

Description

Method and device for depositing n-doped SiC

Technical Field

[0001] The invention relates to a method for depositing a SiC layer on a substrate in a process chamber of a CVD reactor, wherein the walls of the process chamber are heated to a process temperature by a heating device. A process gas flow is fed into the process chamber through a gas inlet. The process gas flow passes through the process chamber and flows over the substrates arranged therein in a horizontal direction. The process gas flow contains growth gas streams comprising a silicon-containing and a carbon-containing reactive gas. The process gas flow further contains dopant gas streams comprising gaseous dopant carriers. The carbon- and nitrogen-containing reactive gases decompose at the process temperature in the process chamber, on the surfaces of the heated walls of the process chamber, and on the substrate surface. The decomposition products of the reactive gases deposit as a single-crystalline layer on the substrate. Similarly, the dopant carriers decompose in the process chamber, on the surfaces of the process chamber walls, or on the substrate surface. The decomposition products of the dopant carriers are incorporated into the SiC layer as dopant. Preferably, the dopant results in an n-doped layer. The dopant is preferably nitrogen.

State of the Art

[0002] In another prior art method described in DE 10 2011 054 566 A1, namely during the deposition of GaN layers, the process gas emerging from the cold gas inlet first heats up in a pre-flow zone. In this phase, parasitic growth occurs on the surface of the pre-flow zone. As the process gas flows over the substrate, the concentration or partial pressure of the reactive gases in the carrier gas flow

passing through the process chamber decreases. This leads to a progressive depletion in the direction of the process gas flow. As a result, the growth rate of the layer or the transport of the dopant from the gas phase toward the substrate surface decreases steadily in the direction of flow. If the substrate is rotated
5 about a vertical axis during deposition, this effect can be compensated for. If the depletion curve above the substrate follows a straight line sloping downward in the direction of flow, a layer with a homogeneous thickness can still be deposited.

[0003] In reality, however, the depletion curve does not follow an ideal straight
10 line, but rather a curved line. The aforementioned DE 10 2011 054 566 A1 describes a method in which various reactive gases are fed into the process chamber through a gas inlet device arranged in the center of the process chamber via vertically stacked gas inlet zones. The partial pressures of the reactive gases used decrease along non-linear depletion curves due to the depletion effect
15 described above. By appropriately mixing the reactive gases flowing through different gas inlet zones, a lateral profile of the layer thickness can be influenced.

[0004] US 2020/0043725 A1 describes a device and a method for depositing n-doped SiC, wherein NH_3 and N_2 are used as dopants.

[0005] JP 2015-143168 A describes a method in which a process gas containing
20 a silicon compound, a carbon compound, and NH_3 is fed into a process chamber heated on all sides. The surfaces of the process chamber walls are coated with SiC. On a substrate rotating about an axis of rotation, n-doped SiC is deposited using NH_3 as a dopant carrier. The partial pressure of the components of the process gas decreases steadily in the direction of flow.

[0006] From the publication "Experimental Study of the Pyrolysis of NH_3 under Flow Reactor Conditions, Mario Benés, et al, 2021 American Chemical Society, p. 7193," it is known that at high temperatures, nitrogen-containing intermediates, such as HCN or Si_3N , form on SiC surfaces from ammonia,
 5 methane or ethane, trichlorosilane, and hydrogen.

[0007] WO 2022/053963 A1 describes a similar method for depositing n-doped SiC.

[0008] The depletion described above does not occur when N_2 is used as a dopant carrier. However, N_2 reacts catalytically on the surface of the process
 10 chamber, particularly in the immediate vicinity of the substrate or on the surface of a pre-flow zone located between the gas inlet and the substrate. HCN can form in this area. The amount of HCN reaching the substrate depends primarily on the geometry of the pre-flow zone and, in particular, on the cover plate located there and its surface. As a result, during the deposition of
 15 nitrogen-doped SiC, an excess of dopant incorporation is observed in the area of the edge of the substrate, which rotates during deposition. The dopant distribution in the deposited SiC layer thus depends on the concentration of N_2 , HCN, and the carbon-containing reactive gas in the gas phase.

Summary of the Invention

[0009] The invention is based on the task of improving dopant homogeneity
 20 during the deposition of n-doped SiC, particularly in a CVD reactor in which a gas inlet is surrounded by substrates to be coated, which are simultaneously coated with a SiC layer.

[0010] The problem is solved by the method specified in the claims or the claimed device. The subclaims not only represent advantageous further

developments of the technical teachings specified in the adjacent claims but are also independent solutions to the problem.

[0011] First and foremost, it is proposed to divide the process gas flow among several gas inlet zones arranged vertically one above the other and to select the pairing of the various dopant carriers such that the dopant carrier of the first dopant gas flow generates a lateral doping profile in an SiC layer, which, particularly at the edge of the substrate, has a different course than a lateral doping profile generated by the dopant carrier of the second doping gas flow in the SiC layer. In particular, it may be provided that the lateral doping profile generated by the first dopant gas flow exhibits a dopant concentration that decreases toward the edge of the substrate, and the second lateral doping profile exhibits a dopant concentration that increases toward the edge of the substrate. By appropriately selecting the dopant gas flows, i.e., the mass flows of the dopant carriers into the process chamber, a superimposed doping profile can be generated, which is produced by both the first dopant carrier and the second dopant carrier. A sum profile is formed. The edge elevation produced by one dopant gas flow can be compensated for by an edge reduction of the sum profile caused by the other dopant gas flow. For example, one of the dopant gas flows can produce a dopant profile, measured along a diametrical line through the substrate, that is A-, U-, V-, or W-shaped. The other of the dopant gas flows can produce a dopant profile opposite to this dopant profile, which corresponds, for example, to the shape of an inverted A, U, V, or W. The different dopant carriers are fed into the process chamber in particular through gas inlet zones that are separate from one another, wherein the gas inlet zones are located at different vertical levels. The dopant carrier of a first dopant gas flow can, for example, produce a doping profile that curves upward in the middle. The dopant carrier of a second dopant gas flow can, for example, produce a doping profile that curves downward in the middle. An effective

doping profile can be established by appropriately mixing the two dopant gas flows.

[0012] The dopant carriers are preferably gases containing nitrogen. For example, the first dopant carrier may be NH_3 and the second dopant carrier
5 may be N_2 . It is particularly preferred that the nitrogen atoms in the molecules of the dopant carriers are bound to the remaining atoms of the molecules with varying bond strengths. Thus, it may be provided that, in one dopant carrier, the nitrogen is bound to the remaining molecules via a single bond, and in
10 another dopant carrier, the nitrogen is bound to the remaining molecules via a double or triple bond. In particular, it is provided that the dopant carriers used react at different reaction rates on the surface of the substrate, on the surface of the run-up zone, and/or with the growth gases.

[0013] It may further be provided that a dopant gas flow containing NH_3 does not flow through the same gas inlet zone through which a growth gas flow
15 containing molecules with the element chlorine, for example trichlorosilane, flows. Another growth gas flow may contain molecules containing the element carbon, such as methane or ethene. However, the growth gas flow may also contain dichlorosilane. In this case, HCl may additionally be fed into the process chamber.

20 [0014] The following nitrogen compounds are particularly suitable as dopant carriers: N_2 , NH_3 , HCN , pyridine ($\text{C}_5\text{H}_5\text{N}$), hydrazine (N_2H_4), dimethylhydrazine ($\text{C}_2\text{H}_8\text{N}_2$), or unsymmetrical dimethylhydrazine.

[0015] According to a preferred embodiment of the method, the process gas flow introduced into the process chamber through at least three gas inlet zones
25 arranged vertically one above the other comprises two distinct dopant gas

flows, which are introduced through different gas inlet zones. The dopant gas flows can each be fed into the process chamber through the same gas inlet zone together with a growth gas flow, i.e., a gas containing molecules with the element carbon or a gas containing molecules with the element silicon. In particular, exactly three gas inlet zones arranged vertically one above the other are provided, namely a gas inlet zone arranged at the top, a gas inlet zone arranged at the bottom, and a gas inlet zone arranged in the middle. However, additional gas inlet zones may also be provided.

[0016] According to one variant of the invention, a first dopant gas flow is fed through a gas inlet zone located at the top, and a second dopant gas flow is fed into a lower-lying gas inlet zone. Another variant provides that the first dopant gas flow flows through the same gas inlet zone together with a first growth gas flow. In this case, it may be provided that NH_3 flows through the same gas inlet zone together with C_2H_4 through the same gas inlet zone. In a further variation, it may be provided that the second dopant gas flow, for example N_2 , is fed into the process chamber together with a second growth gas flow, for example a growth gas flow containing molecules with the element silicon, such as HCl_3Si . Another variant provides for a third growth gas flow to flow through a gas inlet zone located at the very bottom, which contains, in particular, molecules containing the element carbon. It may be provided that a growth gas flow containing molecules with the element carbon flows through all gas inlet zones, and that a growth gas flow containing molecules with the element silicon and, in particular, a growth gas flow containing molecules with the element chlorine flows only through a middle gas inlet zone. It may also be provided that no dopant gas flow passes through the lowest gas inlet zone or that no dopant gas flow passes through the uppermost gas inlet zone. It may also be provided that the dopant carriers of the various dopant gas flows do not differ. In this case, the various dopant gas flows are fed in through gas inlet zones that differ from one another. The vertical height of the gas inlet zone influences the shape of the

doping profile, so that the doping profile can be influenced solely by the choice of gas inlet zone. In particular, it is provided that the two doping gas flows are fed into the process chamber through the gas inlet zones that are furthest apart vertically; for example, NH_3 and, through a gas inlet zone located at the very
 5 bottom, NH_3 can also be fed into the process chamber. Preferably, no dopant gas flows through the gas inlet zones located in between.

[0017] The device according to the invention comprises a CVD reactor, a gas mixing device, and a control device. The gas mixing device comprises storage tanks for the reactive gases containing silicon and carbon. It further comprises
 10 storage tanks for at least one dopant carrier, but preferably storage tanks for at least two dopant carriers. The gas mixing device also comprises mass flow controllers and valves to appropriately distribute the reactive gases and the dopant carriers as growth gas flows and dopant gas flows to the gas inlet zones of the gas inlet assembly, which are arranged vertically one above the other.
 15 The mass flow controllers and the valves are controlled by the control device according to a control program. The reactive gases are fed into the gas inlet zones together with H_2 .

[0018] The CVD reactor is equipped with a gas inlet. The gas inlet is located at the center of a process chamber. The gas inlet is surrounded by a susceptor,
 20 which features substrate holders arranged in an arc around the center of the gas inlet. The substrate carriers may be circular disc-shaped bodies, each of which is seated in a pocket on an upward-facing surface of the susceptor. A gas supply line opens into the bottom of each pocket, through which a purge gas is fed into the pocket, so that the substrate carrier is lifted and rotated while floating on a
 25 gas cushion. At least one substrate may be arranged on the substrate carrier, which is rotated about a vertical axis during the deposition of the SiC layer. The susceptor may rotate about a central axis. The susceptor and a process chamber

ceiling opposite the susceptor may be made of graphite. The surface of these graphite parts is coated, in particular with SiC or TaC. The gas inlet member may also be made of graphite. Preferably, however, the gas inlet member is made of quartz, steel (stainless steel), or a ceramic material. The surface of the
 5 susceptor may also be covered with cover plates made of graphite, in particular graphite coated with SiC or TaC, or made of SiC or TaC. The substrate carriers may consist of the same coated or uncoated graphite material. The process chamber ceiling may be supported by a carrier. This carrier may consist of a different material.

10 [0019] The following describes a method for determining mass flow rates of the dopant gas flows that can be used to produce a lateral profile of the dopant concentration in a layer that is as flat as possible. To this end, it is proposed that a first layer be deposited on a substrate in a process chamber of the CVD reactor. During the deposition of the first layer, in addition to the growth gas
 15 flows, only one of the dopant gas flows, for example NH_3 , is fed into the process chamber. It may be provided that an optimization is performed in this process step such that the mass flow of the first dopant gas flow or the mass flows of the growth gas flows are varied. The variation is performed with the aim of creating a lateral profile of the dopant concentration in the layer that is as flat as
 20 possible.

[0020] One criterion for a lateral profile that is as flat as possible can be, for example, the sum of the squares of the deviations of dopant concentrations measured at various radial positions from a mean value. This sum should be minimized.

25 [0021] In a subsequent step, a second lateral profile is determined. A second layer is deposited on a substrate in the process chamber. In this process,

predetermined growth gas flows are again fed into the process chamber. Preferably, these are the same growth gas flows used in the first step, in particular the growth gas flows resulting from the optimization of the first lateral profile. In the second step, however, a different dopant gas flow is fed
 5 into the process chamber, namely, in particular, the second dopant gas flow.

[0022] Measurements of the dopant concentration within the layers are then taken on the two layers that have been deposited on two different substrates. Measurement values are obtained at different radial positions. Various measurements can be taken along an arc around the center of the substrate. An
 10 average value can be calculated from these measurements.

[0023] From the measured values, in particular the respective mean values of dopant concentrations at different radial positions, efficiency values E1 and E2 are then calculated as follows:

$$E1(R) = n1(R) / D1; E2(R) = n2(R) / D2$$

15 where n1(R) and n2(R) are each a dopant concentration at a radial position R.

[0024] Using the efficiency values E1 and E2, an optimization can then be performed by calculating the expected dopant concentration n(R) in a layer when all dopant gas flows are utilized

$$n(R) = (E1'/D1') + (E2'/D2')$$

20 where D1' and D2' are the dopant gas flows to be optimized. During optimization, the dopant gas flows D1' and D2' are varied such that the flattest possible third lateral doping profile is formed.

Brief Description of the Drawings

[0025] The invention is described in more detail below with reference to embodiments. They show:

- Fig. 1 shows, schematically in the manner of a half-section along line I-I in Figure 2, a CVD reactor 1,
- 5 Fig. 2 the section along line II in Figure 1,
- Fig. 3 shows a schematic diagram of a device for depositing SiC layers with a gas mixing system and a CVD reactor,
- Fig. 4 a diagram showing, at the top, two dopant profiles through a SiC layer and, at the bottom, two dopant profiles each
10 generated by different dopant carriers,
- Fig. 5 a schematic representation of a second embodiment regarding the composition and distribution of the process gas flow,
- Fig. 6 a representation according to Figure 5 of a third embodiment,
- Fig. 7 a view according to Figure 5 of a fourth embodiment,
- 15 Fig. 8 a view according to Figure 5 of a fifth embodiment,
- Fig. 9 a view according to Figure 5 of a sixth embodiment, and
- Fig. 10 a representation of lateral dopant profiles a, b determined by experiments and a calculated dopant profile.

Description of the embodiments

[0026] Figures 1 and 2 schematically show the structure of a CVD reactor 1. Inside a housing of the CVD reactor 1, which may be made of stainless steel, there is a susceptor 10, which may be made of graphite and whose surface may be coated with SiC. The susceptor can be rotated about a central axis. The
 5 susceptor has the circular disc shape shown in Figure 2.

[0027] Above the susceptor 10 is a process chamber 2, which is bounded at the top by a process chamber ceiling. The process chamber ceiling is formed by a ceiling plate 19, which may be supported on a retaining element 18. The ceiling plate 19 may also be supported on a gas outlet element 9 arranged around the
 10 susceptor 10. The ceiling plate 19 may consist of SiC-coated graphite. The gas outlet element 9 may likewise consist of this material. However, it may also be made of a ceramic material.

[0028] The susceptor 10 is covered with cover plates 15, 16, which may also consist of SiC-coated graphite. However, they may also consist of SiC.
 15 Pockets 17 are formed, each having a pocket bottom into which a gas supply line 13 opens. The purge gas, such as hydrogen, flowing from the gas supply line 13 can generate a rotating gas cushion that suspends a substrate holder 11 – which may also consist of SiC-coated or uncoated graphite – and drives the substrate holder 11 to rotate about an axis of rotation.

20 [0029] A heating device 14 is provided below the susceptor 10; this may be an RF heater used to heat the susceptor 10. In addition, a further heating device (not shown) may be provided to heat the process chamber ceiling, i.e., the ceiling plate 19, so that the process chamber 2 is heated from all sides. However, it is preferred that the ceiling plate 19 not be actively heated. The ceiling
 25 plate 19 is passively heated by thermal radiation from the susceptor 10 or from

the cover plates 15, 16, so that the surface temperature of the ceiling plate 19 is significantly lower than the surface temperature of the cover plates 15, 16. As a result, different surface reactions occur on the ceiling plate 19 than on the cover plates 15, 16 or on the susceptor 10. The intermediate products mentioned at the outset, which are formed during the decomposition of NH_3 or N_2 , can thus be produced to a lesser extent in the upper region of the process chamber 2. This can also influence the doping profile.

[0030] In the center of the process chamber 2 is a gas inlet element 3, which may consist of a ceramic material, stainless steel, quartz, or SiC-coated graphite. The gas inlet element 3 forms three (see Figure 3) gas inlet zones 4, 5, 6 arranged one above the other, each of which is connected to a supply line 24, 25, 26 through which portions of a process gas flow can be fed into the respective gas inlet zone 4, 5, 6. The process gas flow is provided by a gas mixing system that includes a gas source 27 for nitrogen, a gas source 28 for ammonia, a gas source 29 for trichlorosilane, and a gas source 30 for ethene (C_2H_4). A gas source for HCl may also be provided.

[0031] In a non-illustrated embodiment, the gas inlet member 3 has, for example, four or five or more gas inlet zones arranged one above the other.

[0032] Each of the gas sources 27 through 30 is connected via valves 22 and mass flow controllers 21 to at least one of the supply lines 24, 25, 26. The mass flow controllers 21 and the valves 20 are controlled according to a program of the control device 20.

[0033] The gas mixing system provides at least two dopant gas flows D1, D2, each of which contains a dopant carrier, for example N_2 or NH_3 or one of the aforementioned nitrogen compounds that can also be used. The gas mixing

system also provides at least two growth gas flows Q1, Q2, but preferably several growth gas flows Q1, Q2, Q3, Q4, Q5. The growth gas flows contain carbon and silicon. One of these gases may also contain chlorine, for example trichlorosilane, dichlorosilane, or HCl.

5 [0034] The dopant gas flows D1, D2, and optionally D3 or D4 are fed into the process chamber 2 through the gas inlet zones 4, 5, 6 – which are distinct from one another and arranged vertically one above the other – together with the multiple growth gas flows Q1 through Q5. The process gas flow thus formed first passes through a preheating zone 7 of the process chamber 2, which is
10 heated by the heating device 14 or by another heating device arranged above and not shown. In this preheating zone 7, the process gas, which may in particular contain hydrogen as a carrier gas, is heated to a process temperature.

[0035] At the end of the preheating zone 7, the dopant gas flows D1, D2, D3, D4 and the growth gas flows Q1 through Q5 reach a temperature at which the
15 components of the dopant gas flows and the growth gas flows can decompose or react with one another. Furthermore, the components of the dopant gas flows and the growth gas flows can react catalytically on the surfaces of the cover plates 15 or the top plate 19. In the process, intermediate products and, in particular, decomposition products are formed. The intermediate or
20 decomposition products and, if applicable, undecomposed dopant carriers (e.g., N₂) migrate from the gas phase above the substrate holder 11 in a deposition zone 8 toward the surface of a rotating substrate 12 resting on the substrate holder 11. This occurs primarily through diffusion due to a depletion of the gas phase caused by the condensation or consumption of the intermediate or
25 decomposition products on the substrate surface 12.

[0036] Due to this consumption of Si, C, and N at the surface of the substrate 12 or the n-doped SiC layer deposited there, the partial pressure of the growth gas and the dopant carrier in the gas phase above the substrate 12 decreases. Figure 1 schematically shows two doping profiles a and b, measured
 5 across a diameter of the substrate 2. The linear doping profiles a and b, depicted as curved lines, are rotationally symmetric and represent a cross-section of the lateral doping profile in the layer deposited on the substrate 12.

[0037] Doping profile a is generated in a SiC layer deposited on substrate 11 when substrate 11 is rotated during deposition and only the first dopant gas
 10 flow D1 is fed into the process chamber 2 through the gas inlet zone 6. The dopant profile b is produced in a SiC layer deposited on the substrate 11 when the substrate 11 is rotated during deposition and only the second dopant gas flow D2 is fed into the process chamber 2 through the gas inlet zone 5.

[0038] In the embodiment, the dopant carrier for the first dopant gas flow D1
 15 is NH_3 , and the dopant carrier for the second dopant gas flow D2 is N_2 . It can be seen that the two doping profiles are not straight but curved. The selection of the dopant carriers, or the selection of the gas inlet zones 4, 5, 6 through which the respective dopant gas flows D1 and D2 pass, is made such that two doping profiles a and b are formed, which are curved in opposite directions. For
 20 example, in the embodiment, doping profile a is curved upward and doping profile b is curved downward. By varying the mass flows of the two doping gas flows D1, D2, a doping profile can be set that runs nearly straight. In the case of a rotationally driven substrate 12, a straight-line doping profile results in the formation of a nearly homogeneous dopant distribution in the SiC layer
 25 deposited on the substrate 12.

[0039] The selection of the dopant carriers and the selection of the gas inlet zones 4, 5, 6 through which the dopant carriers are fed into the process chamber can be made such that the inhomogeneous rotationally symmetric doping profile generated by one dopant carrier is compensated by the likewise
 5 inhomogeneous rotationally symmetric doping profile generated by another dopant carrier, resulting in a homogeneous rotationally symmetric sum profile. One doping profile may, for example, be U-shaped. The other doping profile may be in the shape of an inverted U.

[0040] In the first embodiment shown in Figure 1, hydrogen and a fourth
 10 growth gas flow Q4, which is C_2H_4 , are fed into the gas inlet zone 4 located at the very bottom. The mass flow of the fourth growth gas flow Q4 corresponds to approximately 10% of the sum of all carbon-containing growth gas flows $Q1 + Q3 + Q4$. In the middle gas inlet zone 5, in addition to hydrogen, a third growth gas flow Q3 containing C_2H_4 and a second growth gas flow Q2
 15 containing HCl SI are fed in. The third growth gas flow Q3 accounts for approximately 80% of the sum of all carbon-containing growth gas flows. In addition, a second dopant gas flow D2, which is nitrogen, is fed through the middle gas inlet zone 5. Nitrogen as well as a first growth gas flow Q1, which contains C_2H_4 , is fed through the uppermost gas inlet zone 6. The mass flow of
 20 this growth gas flow Q1 corresponds to approximately 10% of the total of all carbon-containing growth gas flows. Additionally, a first dopant gas flow D1, which contains NH_3 , is also fed in through the uppermost gas inlet zone 6.

[0041] Figure 4 illustrates the effect that the introduction of various dopant gas flows D1, D2 through gas inlet zones 5, 6 arranged at different levels has on the
 25 dopant distribution within the deposited layer. The upper curve c, depicted as open and closed triangles, shows a cross-section through the center of a layer deposited on the substrate 12 and the dopant distribution in the layer, which is

nearly uniform. Only in the region near the edge of the layer of the circular disc-shaped substrate 12 is a slight reduction in the dopant concentration observed.

[0042] The two lower curves a, b show the dopant incorporation that only one
 5 of the two different dopant carriers would produce. The open and closed squares (curve b) represent the dopant incorporation that only N_2 would cause. When using N_2 exclusively as the dopant carrier, a strong edge enhancement of the dopant incorporation is observed. The open and closed circles (curve a)
 10 represent the dopant incorporation that would result from using only NH_3 . When using NH_3 exclusively as the dopant carrier, a strong center enhancement of the dopant incorporation is observed. By appropriately selecting the ratio of the mass flows of N_2 and NH_3 , or by appropriately selecting the vertical height of the gas inlet zones through which the different dopant carriers are fed into the process chamber, a doping profile can be
 15 generated that compensates for the central excess or the edge excess.

[0043] In the embodiment shown in Figure 5, unlike the embodiment shown in Figure 1, a third dopant gas flow D3, which is NH_3 , is additionally fed in through the gas inlet zone 4 located at the very bottom.

[0044] In the embodiment shown in Figure 6, no dopant gas flow is fed into
 20 the process chamber 2 through the uppermost gas inlet zone 6. Here, a first dopant gas flow D1 (NH_3) is fed in only through the lowest gas inlet zone 4, and a second dopant gas flow D2 (N_2) is fed in through the middle or immediately upper gas inlet zone.

[0045] In the embodiment shown in Figure 7, two dopant gas flows D1 and D2
 25 are fed into the process chamber 2, each having NH_3 as the dopant carrier. The

two dopant gas flows D1 and D2 are fed into the process chamber 2 through the lowest gas inlet zone 4 and the uppermost gas inlet zone 6, respectively. Simply by selecting the vertically separate or spaced-apart gas inlet zones 4 and 6, the shape of the depletion curves a and b can be adjusted here.

5 [0046] In the embodiment shown in Figure 8, two dopant gas flows D1 and D2 are fed simultaneously into the process chamber 2 through the uppermost gas inlet zone 6. In this embodiment, N_2 and NH_3 are fed into the process chamber 2 through the same gas inlet zone 6. It may be provided that the dopant gas
10 flows D1, D2 are fed into the process chamber exclusively through the uppermost gas inlet zone 6, and that no dopant gas flows, but at most a carrier gas or growth gas flows, pass through the remaining gas inlet zones 5, 4. In particular, it is provided that a gas mixture comprising two different dopant carriers flows through a gas inlet zone 6, wherein the gas mixture consists of NH_3 and N_2 .

15 [0047] In the embodiment shown in Figure 9, two different dopant gas flows D1, D2, D3, D4 are each fed into the process chamber 2 through two different gas inlet zones 5, 6, which are preferably upper gas inlet zones. The mass flows of the dopant gas flows D1, D2, D3, D4 fed through the different gas inlet zones 5, 6 then differ. As in the embodiment shown in Figure 8, it may be
20 provided that a gas mixture comprising two different dopant carriers flows through a gas inlet zone 5, 6. The gas mixture may consist of NH_3 and N_2 in each case. The NH_3 flow through gas inlet zone 5 may differ from the NH_3 flow through gas inlet zone 6. Similarly, the two N_2 flows may differ.

[0048] By feeding the dopant gases at different feed levels, it is possible to
25 precisely control the dopant profile. For this purpose, the following procedure can be used, for example: First, a doped layer is deposited using only an NH_3

flow. The dopant profile is determined for this layer. A second layer is deposited on a second substrate, using only an N_2 flow as the dopant. Alternatively, the second layer can also be deposited by simultaneously feeding an NH_3 flow and an N_2 flow into the process chamber. The dopant profile is then measured on these layers. The NH_3 flow or N_2 flow is then adjusted/varied – i.e., increased or decreased – for example in model calculations or in further experiments, until an acceptable “flat” doping profile is achieved.

[0049] It is considered essential that, when using NH_3 , a gas inlet zone 4 or 6 be used through which no chlorine-containing gas mixture flows. It is thus specifically provided that a chlorine-containing growth gas flow be fed into the process chamber exclusively through a central gas inlet zone 5.

[0050] It may be provided that a gas flow of a carbon-containing growth gas flows through all gas inlet zones 4, 5, 6.

[0051] When selecting the combinations of dopant carriers, it may be advantageous if the dopant carriers have different nitrogen bonds (single, double, or triple bonds), or if the dopant are bound within the dopant carrier molecule via chemical bonds of varying strength. It can be assumed that these dopant carriers decompose differently and thus exhibit distinct depletion curves, allowing the dopant profile within the layer to be cut to be adjusted.

[0052] It may be advantageous if NH_3 is fed through the uppermost and lowermost gas inlet zones 4, 6, respectively, and N_2 is fed through the middle gas inlet zone 5.

[0053] The carbon-containing reaction gas, for example C_2H_4 , is preferably fed into the process chamber 2 in the following mass distribution: 10% each through the bottom-most and top-most gas inlet zones 4, 6, and 80% through the middle gas inlet zone 5. The silicon-containing reactive gas, in particular trichlorosilane or dichlorosilane, is preferably fed into the process chamber 2 exclusively through the middle gas inlet zone 5.

[0054] Figure 10 shows an initial lateral dopant profile a measured in a SiC layer deposited on a substrate. The profile represents the N concentration measured in the layer as a function of the distance R from the center of the circular substrate. Only NH_3 was used as the dopant carrier during the deposition of the layer.

[0055] The growth gas flows Q1 and Q2 were varied such that profile a is as flat as possible.

[0056] Using the same growth gas flows Q1 and Q2, a SiC layer was deposited on a second substrate, whereby only N_2 was used as the dopant carrier during the deposition of the layer.

[0057] Curve c shows a calculated lateral dopant profile of the N concentration in a layer when both NH_3 and N_2 are used as dopant carriers. The mass flows of the dopant gas flows D1', D2' were optimized such that curve c is as flat as possible.

[0058] The foregoing descriptions serve to explain the inventions covered by the application as a whole, which each independently advance the prior art at least through the following combinations of features, whereby two, several, or all of these combinations of features may also be combined, namely:

[0059] A method characterized in that the mass flows of the first and second dopant gas flows D1, D2 or the vertical position of the gas inlet zones 4, 5, 6 through which the two dopant gas flows D1, D2 flow are selected such that the lateral profiles a, b exhibit different surface curvature profiles from one another.

- 5 [0060] A method characterized in that the first dopant carrier is a nitrogen-containing gas, in particular NH_3 , and the second dopant carrier is a nitrogen-containing gas, in particular N_2 .

[0061] A method characterized in that the binding forces of a nitrogen atom to other atoms of the second dopant carrier are greater than the binding forces of a
10 nitrogen atom to other atoms of the first dopant carrier.

[0062] A method characterized in that the second growth gas flow Q2 contains chlorine and the first growth gas flow Q1 does not flow together with the NH_3 -containing first dopant gas flow D1 through the same gas inlet zone 4, 5, 6.

- [0063] A method characterized in that the first and second dopant carriers and
15 the mass flows of the dopant gas flows D1, D2 carrying them are selected such that a sum of the two profiles a, b, weighted by the ratio of the mass flows, approximates a plane.

[0064] A method characterized in that the dopant carriers are selected from the following nitrogen compounds: N_2 , NH_3 , HCN, pyridine ($\text{C}_5\text{H}_5\text{N}$), hydrazine
20 (N_2H_4), dimethylhydrazine ($\text{C}_2\text{H}_8\text{N}_2$) or unsymmetrical dimethylhydrazine.

[0065] A method characterized in that the process gas flow is fed into a central gas inlet element 3, which is surrounded by substrate holders 11 arranged in a circular pattern around the gas inlet element 3 and seated in pockets 17 of a

susceptor 10, wherein the substrate holders 11 are supported by a gas cushion and driven in rotation.

[0066] A method characterized in that the first dopant gas flow D1 flows through a topmost gas inlet zone 6 and the second dopant gas flow D2 flows
5 through a lower gas inlet zone 5, and/or that the first dopant gas flow D1 flows together with the first growth gas flow Q1 through the same gas inlet zone 6, and/or that the second dopant gas flow D2 flows together with the second growth gas flow Q2 through the same gas inlet zone 5, and/or that a third growth gas flow Q3 flows through a gas inlet zone 4 located at the very bottom,
10 and no dopant gas flow flows through the gas inlet zone 4 located at the very bottom, and/or that a third dopant gas flow D3 flows through a gas inlet zone 4 located at the very bottom and/or that the first dopant gas flow D1 flows through a gas inlet zone 4 located at the very bottom and the second dopant gas flow D2 flows through a gas inlet zone 5 located above it and/or that the first
15 dopant gas flow D1 and the second dopant gas flow D2 contain the same dopant carrier, wherein the first dopant gas flow D1 flows through a gas inlet zone 6 arranged at the very top and the second dopant gas flow D2 flows through a gas inlet zone 4 arranged at the very bottom, and/or that through a gas inlet zone 6, in particular the uppermost gas inlet zone, or through two gas
20 inlet zones 5, 6, in particular through the upper gas inlet zones 5, 6, two different dopant gas flows D1, D2; D3, D4 are fed into the process chamber 2, wherein the dopant gas flows D1, D2; D3, D4 flowing through a common gas inlet zone 5, 6 comprise different dopant carriers.

[0067] A device characterized in that the control device 20 is configured to
25 carry out a method according to one of the preceding claims.

[0068] The invention also relates to the following:

A method for determining mass flow rates of the dopant gas flows for carrying out a method according to any one of claims 1-8, comprising the following steps:

- Determining a first lateral dopant profile (a), wherein a first layer is deposited in the process chamber (2), wherein only one of the dopant gas flows (D1, D2) is fed into the process chamber (2) in addition to predetermined growth gas flows (Q1, Q2);
- Determining a second lateral dopant profile (b), wherein a second layer is deposited in the process chamber (2), wherein only a different one of the dopant gas flows (D1, D2) is fed into the process chamber (2) in addition to the predetermined growth gas flows (Q1, Q2);
- Calculating efficiency values (E1, E2) of the dopant incorporation for the two lateral dopant profiles (a), wherein values of the dopant concentration (D2) are determined at radially spaced locations in the first and second layers, and these values are divided by the mass flow rate of the respective dopant gas flow (D1, D2);
- Using these efficiency values (E1, E2) to calculate an optimized expected third lateral dopant profile (c) that forms in a layer when, in addition to the specified growth gas flows (Q1, Q2), all dopant gas flows (D1, D2) are introduced, wherein mass flow rates of the two dopant gas flows (D1, D2) are varied.

[0069] A method according to the preceding claim, characterized in that, when varying the mass flow values, an average value of all dopant concentrations (D1, D2) calculated at the radially spaced locations is calculated,

and a sum of the squares of the differences between the calculated dopant concentrations and the average value is minimized.

[0070] A method according to the preceding claims, characterized in that, when determining the first lateral dopant profile (a), the mass flow of the
5 dopant gas flow (D1) and the mass flows of the growth gas flows (Q1, Q2) are varied such that a lateral profile (a) that is as flat as possible is established.

[0071] A method according to the features of one of the preceding claims, characterized in that, when determining the second lateral dopant profile (b), the same growth gas flows (Q1, Q2) are used as those obtained when
10 determining the first lateral profile (a).

[0072] All disclosed features are essential to the invention (both individually and in combination with one another). The disclosure of the application hereby fully incorporates the disclosure content of the associated/attached priority documents (transcript of the prior application), including for the purpose of
15 incorporating features of these documents into the claims of the present application. The subclaims characterize, even without the features of a referenced claim, independent inventive advancements over the prior art with their own features, in particular for the purpose of filing divisional applications based on these claims. The invention specified in each claim may additionally
20 include one or more of the features described in the preceding description, in particular those marked with reference numbers and/or listed in the list of reference numbers. The invention also relates to embodiments in which some of the features mentioned in the preceding description are not implemented, in particular where they are recognizably dispensable for the respective intended
25 use or can be replaced by other means having the same technical effect.

List of Reference Numbers

1	CVD reactor	29	Gas source, trichlorosilane
2	Process chamber	30	Gas source, ethene
3	Gas inlet		
4	Gas inlet zone		
5	Gas inlet zone		
6	Gas inlet zone		
7	Inlet zone		
8	Deposition zone	D1	Doping gas flow
9	Gas outlet	D2	Doping gas flow
10	Susceptor	D3	Doping gas flow
11	Substrate holder	D4	Doping gas flow
12	Substrate	Q1	Growth gas flow
13	Gas line	Q2	Growth gas flow
14	Heating device	Q3	Growth gas flow
15	Cover plate	Q4	Growth gas flow
16	Cover plate	Q5	Growth gas flow
17	Pocket	S	Flow direction
18	Retaining element		
19	Ceiling panel		
20	Control device		
21	Mass flow controller		
22	Valve	a	Doping profile
24	Supply line	b	Doping profile
25	Supply line		
26	Supply line		
27	Gas source, nitrogen		
28	Gas source, ammonia		

Claims

1. A method for depositing a SiC layer on a substrate (12)
in a process chamber (2) of a CVD reactor (1) heated to a process
temperature by a heating device (14), wherein a process gas flow is fed
into the process chamber (2) through a gas inlet (3) and flows in a
horizontal direction in a flow direction (S) over the rotationally driven
substrate (12), wherein the process gas flow comprises at least one dopant
gas flow (D1), which contains a first gaseous dopant carrier, a second
dopant gas flow (D2), which contains a second gaseous dopant carrier, a
carbon-containing first growth gas flow (Q1), and a silicon-containing
second growth gas flow (Q2), wherein the dopant carriers decompose into
decomposition products as they flow through the process chamber (2),
wherein the decomposition products are incorporated into the SiC layer as
dopants at the surface of the SiC layer growing on the substrate, and
wherein the two dopant gas flows (D1, D2) are fed into the process
chamber (2) separately via vertically stacked gas inlet zones (4, 5, 6) into
the process chamber (2), wherein each of the two dopant gas flows (D1,
D2) generates a lateral profile (a, b) of its dopant with a characteristic
surface curvature profile in an SiC layer, characterized in that the mass
flows of the first and second dopant gas flows (D1, D2) and/or the vertical
position of the gas inlet zones (4, 5, 6) through which the two dopant gas
flows (D1, D2) pass are selected such that the lateral profiles (a, b) exhibit
surface curvature profiles that differ from one another.
2. Method according to claim 1, characterized in that the first dopant carrier
is a nitrogen-containing gas, in particular NH_3 and, and the second dopant
carrier is a nitrogen-containing gas, in particular N_2 .

3. A method according to one of the preceding claims, characterized in that the binding forces of a nitrogen atom to other atoms of the second dopant carrier are greater than the binding forces of a nitrogen atom to other atoms of the first dopant carrier.
- 5 4. A method according to any one of the preceding claims, characterized in that the second growth gas flow (Q2) contains chlorine and the first growth gas flow (Q1) does not flow together with the NH₃-containing first dopant gas flow (D1) through the same gas inlet zone (4, 5, 6).
- 10 5. A method according to one of the preceding claims, characterized in that the first and second dopant carriers and the mass flows of the dopant gas flows (D1, D2) carrying them are selected such that a sum of the two profiles (a, b), weighted by the ratio of the mass flows, approximates a plane.
- 15 6. A method according to any of the preceding claims, characterized in that the dopant carriers are selected from the following nitrogen compounds: N₂, NH₃, HCN, pyridine (C₅H₅N), hydrazine (N₂H₄), dimethylhydrazine (C₂H₈N₂) or unsymmetrical dimethylhydrazine.
- 20 7. A method according to any of the preceding claims, characterized in that the process gas flow is fed into a central gas inlet member (3) which is surrounded by substrate holders (11) arranged in a circle around the gas inlet member (3) and which are located in pockets (17) of a susceptor (10), wherein the substrate holders (11) are supported by a gas cushion and are driven in rotation.

8. A method according to any one of the preceding claims, characterized in that the first dopant gas flow (D1) flows through a gas inlet zone (6) arranged at the top and the second dopant gas flow (D2) flows through a lower-lying gas inlet zone (5) and/or that the first dopant gas flow (D1) flows together with the first growth gas flow (Q1) through the same gas inlet zone (6) and/or that the second dopant gas flow (D2) flows together with the second growth gas flow (Q2) through the same gas inlet zone (5) and/or that a third growth gas flow (Q3) flows through a gas inlet zone (4) located at the very bottom and no dopant gas flow flows through the gas inlet zone (4) located at the very bottom and/or that a third dopant gas flow (D3) flows through a gas inlet zone (4) and/or that the first dopant gas flow (D1) flows through a gas inlet zone (4) located at the very bottom and the second dopant gas flow (D2) flows through a gas inlet zone (5) located above it and/or that the first dopant gas flow (D1) and the second dopant gas flow (D2) contain the same dopant carrier, wherein the first dopant gas flow (D1) flows through a gas inlet zone (6) located at the very top and the second dopant gas flow (D2) flows through a gas inlet zone (4) located at the very bottom, and/or that through a gas inlet zone (6), in particular the gas inlet zone arranged at the top, or through two gas inlet zones (5, 6), in particular through gas inlet zones (5, 6) arranged at the top, two different dopant gas flows (D1, D2; D3, D4) are fed into the process chamber (2), wherein the dopant gas flows (D1, D2; D3, D4) flowing through a common gas inlet zone (5, 6) comprise different dopant carriers.
9. Apparatus comprising a CVD reactor (1) having a susceptor (10) extending in a horizontal plane for receiving substrates (12) and a gas inlet member (3) comprising a plurality of gas inlet zones (4, 5, 6) arranged vertically one above the other, wherein the gas inlet zones (4, 5, 6) are connected via supply lines (24, 25, 26) and mass flow controllers (21) and

valves (22) arranged in the supply lines to gas sources (27, 28, 29, 30), in which first and second dopant carriers, as well as a carbon-containing reactive gas and a silicon-containing reactive gas, are stored separately from one another, and comprising a control device (20) for controlling the mass flow controllers (21) and valves (22), characterized in that the control device (20) is configured to carry out a method according to one of the preceding claims.

10. A method or apparatus characterized by one or more of the defining features of any of the preceding claims.