US008080836B2

(12) **United States Patent** (10) **Patent No.:** **US 8,080,836 B2**
Quick et al. (45) **Date of Patent:** **Dec. 20, 2011**

(54) **EMBEDDED SEMICONDUCTOR COMPONENT**

(75) Inventors: **Nathaniel R. Quick**, Lake Mary, FL (US); **Aravinda Kar**, Oviedo, FL (US); **Islam A. Salama**, Chandler, AZ (US)

(73) Assignee: **University of Central Florida** FL (US), part interest

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 113 days.

(21) Appl. No.: **11/825,809**

(22) Filed: **Jul. 9, 2007**

(65) **Prior Publication Data**

US 2008/0017896 A1 Jan. 24, 2008

(51) **Int. Cl.**
H01L 21/02 (2006.01)
(52) **U.S. Cl.** **257/284**; 257/77; 257/E21.102; 257/E21.134; 257/E21.17
(58) **Field of Classification Search** 257/284, 257/E21.102, E21.131, 77, E21.134, E21.17
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,214,315 A	10/1965	Hildebrand
3,396,401 A	8/1968	Nonomura
3,419,321 A	12/1968	Barber et al.
3,605,469 A	9/1971	Queralto
3,788,120 A	1/1974	Takeo et al.
3,854,123 A	12/1974	Banach
3,865,564 A	2/1975	Jaeger et al.
3,874,240 A	4/1975	Rembaum
3,943,324 A	3/1976	Haggerty
3,944,640 A	3/1976	Haggerty et al.

3,945,318 A	3/1976	Landsman
3,965,328 A	6/1976	Locke
3,981,705 A	9/1976	Jaeger et al.
4,043,170 A	8/1977	Erodi et al.
4,135,902 A	1/1979	Oehrle
4,142,088 A	2/1979	Hirsch
4,159,414 A	6/1979	Suh et al.
4,215,263 A	7/1980	Grey et al.
4,309,224 A	1/1982	Shibata
4,339,285 A	7/1982	Pankove

(Continued)

FOREIGN PATENT DOCUMENTS

JP 358095830 A 6/1983

(Continued)

OTHER PUBLICATIONS

Nathaniel R. Quick, Laser Conversion of Ceramic Materials to Electroconductors, International Conference on Electronic Materials-1990, Materials Research Society, Newark, New Jersey, Sep. 17-19, 1990.

(Continued)

*Primary Examiner* — Wael Fahmy
Assistant Examiner — John C Ingham
(74) *Attorney, Agent, or Firm* — Frijouf, Rust & Pyle P.A.

(57) **ABSTRACT**

A process is disclosed for in-situ fabricating a semiconductor component imbedded in a substrate. A substrate is ablated with a first laser beam to form a void therein. A first conductive element is formed in the void of the substrate with a second laser beam. A semiconductor material is deposited upon the first conductive element with a third laser beam operating in the presence of a depositing atmosphere. A second conductive element is formed on the first semiconductor material with a fourth laser beam. The process may be used for fabricating a Schottky barrier diode or a junction field effect transistor and the like.

23 Claims, 9 Drawing Sheets
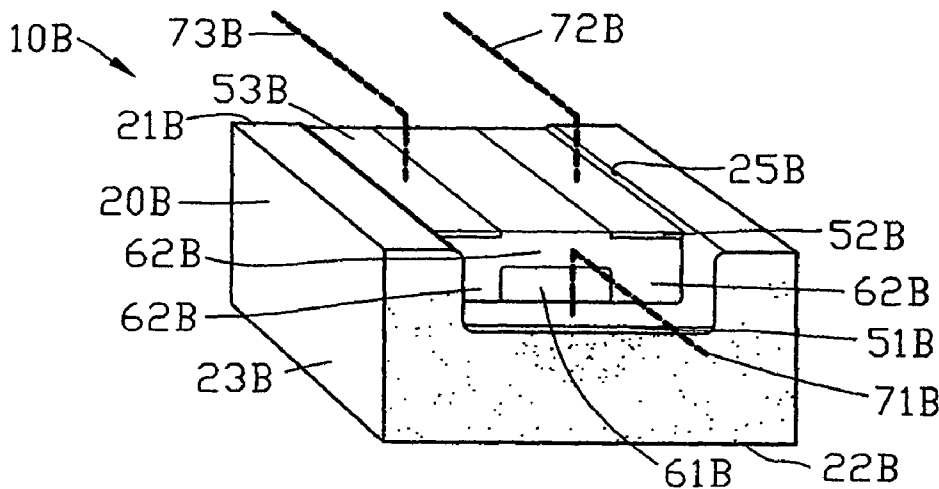
U.S. PATENT DOCUMENTS

4,372,989 A	2/1983	Menzel	
4,383,843 A	5/1983	Iyengar	
4,496,607 A	1/1985	Mathias	
4,539,251 A	9/1985	Sugisawa et al.	
4,547,650 A	10/1985	Arditty et al.	
4,565,712 A	1/1986	Noguchi et al.	
4,620,264 A	10/1986	Ushifusa et al.	
4,624,934 A	11/1986	Kokubu et al.	
4,663,826 A	5/1987	Bauerle	
4,691,091 A	9/1987	Lyons et al.	
4,710,253 A	12/1987	Soszek	
4,761,339 A	8/1988	Komatsu et al.	
4,791,239 A	12/1988	Sirahata et al.	
4,840,853 A	6/1989	Lio et al.	
4,847,138 A	7/1989	Boylan et al.	
4,860,442 A	8/1989	Ainsworth et al.	
4,872,923 A	10/1989	Borodin	
4,880,770 A	11/1989	Mir et al.	
4,901,550 A	2/1990	Koide	
4,912,087 A	3/1990	Aslam et al.	
4,924,033 A	5/1990	Iyogi et al.	
4,950,558 A	8/1990	Sarin	
4,962,085 A	10/1990	deBarbadillo, II et al.	
4,988,564 A	1/1991	D'Angelo et al.	
5,015,618 A	5/1991	Levinson	
5,055,967 A	10/1991	Sukonnik et al.	
5,063,421 A	11/1991	Suzuki et al.	
5,127,364 A	7/1992	Savkar et al.	
5,145,741 A	9/1992	Quick	
5,149,681 A	9/1992	Ohkawa et al.	
5,180,440 A	1/1993	Siegel et al.	
5,243,204 A	9/1993	Suzuli et al.	
5,336,360 A	8/1994	Nordine	
5,391,841 A	2/1995	Quick	
5,405,481 A	4/1995	Licoppe et al.	
5,416,342 A	5/1995	Edmond et al.	
5,459,098 A	10/1995	Maya	
5,493,096 A	2/1996	Koh	
5,549,971 A	8/1996	Nordine	
5,629,532 A	5/1997	Myrick	
5,680,200 A	10/1997	Sugaya et al.	
5,695,828 A	12/1997	Ghosh et al.	
5,733,609 A	3/1998	Wang	
5,754,299 A	5/1998	Sugaya et al.	
5,793,042 A	8/1998	Quick	
5,823,039 A	10/1998	Umeda et al.	
5,837,607 A	11/1998	Quick	
5,847,418 A	12/1998	Nakamura et al.	
5,889,234 A	3/1999	Ghosh et al.	
5,906,708 A	5/1999	Robinson et al.	
5,961,877 A	10/1999	Robinson et al.	
6,025,609 A	2/2000	Quick	
6,054,375 A	4/2000	Quick	
6,064,081 A	5/2000	Robinson et al.	
6,203,861 B1	3/2001	Kar et al.	
6,221,154 B1	4/2001	Lee et al.	
6,252,197 B1	6/2001	Hoekstra et al.	
6,255,671 B1	7/2001	Bojarczuk et al.	
6,271,576 B1 *	8/2001	Quick	257/588
6,274,234 B1	8/2001	Dujardin et al.	
6,313,015 B1	11/2001	Lee et al.	
6,329,213 B1 *	12/2001	Tuttle et al.	438/19
6,334,939 B1	1/2002	Zhou et al.	
6,407,443 B2	6/2002	Chen et al.	
6,468,638 B2 *	10/2002	Jacobsen et al.	428/209
6,526,327 B2	2/2003	Kar et al.	
6,566,704 B2 *	5/2003	Choi et al.	257/314
6,621,448 B1	9/2003	Lasky et al.	
6,670,693 B1	12/2003	Quick	
6,732,562 B2	5/2004	Quick et al.	
6,900,465 B2	5/2005	Nakamura et al.	
6,930,009 B1	8/2005	Quick	
6,939,748 B1	9/2005	Quick	
6,998,690 B2	2/2006	Nakamura et al.	
7,045,375 B1	5/2006	Wu et al.	
7,051,429 B2 *	5/2006	Kerr et al.	29/825
7,237,422 B2	7/2007	Quick	
7,253,735 B2 *	8/2007	Gengel et al.	340/572.7
7,268,063 B1	9/2007	Quick	
7,362,785 B2 *	4/2008	Kohara et al.	372/36
7,416,993 B2 *	8/2008	Segal et al.	438/742
7,419,887 B1	9/2008	Quick	
7,630,147 B1	12/2009	Kar et al.	
7,811,914 B1	10/2010	Quick et al.	
7,897,492 B2	3/2011	Quick	

FOREIGN PATENT DOCUMENTS

JP	358095830 A	6/1983	
JP	405024975 A	2/1993	
JP	405024975 A	2/1993	
WO	WO 03013757	2/2003	

OTHER PUBLICATIONS

Nathaniel R. Quick, Direct Conversion of Conductors on Ceramic Substrates, International Society for Hybrid Microelectronics, ISHM 90 Proceedings 1990.

Nathaniel R. Quick and Jeffrey A. Phillips, Laser Processes for Integrating Substrate Fabrication, Proceedings of the International Conference on Lasers '91, The Society for Optical & Quantum Electronics, pp. 537-544 San Diego, CA Dec. 9-13, 1991.

Nathaniel R. Quick and Richard J. Matson, Characterization of a Ceramic Electrical Conductor Synthesized by a Laser Conversion Process, Proceedings of the International Conference on Lasers '91, The Society for Optical & Quantum Electronics, pp. 545-552 San Diego, CA Dec. 9-13, 1991.

Nathaniel R. Quick, Characterization of a Ceramic Sensor Synthesized by a Laser Conversion Process, Proceedings of the International Conference on Lasers '92, The Society for Optical & Quantum Electronics, pp. 881-887 Houston, Texas Dec. 7-10, 1992.

Nathaniel R. Quick, Characterization of a Ceramic Thermal Sensor Synthesized by a Laser Conversion Process, ICALEO '92 (International Congress on Applications of Lasers and Electro-Optics), vol. 75 Laser Materials Processing, Laser Institute of America, pp. 394-404 Oct. 25-29, 1992.

D. K. Sengupta, N. R. Quick and A. Kar, Laser Direct Write of Conducting and Insulating Tracks in Silicon Carbide, Materials Research Society Symposium Proceedings vol. 624 pp. 127-133 2000.

D. K. Sengupta, N. R. Quick and A. Kar, Laser Conversion of Electrical Properties for Silicon Carbide Device Applications, Journal of Laser Applications., 2001, vol. 13, pp. 26-31.

I.A. Salama, N.R. Quick and A. Kar, Laser Doping of Silicon Carbide Substrates, Journal of Electronic Materials, vol. 31, 2002, pp. 200-208.

I.A. Salama, N. R. Quick and A. Kar, Microstructural and electrical resistance analysis of laser-processed SiC substrates for wide bandgap semiconductor materials, Journal of Materials Science, vol. 40, 2005, pp. 3969-3980.

I.A. Salama, N. R. Quick and A. Kar, Laser Synthesis of Carbon-Rich SiC Nanoribbons, Journal of Applied Physics, vol. 93, 2003, pp. 9275-9281.

I.A. Salama, N.R. Quick, and A. Kar, Laser Direct Write Doping of Wide-Bandgap Semiconductor Materials, IEEE ISCS 2003 Proceedings.

A. Salama, C. F. Middleton, N. R. Quick G. D. Boreman and A. Kar, Laser-Metallized Silicon Carbide Schottky Diodes for Millimeter Wave Detection and Frequency Mixing, Symposium N1 Nitride and Wide Bandgap Semiconductors for Sensors, Photonics and Electronics IV, 204th Meeting of the Electrochemical Society, Orlando, Florida Oct. 12-16, 2003.

A. Salama, N. R. Quick and A. Kar, Laser Direct Metallization of Silicon Carbide without Metal Deposition, Symposium C, New Applications for Wide Bandgap Semiconductors, Materials Research Society, Apr. 23-24, 2003.

I. A. Salama, N. R. Quick and A. Kar, Laser-induced Dopant Incorporation in Wide Bandgap Materials: SiC and GaN, ICALEO 2003 (International Congress on Applications of Lasers and Electro-Optics) Proceedings, 2003.

I.A. Salama, N.R. Quick, and A. Kar, Laser Direct Writing and Doping of Diamond-like Carbon, Polycrystalline Diamond and Single Crystal Silicon Carbide, Journal of Laser Applications, vol. 16, 2004, pp. 92-99.

Z. Tian, N. R. Quick and A. Kar, Laser Direct Write and Gas Immersion Laser Doping Fabrication of SiC Diodes, J: Silicon Carbide Materials, Procesing and Devices, Symposium J Apr. 14-15, 2004.

Z. Tian, N. R. Quick and A. KAr, Laser Doping of Silicon Carbon and PIN Diode Fabrication, 23rd International Congress on Applications of Lasers & Electro-Optics 2004.

A. Kar and N. R. Quick, Laser Processing for Wide Bandgap Semiconductor Device Fabrication, 2004 Meeting of Optical Society of America, 2004.

Z. Tian, I.A. Salama, N. R. Quick and A. Kar, Effects of Different laser Sources and Doping Methods used to Dope Silicon Carbide, Acta Materialia, vol. 53, 2005, pp. 2835-2844.

Z. Tian, N. R. Quick and A. Kar; Characteristics of 6H-Silicon Carbide PIN Diodes Prototyping by Laser Doping, Journal of Electronic Materials, vol. 34, 2005, pp. 430-438.

Chong Zhang, A. Salama, N. R. Quick and A. Kar, Two-Dimensional Transient Modeling of CO2 Laser Drilling of Microvias in High Density Flip Chip Substrates, ICALEO 2005 (International Congress on Applications of Lasers and Electro-Optics), Laser Institute of America, Oct. 31- Nov. 3, 2005.

Chong Zhang, S. Bet, A. Salama, N. R. Quick and A. Kar, CO2 Laser Drilling of Microvias Using Diffractive Optics Techniques: I Mathematical Modeling, InterPack 05, The ASME/Pacific Rim Technical Conference on Integration and Packaging of MEMS, NEMS and Electronic Systems, San Francisco, CA Jul. 17-22, 2005.

Z. Tian, N. R. Quick and A. Kar, Laser Synthesis of Optical Structures in Silicon Carbide, 207th Meeting of the Electrochemical Society Proceedings, May 15-20, 2005.

Z. Tian, N. R. Quick and A. Kar, Laser-enhanced diffusion of nitrogen and aluminum dopants in silicon carbide, Acta Materiallia, vol. 54, 2006, pp. 4273-4283.

Z. Tian, N. R. Quick and A. Kar,Laser Direct Write Doping and Metallization Fabrication of Silicon Carbide PIN Diodes, Materials Science Forum, vols. 527-529, 2006, pp. 823-826.

S. Dakshinamurthy, N.R. Quick and A. Kar, SiC-based Optical Interferometry at high pressures and temperatures for pressure and chemical sensing, Journal of Applied Physics, vol. 99, 2006, pp. 094902-1 to 094902-8.

C. Zhang, A. Salama, N. R. Quick and A. Kar, Modelling of Microvia Drilling with a Nd:YAG Laser, Journal of Physics D: Applied Physics 39 (2006) 3910-3918.

Z. Tian, N. R. Quick and A. Kar, Laser Endotaxy and PIN Diode Fabrication of Silicon Carbide, 2006 Spring Meting of Materials Research Society, 2006.

Z. Tian, N. R. Quick and A. Kar, Characteristics of Laser-Fabricated Diodes on Endotaxial Silicon Carbide Substrates, ESCRM (European Conference on Silicon Carbide and Related Materials) Proceedings 2006.

S. Bet, N.R. Quick and A. Kar, Laser Doping of Chromium and Selenium in p-type 4H-SiC, ICSCRM 2007 Symposium.

N. Quick, S. Bet and A. Kar, Laser Doping Fabrication of Energy Conversion Devices Materials Science and Technology 2007 Conference and Exhibition.

S. Bet, N.R. Quick and A. Kar, Effect of Laser Field and Thermal Stress on Diffusion in Laser Doping of SiC, Acta Materialia 55 (2007) 6816-6824.

S. Bet, N. R. Quick and A. Kar, Laser-Doping of Silicon Carbide for p-n Junction and LED Fabrication, Physica Status Solidi (A), vol. 204, No. 4, 2007, pp. 1147-1157.

S. Dakshinamurthy, N.R. Quick and A. Kar, Temperature-dependent Optical Properties of Silicon Carbide for Wireless Temperature Sensors, Journal of PhysicsD: Applied Physics 40 (2007)353-360.

S. Dakshinamurthy, N.R. Quick and A. Kar, High temperature optical properties of silicon carbide for wireless thermal sensing, Journal of Physics D: Applied Physics, vol. 40, No. 2, 2007, pp. 353-360.

Chong Zhang, A. Salama, N. R. Quick and A. Kar, Determination of Thermophysical Properties for Polymer Films using Conduction Analysis of Laser Heating, International Journal of Thermophysics, vol. 28, No. 3, Jun. 2007.

N. R. Quick, S. Bet and A. Kar, Laser Doping Fabrication of Energy Conversion Devices, Materials Science and Technology 2007 Conference and Exhibition, Sep. 19, 2007.

S. Bet, N. R. Quick and A. Kar, Laser Doping of Chromium in 6H-SiC for White Light Emitting Diodes, Laser Institute of America, Journal of Laser Applications Vo. 20 No. 1 pp. 43-49 Feb. 2008.

Z. Tian, N. R. Quick and A. Kar, Laser Endotaxy in Silicon Carbide and PIN Diode Fabrication, Laser Institute of America, Journal of Laser Applications, vol. 20 No. 2 pp. 106-115, May 2008.

I. Salama, N. Quick and A. Kar, Laser Direct Write Doping of Wide-Bandgap Semiconductor Materials, ISCS 2003 Proceedings , 2003.

I. Salama, N. Quick and A. Kar, Laser Microprocessing of Wide Bandgap Materials, Proceedings of International Congress on Laser Advanced Materials Processing (LAMP 2002).

S. Bet, N. Quick and A. Kar, Laser Doping of Chromium and Selenium in P-Type 4H-SiC, Materials Science Forum vols. 600-603 (2009) pp. 627-630.
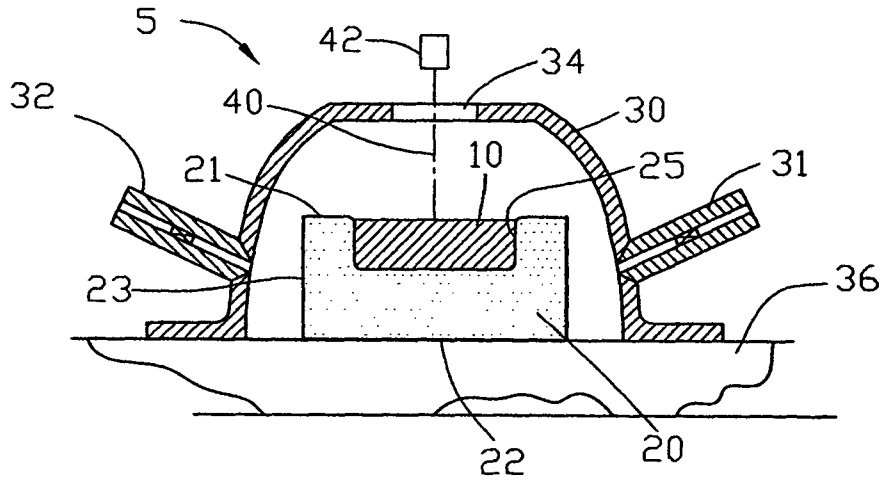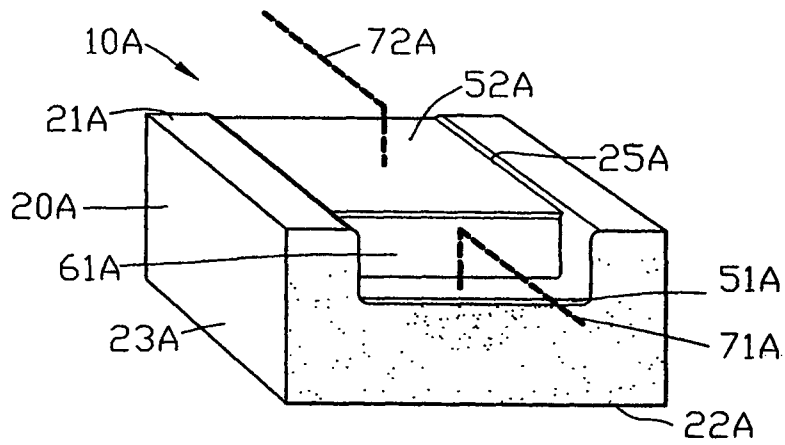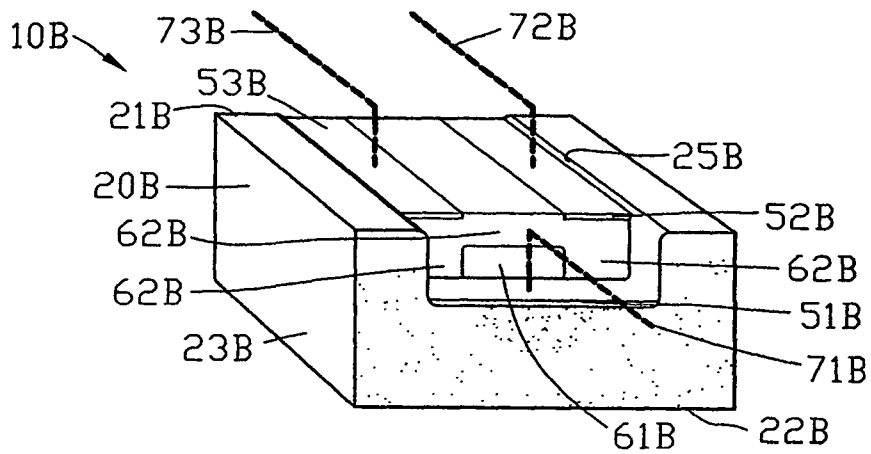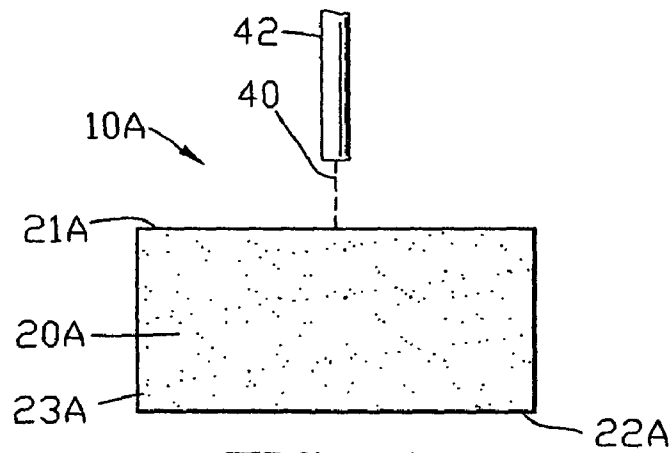
* cited by examiner

FIG. 1

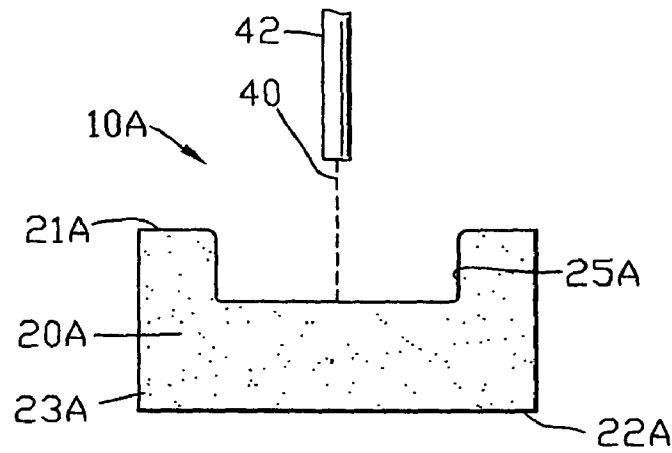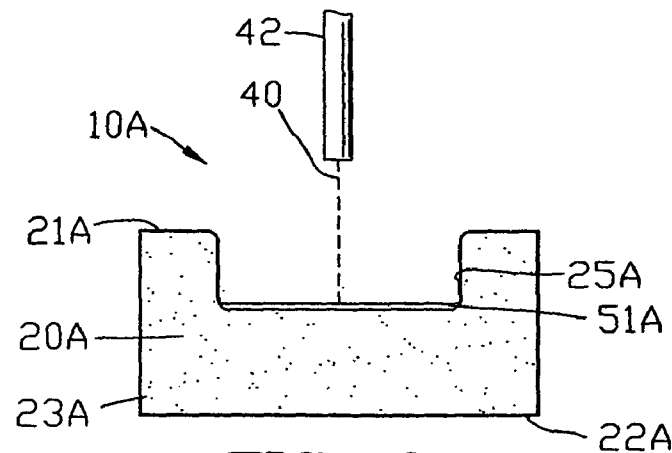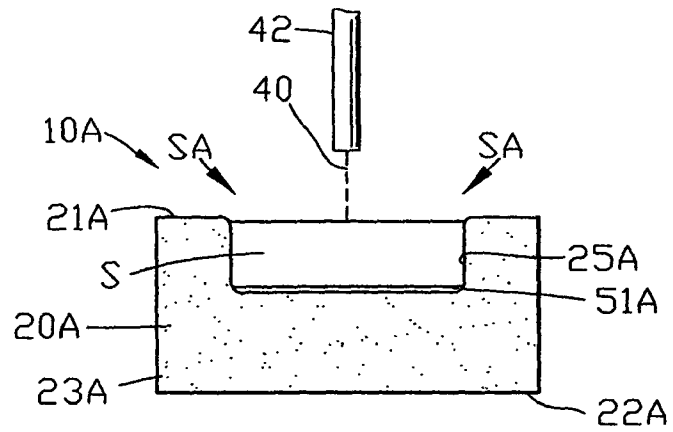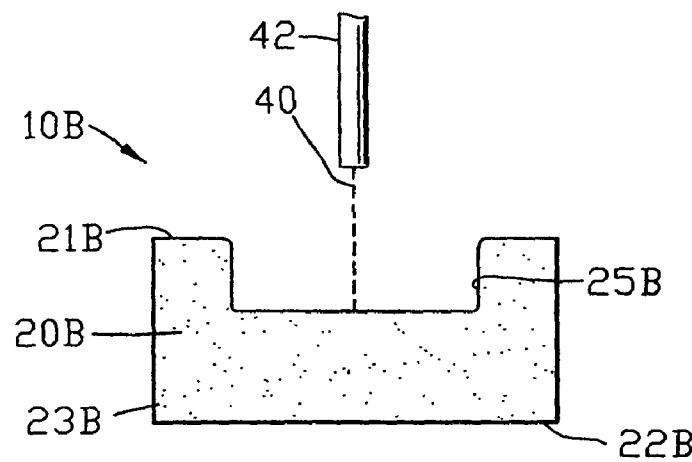
FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

42

40

10A　SA　　SA

21A

S

25A

51A

20A

23A

22A

FIG. 7

42

40

10A　P　　P

21A

61A

25A

51A

20A

23A

22A

FIG. 8

42

40

10A

21A

52A

61A

25A

51A

20A

23A

22A

FIG. 9

FIG. 10

FIG. 11

FIG. 12

42
40

10B
SA   SA

21B
25B
S
51B
20B
23B   22B

FIG. 13

42
40

10B
P   P

21B
25B
61B
51B
20B
23B   22B

FIG. 14

42   42
40   40

10B
N   N

21B
25B
62B
62B
20B
51B
23B   22B

FIG. 15

42

40

10B

TA   TA

21B
T
62B   25B
62B
51B
20B
23B
61B   22B

FIG. 16

42

40

10B

N   N

21B
63B   25B
62B   62B
51B
20B
23B
61B   22B

FIG. 17

42   42

40   40

10B   52B   53B

21B
63B   25B
62B   62B
51B
20B
23B
61B   22B

FIG. 18

10C
21C
61C
65C
61C
65C
61C
65C
61C
20C
23C
61C

75C
55C
74C
54C
73C
53C
72C
52C
25C
51C
71C
22C

FIG. 19

10C
21C
20C
23C
25C
22C

FIG. 20

FIG. 21

FIG. 22

10C
21C
61C
65C
61C
65C
61C
65C
61C
20C
25C
51C
23C
61C
22C

FIG. 23

10C
21C
61C
65C
61C
65C
61C
65C
61C
20C
55C
54C
53C
52C
25C
51C
23C
61C
22C

FIG. 24

EMBEDDED SEMICONDUCTOR COMPONENT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims benefit of United States Patent Provisional application Ser. No. 60/575,851 filed June 1, 2004. All subject matter set forth in provisional application Ser. No. 60/575,851 is hereby incorporated by reference into the present application as if fully set forth herein.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the fabrication of semiconductor components and more particularly to the in-situ fabrication of semiconductor components imbedded within a substrate through a laser synthesis process.
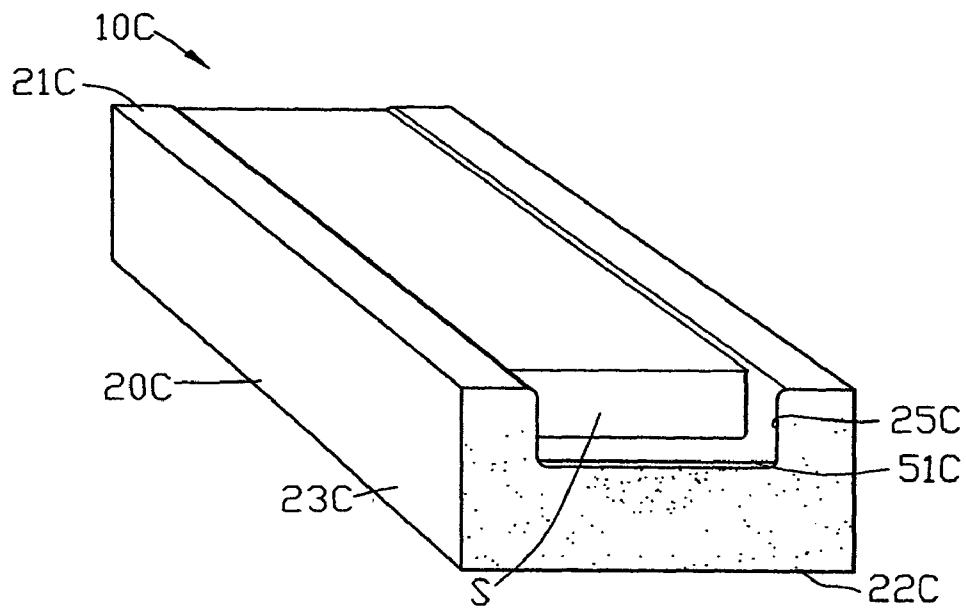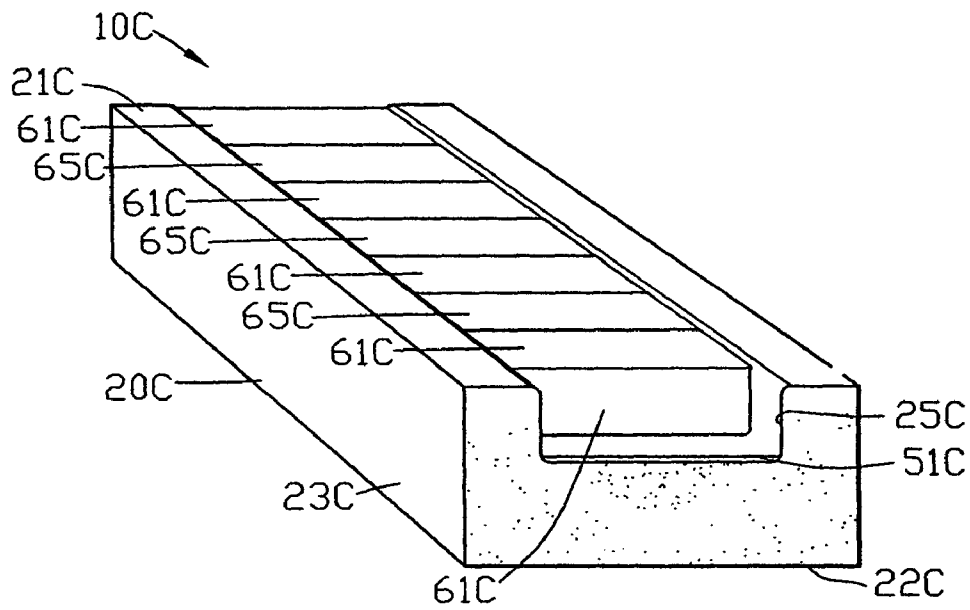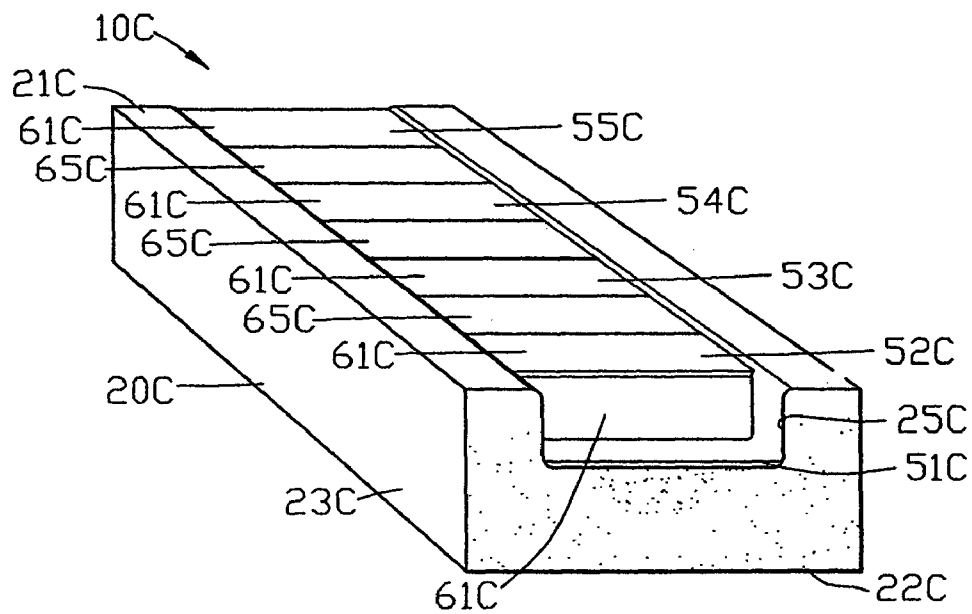
2. Description of the Related Art

Certain ceramics, such as silicon carbide (SiC) and aluminum nitride (AlN), are known to exhibit Certain ceramics, such as silicon carbide (SiC) and aluminum nitride (AlN), are known to exhibit electrical properties ranging including insulating properties, semiconducting properties as well as conducting properties. It is well known alumina (Al2O3) dominates the dielectric market as an integrating substrate or device carrier in electronics packaging. BN, AlN, SiC and diamond are also of interest, due to the thermal coefficient of expansion (TCE) and for the dielectric constant and higher thermal conductivity than that of Al2O3. SiC, AlN, BN, 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 packing.

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 AlN and SiC, have not been completely solved. Copper and silver paste exhibits a TCE mismatch aggravated by high temperatures as well as being subject to oxidation that increases the resistivity. In particular, bonding of copper to AlN has proved to be nontrivial. Alumina or stoichiometric aluminum oxynitride (AlON) coatings must be developed on the AlN surface through passivation processes. These passivation processes have poor reproducibility. Thus, the direct laser synthesis of conductors in AlN, SiC 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. The following U.S. patents illustrate apparatuses and methods represent some of the attempts of the prior art for developing conductor and semiconductor components.

U.S. Pat. No. 5,906,708 to Robinson et al discloses silicon-germanium-based compositions comprising silicon, germanium, and carbon (Si—Ge—C), methods for growing Si—Ge—C epitaxial layer(s) on a substrate, etchants especially suitable for Si—Ge—C etch-stops, and novel methods of use for Si—Ge—C compositions. In particular, the inven-

tion relates to Si—Ge—C compositions, especially for use as etch-stops and related processes and etchants useful for microelectronic and nanotechnology fabrication.

U.S. Pat. No. 5,961,877 to Robinson et al discloses silicon-germanium-based compositions comprising silicon, germanium, and carbon Si—Ge—C, methods for growing Si—Ge—C epitaxial layer(s) on a substrate, etchants especially suitable for Si—Ge—C etch-stops, and novel methods of use for Si—Ge—C compositions. In particular, the invention relates to Si—Ge—C compositions, especially for use as etch-stops and related processes and etchants useful for microelectronic and nanotechnology fabrication.

U.S. Pat. No. 6,064,081 to Robinson et al discloses silicon-germanium-based compositions comprising silicon, germanium, and carbon (Si—Ge—C), methods for growing Si—Ge—C epitaxial layer(s) on a substrate, etchants especially suitable for Si—Ge—C etch-stops, and novel methods of use for Si—Ge—C compositions. In particular, the invention relates to Si—Ge—C compositions, especially for use as etch-stops and related processes and etchants useful for microelectronic and nanotechnology fabrication.

U.S. Pat. No. 6,221,154 to Lee et al. discloses a method and an apparatus developed to grow beta-silicon carbide nano-rods, and prepare patterned field-emitters using different kinds of chemical vapor deposition methods. The apparatus includes graphite powder as the carbon source, and silicon powder as silicon sources. Metal powders (Fe, Cr and/or Ni) are used as catalyst. Hydrogen was the only feeding gas to the system.

U.S. Pat. No. 6,274,234 to Dujardin et al. discloses atomic wires of great length and great stability formed on the surface of a SiC substrate as straight chains of dimers of an element chosen from amongst SiC and C. In order to produce same, layers of the element are formed on the surface and the assembly is constructed by means of annealings of the surface provided with the layers. The resulting wires have application to nanoelectronics.

U.S. Pat. No. 6,313,015 to Lee et al. discloses silicon nanowires and silicon nanoparticle chains formed by the activation of silicon monoxide in the vapor phase. The silicon monoxide source may be solid or gaseous, and the activation may be by thermal excitation, laser ablation, plasma or magnetron sputtering. The present invention produces large amounts of silicon nanowires without requiring the use of any catalysts that may cause contamination.

U.S. Pat. No. 6,334,939 to Zhou et al. discloses a nano-structure based material capable of accepting and reacting with an alkali metal such as lithium. The material exhibits a reversible capacity ranging from at least approximately 900 mAh/g-1,500 mAh/g. The high capacity of the material makes it attractive for a number of applications, such as a battery electrode material.

U.S. Pat. No. 6,407,443 to Chen et al. discloses a method for forming a platen useful for forming nanoscale wires for device applications comprising: (a) providing a substrate having a major surface; (b) forming a plurality of alternating layers of two dissimilar materials on the substrate to form a stack having a major surface parallel to that of the substrate; (c) cleaving the stack normal to its major surface to expose the plurality of alternating layers; and (d) etching the exposed plurality of alternating layers to a chosen depth using an etchant that etches one material at a different rate than the other material to thereby provide the surface with extensive strips of indentations and form the platen useful for molding masters for nano-imprinting technology. The pattern of the platen is then imprinted into a substrate comprising a softer material to form a negative of the pattern, which is then used

in further processing to form nanowires. The nanoscale platen thus comprises a plurality of alternating layers of the two dissimilar materials, with the layers of one material etched relative the layers of the other material to form indentations of the one material. The platen is then oriented such that the indentations are perpendicular to a surface to be imprinted.

In the prior United States patents of one of the inventors of the present invention, Dr. Nathanial R. Quick disclosed various processes for forming diverse types of apertures or vias, conductors, semiconductors, insulators and semiconductor components within a wide band gap semiconductor substrate. Many of these processes incorporated the laser synthesis of a wide-bandgap semiconductor substrate.

The prior patents of Dr. Nathanial R. Quick include the following United States Letters Patent, namely U.S. Pat. Nos. 5,145,741, 5,391,841, 5,837,607, 6,025,609, 6,054,375 and 6,271,576.

It is a primary object of the present invention to provide further process for fabricating semiconductor components based on the previous inventions of Dr. Nathanial R. Quick.

Another object of this invention is to provide an improved process for fabricating semiconductor components that locates a component and orients the semiconductor components

Another object of this invention is to provide an improved process for fabricating semiconductor components such as diodes, field effect transistors and the like.

Another object of this invention is to provide an improved process for fabricating semiconductor components with enhanced high frequency and high power performance.

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 and the detailed description describing the preferred embodiment of the invention.

SUMMARY OF THE INVENTION

A specific embodiment of the present invention is shown in the attached drawings. For the purpose of summarizing the invention, the invention relates to an improved process for in-situ fabricating a semiconductor component in a substrate. A substrate is ablated with a first laser beam to form a void therein. A first conductive element is formed in the void of the substrate with a second laser beam. A semiconductor material is deposited upon the first conductive element with a third laser beam operating in the presence of a depositing atmosphere. A second conductive element is formed on the first semiconductor material with a fourth laser beam. The process may be used for fabricating a Schottky barrier diode or a junction field effect transistor and the like.

In a more specific embodiment of the invention, a first laser beam is directed onto the substrate for ablating the substrate to form a void. A second laser beam is directed within the void for forming a first conductive element. A third laser beam is directed within the void in the presence of a first depositing atmosphere for depositing a first semiconductor material upon the first conductive element to accumulate within the void with the first semiconductor material. A fourth laser beam is directed onto the second semiconductor material for forming a second conductive element in electrical contact with the first semiconductor material.

In another embodiment of the invention, the invention relates to an improved process of fabricating a semiconductor component in a substrate. A first laser beam is directed onto the substrate for ablating the substrate to form a void. A second laser beam is directed within the void for forming a first conductive element. A third laser beam is directed within the void in the presence of a first depositing atmosphere for depositing a first semiconductor material upon the first conductive element to accumulate within the void with the first semiconductor material. A fourth laser beam is directed within the void in the presence of a second depositing atmosphere for depositing a second semiconductor material upon the first semiconductor material to accumulate within the void. A fifth laser beam is directed onto the second semiconductor material for forming a second conductive element.

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 matter 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.

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 semiconductor substrate for forming a semiconductor component in a substrate;

FIG. 2 is an enlarged isometric view of a first example of the semiconductor component formed in the substrate through the process of FIG. 1;

FIG. 3 is an enlarged isometric view of a second example of the semiconductor component formed in the substrate through the process of FIG. 1;

FIG. 4 is a first step in the process of forming the semiconductor component of FIG. 2 illustrating a first laser beam directed onto the substrate;

FIG. 5 is a second step in the process of forming the semiconductor component of FIG. 2 illustrating the ablation of the substrate to form a void therein;

FIG. 6 is a third step in the process of forming the semiconductor component of FIG. 2 illustrating a second laser beam directed into the void for forming a first conductive element;

FIG. 7 is a fourth step in the process of forming the semiconductor component of FIG. 2 illustrating a third laser beam directed into the void in the presence of a depositing atmosphere for depositing a semiconductor material upon the first conductive element to accumulate within the void;

FIG. 8 is a fifth step in the process of forming the semiconductor component of FIG. 2 illustrating a fourth laser beam directed into the deposited semiconductor material in the presence of a doping atmosphere for converting the deposited semiconductor material into a first type of semiconductor;

FIG. 9 is a sixth step in the process of forming the semiconductor component of FIG. 2 illustrating a fifth laser beam

directed onto the converted semiconductor material for forming a second conductive element;

FIG. 10 is a first step in the process of forming the semiconductor component of FIG. 3 illustrating a first laser beam directed onto the substrate;

FIG. 11 is a second step in the process of forming the semiconductor component of FIG. 3 illustrating the ablation of the substrate to form a void therein;

FIG. 12 is a third step in the process of forming the semiconductor component of FIG. 3 illustrating a second laser beam directed into the void for forming a first conductive element;

FIG. 13 is a fourth step in the process of forming the semiconductor component of FIG. 3 illustrating a third laser beam directed into the void in the presence of a first depositing atmosphere for depositing a first semiconductor material upon the first conductive element to accumulate within the void;

FIG. 14 is a fifth step in the process of forming the semiconductor component of FIG. 3 illustrating a fourth laser beam directed onto the deposited first semiconductor material in the presence of a first doping atmosphere for converting a first portion of the deposited first semiconductor material into a first type of semiconductor;

FIG. 15 is a sixth step in the process of forming the semiconductor component of FIG. 3 illustrating a fifth laser beam directed onto the deposited first semiconductor material in the presence of a second doping atmosphere for converting a second portion of the deposited first semiconductor material into a second type of semiconductor;

FIG. 16 is a seventh step in the process of forming the semiconductor component of FIG. 3 illustrating a sixth laser beam directed into the void in the presence of a second depositing atmosphere for depositing a second semiconductor material to accumulate within the void; and

FIG. 17 is an eight step in the process of forming the semiconductor component of FIG. 3 illustrating a seventh laser beam directed onto the deposited second semiconductor material in the presence of a second doping atmosphere for converting a second portion of the deposited second semiconductor material into a second type of semiconductor;

FIG. 18 is a ninth step in the process of forming the semiconductor component of FIG. 3 illustrating an eighth laser beam directed onto the converted second semiconductor material for forming a second and a third conductive element;

FIG. 19 is an enlarged isometric view of a third example of the an array of semiconductor components formed in the substrate through the process of FIG. 1;

FIG. 20 is a first step in the process of forming the array of semiconductor components of FIG. 19 illustrating the ablation of the substrate to form a void therein;

FIG. 21 is a second step in the process of forming the array of semiconductor components of FIG. 19 illustrating the formation of a first conductive element;

FIG. 22 is a third step in the process of forming the array of semiconductor components of FIG. 19 illustrating the deposition of a semiconductor material within the void;

FIG. 23 is a fourth step in the process of forming the array of semiconductor components of FIG. 19 illustrating the conversion of the deposited semiconductor material into alternating bands of a first type of semiconductor and an insulator;

FIG. 24 is a fifth step in the process of forming the array of semiconductor components of FIG. 19 illustrating formation of a conductive element upon the array of the first type of semiconductors.

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 5 for in-situ forming a semiconductor component 10 in a semiconductor substrate 20. The semiconductor substrate 20 is shown 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 laser beam transmission window 34 disposed for transmitting a laser beam into the chamber 30. The chamber 30 is dispose on a support member 36 forming an airtight seal therewith.

The semiconductor substrate 20 defines a first and a second side 21 and 22 and a peripheral edge 23. Although the semiconductor substrate 20 is shown as a square, the present invention is not limited by the physical configuration of the semiconductor substrate 20 as shown herein. The semiconductor substrate 20 may be formed as a monolith or a thin film substrate having suitable properties for forming the semiconductor component 10 in the semiconductor substrate 20.

A thermal energy beam 40 is shown emanating from a source 42 to impinge on the first surface 21 of the semiconductor substrate 20 for forming the semiconductor component 10. 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. The source 42 of the beam of charged particles is located within the chamber 40. 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 2_ω Nd:YAG laser or an Excimer laser. The source 42 of the beam of electromagnetic radiation may be located outside of the chamber 30 and being transferred through the airtight laser beam transmission window 34.

FIG. 2 is an enlarged isometric view of a first example of the semiconductor component 10A formed by the process shown in FIG. 1. In this example, the semiconductor component 10A is a nanosize semiconductor diode shown as a Schottky barrier diode. Although the semiconductor component 10A has been shown as a Schottky barrier diode, it should be understood that the present process may be used for fabricating various types of semiconductor component 10A.

The semiconductor substrate 20A defines a first and a second side 21A and 22A and a peripheral edge 23A with the semiconductor component 10A formed within the void 25A. The semiconductor component 10A comprises a first and a second conductive element 51A and 52A. The first conductive element 51A forms an Ohmic connection with one side of the first type of semiconductor material 61A. The second conductive element 52A forms a barrier junction with the other side of the first type of semiconductor material 61A. Electrical connectors 71A and 72A are affixed to the first and second conductive elements 51A and 52A, respectively.

FIG. 3 is an enlarged view of a second example of the semiconductor component 10B formed by the process shown in FIG. 1. In this example, the semiconductor component 10B is a nanosize semiconductor transistor shown as a junction field effect transistor (JFET). Although the semiconductor component 10B has been shown as a junction field effect transistor (JFET), it should be understood that the present process may be used for fabricating various types of semiconductor component 10B.

The semiconductor substrate 20B defines a first and a second side 21B and 22B and a peripheral edge 23B with the semiconductor component 10B formed within the void 25B. The semiconductor component 10B comprises a first, a sec-

ond and a third conductive element **51B**, **52B** and **53B**. The first conductive element **51B** forms an ohmic connection with the first type of semiconductor material **61B**. The second and third conductive elements **52B** and **53B** form ohmic connections with the second type of semiconductor material **62B**. The first conductive element **51B** is connected to a gate of the junction field effect transistor (JFET) **10B** whereas the second and third conductive elements **52B** and **53B** are connected to a source and a drain of the junction field effect transistor (JFET) **10B**. Electrical connectors **71A**, **72A** and **73A** are affixed to the first, second and third conductive elements **51A**, **52A** and **53A**, respectively.

FIGS. **4-9** illustrate the process steps of forming the semiconductor component **10A** shown in FIG. **2**. The semiconductor component **10A** is formed in situ by a laser synthesis process shown in FIG. **1**. It should be appreciated that the apparatus of FIG. **1** may be used with various types of semiconductor substrate materials and various types of doping and/or depositing atmospheres.

The term "laser synthesis" and "laser synthesized" is used to broadly define the rapid thermal heating and/or melting and the rapid cooling and/or solidification of a selected area of the semiconductor substrate by a laser beam to cause a change in the chemical, electrical and/or physical change to selected area of the semiconductor substrate. The thermal heating and/or melting by the laser beam may be accompanied by the use of gases, such as air, oxygen or other gas/vapor mixtures to cause further changes in the chemical, electrical and/or physical change to selected area of the semiconductor substrate.

FIG. **4** is a first step in the process of forming the semiconductor component **10A** of FIG. **2** illustrating a first laser beam **40** directed onto the substrate **20A**. The semiconductor component **10A** is formed within a semiconductor substrate **20A**. Preferably, the semiconductor substrate **20** has a bandgap greater than 2.0 electron volts. In one example, the semiconductor substrate **20** is selected from the IV group of the periodic table and having bandgap greater than 2.0 electron volts.

In still a more specific example of the invention, the semiconductor substrate **20A** may be essentially a single crystal compound. The elements of the single crystal compound selected are from the III group and the V group of the periodic table and having bandgap greater than 2.0 electron volts. Preferably, one element of the compound has a higher melting point element than the other element of the compound. Specific examples of the wide-bandgap semiconductor compound are selected from the group consisting of Aluminum Nitride, Silicon Carbide, Boron Nitride, Gallium Nitride and diamond.

In this example the semiconductor substrate **20A** is shown as a semi-insulating or insulating vanadium doped silicon carbide wafer. The vanadium doped silicon carbide wafer may be formed through a laser doping process using a metal-organic atmosphere to provide a source for the vanadium doping.

FIG. **5** is a second step in the process of forming the semiconductor component **10A** of FIG. **2** illustrating the ablation of the semiconductor substrate **20A** to form a void **25A** therein. The step of ablating comprises directing a first laser beam **40** onto the semiconductor substrate **20A** to form a void **25A** within the semiconductor substrate **20A**. Preferably, the process of ablating the semiconductor substrate **20A** converts a portion of the semiconductor substrate material **20A** directly into a gas phase by evaporation and/or sublimation.

The following is an example of the parameters used for forming the void **25A** within the semiconductor substrate **20A**. The void **25A** was formed in an inert atmosphere such as argon or in a vacuum.

EXAMPLE I

A complete conversion of silicon carbide to the gas phase is accomplished at temperatures equal to or greater than 3500° C. Nd:YAG laser operating at 1064 nm wavelength, 2 KHz pulse repetition rate, 42 watts power, 0.025 cm beam diameter for the ablation process of silicon carbide. A volume of 3×10^{-5} cc can be removed in 5 seconds from a 0.0635 cm thick silicon carbide wafer (vanadium doped) substrate. This ablation process yields an ablation rate of 6×10^{-6} cc/sec. An ablation rate of 6×10^{-6} cc/sec. corresponds to a power density (intensity) of 5350 W/cm2 at a pulse repetition rate of 2 KHz.

Preferably, an excimer laser in the range 157 nm-351 nm (Lambda Physik) is used in the ablation process since structural dimensions of the semiconductor component **10A** are limited to one half (½) of the laser wavelength. The excimer laser enables structural dimensions of the semiconductor component **10A** to be reduced to 80-175 mn. It should be appreciated by those skilled in the art that other optical devices such as diffractive optical elements and the like can further reduce the size of structural dimensions of the semiconductor component **10A** as is well know in the art.

FIG. **6** is a third step in the process of forming the semiconductor component **10A** of FIG. **2** illustrating a second laser beam **40** directed into the void **25A** for forming a first conductive element **51A**. The conductive element **51A** is formed by directing a thermal energy beam onto the semiconductor substrate **20A** to heat a region for changing the structure of the semiconductor substrate **20A** into the conductive element **51A**. The exact mechanism of forming the conductive element **51A** within the semiconductor **20A** is not fully understood at this time. One theory of the mechanism of forming the conductive element **51A** comprises the transformation of either a single crystal semiconductor **20A** or an aligned polycrystalline semiconductor **20A** to a carbon rich silicon carbide phase.

It is believed the thermal energy beam **40** changes the crystal structure of a semiconductor substrate **20A** formed as a single crystal or an aligned polycrystalline elemental material to provide the conductive element **51A**. It is further believed the thermal energy beam **40** increasing the concentration of the higher melting point element of a single crystal or an aligned polycrystalline compound material to provide the conductive element **51A**. In the example of silicon carbide, the higher melting point element carbon of the silicon carbide provides the conductive element **51A**. The conductive element **51A** has conductive properties less than 10-2 ohm-cm.

The following is an example of the parameters used for forming the conductive element **51** in FIG. **6**. The conductive element **51** was formed in an atmosphere of nitrogen but it should be understood the conductive element **51** may be formed in other atmospheres including argon and the like.

EXAMPLE II

4H-Silicon Carbide single crystal substrate was irradiated with Nd:YAG, 1064 nm wavelength emisson, having a 260 ns pulse width, 35 kHz pulse repetition rate Q-switched laser, using an optimal power of 69.3 W. The 4H-Silicon Carbide single crystal substrate was positioned in an air-tight chamber with an atmosphere of Nitrogen gas. The laser beam was transmitted through a soda-lime glass window. Beam scanning was achieved either by a galvo-mirror or an x-y programmable table. Nanoribbon conductors having a nano-polycrystalline structure, as analyzed by high resolution transmission electron microscopy (Techni F30) using selected area electron diffraction (SAED) after focused ion beam

milling, were formed within the substrate using an optimal intensity of 8820 W/cm^2 in a nitrogen environment. The heating rate and cooling rate was approximately a factor of 10 (an order or magnitude) than for microconductors formed in the prior art. The intensity used for the micro-conductors was 1003 W/cm^2. These process conditions resulted in a laser-material interaction time greater than 0.01 sec. The nano-ribbon conductors formed a heterostructure having a carbon atomic % ranging from 75-100% and a resistivity less than 10^{-2} ohm-cm. The nano-ribbon conductors formed in bundles 50-60 nm thick incorporating 15-17 layers.

A more through discussion for forming the conductive element 51 within the semiconductor substrate 20A is set forth in U.S. patent application Ser. No. 10/262,310 filed Sep. 30, 2002 the disclosure of which is hereby incorporated by reference into the present application as if fully set forth herein.

FIG. 7 is a fourth step in the process of forming the semiconductor component 10A of FIG. 2 illustrating a third laser beam directed into the void 25A in the presence of a first depositing atmosphere (SA) for depositing a first semiconductor material S upon the first conductive element 51A to accumulate within the void 25A.

The step of depositing a semiconductor material S upon the first conductive element 51A comprises directing a third laser beam within the void 25A in the presence of a first depositing atmosphere SA for depositing the semiconductor material S upon the first conductive element 5 1A to accumulate within the void 25A. In the example of silicon carbide, intrinsic silicon carbide semiconductor accumulates within the void 25A of the semiconductor substrate 20A.

The semiconductor material S is added within the void 25A by directing the laser beam onto a selected portion of the void 25A of the semiconductor substrate in the presence of a depositing gas SA. The laser beam heats the selected portion of the semiconductor substrate 20A as well as heating and/or dissociating the depositing gas SA. The heated and/or dissociated depositing gas component interacts with the heated selected portion of the semiconductor substrate 20A to promote the growth of crystal of the semiconductor material (s) within the void.

The following is a specific example of the depositing a semiconductor material S upon the first conductive element 51A comprises directing a third laser beam within the void 25A.

EXAMPLE IV

A gas such as tetramethylsilane (TMS) or diethylsilane (DES), single gas sources for both carbon and silicon or gaseous mixtures of silane (a source for silicon) and methane or acetylene (sources for carbon) are used. TMS and DES type sources are preferred. The laser dissociates the gas(es) and directs the deposition of silicon and carbon. This is a maskless process. Laser power

densities on the order of 100 W/cm^2 are used, which are an order of magnitude less than those used for synthesis, doping and ablation. Deposition rates as high as 4.5× 10^{-3} cm/s in the area of the beam are obtained (ref: J. V. Thompkins et al, Advances in Selective Area Laser Deposition of Silicon Carbide", Solid Freeform Fabrication Proceedings, 1994, pp. 412-421.)

FIG. 8 is a fifth step in the process of forming the semiconductor component 10A of FIG. 2 illustrating the step of converting the deposited semiconductor material S into a first type of semiconductor 61A. The step of converting the deposited semiconductor material S into the first type of semiconductor 61A comprises directing a fourth laser beam into the deposited semiconductor material S in the presence of a doping atmosphere N for converting the deposited semiconductor material S into a first type of semiconductor 61A.

The deposited semiconductor material S may be doped by directing the laser beam 40 onto a selected portion of the deposited semiconductor material S in the presence of a doping gas N. The laser beam 40 heats the selected portion of the deposited semiconductor material S as well as heating and/or dissociating the doping gas N. The heated and/or dissociated doping gas component diffuses into the heated selected portion of the deposited semiconductor material S to create a specific type of the doped semiconductor material 61A.

A chemical doping during the laser synthesis or conversion process may enhance the change in the chemical, electrical and/or physical properties of the semiconductor substrate 20A. The doping process occurs within the chamber 30 of FIG. 1 simultaneously with the irradiating by the laser beam 40 of selected areas of the semiconductor substrate 20A. The laser beam 40 causes the doping gas N to chemically disassociate and diffuse into the selected areas of the semiconductor substrate 20A. The combination of the irradiation by the laser beam 40 and the diffusion of a doping gas N cause chemical, electrical and physical changes in the properties of the semiconductor substrate 20A.

In the example of Silicon Carbide, a nitrogen doping gas the deposited semiconductor material S results in a N-type semiconductor material 61A. Although the FIG. 8 sets forth a separate process step of doping the deposited semiconductor material S, it should be understood that the process step of doping the deposited semiconductor material S may be accomplished simultaneously with the process step of depositing the semiconductor material S upon the first conductive element 51A shown in FIG. 7. In the case of Silicon Carbide, the process sets of FIGS. 7 and 8 may be accomplished simultaneously by mixing a nitrogen gas with a metal-organic gas.

The following is an example of the dopants and materials generated by a laser synthesis process of the present invention.

EXAMPLE III

DOPANTS AND MATERIALS GENERATED BY LASER SYNTHESIS

Dopant Source	Dopant	RESULTANT MATERIALS (No Oxygen Present) Aluminum Nitride	RESULTANT MATERIALS (No Oxygen Present) Silicon Carbide
Di-Borane	Boron	Boron Boron Nitride(s) Aluminum Boride	Boron(p-type) Boron Carbide(i)

US 8,080,836 B2

11

12

-continued

DOPANTS AND MATERIALS GENERATED BY LASER SYNTHESIS

Dopant Source	Dopant	RESULTANT MATERIALS (No Oxygen Present) Aluminum Nitride	RESULTANT MATERIALS (No Oxygen Present) Silicon Carbide
Silane	Silicon	Silicon(s)	Silicon(s)
		Silicon Nitride(i)	Silicon Carbide(s)
Phosphine	Phosphorous	Phosphorous	Phosphorous(n-type)
Titanium tetra chloride	Titanium	Titanium(c)	Titanium(s)
		Aluminum-Phosphide(s)	Boron
Titanium ethoxide		Titanium nitride(c)	Titanium Silicide(s)
		Titanium Aluminide(c)	Titanium Carbide
Aluminum sec-butoxide	Aluminum	Aluminum	Aluminum(p-type)
		Aluminum Nitride(s)	Aluminum Carbide
Tetra Carbonyl	Nickel	Nickel	Nickel(c)
Nickel		Nickel Aluminide(c)	Nickel Carbide
			Nickel Silicide
Tungsten	Tungsten	Tungsten	Tungsten(c)
hexafluoride		Tungsten Nitride	Tungsten-Carbide(c)
			Tungsten
Nitrogen	Nitrogen	Nitrogen	Nitrogen(n-type)
Trimethylaluminum	Aluminum	Aluminum	Aluminum(p-type)
Vanadium tris-acetylacetonate	Vanadium	Vanadium	Vanadium(semi-insulating)

A more through discussion for doping a first semiconductor material 61A is set forth in U.S. Pat. Nos. 5,145,741, 5,391,841, 5,837,607, 6,025,609, 6,054,375 and 6,271,576 the disclosure of which is hereby incorporated by reference into the present application as if fully set forth herein.

FIG. 9 is a sixth step in the process of forming the semiconductor component of FIG. 2 illustrating the forming a second conductive element 52A upon the converted semiconductor material 61A. The process of forming a second conductive element 52A comprises directing a fifth laser beam onto the converted semiconductor material 61A for forming a second conductive element 52A. The process of forming the second conductive element 52A upon the converted semiconductor material 61A is similar to the process of forming the first conductive element 51A within the void 25A as previously set forth with reference to FIG. 6.

In contrast to the Ohmic connection between the first conductive element 51A and the first semiconductor material 61A, a barrier junction is created between the second conductive element 52A and the first semiconductor material 61A. The control of the laser intensity, laser duration and the dopants during the formation of the first semiconductor material 61A creates the barrier junction between the second conductive element 52A and the first semiconductor material 61A. The barrier junction creates a Schottky barrier diode. In the case of Silicon Carbide, an enhanced rectifying barrier junction is formed directly by appropriate selection of laser parameters to create a silicon rich phase or by directing a fifth laser beam onto the converted semiconductor material 61A in the presence of a doping material such as a silane gas for forming a second conductive element 52A.

The completed semiconductor component 10 is shown in FIG. 2. The electrical connectors 71 and 72 are shown affixed to the first and second conductive elements 51A and 52A, respectively. The first conductive elements 51A extends beyond the semiconductor material 61A for facilitating the connection of the electrical connector 71 to the first conductive element 51A. Although the semiconductor component 10A has been shown as a diode, it should be understood that the present process can be used for fabricating various types of semiconductor component 10A.

The length of the first semiconductor material 61A and conductive elements 51A and 52A controls the power handling capacity of the semiconductor component 10A. The length of the first semiconductor material 61A can range from nanometers to any size limited only by the size of the semiconductor substrate 20A. The length of the first semiconductor material 61A and conductive elements 51A and 52A may take various geometrical forms such as a linear geometrical form, a curved geometrical form, a serpentine geometrical form and the like. Furthermore, the first semiconductor material 61A and conductive elements 51A and 52A may extend on multiple surfaces of the semiconductor substrate 20A.

FIGS. 10-18 illustrate the process steps of forming the semiconductor component 10B shown in FIG. 3. The semiconductor component 10 is formed by a laser synthesis the process shown in FIG. 1. The semiconductor component 10 is a nanosize semiconductor transistor shown as a junction field effect transistor (JFET) but it should be understood that the present process may be used for fabricating various types of semiconductor component 10B.

FIG. 10 is a first step in the process of forming the semiconductor component 10B of FIG. 3 illustrating a first laser beam 40 directed onto the semiconductor substrate 20B. The semiconductor substrate 20B may have the same chemical, electrical and/or physical properties as the semiconductor substrate 20A shown in FIGS. 4-9.

FIG. 11 is a second step in the process of forming the semiconductor component 10B of FIG. 3 illustrating the ablation of the semiconductor substrate 20B to form a void 25B therein. The step of ablating comprises directing a first laser beam 40 onto the semiconductor substrate 20B to form a void 25B within the semiconductor substrate 20B. The process of ablating the semiconductor substrate 20B of FIG. 11 is substantially similar to the process of ablating the semiconductor substrate 20A shown in FIG. 5.

FIG. 12 is a third step in the process of forming the semiconductor component 10B of FIG. 3 illustrating a second laser beam 40 directed into the void 25B for forming a first conductive element 51B. The conductive element 51B is formed by directing a thermal energy beam onto the semiconductor substrate 20B to heat a region for changing the structure of the semiconductor substrate 20B into the conduc-

tive element **51**B. The process of forming the first conductive element **51**B of FIG. **12** is substantially similar to the process of forming the first conductive element **51**A of FIG. **6**. In contrast to FIG. **6**, the first conductive element **51**B of FIG. **12** extends only partially along the length of the void **25**B.

FIG. **13** is a fourth step in the process of forming the semiconductor component of FIG. **3** illustrating a third laser beam directed into the void **25**B in the presence of a first depositing atmosphere (SA) for depositing a first semiconductor material S upon the first conductive element **51**B to accumulate within the void **25**B.

The step of depositing the first semiconductor material (S) upon the first conductive element **51**B comprises directing a third laser beam within the void **25**B in the presence of a first depositing atmosphere (SA) for depositing the first semiconductor material S. The first semiconductor material S is deposited within the void **25**B to extend along the entire length of the void **25**B.

FIG. **14** is a fifth step in the process of forming the semiconductor component **10**B of FIG. **3** illustrating a fourth laser beam directed onto the deposited semiconductor material S for forming a first semiconductor material **61**B within the void **25**B. The process of forming a first semiconductor material **61**B within the void **25**B is substantially similar to the process of forming a first semiconductor material **61**A within the void **25**A shown in FIG. **5**.

The process of forming the semiconductor component **10**B includes the step of converting a portion of the deposited semiconductor material S into a first type of semiconductor **61**B. The step of converting the portion of the deposited semiconductor material S into the first type of semiconductor **61**A comprises directing the fourth laser beam **40** into the selected area of the deposited semiconductor material S in the presence of a doping atmosphere P for converting the deposited semiconductor material S into the first type of semiconductor **61**B.

The deposited semiconductor material S is doped by directing the laser beam **40** onto the selected portion of the deposited semiconductor material S in the presence of the doping gas P. The laser beam **40** heats the selected portion of the deposited semiconductor material S as well as heating and/or dissociating the doping gas P. The heated and/or dissociated doping gas component P diffuses into the heated selected portion of the deposited semiconductor material S to create a specific type of the doped semiconductor material **61**B. In the example of Silicon Carbide, a trimethylaluminum doping gas/vapor the deposited semiconductor material S results in a P-type semiconductor material **61**A.

FIG. **15** is a sixth step in the process of forming the semiconductor component **10**B of FIG. **3** illustrating a fifth laser beam directed onto the deposited semiconductor material S for forming a second semiconductor material **62**B within the void **25**B. The process of forming a second semiconductor material **62**B within the void **25**B is substantially similar to the process of forming a first semiconductor material **61**A within the void **25**A shown in FIG. **14**.

The process of forming the semiconductor component **10**B includes the step of converting portions of the deposited semiconductor material S into a second type of semiconductor **62**B. The step of converting the portions of the deposited semiconductor material S into the second type of semiconductor **62**A comprises directing the fifth laser beam **40** into the selected areas of the deposited semiconductor material S in the presence of a doping atmosphere N for converting the deposited semiconductor material S into the second type of semiconductor **62**B.

The deposited semiconductor material S is doped by directing the laser beam **40** onto the selected portions of the deposited semiconductor material S in the presence of the doping gas N. The laser beam **40** heats the selected portion of the deposited semiconductor material S as well as heating and/or dissociating the doping gas N. The heated and/or dissociated doping gas component N diffuses into the heated selected portion of the deposited semiconductor material S to create a specific type of the doped semiconductor material **62**B. In the example of Silicon Carbide, a nitrogen doping gas the deposited semiconductor material S results in a N-type semiconductor material **62**A.

FIG. **16** is a seventh step in the process of forming the semiconductor component **10**B of FIG. **3** illustrating a sixth laser beam **40** directed into the void **25**B in the presence of a second depositing atmosphere for depositing addition second semiconductor material T to accumulate within the void **25**B.

The step of depositing the second semiconductor material (T) comprises directing a sixth laser beam **40** within the void **25**B in the presence of a second depositing atmosphere (TA) for depositing the second semiconductor material T. The second semiconductor material T is deposited within the void **25**B to extend along the entire length of the void **25**B. The process of depositing the second semiconductor material (T) within the void **25**B is substantially similar to the process of depositing the first semiconductor material (S) within the void **25**B within the void **25**A shown in FIG. **13**.

FIG. **17** is a eighth step in the process of forming the semiconductor component **10**B of FIG. **3** illustrating a seventh laser beam **40** directed onto the second deposited semiconductor material T for forming a second semiconductor material **63**B within the void **25**B. The process of forming a second semiconductor material **63**B within the void **25**B is substantially similar to the process of forming a second semiconductor material **62**A within the void **25**A shown in FIG. **15**.

The process of forming the semiconductor component **10**B includes the step of converting the second deposited semiconductor material T into a second type of semiconductor **6T**B. The step of converting the second deposited semiconductor material T into the second type of semiconductor **63**A comprises directing the seventh laser beam **40** into the second deposited semiconductor material T in the presence of a doping atmosphere N for converting the second deposited semiconductor material T into the second type of semiconductor **63**B.

Preferably, the step of converting the second deposited semiconductor material T into the second type of the semiconductor **63**A established the semiconductor **63**A to be identical to the semiconductor **62**A.

The completed semiconductor component **10**B is shown in FIG. **3**. The electrical connectors **71**B, **72**B and **73**B are shown affixed to the first, second and third conductive elements **51**B **52**B and **53**B, respectively. The first conductive elements **51**B extends beyond the semiconductor material **61**B for facilitating the connection of the electrical connector **71**B to the first conductive element **51**B. Although the semiconductor component **10**B has been shown as a field effect transistor, it should be understood that the present process can be used for fabricating various types of semiconductor component **10**B.

The length of the first semiconductor material **61**B controls the power handling capacity of the semiconductor component **10**B. The length of the first semiconductor material **61**B can range from nanometers to any size limited only by the size of the semiconductor substrate **20**B. The length of the first semiconductor material **61**B may take various geometrical forms

such as a linear geometrical form, a curved geometrical form, a serpentine geometrical form and the like. Furthermore, the first semiconductor material **61**B may extend on multiple surfaces of the semiconductor substrate **20**B.

FIG. **19** is an enlarged isometric view of a third example of an array of semiconductor components **10**C formed in the substrate **20**C through the process of FIG. **1**. In this example, the semiconductor component **10**C is an array of a nanosize semiconductor diode shown as a Schottky barrier diode. Although the semiconductor component **10**C has been shown as a Schottky barrier diode, it should be understood that the present process can be used for fabricating various types of semiconductor component **10**C.

The semiconductor substrate **20**C defines a first and a second side **21**C and **22**C and a peripheral edge **23**C with the semiconductor component **10**C formed within the void **25**C. The semiconductor component **10**C comprises a plurality of conductive element **51**C-**55**C. A conductive element **51**C forms an Ohmic connection with one side of each of the array of the first type of semiconductor material **61**C. The conductive elements **52**C-**55**C form barrier junctions with the other side of each of the array of the first type of semiconductor material **61**C. An array of insulators **65**C is interposed between each of the array of the first type of semiconductor material **61**C. An electrical connector **71**C is affixed to the conductive element **51**C whereas the electrical connectors **71**C-**75**C are affixed to the conductive elements **51**C-**55**C, respectively.

FIG. **20** is a first step in the process of forming the array of semiconductor components **10**C of FIG. **19** illustrating the ablation of the substrate **20**C to form a void **25**C therein. The process of the ablation of the substrate **20**C to form the void **25**C is substantially similar to the process of ablation of the substrate **20**A shown in FIG. **5**.

FIG. **21** is a second step in the process of forming the array of semiconductor components **10**C of FIG. **19** illustrating the formation of a first conductive element **51**C. The process of the formation of a first conductive element **51**C is substantially similar to the process of the formation of a first conductive element **51**A shown in FIG. **6**.

FIG. **22** is a third step in the process of forming the array of semiconductor components **10**C of FIG. **19** illustrating the deposition of a semiconductor material S within the void **25**C. The process of the deposition of the semiconductor material S within the void **25**C is substantially similar to the process of the deposition of the semiconductor material S within the void **25**A shown in FIG. **7**.

FIG. **23** is a fourth step in the process of forming the array of semiconductor components **10**C of FIG. **19** illustrating the conversion of the deposited semiconductor material into alternating bands of a first type of semiconductor **61**C and alternating bands of an insulator **65**C. The process of the conversion of the deposited semiconductor material into alternating bands of a first type of semiconductor **61**C is substantially similar to the process of the formation of conductive element **52**A upon the first type of semiconductors **61**A shown in FIG. **9**. The process of the conversion of the deposited semiconductor material into alternating bands of the insulator **65**C is formed in a similar manner in the presence of a suitable doping gas. In the example of silicon carbide, a doping of vanadium, from a metal-organic such as vanadium trisacetylacetonate, will provide the insulator **65**C.

FIG. **24** is a sixth step in the process of forming the array of semiconductor components **10**C of FIG. **19** illustrating formation of conductive element **52**C-**55**C upon the array of the first type of semiconductors **10**C. The process of the formation of conductive element **52**C-**55**C upon the array of the first

type of semiconductors **61**C is substantially similar to the process of the formation of conductive element **52**A upon the first type of semiconductors **61**A shown in FIG. **9**.

The present invention provides an improved process for forming a semiconductor component **10** in the semiconductor substrate **20**. The semiconductor component **10** is formed in situ on the semiconductor substrate **20** through the use of a thermal energy beam **40**. The semiconductor component **10** is formed by direct conversion of selected areas of the semiconductor substrate **20** through the use of a thermal energy beam **40**.

Although the 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. An embedded wide bandgap semiconductor component, comprising:
   a wide bandgap monolithic substrate extending between a first and a second side surface;
   a laser ablated void only partially extending into said wide bandgap monolithic substrate defining a bottom surface of said laser ablated void;
   a first conductive element located within said laser ablated void and extending along said first side surface of said wide bandgap substrate onto said bottom surface of said laser ablated void;
   a wide bandgap semiconductor material deposited within said laser ablated void and in electrical contact with said first conductive element disposed on said bottom surface of said laser ablated void; and
   a second conductive element connected to said wide bandgap semiconductor material.

2. An embedded wide bandgap semiconductor component as set forth in claim **1**, wherein said wide bandgap monolithic substrate is selected form the group consisting of Aluminum Nitride, Silicon Carbide, Boron Nitride, Gallium Nitride or diamond.

3. An embedded wide bandgap semiconductor component as set forth in claim **1**, wherein said wide bandgap semiconductor component is a nano-size wide bandgap semiconductor component.

4. An embedded wide bandgap semiconductor component as set forth in claim **1**, wherein said wide bandgap semiconductor component is a Schottky barrier diode.

5. An embedded wide bandgap semiconductor component as set forth in claim **1**, wherein said wide bandgap semiconductor component is a junction field effect transistor.

6. An embedded wide bandgap semiconductor component as set forth in claim **1**, wherein said first conductive element comprises a laser synthesized conductive element having an atomic component common with the wide bandgap substrate.

7. An embedded wide bandgap semiconductor component as set forth in claim **1**, wherein said wide bandgap semiconductor material deposited within is a laser doped wide bandgap semiconductor material.

8. An in situ laser synthesized semiconductor component embedded within a wide bandgap monolithic substrate, the wide bandgap monolithic substrate defined between a first and a second side, comprising:
   a laser ablated void defined within the wide bandgap monolithic substrate;
   said laser ablated void partially extending within the wide bandgap monolithic substrate and terminating in a bot-

tom surface located between the first and second sides of the wide bandgap monolithic substrate;

a first conductive element located within said laser ablated void and extending to an outside surface of said wide bandgap monolithic substrate onto said bottom surface of said laser ablated void;

a wide bandgap semiconductor component deposited within said laser ablated void having a surface located within said void with said surface of said wide bandgap semiconductor component disposed in electrical contact with said first conductive element on said bottom surface of said laser ablated void; and

a second conductive element connected in electrical contact with said wide bandgap semiconductor component.

9. A wide bandgap semiconductor component embedded within a wide bandgap monolithic substrate as set forth in claim **8**, wherein said wide bandgap monolithic substrate is selected form the group consisting of Aluminum Nitride, Silicon Carbide, Boron Nitride, Gallium Nitride or diamond.

10. A wide bandgap semiconductor component embedded within a wide bandgap monolithic substrate as set forth in claim **8**, wherein said wide bandgap semiconductor component is a nano-size wide bandgap semiconductor component.

11. A wide bandgap semiconductor component embedded within a wide bandgap monolithic substrate as set forth in claim **8**, wherein said wide bandgap semiconductor component is a Schottky barrier diode.

12. A wide bandgap semiconductor component embedded within a wide bandgap monolithic substrate as set forth in claim **8**, wherein said wide bandgap semiconductor component is a junction field effect transistor.

13. A diode embedded within a wide bandgap monolithic substrate, the wide bandgap monolithic substrate defined between a first and a second side, comprising:

a laser ablated void defined within the wide bandgap monolithic substrate;

said laser ablated void partially extending within the wide bandgap monolithic substrate and terminating in a bottom surface located between the first and second sides of the wide bandgap monolithic substrate;

a first conductive element located in said laser ablated void and extending to an outside surface of said wide bandgap monolithic substrate onto said bottom surface of said laser ablated void;

a wide bandgap semiconductor diode deposited in situ within said laser ablated void with an internal surface of said diode located on said bottom surface of said laser ablated void;

said first conductive element on said bottom surface of said laser ablated void connected to said internal surface of said diode within said laser ablated void; and

a second conductive element connected to said wide bandgap semiconductor material for forming a connection with an external surface of said diode.

14. A diode embedded within a wide bandgap monolithic substrate as set forth in claim **13**, wherein said wide bandgap monolithic substrate is selected form the group consisting of Aluminum Nitride, Silicon Carbide, Boron Nitride, Gallium Nitride or diamond.

15. A diode embedded within a wide bandgap monolithic substrate as set forth in claim **13**, wherein one of said first and second conductive elements forms an ohmic contact with said diode; and

the other of said first and second conductive elements forming a barrier junction contact with said diode.

16. A diode embedded within a wide bandgap monolithic substrate as set forth in claim **15**, wherein said diode is a Schottky barrier diode.

17. A diode embedded within a wide bandgap monolithic substrate as set forth in claim **13**, wherein said diode is a nano-size diode.

18. A transistor embedded within a wide bandgap monolithic substrate, comprising:

a laser ablated void defined within the wide bandgap monolithic substrate;

said laser ablated void partially extending within the wide bandgap monolithic substrate and terminating in a bottom surface located between the first and second sides of the wide bandgap monolithic substrate;

a wide bandgap semiconductor transistor deposited in situ within said laser ablated void with substantially all of said wide bandgap semiconductor transistor located within said laser ablated void;

a first conductive element being in contact with a first portion of said wide bandgap semiconductor transistor;

a second conductive element being in contact with a second portion of said wide bandgap semiconductor transistor;

a third conductive element being in contact with a third portion of said wide bandgap semiconductor transistor; and

at least one of said conductive elements being located on said bottom surface of said laser ablated void of said wide bandgap monolithic substrate.

19. A transistor embedded within a wide bandgap monolithic substrate as set forth claim **18**, wherein said wide bandgap monolithic substrate is selected form the group consisting of Aluminum Nitride, Silicon Carbide, Boron Nitride, Gallium Nitride or diamond.

20. A transistor embedded within a wide bandgap monolithic substrate as set forth in claim **18**, wherein said first conductive element forms a contact with first component of said wide bandgap semiconductor transistor located on said internal surface of said wide bandgap semiconductor material located with said laser ablated void; and

said second and third conductive elements forming contacts with said second and third components of said wide bandgap semiconductor transistor.

21. A transistor embedded within a wide bandgap monolithic substrate as set forth in claim **18**, wherein said wide bandgap semiconductor transistor is a nano-size transistor.

22. A transistor embedded within a wide bandgap monolithic substrate as set forth in claim **18**, wherein said wide bandgap semiconductor transistor is a junction field effect transistor.

23. An embedded wide bandgap semiconductor component, comprising:

a wide bandgap monolithic substrate extending between a first and a second side surface;

a laser ablated void only partially extending into said wide bandgap substrate terminating in a bottom surface;

a first laser synthesized conductive element having an atomic component common with the wide bandgap monolithic substrate disposed within said void

a wide bandgap semiconductor material deposited in situ within said void from a depositing atmosphere in said void and in electrical contact with said first conductive element; and

a second conductive element connected to said wide bandgap semiconductor material.

* * * * *