate or device carrier in electronics packaging. Boron nitride (BN), aluminum nitride (AIN), silicon carbide (SiC) and diamond are also of interest due to the thermal coefficient of expansion (TCE) for the dielectric constant and higher thermal conductivity than that of aluminum oxide (Al₂O₃). Silicon carbide (SiC), aluminum nitride (AIN), boron nitride (BN), gallium nitride (GaN) and diamond also exhibit a wide-band gap and chemical resistance as well as exhibiting properties from a semiconductor to an insulator. These properties are of substantial interest for high temperature applications approaching 1000°C and for aggressive environment applications. In addition, these properties are desirable for high density integrated circuit packaging.

In the prior art, metallization methods, including dry-film imaging and screen printing have been used for the production of conductive patterns on alumina. However, metal compatibility difficulties with high thermal conductivity ceramic materials such as aluminum nitride (AlN) and silicon carbide (SiC), have not been completely solved. Copper and silver paste exhibits a thermal coefficient of expansion (TCE) mismatch aggravated by high temperatures as well as being subject to oxidation that increases the resistivity. In particular, bonding of copper to aluminum nitride (AIN) has proved to be nontrivial. Alumina or stoichiometric aluminum oxynitride (AlON) coatings must be developed on the aluminum nitride (AIN) surface through passivation processes. These passivation processes have poor reproducibility. Thus, the direct laser synthesis of conductors in aluminum nitride (AIN) and diamond substrates appears to provide solutions to this long standing prior art problem with regard to metallization and for more simple processing techniques for creating devices and circuitry that are compatible with selected ceramic substrates, while satisfying the need for higher temperature, aggressive environment, and higher density integrated circuit packaging applications.


Therefore, it is an object of this invention to provide a process for forming graphene on or in a substrate.

Another object of this invention is to provide an improved process for forming graphene on or in a substrate wherein carbon is photolytically reacted with the substrate to grow graphene.

The foregoing has outlined some of the more pertinent objects of the present invention. These objects should be construed as being merely illustrative of some of the more prominent features and applications of the invention. Many other beneficial results can be obtained by modifying the invention within the scope of the invention. Accordingly other objects in a full understanding of the invention may be had by referring to the summary of the invention, the detailed description describing the preferred embodiment in addition to the scope of the invention defined by the claims taken in conjunction with the accompanying drawings.

SUMMARY OF THE INVENTION

The present invention is defined by the appended claims with specific embodiments being shown in the attached drawings. For the purpose of summarizing the invention, the invention relates to an improved apparatus and a method for synthesizing graphene, comprising the steps of providing a substrate. A laser beam is focused in the presence of a carbon dopant gas to induce photolytic decomposition of the gas to atomic carbon. Continued focusing of the laser beam photolytically reacts the carbon with the substrate to grow graphene.

In another embodiment, the method comprises the steps of providing a silicon substrate. A laser beam is focused in the presence of a carbon doping gas to induce photolytic decomposition of the gas to atomic carbon. Continued focusing the laser beam photolytically reacts the carbon with the silicon substrate to grow graphene.

Preferably, the laser is a frequency doubled Nd:YAG laser produces a 532 nm wavelength to create two-photon absorption in silicon to limit temperature below the melting point of
silicon. The laser radiation-silicon interaction catalyzes the silicon for carbon chemisorption. Ideally, the graphene is limited to 3 planes of hexagonically oriented carbon. The laser beam may be focused on a portion of the silicon substrate to create islands and connecting lines of graphene on the surface of the silicon substrate.

In a more specific embodiment, the method comprises the steps of providing a silicon substrate transparent to 532 nm wavelength. A top surface of the silicon substrate is immersed in carbon containing doping gas. A 532 nm laser is focused from a bottom surface to the top surface of the silicon substrate to photolytically decompose the carbon on the top surface of the silicon substrate forming graphene on the top surface of the silicon substrate.

The foregoing has outlined rather broadly the more pertinent and important features of the present invention in order that the detailed description that follows may be better understood so that the present contribution to the art can be more fully appreciated. Additional features of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and the specific embodiments disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature and objects of the invention, reference should be made to the following detailed description taken in connection with the accompanying drawings in which:

FIG. 1 is a side view of an air-tight chamber with a thermal energy beam impinging on a non-wide bandgap material for forming a layer of a wide bandgap material in the non-wide bandgap material;

FIG. 2 is an enlarged isometric view of the layer of the wide bandgap material formed in the non-wide bandgap material;

FIG. 3 is an enlarged partial sectional view of a first embodiment of silicon carbide (SiC) wide bandgap material formed in a silicon (Si) non-wide bandgap material;

FIG. 4 is an enlarged partial sectional view of a second embodiment of an aluminum nitride (AlN) wide bandgap material formed in an alumina (Al₂O₃) non-wide bandgap material;

FIG. 5 is an enlarged partial sectional view of a third embodiment of a silicon carbide (SiC) wide bandgap material formed in a silica (SiO₂) non-wide bandgap material;

FIG. 6 is an enlarged partial sectional view of a fourth embodiment of a diamond-like carbon material formed in the silicon carbide (SiC) wide bandgap material defined in a silica (SiO₂) non-wide bandgap material;

FIG. 7 is an enlarged isometric view of a fifth embodiment of an improved component formed in the wide bandgap material;

FIG. 8 is a sectional view along line 8-8 in FIG. 7;

FIG. 9 is a sectional view along line 9-9 in FIG. 7;

FIG. 10 is an enlarged isometric view of a sixth embodiment of an improved semiconductor device formed in the wide bandgap material;

FIG. 11 is a sectional view along line 11-11 in FIG. 10;

FIG. 12 is a sectional view along line 12-12 in FIG. 10;

FIG. 13 is a side view of an apparatus similar to FIG. 1 for forming further embodiments of the invention;

FIG. 14 is a first step in the process of increasing the thermal conductivity in a non-wide bandgap substrate illustrating the scanning of a first thermal energy beam across the substrate in the presence of a doping gas to create a layer of wide bandgap material;

FIG. 15 is a second step in the process of increasing the thermal conductivity in a substrate illustrating the scanning of a second thermal energy beam across the layer of wide bandgap material to create a layer of thermal conducting material in the wide bandgap material;

FIG. 16 is a third step in the process of increasing the thermal conductivity in a substrate illustrating the focusing of a third thermal energy beam inside of the thermal conducting material to aligning the molecular planes of the thermal conducting material to extend outwardly from the substrate;

FIG. 17 illustrates the cutting is a substrate into a plurality of sheets;

FIG. 18 is a side sectional view of one of the plurality of dies of FIG. 17 incorporating electronic components with the increasing the thermal conductivity in a substrate cooling the electronic components;

FIG. 19 is a side sectional view of a conventional die of the prior art incorporated into a conventional heat spreader and a conventional heat sink of the prior art;

FIG. 20 is a side sectional view of a silicon substrate;

FIG. 21 is a side sectional view of the silicon substrate of FIG. 20 with a layer of silicon carbide material deposited onto the silicon substrate by a conventional vapor deposition process;

FIG. 22 is a side sectional view of the substrate of FIG. 21 with a layer of carbon thermal conducting material deposited onto the silicon carbide material by a conventional vapor deposition process;

FIG. 23 is a magnified view of a portion of FIG. 22 illustrating the alignment of the molecular planes of the carbon thermal conducting material;

FIG. 24 is a side sectional view of a silicon substrate;

FIG. 25 is a side sectional view of the silicon substrate of FIG. 24 with a layer of the silicon carbide material being converted into silicon carbide material by a thermal energy beam in the presence of a doping gas;

FIG. 26 is a side sectional view of the substrate of FIG. 25 with a layer of the silicon carbide material being converted into a carbon thermal conducting material by a thermal energy beam in the presence of a reacting gas;

FIG. 27 is a magnified view of a portion of FIG. 26 illustrating the alignment of the molecular planes of the carbon thermal conducting material;

FIG. 28 is a side sectional view of the substrate of FIG. 27 with the molecular planes of the layer of carbon thermal conducting material being oriented to be generally perpendicular to an external surface of the substrate formed by focusing a thermal energy beam within the layer of carbon thermal conducting material;

FIG. 29 is a magnified view of a portion of FIG. 28 illustrating the orientation of the molecular planes of the carbon thermal conducting material;

FIG. 30 is a side sectional view of a silicon carbide substrate;

FIG. 31 is a side sectional view of the substrate of FIG. 30 with a layer of the silicon carbide material being converted into a carbon thermal conducting material by a thermal energy beam in the presence of a reacting gas;

FIG. 32 is a side sectional view of the substrate of FIG. 31 with the molecular planes of the layer of carbon thermal conducting material being oriented to extend from the sub-
strate formed by focusing a thermal energy beam within the layer of carbon thermal conducting material;

FIG. 33 is a graph of the thermal conductivity of different materials;

FIG. 34 is a list of the thermal conductivity of various materials;

FIG. 35A is a representation of silicon Si atoms at the surface of a substrate;

FIG. 35B is a representation similar to FIG. 35A illustrating a first graphene layer on the surface of a substrate;

FIG. 35C is a representation similar to FIG. 35B illustrating a second graphene layer on the surface of a substrate; and

FIG. 36 is an isometric view of graphene islands located on a substrate.

Similar reference characters refer to similar parts throughout the several Figures of the drawings.

DETAILED DISCUSSION

FIG. 1 is a side view of an apparatus for forming a layer of a wide bandgap material 10 in a non-wide bandgap material 15. The non-wide-bandgap material 15 is shown as a substrate 20 located in an air-tight chamber 30. The chamber 30 has an inlet and valve combination 31 and outlet and valve combination 32 connected to the side wall of the chamber 30 for injecting and removing gases into and therefrom, respectively. The chamber 30 includes an airtight transmission window 34. The chamber 30 is disposed on a support member 36 forming an airtight seal therewith.

FIG. 2 is an enlarged isometric view of the wide bandgap material 10 formed in the substrate 20 shown in FIG. 1. The wide bandgap material 10 defines a first and a second surface 11 and 12 and a peripheral edge 13. The substrate 20 defines a first and a second surface 21 and 22 and a peripheral edge 23. Although the substrate 20 is shown as a square, the present invention is not limited by the physical configuration of the substrate 20 as shown herein.

A thermal energy beam 40 is shown emanating from a source 42 and passing through the airtight transmission window 34 to impinge on the first surface 21 of the substrate 20. In one example, the thermal energy beam 40 is a beam of charged particles such as a beam of electrons or a beam of ions. In another example, the thermal energy beam 40 is a beam of electromagnetic radiation such as a laser beam. Examples of a suitable source of the laser beam include a Nd:YAG laser, a frequency double Nd:YAG laser, a Nd:YAG laser, a frequency double Nd:YAG laser, and an Excimer laser.

The thermal energy beam 40 is scanned in two dimensions across the first surface 21 of the substrate 20 to form the wide bandgap material 10. In this example, the wide bandgap material 10 is shown partially formed within the first surface 21 of the substrate 20 after a partial scan of the thermal energy beam 40 across the first surface 21 of the substrate 20.

The first surface 11 of the wide bandgap material 10 is coincident with the first surface 21 of the wideband gap semiconductor substrate 20 with the remainder of the wide bandgap material 10 including the second surface 12 and the peripheral surface 13 being embedded between first and second surfaces 21 and 22 of the substrate 20. It should be emphasized that all material interfaces are not discrete but are continuous or diffuse. Lines are used in the figures to show regions only as a convenience.

The substrate 20 may be formed as a monolithic or a thin film substrate having suitable properties for forming the wide bandgap material 10. The non-wide bandgap material 15 has a bandgap equal to or less than two electron volts (2 eV). The wide bandgap bandgap material 10 has a bandgap greater than two electron volts (2 eV).

Preferably, the non-wide bandgap material 15 is sensitive to a thermal conversion process for transforming a layer of the non-wide bandgap material 15 into the wide bandgap material 10. In one example, the non-wide bandgap material 15 is selected from the group consisting of a silicon material (Si), a gallium arsenide material (GaAs), an alumina material (Al2O3), a silica material (SiO2). Preferably, the non-wide bandgap material 15 is capable of being transformed from a non-wide bandgap material 15 into the wide bandgap material 10 and is capable of being subsequently transformed into an electrical component or device upon further irradiating by the thermal energy beam 40.

Table 1 contrasts various properties of two popular non-wide bandgap semiconductor materials namely silicon (Si) and gallium arsenide (GaAs) with wide bandgap semiconductors namely silicon carbide (SiC) and diamond.

<table>
<thead>
<tr>
<th>Property</th>
<th>Silicon</th>
<th>Gallium Arsenide</th>
<th>6 H Silicon Carbide</th>
<th>Diamond</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band Gap</td>
<td>1.12 eV</td>
<td>1.442 eV</td>
<td>3 eV</td>
<td>5.45 eV</td>
</tr>
<tr>
<td>Breakdown field</td>
<td>0.3 MV/cm</td>
<td>0.4 MV/cm</td>
<td>3 MV/cm</td>
<td>10 MV/cm</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>13.7</td>
<td>12.0</td>
<td>10</td>
<td>5.5</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>130 W/K·cm</td>
<td>55 W/K·cm</td>
<td>500 W/K·cm</td>
<td>2200 W/K·cm</td>
</tr>
<tr>
<td>Saturation electron drift velocity</td>
<td>$1 \times 10^7$ cm/sec</td>
<td>$1 \times 10^7$ cm/sec</td>
<td>$2 \times 10^7$ cm/sec</td>
<td>$2.7 \times 10^7$ cm/sec</td>
</tr>
</tbody>
</table>

Table 1 illustrates the advantageous properties of wide bandgap materials 10. Unfortunately, wide bandgap materials 10 are currently expensive due to high processing costs and poor yields emanating from wafer growth through device packaging. The present invention transforms a layer of the non-wide bandgap material 15 into a wide bandgap material 10 to provide the advantages of the properties of the wide bandgap material 10 with the cost advantages of the non-wide bandgap material 15.

The present invention may utilize a conventional semiconductor material such as silicon (Si) or gallium arsenide (GaAs) as the non-wide bandgap material 15. In the alternative, the present invention may utilize a low cost ceramic material such as alumina (Al2O3) or a low cost glass material such as silica (SiO2).

FIG. 3 is an enlarged sectional view of a first embodiment of the invention illustrating a wide bandgap material 10A formed in the substrate 20A. In this example, the non-wide bandgap material 15A of the substrate 20A is a silicon (Si) material whereas the wide bandgap material 10A is silicon carbide (SiC).
The silicon (Si) non-wide bandgap material 15A is converted into the silicon carbide (SiC) wide bandgap material 10A as the thermal energy beam 40 scans across the first surface 21A of the substrate 20A. The thermal energy beam 40 scans across the first surface 21A of the substrate 20A in an atmosphere of methane gas or acetylene gas. The thermal energy beam 40 heats the silicon atoms of the non-wide bandgap material 15A. The heated silicon atoms of the non-wide bandgap material 15A react with the carbon atoms of the methane gas or acetylene gas atmosphere to create the silicon carbide (SiC) wide bandgap material 10A.

FIG. 4 is an enlarged sectional view of a second embodiment of the invention illustrating a wide bandgap material 10B formed in the substrate 20B. In this example, the non-wide bandgap material 15B of the substrate 20B is silicon oxide (SiO₂) material whereas the wide bandgap material 10B is aluminum nitride (AlN).

The aluminum oxide (Al₂O₃) non-wide bandgap material 15B is converted into the aluminum nitride (AlN) wide bandgap material 10B as the thermal energy beam 40 scans across the first surface 21B of the substrate 20B. The thermal energy beam 40 scans across the first surface 21B of the substrate 20B in an atmosphere of nitrogen to create the aluminum nitride (AlN).

Gallium arsenide (GaAs) non-wide bandgap material (thermal conductivity 55 W/m-K) is converted to gallium nitride (GaN) wide bandgap material (thermal conductivity 130 W/m-K) by this method shown for converting aluminum oxide to aluminum nitride.

Typically, the formation of aluminum nitride (AlN) is not chemical and thermodynamically feasible because of the preferred affinity of aluminum for oxygen. A reacting getter such as source of heated carbon is used to remove the oxygen from reacting with the aluminum since oxygen has preferred reactions with carbon. The carbon can be a solid source or a gaseous source such as methane or acetylene. With the gaseous carbon sources the thermal energy beam 40 would be conducted under a mixed atmosphere of methane and nitrogen in simultaneous or subsequent steps.

The thermal carbon process described above or a similar process is used only when the chemistry of the existing substrate is more stable than that of the desired or new substrate surface composition. Once the oxygen is removed, the surface 21B of the substrate 20B can be scanned with the thermal energy beam 40 in the presence of a doping nitrogen gas to create aluminum nitride (AlN). Subsequently, the aluminum nitride (AlN) wide bandgap material 10B may be converted to semiconductors and conductors, or other device in accordance with the teaching of my previously mentioned U.S. Patents.

FIG. 5 is an enlarged sectional view of a third embodiment of the invention illustrating a wide bandgap material 10C formed in the substrate 20C. In this example, the non-wide bandgap material 15C of the substrate 20C is a silica (SiO₂) material whereas the wide bandgap material 10C is silicon carbide (SiC).

The silica (SiO₂) non-wide bandgap material 15C is converted into the silicon carbide (SiC) wide bandgap material 10C as the thermal energy beam 40 scans across the first surface 21C of the substrate 20C. The thermal energy beam 40 scans across the first surface 21C of the substrate 20C in an atmosphere of methane gas or acetylene gas. The thermal energy beam 40 heats the silicon atoms of the non-wide bandgap material 15C. The heated silicon atoms of the non-wide bandgap material 15C react with the carbon atoms of the methane gas or acetylene gas atmosphere to create the silicon carbide (SiC) wide bandgap material 10C.

FIG. 6 is an enlarged sectional view of a fourth embodiment of the invention illustrating a component 50D defined in a wide bandgap material 10D formed in the substrate 20D. In this example, the component 50D is a diamond like carbon material (DLC) formed in the silicon carbide (SiC) wide bandgap material 10D defined in a silica (SiO₂) non-wide bandgap material 15D. The silica (SiO₂) non-wide bandgap material 15D is converted into the silicon carbide (SiC) wide bandgap material 10D as the thermal energy beam 40 scans across the first surface 21D of the substrate 20D as set forth with reference to FIG. 3.

After the silica (SiO₂) non-wide bandgap material 15D is converted into the silicon carbide (SiC) wide bandgap material 10D, the silicon carbide (SiC) is converted into the diamond like carbon material (DLC) by selectively removing silicon atoms to create vacancies. The vacancies are then filled with carbon creating the diamond like carbon material (DLC). The thermal energy beam 40 irradiation of the SiC region in a CO/CO₂ containing atmosphere diffuses silicon to the surface where the silicon reacts with CO₂ to form SiO gas. An increased number of vacancies are left behind in the lattice.

An excimer laser (50 mJ/pulse, 10 Hz pulse repetition rate, 60 pulses, 193 nm wavelength, 20 ns pulse time, CO (partial pressure)/CO₂ (partial pressure)=5x10⁻⁵) creates the temperature range 2000-2300°C necessary to energize silicon (SiO₂) self diffusion in silicon carbide (SiC). Carbon is then diffused into the substrate to fill the vacancies by laser irradiation, for example by (Nd:YAG, excimer etc.) in a methane or acetylene atmosphere to dissociate the hydrocarbon and drive (diffuse) atomic carbon into the silicon carbide (SiC) and if necessary orient or recrystallize the crystal structure.

FIG. 7 is an enlarged isometric view of a fifth embodiment of the invention illustrating a semiconductor device 50E defined in the wide bandgap material 10E formed in the substrate 20E. The semiconductor device 50E may be one or more of a variety of devices such as an active or passive electrical device, a photonic device, an optical device, a sensor device, a spintronic device or any other suitable semiconductor device. In this example, the semiconductor device 50E is shown as a first semiconductor device 51E and a second semiconductor device 52E.

FIG. 8 is a sectional view along line 8-8 in FIG. 7 illustrating the first semiconductor device 51E of FIG. 7. The first semiconductor device 51E is defined in the wide bandgap material 10E. The first semiconductor device 51E is connected by an electrode 61E to a first conductor 71E. An electrode 62E connects the first semiconductor device 51E to a connector 73E.

FIG. 9 is a sectional view along line 9-9 in FIG. 7 illustrating the second semiconductor device 52E of FIG. 7. The second semiconductor device 52E is defined in the wide bandgap material 10E. The second semiconductor device 52E is connected by an electrode 63E to a second conductor 72E. An electrode 64E connects the second semiconductor device 52E to the connector 73E.

Preferably, the first and/or second semiconductor device 51E and 52E are formed in the wide bandgap material 10E by scanning the thermal energy beam 40 across selected portions of the wide bandgap material 10E in the presence of a doping atmosphere to form the first and/or second semiconductor device 51E and 52E. In the alternative, the first and/or second semiconductor device 51E and 52E may be formed in a conventional manner as should be well known in the art.

FIG. 10 is an enlarged isometric view of a sixth embodiment of the invention illustrating a first semiconductor device
The first semiconductor device 51F is defined in the wide band gap material 15F. The second semiconductor device 52F is defined in the non-wide band gap material 15G. The thermal energy beam 40G is directed to define the second semiconductor device 52F of FIG. 10. The second semiconductor device 52F is connected by an electrode 63F to a second conductor 72F. An electrode 64F connects the second semiconductor device 52F to the connector 73F. Preferably, the second semiconductor device 52F is defined in the wide band gap material 15F in a conventional manner as should be well known in the art. FIG. 12 is a sectional view along line 12-12 in FIG. 10 illustrating the second semiconductor device 52F of FIG. 10. The second semiconductor device 52F is defined in the wide band gap material 15F. The second semiconductor device 52F is connected by an electrode 63F to a second conductor 72F. An electrode 64F connects the second semiconductor device 52F to the connector 73F. Preferably, the second semiconductor device 52F is defined in the wide band gap material 15F in a conventional manner as should be well known in the art. In the alternative, the second semiconductor device 52F may be formed by scanning the thermal energy beam 40G across selected portions of the wide band gap material 15F to form the second semiconductor device 52F.

The thermal energy beam 40G conversion and doping technology can be applied to the fabrication of conductors, different semiconductor and insulator phases in silicon carbide (SiC). Conductors can be fabricated by doping titanium into silicon carbide (SiC) by laser scanning in a titanium tetra chloride, or other titanium metallo-organic gas atmosphere. Different semiconductor phases can be created by scanning a material with the thermal energy beam 40G in an atmosphere of nitrogen (n-type), phosphine (n-type) or diborane (p-type), trimethylaluminum (p-type) etc. Insulators can be created by scanning a material with the thermal energy beam 40G in an atmosphere of oxygen.

FIG. 13 is a side view of an apparatus similar to FIG. 1 for increasing the thermal conductivity in a substrate 20G formed from a non-wide band gap material 15G. The substrate 20G is located in an air-tight chamber 30G. The chamber 30G has an inlet and valve combination 31G and outlet and valve combination 32G connected to the side wall of the chamber 30G for injecting and removing gases such as doping and/or reacting gases. An airtight transmission window 34G is located within the chamber 30G. The chamber 30G is disposed on a support member 36G forming an airtight seal therewith.

A thermal energy beam 40G is shown emanating from a source 42G and passing through the airtight transmission window 34G to impinge on the first surface 21G of the substrate 20G. The thermal energy beam 40G may comprise a beam of charged particles such as a beam of electrons or a beam of ions or a beam of electromagnetic radiation such as a laser beam. Examples of a suitable source of the laser beam include a Nd:YAG laser, a frequency double 26G Nd:YAG laser or an Excimer laser. FIG. 14 is an enlarged isometric view of the substrate 20G of the non-wide band gap material 15G shown in FIG. 13. The non-wide band gap material 15G is indicated as NON-WBG. The substrate 20G defines a first and a second surface 21G and 22G and a peripheral edge 23G. In this example, a first region of the substrate 20G is located in proximity to the first surface 21G of the substrate 20G whereas a second region of the substrate 20G is located in proximity to the second surface 22G of the substrate 20G.

The substrate 20G may be formed as a monolith or a thin film substrate 20 having suitable properties for forming the wide band gap material 10G. The non-wide band gap material 15G has a band gap to or less than two electron volts (2 eV).

The non-wide band gap material 15G is sensitive to a thermal conversion process. Preferably, the non-wide band gap material 15G can be transformed from the non-wide band gap material 15G into the wide band gap material 10G. Furthermore, the transformed wide band gap material 10G can be transformed further into a thermal conducting material 50G upon further irradiating by a thermal energy beam 40G. In one example, the non-wide band gap material 15G is selected from the group consisting of a silicon material (Si), a gallium arsenide material (GaAs), an alumina material (Al2O3), a silica material (SiO2).

FIG. 14 illustrates a first step in the process of increasing the thermal conductivity in the non-wide band gap substrate 20G. A doping gas is applied to the first surface 21G of the non-wide band gap substrate 20G within the air-tight chamber 30G. In one example, the doping gas is selected from the group consisting of methane, acetylene and nitrogen.

The thermal energy beam 40G is scanned in two dimensions as indicated by the arrows 17G across the first surface 21G of the substrate 20G in the presence of the doping gas to form the wide band gap material 10G within the first region of the substrate 20G. In this example, the wide band gap material 10G is shown partially formed within the first region of the substrate 20G adjacent to the first surface 21G of the substrate 20G. The wide band gap material 10G is indicated as WBG. The thermal energy beam 40G continues to scan in two dimensions as indicated by the arrows 17G until the entire first region of the substrate 20G is converted into the wide band gap material 10G.

The wide band gap material 10G defines a first and a second surface 11G and 12G and a peripheral edge 13G. The first surface 11G of the wide band gap material 10G is coincident with the first surface 21G of the substrate 20G with the remainder of the wide band gap material 10G being embedded between first and second surfaces 21G and 22G of the substrate 20G. The wide band gap material 10G has a higher thermal conductivity than the non-wide band gap substrate 20G. The wide band gap material 10G embedded within the substrate 20G enhances the thermal conductivity between the first and the second regions of the substrate 20G.

The wide band gap material 10G has a band gap greater than two electron volts (2 eV). In one example, the wide band gap material 10G is selected from the group consisting of silicon carbide, diamond, diamond like carbon, aluminum nitride, boron nitride and gallium nitride.

FIGS. 13-14 illustrate a line interface separating the wide band gap material 10G and the non-wide band gap material 15G. However, it should be appreciated that the actual interface between the wide band gap material 10G and the non-wide band gap material 15G is a continuous or a diffuse interface.

FIG. 15 illustrates the forming of thermal conducting material 50G within the wide band gap material 10G of the sub-
strate 20G. The thermal conducting material 50G is indicated as CM. A second doping gas is applied to the wide bandgap material 10G. A second thermal energy beam 40G' is scanned across the wide bandgap material 10G of the substrate 20G. The irradiation of the wide bandgap material 10G of the substrate 200 by the second thermal energy beam 40G' in the presence of the second doping gas converts a portion of the wide bandgap material 10G into a layer of thermal conducting material 50G. The second thermal energy beam 40G' continues to scan in two dimensions as indicated by the arrows 17G until the entire first region of the substrate 20G is converted into the thermal conducting material 50G.

The thermal conducting material 50G defines a first and a second surface 51G and 52G and a peripheral edge 53G. The first surface 51G of the thermal conducting material 50G is coincident with the first surface 11G of the wide bandgap material 10G with the remainder of the thermal conducting material 50G being embedded between first and second surfaces 11G and 12G of the wide bandgap material 10G.

The thermal conducting material 50G has a higher thermal conductivity than the wide bandgap material 10G. The thermal conducting material 50G embedded within the wide bandgap material 10G further enhances the thermal conductivity between the first and the second regions of the substrate 20G.

In many examples, the thermal conducting material 50G is formed within the wide bandgap material 10G having molecular planes including basal planes 55G. The second thermal energy beam 40G' forms the basal planes 55G that are disposed parallel to an external surface of the substrate 20G. In this example, the external surface of the substrate 20G is shown as the first surface 21G of the substrate 20G.

FIG. 16 illustrates the focusing of a third thermal energy beam 40G" inside of the thermal conducting material 50G. The third thermal energy beam 40G" is scanned in two dimensions across the thermal conducting material 50G while simultaneously altering the focal point of the third thermal energy beam 40G" inside of the thermal conducting material 50G. Initially, the focal point of the third thermal energy beam 40G" is positioned inside of the thermal conducting material 50G with the focal point being gradually moved toward the external surface or the first surface 21G of the substrate 20G.

The altering of the focal point of the third thermal energy beam 40G" inside of the thermal conducting material 50G orients the basal planes 55G of the thermal conducting material 50G to extend from the substrate 20G. In this example, the altering of the focal point of the third thermal energy beam 40G" inside of the thermal conducting material 50G aligns the basal planes 55G to be generally perpendicular to the external surface or the first surface 21G of the substrate 20G. The alignment of the basal planes 55G of the thermal conducting material 50G to extend from the external surface of the substrate 20G further enhances the thermal conductivity between the first and the second regions of the substrate 20G. The thermal conducting material 50G having aligned basal planes 55G is indicated as ACM.

FIG. 17 illustrates the substrate 20G severed into a plurality of dies 60G. Each of the plurality of dies 60G defines a first region 61G and a second region 62G. The first region 61G comprises the thermal conducting material 50G whereas the second region 62G comprises the non-wide bandgap material 15G.

FIG. 18 is a side sectional view of one of the plurality of dies 60G of FIG. 17. The basal planes 55G of the thermal conducting material 50G act as a plurality of micro fins 65G extending in a parallel relationship to be orientated generally perpendicular to the external surface shown as the first surface 21G of the substrate 20G. The plurality of micro fins 65G effectively increase the surface area of first region 61G for increasing the transfer of heat between the first region 61G and an ambient such as ambient air or ambient vacuum. The plurality of micro fins 65G creates an integral heat exchanger with the substrate 20G.

The die 60G may be further fabricated into various types of devices such as sensors, detectors, electrical components, integrated circuits and the like. In this example, plural electronic components 71G and 72G are formed within the non-wide bandgap material 15G. Preferably, the plural electronic components 71G and 72G are formed in the non-wide bandgap material 15G in a conventional manner as should be well known in the art. However, the plural electronic components 71G and 72G may be formed by scanning the thermal energy beam 40 across selected portions of the non-wide bandgap material 15G in the presence of a doping atmosphere to form the plural electronic components 71G and 72G.

It is evident that increased thermal conductivity of the dies 60G may transfer heat from the plural electronic components 71G and 72G on the second region 62G to the first region 61G to cool the plural electronic components 71G and 72G. However, it should be appreciated by those skilled in the art that increased thermal conductivity of the die 60G can transfer heat from the first region 61G to heat the plural electronic components 71G and 72G on the second region 62G.

FIG. 19 is a side sectional view of a convention die 601 of the prior art incorporated into a conventional heat spreader 801 and a conventional heat sink 901 of the prior art. The die 601 defines a first region 611 and a second region 621. Plural electronic components 711 and 721 are located on the second region 621 of the die 601.

The conventional heat spreader 801 defines a first surface 811 and a second surface 821 whereas the conventional heat sink 901 defines a first surface 911 and a second surface 921. The first surface 911 of the conventional heat sink 901 defines a plurality of fins 951.

Heat generated by the plural electronic components 711 and 721 is transferred from the second region 621 to the first region 611 of the die 601. Heat from the first region 611 of the die 601 is transferred through the heat spreader 801 to the heat sink 901. The thermal conductivity between the first region 611 of the die 601 and the plurality of fins 951 is substantially reduced by the interfaces located at the first and second surfaces 811 and 821 of the conventional heat spreader 801.

The die 60G of the present invention incorporates several advantages over the die 601 of the prior art. Firstly, the substrate 20G has a higher thermal conductivity due to the presence of the wide bandgap material 10G and/or the presence of the thermal conducting material 50G. Secondly, the interfaces between the non-wide bandgap material 15G, the wide bandgap material 10G and/or the thermal conducting material 50G do not impede the thermal conductivity between the first region and second regions 61G and 62G of the die 60G. Thirdly, the die 60G of the present invention is an integral unit in contrast to the assembly of the die 601 of the prior art. Finally, the die 60G of the present invention is smaller than the assembly of the die 601 of the prior art.

FIGS. 20-23 illustrate a process for increasing the thermal conductivity of a substrate 201 formed from a silicon material 151. The process for increasing the thermal conductivity shown in FIGS. 20-23 may or may not be a part of the prior art.

FIG. 20 is a side sectional view of a silicon substrate 201 formed from a silicon material 151. The substrate 201 defines
a first and a second surface 211 and 221 and a peripheral edge 231. In this example, a first region 611 of the substrate 201 is located in proximity to the first surface 211 of the substrate 201 whereas a second region 621 of the substrate 201 is located in proximity to the second surface 221 of the substrate 201.

FIG. 21 is a side sectional view of the silicon substrate 201 of FIG. 20 with a layer of silicon carbide material 101 deposited onto the first side 211 of the silicon substrate 201 by a conventional vapor deposition process. The process of depositing a silicon carbide material 101 onto a substrate 201 by a conventional vapor should be well known to those skilled in the art.

FIG. 22 is a side sectional view of the substrate 201 of FIG. 21 with a layer of thermal conducting material 501 deposited onto the silicon carbide material 501 by a conventional vapor deposition process. The thermal conducting material 501 is shown as a carbon material 541.

FIG. 23 is a magnified view of a portion of FIG. 22 illustrating the alignment of the molecular basal planes 551 of the carbon material 541. The basal planes 551 of the carbon material 541 are shown as planes A-B-A. The planes A-B-A of the basal planes 551 are formed to be generally parallel to the first side 211 of the silicon substrate 201 by the conventional vapor deposition process.

FIGS. 20-23 illustrate a process for increasing the thermal conductivity of a substrate 201 formed from a silicon material 151. The process for increasing the thermal conductivity shown in FIGS. 20-23 increases the thickness of the assembly as the layers of silicon carbide material 101 and the thermal conducting material 501 are added onto the silicon substrate 201. Furthermore, the conventional vapor deposition processes creates an interface between the silicon substrate 201 and the silicon carbide material 101 as well as creating an interface between the silicon carbide material 101 and the thermal conducting material 501.

FIGS. 24-29 illustrate a process of the present invention for increasing the thermal conductivity of a substrate 201 formed from a silicon material 151. As will be described in greater detail hereinafter, the process utilizes the thermal energy beams in a manner similar to the process shown in FIGS. 13-16.

FIG. 24 is a side sectional view of a silicon substrate 201 formed from a silicon material 151. The substrate 201 defines a first and a second surface 211 and 221 and a peripheral edge 231. In this example, a first region 611 of the substrate 201 is located in proximity to the first surface 211 of the substrate 201 whereas a second region 621 of the substrate 201 is located in proximity to the second surface 221 of the substrate 201.

FIG. 25 is a side sectional view of the silicon substrate 201 of FIG. 24 with a portion of the first region 611 being converted into a layer of silicon carbide material 101. A first thermal energy beam (not shown) is directed onto a substrate 201 having lattice vacancies. In this example, a first region 611 of the substrate 201 in the presence of a carbon donating doping gas to diffuse carbon into the lattice vacancies to create a carbon rich layer having an atomic structure defining basal planes 551. The carbon donating doping gas may be selected from the group consisting of methane and acetylene.

Table 3 lists various parameters for converting a portion of the silicon substrate 201 into a layer of silicon carbide material 101.

A second thermal energy beam (not shown) in combination with the second reacting gas diffuses silicon of the silicon carbide material 101 to the first surface 211 thereby creating a layer of silicon carbide material 101 having lattice vacancies. The second reacting gas may be selected from the group consisting of carbon monoxide and carbon dioxide. The carbon monoxide and/or carbon dioxide react with the diffused silicon to form a silicon oxide gas and prevent oxidation of the substrate surface.

Table 4 lists various parameters for diffusing carbon into the lattice vacancies to create a carbon rich layer having an atomic structure defining basal planes 551.

FIG. 26 is a side sectional view of the substrate 201 of FIG. 25 with portion of the silicon carbide material 101 being converted into a layer of thermal conducting carbon material 501. A second thermal energy beam (not shown) is scanned in two dimensions across the wide bandgap material 101 in the presence of second reacting gas.

The second thermal energy beam (not shown) in combination with the second reacting gas diffuses silicon of the silicon carbide material 101 to the first surface 211 thereby creating a layer of silicon carbide material 101 having lattice vacancies. The second reacting gas may be selected from the group consisting of carbon monoxide and carbon dioxide. The carbon monoxide and/or carbon dioxide react with the diffused silicon to form a silicon oxide gas and prevent oxidation of the substrate surface.

Table 2 lists various parameters for converting a portion of the silicon substrate 201 into a layer of silicon carbide material 101.

<table>
<thead>
<tr>
<th>Laser Type</th>
<th>Excimer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength (nm)</td>
<td>248</td>
</tr>
<tr>
<td>Laser Fluence (J/cm²)</td>
<td>1.5</td>
</tr>
<tr>
<td>Pulse Repetition Rate (kHz)</td>
<td>1.0</td>
</tr>
<tr>
<td>Number of Pulses</td>
<td>600</td>
</tr>
<tr>
<td>Beam Area (2 mm x 2.5 mm)</td>
<td>5.0</td>
</tr>
<tr>
<td>Scanning Phase (mm/s)</td>
<td>X - Y (surface)</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>Methane</td>
</tr>
</tbody>
</table>

A third thermal energy beam (not shown) is directed onto the layer of silicon carbide material 101 having lattice vacancies in the presence of a third carbon donating doping gas to diffuse carbon into the lattice vacancies to create a carbon rich layer having an atomic structure defining basal planes 551. The third carbon donating doping gas may be selected from the group consisting of methane and acetylene.

Table 4 lists various parameters for diffusing carbon into the lattice vacancies to create a carbon rich layer having an atomic structure defining basal planes 551.

<table>
<thead>
<tr>
<th>Laser Type</th>
<th>Excimer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength (nm)</td>
<td>248</td>
</tr>
<tr>
<td>Laser Fluence (J/cm²)</td>
<td>1.5</td>
</tr>
<tr>
<td>Pulse Repetition Rate (kHz)</td>
<td>1.0</td>
</tr>
<tr>
<td>Number of Pulses</td>
<td>600</td>
</tr>
<tr>
<td>Beam Area (2 mm x 2.5 mm)</td>
<td>5.0</td>
</tr>
<tr>
<td>Scanning Phase (mm/s)</td>
<td>X - Y (surface)</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>Methane</td>
</tr>
</tbody>
</table>

FIG. 27 is a magnified view of a portion of FIG. 26 illustrating the alignment of the crystal lattice basal planes 551 of the carbon material 541. The basal planes 551 of the carbon material 541 are shown as planes A-B-A. The planes A-B-A of
the basal planes are formed to be generally parallel to the first side of the silicon substrate.

FIG. 28 illustrates a side sectional view of the silicon substrate of FIG. 27 with the crystal lattice basal planes being oriented generally perpendicular to the first surface of the substrate. A fourth thermal energy beam is focused inside the carbon material for aligning the basal planes of the carbon material to be generally perpendicular to an external surface of the substrate to enhance the thermal conductivity between the first and the second regions of the substrate for cooling the silicon substrate.

The fourth thermal energy beam (not shown) is scanned in two dimensions across the carbon material while simultaneously altering the focal point inside of the carbon material. The focal point of the fourth thermal energy beam (not shown) is positioned inside of the carbon material with the focal point being gradually moved toward the first surface of the substrate. The movement of the focal point of the fourth thermal energy beam (not shown) within the carbon material is a side sectional view of the substrate formed generally parallel to an external surface shown as the first surface of the substrate.

The three dimensional movement of the fourth thermal energy beam results in the melting and/or solid state diffusion of the basal planes formed generally parallel to the first side of the substrate. The three dimensional movement of the fourth thermal energy beam results in a controlled crystallization or recrystallization of the basal planes to be generally perpendicular to an external surface shown as the first surface of the substrate.

Table 5 lists various parameters for aligning the basal planes of the carbon material to be generally perpendicular to an external surface shown as the first surface of the substrate.

Table 5:

<table>
<thead>
<tr>
<th>Laser Type</th>
<th>Nd:YAG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength (nm)</td>
<td>1064</td>
</tr>
<tr>
<td>Pulse Width (ns)</td>
<td>260</td>
</tr>
<tr>
<td>Pulse Repetition Rate (kHz)</td>
<td>35</td>
</tr>
<tr>
<td>Power (W)</td>
<td>69.3</td>
</tr>
<tr>
<td>Beam Diameter (μm)</td>
<td>1.0</td>
</tr>
<tr>
<td>Beam Scan Rate (mm/s)</td>
<td>5.0</td>
</tr>
<tr>
<td>Scanning Plane (mm/s)</td>
<td>Z - Y, Z - X, Z perpendicular to substrate</td>
</tr>
</tbody>
</table>

FIG. 29 is a magnified view of a portion of FIG. 28 illustrating the alignment of the molecular basal planes of the carbon material. The basal planes of the carbon material are formed to be generally parallel to the first side of the silicon substrate. This configuration, the term aligning the basal planes to be generally parallel to the external surface to the first side of the silicon substrate should be interpreted as a statistical significant number of molecules of the carbon material being oriented within forty-five degrees of a perpendicular extending from the external surface of the first side of the silicon substrate.
mitting the laser beam through the substrate from the bottom materials. The thermal conductivity of silicon carbide is three
tion through the material from a top surface to this bottom
the silicon substrate

...regions do not exceed the melting or sublimation point of the
...where scanning is in the x-y plane. Various allotropes of
...or deposited on the top surface of a wide bandgap material
...is preferred that the laser is focused on the top surface by trans-
...is shown as a graphite structure in FIGS. 23, 27 and 29, it
...of crystalline planes. The energy necessary to form the
...atom. This process creates an excess electron population at
...producing laser beams with polarizations in different directions are
...A high intensity laser beam generates an enormous amount of electric field. The direction of this electric field is given by the polarization
...CRE: Soc. Symp., Proc. Vol 764, 2003 Materials Research Society. See Fig. 3, where conductive tracks are
...be focused to very high intensities in order to induce multiphoton absorption only at the focal point. This method provides a mechanism to control the dissociation of CH₄ in
...plane with carbon-carbon bonds in a hexagonal array. A typical
...substrate surface interface and consequently the formation of a carbon plane with carbon-carbon bonds in a hexagonal array. A typical
...atomic layer of silicon carbide substrate or region to graphene by scanning the laser beam primarily in the x-y plane. It is
...and in a controlled manner by bond engineering using laser polarization.

Since lasers are electromagnetic waves, a high intensity laser beam generates an enormous amount of electric field. The direction of this electric field is given by the polarization
...substrate surface near the laser beam and modifies the substrate surface potential, resulting in an electrostatic field. This field contributes to the energy required for forming the C—C bonds. Thus the Si substrate behaves as a catalyst to facilitate the graphene formation.

FIG. 36 is an isometric view of graphene islands located on a substrate. The present invention can be used to deposit graphene at isolated spots on the substrate surface so that the
graphene islands can be used for fabricating devices such as transistors, diodes and capacitors. This technology can also be used to deposit graphene lines as interconnects among these islands. Preferably, excess graphene creates the required islands and lines.

The methane gas is contained in an absorption cell and a 532 nm wavelength (green) laser beam is focused on the gas-substrate interface to a very high intensities to induce multiphoton absorption. The intensity at the inlet \(I_0\) and outlet \(I_n\) of the cell is measured as a function of the gas pressure. These data are plotted as \(\ln(I_n/I_0)\) versus gas pressure. The slope of this plot is the absorption coefficient. A straight line (linear) plot indicates single photon absorption and a nonlinear plot indicates multiphoton absorption. This technique enables the determination of the laser intensity and gas pressure for multiphoton photolytic laser chemical vapor deposition; the production of pure carbon for deposition on silicon. Raman and FTIR spectroscopy are used for in situ analysis using a chamber with two line of sight windows. A wireless remote chemical sensor is also used that correlates changes in refractive index to chemical changes. This latter technology is the subject of our patent application Ser. No. 11/340,883.

The present invention provides a process for forming a wide bandgap material within a non-wide bandgap substrate to enhance the thermal conductivity and heat dissipation of the substrate. A thermal conducting material may be formed in situ within a wide bandgap material to enhance further the thermal conductivity and heat dissipation thereof. The formation of the wide bandgap material and/or the thermal conducting material in situ creates a continuous or diffuse boundary as opposed to a discrete boundary and matches the coefficient of thermal expansion of the prior art.

The present disclosure includes that contained in the appended claims as well as that of the foregoing description. Although this invention has been described in its preferred form with a certain degree of particularity, it is understood that the present disclosure of the preferred form has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and scope of the invention.

What is claimed is:

1. A method for synthesizing graphene, comprising the steps of:
   providing a substrate;
   focusing a laser beam in the presence of a carbon doping gas to induce two photon photolytic decomposition of the carbon doping gas only near the gas-substrate surface interface at the laser focal point to produce a plane of atomic carbon with carbon-carbon bonds in a hexagonal array; and
   continuing focusing the laser beam to photolytically react the carbon with the substrate to grow graphene.

2. A method for synthesizing graphene, comprising the steps of:
   providing a silicon substrate;
   focusing a laser beam in the presence of a carbon doping gas to induce two photon photolytic decomposition of the carbon doping gas only near the gas-silicon substrate surface interface at the laser focal point to produce a plane of atomic carbon with carbon-carbon bonds in a hexagonal array; and
   continuing focusing the laser beam to photolytically react the carbon with the silicon substrate to grow graphene.

3. A method for synthesizing graphene as set forth in claim 2 wherein the graphene is limited to 3 planes of hexagonally oriented carbon.

4. A method for synthesizing graphene as set forth in claim 2 wherein the step of focusing the laser beam includes focusing the laser beam on portion of the silicon substrate to create islands and connecting lines of graphene on the surface of the silicon substrate.

5. A method of forming graphene, comprising the steps of:
   providing a silicon carbide substrate transparent to 532 nm wavelength;
   immersing a top surface of the silicon carbide substrate in carbon containing doping gas; and
   focusing a 532 nm laser from a bottom surface to the top surface of the silicon carbide substrate to photolytically decompose the carbon on the top surface of the silicon carbide substrate growing graphene on the top surface of the silicon carbide substrate.

6. A method for synthesizing graphene as set forth in claim 7 wherein the graphene is limited to 3 planes of hexagonally oriented carbon.

7. A method of forming graphene, comprising the steps of:
   providing a wide bandgap substrate transparent to 532 nm wavelength;
   immersing a top surface of the wide bandgap substrate in carbon containing doping gas; and
   focusing a 532 nm laser from a bottom surface to the top surface of the wide bandgap substrate to photolytically decompose the carbon on the top surface of the wide bandgap substrate growing graphene on the top surface of the wide bandgap substrate.

* * * * *