

DOPANT COMPOSITIONS FOR ION IMPLANTATION

Field of the Invention

[0001] The present invention relates to a composition comprising a suitable assistant species in combination with a dopant source to produce the beam current of the target ionic species.

Background of the Invention

[0002] Ion implantation is utilized in the fabrication of semiconductor based devices such as Light Emitting Diodes (LED), solar cells, and Metal Oxide Semiconductor Field Effect Transistors (MOSFET). Ion implantation is used to introduce dopants to alter the electronic or physical properties of semiconductors.

[0003] In a traditional ion implantation system, a gaseous species often referred to as the dopant source is introduced into the arc chamber of an ion source. The ion source chamber comprises a cathode which is heated to its thermionic generation temperature to generate electrons. Electrons accelerate towards the arc chamber wall and collide with the dopant source gas molecule present in the arc chamber to generate a plasma. The plasma comprises dissociated ions, radicals, and neutral atoms and molecules of the dopant gas species. The ions are extracted from the arc chamber and then separated to select a target ionic species which is then directed towards the target substrate. The amount of ions produced depends upon various parameters of the arc chamber, including, but not limited to, the amount of energy supplied per unit time to the arc chamber, (i.e. power level) and flow rate of the dopant source and/or assistant species into the ion source.

[0004] Several dopant sources are currently in use today, such as, fluorides, hydrides, and oxides containing the dopant atom or molecule. These dopant sources can be limited in their ability to produce the beam current of the target ionic species and there is a continuous demand for improving the beam current, especially for high dose ion implantation applications, such as source drain/source drain extension implants, polysilicon doping and threshold voltage tuning.

[0005] Today, an increased beam current is achieved by introducing gases which produce ions containing the target dopant species into the plasma. One known

method utilized for increasing the beam current generated from ionizing the dopant gas source is the addition of a co-species to the dopant source to produce more dopant ions. For example, U.S. Patent No. 7,655,931 discloses adding a diluent gas having the same dopant ion as the dopant gas. However, the beam current increase may not be high enough for particular ion implant recipes. In fact, there have been instances where the addition of the co-species actually lowers the beam current. In this regard, U.S. Patent No. 8,803,112 at Fig. 3 and Comparative Examples 3 and 4 demonstrate that adding a diluent of SiH₄ or Si₂H₆, respectively, to a dopant source of SiF₄ actually lowered the beam current in comparison to the beam current generated solely from SiF₄.

[0006] Another method includes using isotopically enriched dopant sources. For example, U.S. Patent No. 8,883,620 discloses adding isotopically enriched versions of a naturally occurring dopant gas, in an attempt to introduce more moles of the dopant ion per unit volume. However, utilizing isotopically enriched gases may require substantial changes to the ion implant process that can require re-qualification, which is a time consuming process. Additionally, the isotopically enriched version does not necessarily generate a beam current that increases in an amount that is proportional to the isotopic enrichment level. Further, isotopically enriched dopant sources are not readily commercially available. Even when commercially available, such sources can be significantly more expensive than their naturally occurring versions as a result of the process required to isolate the desired isotope of the dopant source above its natural abundance levels. This increase in cost of the isotopically enriched dopant source may sometimes not be justified in view of the observed increase in beam current, which for certain dopant sources has been only observed to produce a marginal improvement in beam current relative to its naturally occurring version.

[0007] In view of these drawbacks, there remains an unmet need for improving ion implantation beam current.

Summary of the Invention

[0008] Due to these shortcomings, the present invention relates to a composition suitable for use in an ion implanter for production of a target ionic species to create an ion beam current, comprising a dopant source in combination with an assistant species wherein the dopant source and the assistant species occupy the ion

implanter and interact therein to produce the target ionic species. The criteria for selecting an assistant species is based on the combination of the following properties: ionization energy, total ionization cross sections, bond dissociation energy to ionization energy ratio and a certain composition. It should be understood that other uses and benefits of the present invention will be applicable.

[0009] In one aspect, a composition for ion implantation of a non-carbon target ionic species, comprising: a dopant source comprising the non-carbon target ionic species; an assistant species comprising: (i) a lower ionization energy in comparison to an ionization energy of the dopant source; (ii) a total ionization cross-section (TICS) greater than $2 \text{ \AA}^2$; (iii) a ratio of bond dissociation energy (BDE) of a weakest bond of the assistant species to the lower ionization energy of the assistant species to be 0.2 or higher; and (iv) a composition that is characterized by an absence of the non-carbon target ionic species; wherein the dopant source and the assistant species occupy the ion implanter and interact therein to produce the non-carbon target ionic species with or without an optional diluent.

[0010] In a second aspect, a composition suitable for use in an ion implanter for production of Ge-containing target ionic species to create a Ge-containing ion beam current, said composition comprising: a dopant source comprising GeF_4 from which the Ge-containing target ionic species are derived; and an assistant species comprising CH_3F ; wherein the dopant source and the assistant species occupy the ion implanter and interact therein to produce the Ge-containing target ionic species.

[0011] In a third aspect, a composition suitable for use in an ion implanter for production of B-containing target ionic species to create a B-containing ion beam current, said composition comprising: a dopant source comprising BF_3 from which the B-containing target ionic species are derived; and an assistant species comprising Si_2H_6 ; wherein the dopant source and the assistant species occupy the ion implanter and interact therein to produce the B-containing target ionic species.

Brief Description of the Drawings

[0012] **Figure 1** is a bar graph of relative ^{72}Ge ion beam current data for $^{72}\text{GeF}_4$ gas mixtures ;

[0013] **Figure 2** is a bar graph comparing the relative Ge ion beam current produced from naturally occurring GeF₄ and isotopically enriched ⁷²GeF₄ gas mixtures;

[0014] **Figure 3** is a bar graph of the relative beam current of ¹¹B ions generated from gas mixtures of isotopically enriched ¹¹BF₃;

[0015] **Table 1** is an exemplary listing of assistant species with property values; and

[0016] **Table 2** is an exemplary listing of assistant species and dopant species.

Detailed Description of the Invention

[0017] The relationship and functioning of the various elements of this invention are better understood by the following detailed description. The detailed description contemplates the features, aspects and embodiments in various permutations and combinations, as being within the scope of the disclosure. The disclosure may therefore be specified as comprising, consisting or consisting essentially of, any of such combinations and permutations of these specific features, aspects, and embodiments, or a selected one or ones thereof.

[0018] Unless indicated otherwise, it should be understood that all compositions are expressed as volume percentages (vol %), based on a total volume of the composition.

[0019] As used herein and throughout the specification, the terms "isotopically enriched" and "enriched" dopant gas are used interchangeably to mean the dopant gas contains a distribution of mass isotopes different from the naturally occurring isotopic distribution, whereby one of the mass isotopes has an enrichment level higher than present in the naturally occurring level. By way of example, 58% ⁷²GeF₄ refers to an isotopically enriched or enriched dopant gas containing mass isotope ⁷²Ge at 58% enrichment, whereas naturally occurring GeF₄ contains mass isotope ⁷²Ge at 27% natural abundance levels. Isotopically enriched ¹¹BF₃ as used herein and throughout refers to an isotopically enriched dopant gas containing mass isotope ¹¹B at preferably 99.8% enrichment, whereas natural occurring BF₃ contains mass isotope ¹¹B at 80.1% natural abundance levels. The enrichment levels as used herein and throughout are expressed as volume percentages, based on a total volume of distribution of the mass isotopes contained in the material.

[0020] It should be understood that the dopant source and the assistant species as described herein and throughout may include other constituents (e.g., unavoidable trace contaminants) whereby such constituents are contained in an amount that does not adversely impact the interaction of the assistant species with the dopant source.

[0021] The present disclosure relates to a composition for ion implantation comprising a dopant source and an assistant species wherein the assistant species in combination with the dopant gas produces an ion beam current of the desired dopant ion with or without an optional diluent species. The “target ionic species” is defined as any positively or negatively charged atom or molecular fragment(s) originating from the dopant source that is implanted into the surface of a target substrate, including but not limited to, wafers. As will be explained, the present invention recognizes that there is a need for improvement of current dopant sources, particularly in high dose applications (i.e., greater than 10^{13} atoms/cm²) of ion implantation, and offers a novel solution for achieving the same.

[0022] It should be understood that reference to dopant source and assistant species may also include any isotopically enriched versions of either the dopant source or assistant species, whereby any atom of the dopant source or the assistant species is isotopically enriched greater than natural abundance levels.

[0023] In one aspect, the present invention involves a dopant source comprising the target ionic species and an assistant species comprising the following attributes: (i) a lower ionization energy than the dopant source; (ii) a total ionization cross section greater than $2 \text{ \AA}^2$ (iii) a ratio of bond dissociation energy to ionization energy greater than or equal to 0.2; and (iv) a composition characterized by an absence of the target ionic species. Without being bound by any particular theory, the Applicants have discovered that when an assistant species is selected with the criteria above and co-flowed, sequentially flowed or mixed with a dopant source, the resultant composition can interact with each other to produce the target ionic species with or without an optional diluent species.

[0024] In another aspect, the present invention involves a non-carbon dopant source comprising the target ionic species and an assistant species comprising the following attributes: (i) a lower ionization energy than the non-carbon dopant source; (ii) a total ionization cross section greater than $2 \text{ \AA}^2$ (iii) a ratio of bond dissociation

energy to ionization energy greater than or equal to 0.2; and (iv) a composition characterized by an absence of the target ionic species. The non-carbon dopant source and the assistant species occupy the ion implanter and interact therein to produce the target ionic species.

[0025] Without being bound by any particular theory, the Applicants have discovered that when an assistant species is selected with the criteria above and co-flowed, sequentially flowed or mixed with a dopant source, the resultant composition can interact with each other to produce the target ionic species with or without an optional diluent species.

[0026] In yet another aspect, the present invention involves a dopant source comprising a non-carbon target ionic species and an assistant species comprising the following attributes: (i) a lower ionization energy than the non-carbon dopant source; (ii) a total ionization cross section greater than $2 \text{ \AA}^2$ (iii) a ratio of bond dissociation energy to ionization energy greater than or equal to 0.2; and (iv) a composition characterized by an absence of the non-carbon target ionic species. The dopant source and the assistant species occupy the ion implanter and interact therein to produce the non-carbon target ionic species.

[0027] In another aspect, the dopant source and the assistant species (having the criteria described herein) can interact with each other to produce a higher ion beam current of the non-carbon target ionic species than that generated solely from the dopant source. The ability to produce a higher beam current of the non-carbon target ionic species is surprising, given that the assistant species does not contain the target ionic species and, as a result, is diluting the dopant source and reducing the number of dopant source molecules introduced into the plasma. The assistant species enhances the ionization of the dopant source into forming the desired or non-carbon target ionic species to enable increase of the beam current of the non-carbon target ionic species from the dopant source even though the assistant species does not include the non-carbon target ionic species.

[0028] In another aspect, the dopant source is a non-carbon dopant source and the assistant species (having the criteria described herein) can interact with each other to produce a higher ion beam current of the target ionic species than that generated solely from the non-carbon dopant source. The ability to produce a higher beam current

of the target ionic species is surprising, given that the assistant species does not contain the target ionic species and, as a result, is diluting the non-carbon dopant source and reducing the number of non-carbon dopant source molecules introduced into the plasma. The assistant species enhances the ionization of the non-carbon dopant source into forming the desired or target ionic species to enable increase of the beam current of the target ionic species from the non-carbon dopant source even though the assistant species does not include the target ionic species.

[0029] In yet another aspect, the present invention involves a dopant source comprising the target ionic species and an assistant species comprising the following attributes: (i) a lower ionization energy than the dopant source; (ii) a total ionization cross section greater than $2 \text{ \AA}^2$ (iii) a ratio of bond dissociation energy to ionization energy greater than or equal to 0.2; and (iv) a composition characterized by an absence of the target ionic species. Without being bound by any particular theory, the Applicants have discovered that when an assistant species is selected with the criteria above and co-flowed, sequentially flowed or mixed with the dopant source, the resultant composition can interact with each other to produce the target ionic species which creates the ion beam current having a higher level than that generated solely from the dopant source, with or without an optional diluent species.

[0030] The assistant species can be mixed with the dopant source in a single storage container. Alternatively, the assistant species and dopant source can be co-flown from separate storage containers. Still further, the assistant species and dopant source can be sequentially flowed from separate storage containers. When co-flown or sequentially flowed, the resultant compositional mixture can be produced upstream of the ion chamber or within the ion source chamber. In another example, the compositional mixture is withdrawn in the vapor or gas phase and then flows into an ion source chamber where the gas mixture is ionized to create a plasma. The target ionic species can then be extracted from the plasma and implanted into the surface of a substrate.

[0031] The ionization energy as used herein refers to the energy required to remove an electron from an isolated gas species and form a cation. The values for ionization energy can be obtained from the literature. More specifically, the literature sources can be found in the National Institute of Standards and Technology (NIST)

chemistry webbook (P.J. Linstrom and W.G. Mallard, Eds., NIST Chemistry WebBook, NIST Standard Reference Database Number 69, National Institute of Standards and Technology, Gaithersburg MD, 20899. <http://webbook.nist.gov/chemistry/>). Values for ionization energy can be determined experimentally using electron impact ionization, photoelectron spectroscopy, or photoionization mass spectrometry. Theoretical values for ionization energy can be obtained using density functional theory (DFT) and modeling software, such as commercially available Dacapo, VASP, and Gaussian. Although the energy supplied to the plasma is a discrete value, the species in the plasma are present over a broad distribution of different energies. When an assistant species with a lower ionization energy than the dopant source is added or introduced with the dopant source, the assistant species can ionize over a larger distribution of energies in the plasma. As a result, the overall population of ions in the plasma can increase. Such an increased population of ions leads to “assistant species ion-assisted ionization” of the dopant species as a result of the ions of the assistant species accelerating in the presence of the electric field and colliding with the dopant source to further break it down into more fragments. The net result is an increase in beam current for the target ionic species. On the contrary, if a species with a higher ionization energy than the dopant source is introduced into the dopant source, the added species can form a lower percentage of ions compared to the ions generated from the dopant source which can reduce the overall percentage of ions in the plasma and can reduce the beam current of the target ionic species. In one embodiment, the ionization energy of the assistant species is at least 5% lower than the ionization energy of the dopant source.

[0032] Although having an assistant species with a lower ionization energy than the dopant source is desirable, the lower ionization energy by itself may not increase beam current. Other applicable criteria must be met in accordance with the principles of the present invention. Specifically, the assistant species must have a minimum total ionization cross section. The total ionization cross section (TICS) of a molecule or atom as used herein is defined as the probability of the molecule or the atom forming an ion under electron and/or ion impact ionization represented in units of Area (e.g., cm^2 , $\text{\AA}^2$, m^2) as a function of the electron energy in eV. It should be understood that TICS as used herein and throughout refers to a maximum value at a particular electron energy.

Experimental data and BEB estimates are available in the literature and through the National Institute of Standards and Technology (NIST) database (Kim, Y., K. et al., Electron-Impact Cross Sections for Ionization and Excitation Database 107, National Institute of Standards and Technology, Gaithersburg MD, 20899, <http://physics.nist.gov/PhysRefData/Ionization/molTable.html>.) TICS values can be determined experimentally using electron impact ionization or electron ionization dissociation. The TICS can be estimated theoretically using the binary encounter Bethe (BEB) model. As the number of collision events in the plasma increases, the number of bonds broken increases and the number of ion fragments increases. Hence, besides a lower ionization energy, the present invention has discovered that a sufficient total ionization cross-section for the assistant species is also a desired property to assist with the ionization of the dopant species. In a preferred embodiment, the assistant species has a TICS that is greater than $2 \text{ \AA}^2$. Applicants have discovered that an ionization cross-section greater than $2 \text{ \AA}^2$ provides sufficient likelihood that the necessary collisions can occur. On the contrary, if the ionization cross section is less than $2 \text{ \AA}^2$, applicants have discovered that the number of collision events in the plasma is expected to decrease and, as a result, the beam current can also decrease. As an example, H_2 has a total ionization cross section less than $2 \text{ \AA}^2$, and when added to a dopant source such as GeF_4 , the beam current of Ge^+ is observed to decrease relative to that generated solely from GeF_4 . In other embodiments, the total ionization cross-section of the desired assistant species is greater than $3 \text{ \AA}^2$; greater than $4 \text{ \AA}^2$; or greater than $5 \text{ \AA}^2$. In addition to the requisite ionization energy and TICS, the assistant species that is selected must also have a certain bond dissociation energy (BDE) such that a ratio of the BDE of a weakest bond of the assistant species to the ionization energy of the assistant species is 0.2 or higher. Values for BDE are readily available in the literature, and more specifically from the National Bureau of Standards (Darwent, B. deB., "Bond Dissociation Energies in Simple Molecules", National Bureau of Standards, (1970)) or from textbooks (Speight, J. G., Lange, N. A., *Lange's Handbook of Chemistry*, 16th ed., McGraw-Hill, 2005). BDE values can also be experimentally determined through techniques such as pyrolysis, calorimetry, or mass spectrometry and also can be determined theoretically through density functional theory and modeling software such as commercially available Dacapo, VASP, and Gaussian. The ratio is an indicator of

the proportion of ions produced in the plasma relative to uncharged species. The BDE can be defined as the energy required to break a chemical bond. The bond with the weakest BDE will be the most likely to initially break in the plasma. Therefore, this metric is calculated using the weakest bond dissociation energy in the molecule, as each molecule can have multiple bonds with differing energies.

[0033] Generally speaking, in a plasma, chemical bonds are broken by collisions to produce molecular fragments. For example, GeF_4 can break apart into Ge, GeF , GeF_2 , and GeF_3 and F fragments. If Ge is the target ionic species, then four Ge-F bonds must be broken to produce the Ge target ionic species. Conventional wisdom dictates that a molecule with a lower bond dissociation energy is preferable, as it would more easily form the target ionic species because the chemical bonds would break more easily. However, the applicants have discovered otherwise. It has been discovered that molecules with a higher BDE tend to produce a greater proportion of ions compared to free radicals and/or neutrals. When a chemical bond is broken specifically in a plasma, the resulting species will form either ions, free radicals, or neutral species. The ratio of BDE of the weakest bond to ionization energy is selected in accordance with the principles of the present invention so as to increase the proportion of ions in the plasma while reducing the proportion of free radicals and neutral species, as both the free radicals and neutral species have no charge and, therefore, are not influenced by electric fields or magnetic fields. Further, these species are inert in a plasma and cannot be extracted to form an ion beam. Accordingly, the ratio of the BDE of the weakest bond of the assistant species to the ionization energy is an indicator of the fraction of ions formed in the plasma relative to the free radicals and neutral species. Specifically, when a gas molecule with a bond dissociation of the weakest bond to ionization energy ratio of 0.2 or higher is added to a dopant source, the plasma is more likely to produce a greater proportion of ions compared to free radical and neutral species in the plasma. The greater proportion of ions can increase the beam current of the target ionic species. In another embodiment, the assistant species is selected to have a weakest bond dissociation energy to ionization energy ratio of at least 0.25 or higher; and preferably 0.3 or higher. On the contrary, if the ratio of bond dissociation energy of the weakest bond to ionization energy is below 0.2, the energy supplied to the plasma is coupled to forming a higher proportion of neutral species and/or free radicals

which can flood the plasma and decrease the number of target ionic species produced. Hence, this non-dimensional metric of the present invention allows a better comparison between the ability of species to produce a higher proportion of ions relative to free radicals and/or neutrals in the plasma.

[0034] The assistant species has a composition that is characterized by an absence of the target ionic species. In this regard, Table 2 shows several examples of dopant sources with target ionic species along with examples of suitable assistant species for each dopant source based on the four criteria of ionization energy, TICS and weakest BDE to ionization energy ratio and where the assistant species does not contain the target ionic species. Table 2 comprises examples of suitable assistant species for each dopant source (as indicated by “X”), but it should be understood that the present invention contemplates any species that satisfies the criteria described previously. As can be seen in Table 2, the assistant species does not contain the target ionic species. The ability to utilize such assistant species is unexpected, as less moles of dopant source per unit volume is introduced into the plasma, and thus has the effect of diluting the dopant source in the plasma. However, when the assistant species meets the criteria described previously, the assistant species, when added to the dopant source or vice versa, can increase the beam current of the target ionic species compared to the beam current generated solely from the dopant source. The assistant species enhances the formation of the target ionic species from the dopant source to increase the ion beam current of the target ionic species. The increase in beam current may be 5% or higher; 10% or higher; 20% or higher; 25% or higher; or 30% or higher. The exact percentage by which the ion beam current is increased can be a result of selected operating conditions, such as, by way of example, power level of the ion implanter and/or flow rate of the dopant source and/or the assistant species gases introduced into the ion implanter.

[0035] A preferred assistant species to enhance the beam current of the target ionic species from the dopant source has a lower ionization energy than the dopant source; a total ionization cross-section greater than $2 \text{ \AA}^2$ at the same operating conditions as the dopant source and a weakest bond dissociation energy to ionization energy ratio of 0.2 or higher. Table 1 shows a tabular listing of select assistant species and their respective numerical values for TICS, ionization energy and BDE/IE ratio.

The TICS values shown in Table 1 are published values that are obtained from either the Electron-Impact Cross Sections for Ionization and Excitation Database 107 from NIST; or from Bull, S. et al., *J. Phys. Chem. A* (2012) 116, pp. 767-777. Ionization energy values for each molecule in Table 1 are obtained from the NIST Chemistry WebBook or NIST Standard Reference Database Number 69 (i.e., specifically, the most recent published version as of the filing date of the present invention). The ionization values were based on electron impact ionization, which was the experimental technique used to obtain such values. BDE values used in the calculation of the BDE/IE ratio were obtained from the National Bureau of Standards or “Lange’s Handbook of Chemistry” cited hereinbefore. Table 1 comprises examples of suitable assistant species but any species that follows the criteria described herein in accordance with the principles of the present invention can be utilized. The assistant species does not contain the target ionic species as the purpose of the assistant species is to enhance formation of the target ionic species from the dopant source. The combination of suitable assistant species and dopant source preferably can generate an ion beam capable of doping at least 10^{11} atoms/cm² of the target ionic species from the dopant source.

[0036] Suitable dopant source and assistant species are now described, with reference to Table 2. An example of a dopant source compound is GeF₄ for Ge ion implantation. GeF₄ has an ionization energy of 15.7 eV and a weakest bond dissociation energy to ionization energy ratio of 0.32. In accordance with the principles of the present invention, an example of an assistant species is CH₃F. CH₃F has an ionization energy of 13.1 eV which is lower than GeF₄, a TICS of $4.4 \text{ \AA}^2$, and a weakest bond dissociation energy for the C-H bond to ionization energy ratio of 0.35. For GeF₄, the assistant species will preferably have a TICS of at least $3 \text{ \AA}^2$, and a ratio of BDE of the weakest bond to ionization energy of 0.22 or greater.

[0037] Another example of a dopant source compound is SiF₄ for Si ion implantation. This molecule has an ionization energy of 16.2 eV and a weakest bond dissociation energy to ionization energy ratio of 0.35. An example assistant species is CH₃Cl. This molecule has an ionization energy of 11.3 eV which is lower than SiF₄, a TICS of $7.5 \text{ \AA}^2$, and a weakest bond dissociation energy for the C-Cl bond to ionization energy ratio of 0.31. For SiF₄, the assistant species will preferably have a TICS of at

least $4 \text{ \AA}^2$, and a ratio of BDE of the weakest bond to ionization energy of 0.25 or greater.

[0038] Another example of a dopant source compound is BF_3 for BF_2 and B ion implantation. This molecule has an ionization energy of 15.8 eV and a weakest bond dissociation energy to ionization energy ratio of 0.37. An example assistant species is Si_2H_6 . This molecule has an ionization energy of 9.9 eV which is lower than BF_3 , a TICS of $8.1 \text{ \AA}^2$, and for the Si-H bond a weakest bond dissociation energy to ionization energy ratio of 0.31. For BF_3 , the assistant species will preferably have a TICS of at least $3 \text{ \AA}^2$, and a ratio of BDE of the weakest bond to ionization energy of 0.23 or greater.

[0039] Another example of a dopant source compound is CO for C^+ ion implantation. This molecule has an ionization energy of 14.02 eV and a bond dissociation energy to ionization energy ratio of 0.8. An example assistant species is GeH_4 , which has an ionization energy of 10.5 eV, a TICS of $5.3 \text{ \AA}^2$, and a weakest bond dissociation energy to ionization energy ratio of 0.32. For CO, the assistant species will preferably have a maximum TICS of at least $2.7 \text{ \AA}^2$, and a ratio of BDE of the weakest bond to ionization energy of 0.25 or greater.

[0040] Another aspect of the disclosure relates to choosing a dopant source that contains, for example, but not limited to, germanium, boron, silicon, nitrogen, arsenic, selenium, antimony, indium, sulfur, tin, gallium, aluminum, or phosphorous atoms contained in the target ionic species and then selecting an assistant species having the attributes (i) through (iv) mentioned hereinbefore, and further whereby the assistant species contains one or more functional groups selected from the following: alkanes, alkenes, alkynes, haloalkanes, haloalkenes, haloalkynes, thiols, nitriles, amines, or amides.

[0041] In another aspect of the present invention, the operating conditions of the ion source can be adjusted such that the composition of the dopant source and assistant species is configured to generate an ion beam current that is the same or less than the ion beam current generated solely from the dopant source with or without an optional diluent. Operating at such beam current levels can create other operational benefits. By way of example, some of the operational benefits include but are not limited to reduction of beam glitching, increased beam uniformity, limited space charge

effects and beam expansion, limited particle formation, and increased source lifetime of the ion source, whereby all such operational benefits are being compared to sole use of the dopant source. The operational conditions which may be manipulated, include, but are not limited to, arc voltage, arc current, flow rate, extraction voltage and extraction current or any combination thereof. Additionally, the ion source may include use of one or more optional diluent, which can include H₂, N₂, He, Ne, Ar, Kr, and/or Xe.

[0042] It should be understood that the ions produced from ionization of the assistant species can be selected to be implanted into the target substrate.

[0043] Various operating conditions can be used to carry out the present invention. For example, the arc voltage can be in a range of 50-150 V; the flow rate of each of the dopant gas and assistant species into the ion implanter can be in a range of 0.1-100 sccm; and the extraction voltage can be in a range of 500V to 50 kV. Preferably, each of these operating conditions is selected to achieve a source life of at least 50 hours; with an ion beam current between 10 microamps and 100 mA.

[0044] Various compositions for the assistant species are contemplated. For example, in another aspect of the present invention relates to assistant species that have attributes (i) through (iv) mentioned hereinbefore and have a representative formula CH_yX_{4-y} where X is any halogen and y = 0 to 4. Examples of these species include but are not limited to CH₄, CF₄, CCl₄, CH₃Cl, CH₃F, CH₂Cl₂, CHCl₃, CH₂F₂, CHF₃, CH₃Br, CH₂Br₂, or CHBr₃. Another aspect of the present invention relates to assistant species that have attributes (i) through (iv) mentioned hereinbefore and has the formula CH_iF_jCl_yBr_zI_q where i, j, y, z, and q range from 0 to 4 and i+j+y+z+q = 4. Examples of these species include but are not limited to CClF₃, CH₂ClF, CHF₂Cl, CHCl₂F, CCl₂F₂, and CCl₃F. Another aspect of the present invention relates to assistant species that have attributes (i) through (iv) mentioned hereinbefore and has the formula C_iH_jN_yX_z where X is any halogen species, i ranges from 1 to 4, y and z, range from 0 to 4, and the value of j varies such that each atom has a closed shell of valence electrons. Examples of these species include but are not limited to CH₃CN, CF₃CN, HCN, CH₂CF₄, CH₃CF₃, C₂H₆, and CH₃NH₂. Another aspect of the present invention relates to assistant species that have attributes (i) through (iv) mentioned hereinbefore and has the formula Si_qH_yX_z where X is any halogen species, q ranges from 1 to 4, y, and z, range from 0 to 4, and the values of y and z vary such that each atom has a closed shell of

valence electrons. Examples of these species include but are not limited to SiH_4 , Si_2H_6 , SiH_3Cl , and SiH_2Cl_2 .

[0045] Still further, other assistant species may include CS_2 , GeH_4 , Ge_2H_6 , or B_2H_6 , each of which is paired with a particular dopant source in accordance with the principles of the present invention and as shown in Table 2.

[0046] In another embodiment of the present invention, the present disclosure relates to a composition for ion implantation comprising a dopant source, GeF_4 , and an assistant species, CH_3F , wherein the assistant species in combination with the dopant gas produces a Ge-containing ion beam current with or without an optional diluent species. The term “Ge-containing target ionic species” or “desired dopant ion” as used herein and throughout is defined as any Ge-containing positively or negatively charged atom or molecular fragment(s) originating from the GeF_4 dopant source that is implanted into the surface of a target substrate, including but not limited to, wafers. The term “ GeF_4 ” as used herein and throughout refers to a dopant source in its naturally occurring form. The term “Ge-containing” as used herein and throughout includes any mass isotope of Ge. As will be explained, the present invention recognizes that there is a need for improvement of current dopant sources, particularly in high dose applications (i.e., greater than 10^{13} atoms/cm²) of ion implantation, and offers a novel solution for achieving the same.

[0047] In one aspect, the present invention involves a dopant source GeF_4 comprising the Ge-containing target ionic species and an assistant species comprising CH_3F , in which the assistant species has the following attributes: (i) a lower ionization energy than the dopant source; (ii) a total ionization cross section greater than $2 \text{ \AA}^2$ (iii) a ratio of bond dissociation energy to ionization energy greater than or equal to 0.2; and (iv) a composition characterized by an absence of the target ionic species. Without being bound by any particular theory, the Applicants have discovered that when the assistant species CH_3F with such attributes is co-flowed, sequentially flowed or mixed with the dopant source GeF_4 , the GeF_4 dopant source and the CH_3F assistant species can interact with each other to produce Ge-containing target ionic species.

[0048] In another aspect, the GeF_4 dopant source and the CH_3F assistant species can interact with each other to produce a higher Ge-containing ion beam current of Ge-containing ions than that generated solely from the GeF_4 dopant source. The ability to

produce a higher Ge-containing ion beam current of the Ge-containing target ionic species is surprising, given that the assistant species CH_3F does not contain the Ge-containing target ionic species and, as a result, is diluting the GeF_4 dopant source and reducing the number of GeF_4 dopant source molecules introduced into the plasma. The assistant species CH_3F can enhance the ionization of the dopant source GeF_4 by synergistically interacting with the same to form the Ge-containing target ionic species to enable increase of the Ge-containing ion beam current of the Ge-containing target ionic species from the GeF_4 dopant source, even though the CH_3F assistant species does not include the Ge-containing target ionic species.

[0049] The CH_3F assistant species can be mixed with the GeF_4 dopant source in a single storage container. Alternatively, the CH_3F assistant species and GeF_4 dopant source can be co flown from separate storage containers. Still further, the CH_3F assistant species and GeF_4 dopant source can be sequentially flowed from separate storage containers into an ion implanter to produce the resultant mixture. When co-flown or sequentially flowed, the resultant compositional mixture can be produced upstream of the ion chamber or within the ion source chamber. In one example, the compositional mixture is withdrawn in the vapor or gas phase and then flows into an ion source chamber where the gas mixture is ionized to create a plasma. The Ge-containing target ionic species can then be extracted from the plasma and implanted into the surface of a substrate.

[0050] In yet another embodiment, the present disclosure relates to a composition for ion implantation comprising a dopant source, BF_3 , and an assistant species, Si_2H_6 , wherein the assistant species in combination with the dopant gas produces a B-containing ion beam current. The term “B-containing target ionic species” or “desired dopant ion” as used herein and throughout is defined as any B-containing positively or negatively charged atom or molecular fragment(s) originating from the BF_3 dopant source that is implanted into the surface of a target substrate, including but not limited to, wafers. The term “ BF_3 ” as used herein and throughout refers to a dopant source in its naturally occurring form. The term “B-containing” as used herein and throughout includes any mass isotope of B. As will be explained, the present invention recognizes that there is a need for improvement of current dopant

sources, particularly in high dose applications (i.e., greater than 10^{13} atoms/cm²) of ion implantation, and offers a novel solution for achieving the same.

[0051] In one aspect, the present invention involves a dopant source BF₃ comprising the B-containing target ionic species and an assistant species comprising Si₂H₆ in which the assistant species has the following attributes: (i) a lower ionization energy than the dopant source; (ii) a total ionization cross section greater than 2 Å² (iii) a ratio of bond dissociation energy to ionization energy greater than or equal to 0.2; and (iv) a composition characterized by an absence of the target ionic species. Without being bound by any particular theory, the applicants have discovered that when the assistant species Si₂H₆ with the criteria above is co-flowed, sequentially flowed or mixed with the dopant source BF₃, the BF₃ dopant source and the Si₂H₆ assistant species can interact with each other to produce B-containing target ionic species. It should be understood that the BF₃ dopant source and the Si₂H₆ assistant species as described herein and throughout may include other constituents (e.g., unavoidable trace contaminants) whereby such constituents are contained in an amount that does not adversely impact the interaction of the Si₂H₆ with BF₃.

[0052] In another aspect of the present invention, the BF₃ dopant source and the Si₂H₆ assistant species can interact with each other to produce a higher B-containing ion beam current of B-containing ions than that generated solely from the dopant source, BF₃. The ability to produce a higher B-containing ion beam current of the B-containing target ionic species is surprising, given that the assistant species Si₂H₆ does not contain the B-containing target ionic species and, as a result, is diluting the BF₃ dopant source and reducing the number of BF₃ dopant source molecules introduced into the plasma. The assistant species Si₂H₆ can enhance the ionization of the dopant source BF₃ by synergistically interacting with the same to form the B-containing target ionic species to enable increase of the B-containing ion beam current of the B-containing target ionic species from the BF₃ dopant source, even though the Si₂H₆ assistant species does not include the B-containing target ionic species.

[0053] The Si₂H₆ assistant species can be mixed with the BF₃ dopant source in a single storage container. Alternatively, the Si₂H₆ assistant species and BF₃ dopant source can be co flown from separate storage containers. Still further, the Si₂H₆ assistant species and BF₃ dopant source can be sequentially flowed from separate

storage containers into an ion implanter to produce the resultant mixture. When co-flown or sequentially flowed, the resultant compositional mixture can be produced upstream of the ion chamber or within the ion source chamber. In one example, the compositional mixture is withdrawn in the vapor or gas phase and then flows into an ion source chamber where the gas mixture is ionized to create a plasma. The B-containing target ionic species can then be extracted from the plasma and implanted into the surface of a substrate.

[0054] The present invention contemplates various fields of use for the compositions described herein. For example, some methods include but are not limited to beam line ion implantation and plasma immersion ion implantation mentioned in patent US 9,165,773, which is incorporated herein by reference in its entirety. Further, it should be understood that the compositions disclosed herein may have utility for other applications besides ion implantation, in which the primary source comprises a target species and the assistant species does not contain the target species and is further characterized as meeting the criteria (i), (ii) and (iii) mentioned hereinbefore. For example, the compositions may have applicability for various deposition processes, including, but not limited to, chemical vapor deposition or atomic layer deposition.

[0055] The compositions of the present invention can also be stored and delivered from a container with a vacuum actuated check valve that can be used for sub atmospheric delivery, as described in U.S. Patent Application with Docket No. 14057-US-P1, which is incorporated herein by reference in its entirety. Any suitable delivery package may be employed, including those described in U.S. Patent Nos. 5,937,895; 6,045,115; 6,007,609; 7,708,028; 7,905,247; and U.S. Serial No. 14/638,397 (U.S. Patent Publication No. 2016-0258537), each of which is incorporated herein by reference in its entirety. When the compositions of the present invention are stored as a mixture, the mixture in the storage and delivery container may also be present in the gas phase; a liquid phase in equilibrium with the gas phase wherein the vapor pressure is high enough to allow flow from the discharge port; or an adsorbed state on a solid media, each of which is described in U.S. Patent Application with Docket No. 14057-US-P1. Preferably, the composition of assistant species and dopant source will be able to generate a beam of the target ionic species to implant of 10^{11} atoms/cm² or higher.

[0056] Applicants have performed several experiments as a proof of concept using GeF_4 as a dopant source and CH_3F as an assistant species. In each experiment, the ion beam performance was measured using the Ge ion beam current produced; and the weight change of components was measured within the ion source chamber to measure the performance of the ion source. A cylindrical ion source chamber was used to generate a plasma. The ion source chamber consisted of a helical tungsten filament, tungsten walls, and a tungsten anode perpendicular to the axis of the helical filament. A substrate plate was positioned in front of the anode to keep the anode stationary during the ionization process. A small aperture in the center of the anode and a series of lenses placed in front of the anode were used to generate an ion beam from the plasma and a velocity filter was used to isolate specific ion species from the ion beam. A faraday cup was used to measure the current from the ion beam and all tests were run at an arc voltage of 100 V. The extraction voltage was the same value for each experiment. The entire system was contained in a vacuum chamber capable of reaching pressures less than $1\text{e-}7$ Torr. Figure 1 shows a bar graph of the ^{72}Ge ion beam current relative to the ^{72}Ge ion beam current produced solely by $^{72}\text{GeF}_4$ for each gas mixture tested.

Comparative Example 1 ($^{72}\text{GeF}_4$)

[0057] A test was performed to determine the ion beam performance of the dopant gas composition of $^{72}\text{GeF}_4$ that was isotopically enriched to 50.1 vol%. The $^{72}\text{GeF}_4$ was introduced into the ion source chamber. A current was applied to the filament to generate electrons and a voltage was applied to the anode to ionize the $^{72}\text{GeF}_4$ and produce ^{72}Ge ions. The ^{72}Ge ion beam current was normalized to be the basis for comparing the ^{72}Ge ion beam current of other gas mixtures. Results are shown at Figure 1. A significant filament weight gain occurred of 160 milligrams after 52 minutes of operation at which point the experiment was terminated as the filament could no longer sustain a plasma after 52 minutes. This was equivalent to a filament weight gain rate of 185 mg/hr.

Comparative Example 2 (75 vol% $^{72}\text{GeF}_4$ + 25 vol% Xe/H_2)

[0058] Another test was performed to determine the ion beam performance of the dopant gas composition of 75 vol% $^{72}\text{GeF}_4$ (isotopically enriched in mass isotope ^{72}Ge to 50.1 vol%) mixed with 25 vol% Xe/H_2 . The same ion source chamber was

utilized as that in Comparative Example 1. The $^{72}\text{GeF}_4$ and Xe/H_2 were introduced from separate storage containers and mixed before entering the ion source chamber. A current was applied to the filament to generate electrons and a voltage was applied to the anode to ionize the gas mixture and produce ^{72}Ge ions. The ^{72}Ge ion beam current was measured and determined to be about 16% less than the ^{72}Ge ion beam current produced solely using $^{72}\text{GeF}_4$. Results are shown at Figure 1. A weight loss of 30 milligrams was observed for the filament over the course of 15 hours of operation. The weight change of the filament with time was roughly -2 mg/hour which indicated a significant improvement over $^{72}\text{GeF}_4$.

Example 1 (75 vol% $^{72}\text{GeF}_4$ + 25 vol% CH_3F)

[0059] Another test was performed to determine the ion beam performance of the dopant gas composition of 75 vol% $^{72}\text{GeF}_4$ (isotopically enriched in mass isotope ^{72}Ge to 50.1 vol%) mixed with 25 vol% CH_3F . The same ion source chamber was utilized as that in Comparative Example 1. The $^{72}\text{GeF}_4$ and CH_3F were introduced from separate storage containers and mixed before entering the ion source chamber. A current was applied to the filament to generate electrons and a voltage was applied to the anode to ionize the gas mixture and produce ^{72}Ge ions. The ^{72}Ge ion beam current was measured and determined to be about 14% greater than the ^{72}Ge ion beam current produced using solely $^{72}\text{GeF}_4$ and 30% greater than the ^{72}Ge ion beam current generated with 75 vol% $^{72}\text{GeF}_4$ mixed with 25 vol% Xe/H_2 . The results are shown in Figure 1. A weight loss of 16 milligrams was observed over the course of 12 hours of operation or -1.33 mg/hr indicating a significant improvement over $^{72}\text{GeF}_4$ and similar behavior to the 75 vol% $^{72}\text{GeF}_4$ mixed with 25 vol% Xe/H_2 .

[0060] The results of the experiments in Figure 1 show that although CH_3F diluted the volume of GeF_4 , it improved the Ge ion beam current significantly while also improving the performance of the ion source compared to solely using GeF_4 . Relative to the mixture in Comparative Example 1, the addition of Xe/H_2 improved the performance of the ion source but reduced the Ge ion beam current compared to the Ge ion beam current produced solely from GeF_4 .

Comparative Example 3 (50 vol% $^{72}\text{GeF}_4$ + 50 vol% Xe/H₂)

[0061] Another test was performed to determine the ion beam performance of the dopant gas composition of 50 vol% $^{72}\text{GeF}_4$ (isotopically enriched in mass isotope ^{72}Ge to 50.1 vol%) mixed with 50 vol% Xe/H₂. The same ion source chamber was utilized as for all previous examples. The $^{72}\text{GeF}_4$ and Xe/H₂ were introduced from separate storage containers and mixed before entering the ion source chamber. A current was applied to the filament to generate electrons and a voltage was applied to the anode to ionize the gas mixture and produce ^{72}Ge ions. The flow rate of $^{72}\text{GeF}_4$ in this experiment was significantly higher than the previous examples, thereby making relevant Ge-containing ion beam current comparisons not possible. The ^{72}Ge ion beam current from this mixture was normalized to compare the ^{72}Ge and ^{74}Ge ion beam currents from the naturally occurring GeF_4 mixtures shown in Figure 2. Under the operating conditions in these experiments, the ^{72}Ge ion beam current from 50 vol% $^{72}\text{GeF}_4$ + 50 vol% Xe/H₂ and 75 vol% $^{72}\text{GeF}_4$ + 25 vol% Xe/H₂ were equivalent. Results are shown in Figure 2. A weight gain rate of 0.78 mg/hr was observed, which was significantly lower than the weight gain of 185 mg/hr for $^{72}\text{GeF}_4$ and comparable to the weight loss of 2 mg/hr of 75 vol% $^{72}\text{GeF}_4$ (isotopically enriched) mixed with 25 vol% Xe/H₂.

Examples 2 and 3 (70 vol% GeF_4 + 30 vol% CH_3F)

[0062] Another test was performed to determine the ion beam performance of the dopant gas composition of 70 vol% natural GeF_4 mixed with 30 vol% CH_3F . The same ion source chamber was utilized as for previous examples. The natural GeF_4 and CH_3F were introduced from separate storage containers and mixed before entering the ion source chamber. A current was applied to the filament to generate electrons and a voltage was applied to the anode to ionize the gas mixture and produce both ^{72}Ge and ^{74}Ge ions. The natural GeF_4 had a level for ^{72}Ge of 27.7% and a level for ^{74}Ge of 35.9%, whereas the isotopically enriched $^{72}\text{GeF}_4$ was enriched in ^{72}Ge to 50.1% while the ^{74}Ge had a level of 23.9%. The Ge ion beam current of both ^{72}Ge and ^{74}Ge was measured. Both results are shown in Figure 2 relative to the ^{72}Ge ion beam current from 50 vol% $^{72}\text{GeF}_4$ mixed with 50 vol% Xe/H₂ of Comparative Example 3. The ion beam current of ^{74}Ge from 70 vol% natural GeF_4 with 30 vol% CH_3F was 10% higher

than the ^{72}Ge ion beam current generated from 50 vol% isotopically enriched $^{72}\text{GeF}_4$ with 50 vol% Xe/H_2 .

[0063] A weight gain rate of 2 mg/hr was observed over the course of operation which was similar in behavior to the weight gain of 0.78 mg/hr for 50 vol% isotopically enriched $^{72}\text{GeF}_4$ with 50 vol% Xe/H_2 .

[0064] The results of Figure 2 were surprising given that the level of ^{72}Ge enrichment in isotopically enriched $^{72}\text{GeF}_4$ was 14.2 vol% higher than ^{74}Ge in naturally occurring GeF_4 . It was also surprising that the ^{72}Ge ion beam current from both mixes (Comparative Example 3 and Examples 2 and 3) were observed to be within 1% of each other given that the enrichment level in $^{72}\text{GeF}_4$ was 22.4 vol% higher than in natural GeF_4 , and conventional wisdom would have expected the mixture of 50 vol% Xe/H_2 with 50 vol% enriched $^{72}\text{GeF}_4$ to produce a higher beam current.

[0065] Applicants have performed several additional experiments as a proof of concept using $^{11}\text{BF}_3$ as a dopant source and Si_2H_6 as an assistant species. In each experiment, the ion beam performance was measured using the ^{11}B ion beam current produced. A cylindrical ion source chamber was used to generate a plasma. The ion source chamber consisted of a helical tungsten filament, tungsten walls, and a tungsten anode perpendicular to the axis of the helical filament. A substrate plate was positioned in front of the anode to keep the anode stationary during the ionization process. A small aperture in the center of the anode and a series of lenses placed in front of the anode were used to generate an ion beam from the plasma and a velocity filter was used to isolate specific ion species from the ion beam. A faraday cup was used to measure the current from the ion beam and all tests were run at an arc voltage of 120 V. The extraction voltage was the same value for each experiment. The entire system was contained in a vacuum chamber capable of reaching pressures less than $1\text{e-}7$ Torr. Figure 3 shows a bar graph of the beam current of $^{11}\text{B-}$ ions relative to the beam current of ^{11}B ions solely produced by $^{11}\text{BF}_3$ for each gas mixture tested.

Comparative Example 4 – $^{11}\text{BF}_3$

A test was performed to determine the ion beam performance of isotopically enriched $^{11}\text{BF}_3$ as a dopant gas. $^{11}\text{BF}_3$ was introduced into the ion source chamber from a single bottle. A current was applied to the filament to generate electrons and a voltage was applied to the anode to ionize the mixture and produce ions. The settings of

the ion source were adjusted to maximize the beam current of ^{11}B ions. The beam current of ^{11}B ions was normalized (as shown in Figure 3) to be the basis for comparing against the beam current of ^{11}B ions from other gas mixtures.

Comparative Example 5 – $^{11}\text{BF}_3$ with Xe/ H_2

Another test was performed to determine the ion beam performance of the dopant gas composition of Xe/ H_2 mixed with isotopically enriched $^{11}\text{BF}_3$. The same ion source chamber was utilized as for $^{11}\text{BF}_3$ in Comparative Example 4. The mixture of Xe/ H_2 and $^{11}\text{BF}_3$ was generated from a bottle of pure $^{11}\text{BF}_3$ and a bottle of Xe/ H_2 introduced from separate storage containers and mixed before entering the ion source chamber. A current was applied to the filament to generate electrons and a voltage was applied to the anode to ionize the gas mixture and produce ^{11}B ions. The settings of the ion source were adjusted to maximize the beam current of ^{11}B ions. The mixture of $^{11}\text{BF}_3$ with Xe/ H_2 produced a maximum beam current of ^{11}B ions that was 20% lower than the beam current of ^{11}B ions solely produced by $^{11}\text{BF}_3$ in Comparative Example 4.

Example 4 - $^{11}\text{BF}_3$ with Si_2H_6

[0066] Another test was performed to determine the ion beam performance of the dopant gas composition of Si_2H_6 mixed with isotopically enriched $^{11}\text{BF}_3$. The same ion source chamber was utilized as for $^{11}\text{BF}_3$ in Comparative Example 4. The mixture of Si_2H_6 with $^{11}\text{BF}_3$ was generated from a bottle of $^{11}\text{BF}_3$ and a mixture of Si_2H_6 in $^{11}\text{BF}_3$ introduced from separate storage containers and mixed before entering the ion source chamber. A current was applied to the filament to generate electrons and a voltage was applied to the anode to ionize the gas mixture and produce ^{11}B ions. The settings of the ion source were adjusted to maximize the beam current of ^{11}B ions and the beam current of ^{11}B ions was measured for both mixtures. The mixture Si_2H_6 balanced with $^{11}\text{BF}_3$ generated an ^{11}B ion beam current 4% greater than the ^{11}B ion beam current produced solely from $^{11}\text{BF}_3$ in Comparative Example 4. The results from Si_2H_6 in $^{11}\text{BF}_3$ are unexpected given that the Si_2H_6 added to $^{11}\text{BF}_3$ is diluting the concentration of boron in the gas mixture and Si_2H_6 contains no boron atoms to contribute to the increase in the beam current exhibited by the mixture.

[0067] The results of these tests show that although the addition of Si_2H_6 is diluting the volume of $^{11}\text{BF}_3$, it improves the beam current of ^{11}B ions compared to using pure $^{11}\text{BF}_3$. The addition of Xe/ H_2 does not have the same effect as Si_2H_6 and

instead dilutes the $^{11}\text{BF}_3$ to an extent that the beam current of ^{11}B ions is reduced compared to the ^{11}B ion beam current produced solely from $^{11}\text{BF}_3$.

[0068] While it has been shown and described what is considered to be certain embodiments of the invention, it will, of course, be understood that various modifications and changes in form or detail can readily be made without departing from the spirit and scope of the invention. It is, therefore, intended that this invention not be limited to the exact form and detail herein shown and described, nor to anything less than the whole of the invention herein disclosed and hereinafter claimed.

Claims

1. A composition suitable for use in an ion implanter for production of a non-carbon target ionic species to create an ion beam current, said composition comprising:
 - a. a dopant source comprising the non-carbon target ionic species;
 - b. an assistant species comprising:
 - (i) a lower ionization energy in comparison to an ionization energy of the dopant source;
 - (ii) a total ionization cross-section (TICS) greater than $2 \text{ \AA}^2$;
 - (iii) a ratio of bond dissociation energy (BDE) of a weakest bond of the assistant species to the lower ionization energy of the assistant species to be 0.2 or higher; and
 - (iv) a composition that is characterized by an absence of the non-carbon target ionic species;wherein the dopant source and the assistant species occupy the ion implanter and interact therein to produce the non-carbon target ionic species.
2. The composition of claim 1, wherein the non-carbon target ionic species creates the ion beam current at a level higher than that generated solely from the dopant source.
3. The composition of claim 1, wherein the non-carbon target ionic species creates the ion beam current at level equal to that generated solely from the dopant source.
4. The composition of claim 1, wherein any atom of the dopant source or the assistant species is isotopically enriched greater than natural abundance levels.
5. The composition of claim 1, wherein the assistant species further comprises the lower ionization energy to be at least 5% lower than the ionization energy of the dopant source.
6. The composition of claim 1, wherein the assistant species further comprises the ratio of BDE of the weakest bond of the assistant species to the lower ionization energy of the assistant species to be .25 or higher.

7. The composition of claim 1, wherein the assistant species further comprises the ratio of BDE of the weakest bond of the assistant species to the lower ionization energy of the assistant species to be .3 or higher.
8. The composition of claim 1, further comprising the TICS to be greater than $3\text{\AA}^2$.
9. The composition of claim 1, further comprising the TICS to be greater than $4\text{\AA}^2$.
10. The composition of claim 1, further comprising the TICS to be greater than $5\text{\AA}^2$.
11. The composition of claim 1, wherein the assistant species further comprises the ratio of BDE of the weakest bond of the assistant species to the lower ionization energy of the assistant species to be .25 or higher, and the TICS to be greater than $3\text{\AA}^2$.
12. The composition of claim 1, wherein the assistant species further comprises the ratio of BDE of the weakest bond of the assistant species to the lower ionization energy of the assistant species to be .3 or higher, and the TICS to be greater than $4\text{\AA}^2$.
13. The composition of claim 1, wherein the dopant source is boron trifluoride (BF_3).
14. The composition of claim 1, wherein the dopant source is germanium tetrafluoride (GeF_4).
15. The composition of claim 1, wherein the dopant source is silicon tetrafluoride (SiF_4).

16. The composition of claim 1, wherein the dopant source comprises BF_3 , and further wherein the TICS of the assistant species is greater than $3 \text{ \AA}^2$ and the ratio of bond dissociation energy (BDE) of the weakest bond of the assistant species to the lower ionization energy of the assistant species is 0.23 or higher.
17. The composition of claim 1, wherein the dopant source comprises GeF_4 , and further wherein the TICS of the assistant species is greater than $3 \text{ \AA}^2$ and the ratio of bond dissociation energy (BDE) of the weakest bond of the assistant species to the lower ionization energy of the assistant species is 0.22 or higher.
18. The composition of claim 1, wherein the dopant source comprises SiF_4 , and further wherein the TICS of the assistant species is greater than $4 \text{ \AA}^2$ and the ratio of bond dissociation energy (BDE) of the weakest bond of the assistant species to the lower ionization energy of the assistant species is 0.25 or higher.
19. The composition of claim 1, wherein the non-carbon target ionic species of the dopant source comprises germanium, boron, silicon, nitrogen, arsenic, phosphorous, selenium, antimony, indium, sulfur, tin, gallium, or aluminum.
20. The composition of claim 1 wherein the assistant species has the formula $\text{CH}_i\text{F}_j\text{Cl}_y\text{Br}_z\text{I}_q$ where i, j, y, z, and q range from 0 to 4 and $i+j+y+z+q = 4$.
21. The composition of claim 1 wherein the assistant species has the formula $\text{C}_i\text{H}_j\text{N}_y\text{X}_z$ where X is any halogen species, i ranges from 1 to 4, y and z range from 0 to 4, and the value of j varies such that each atom has a closed shell of valence electrons.
22. The composition of claim 1, wherein the assistant species has the formula $\text{Si}_q\text{H}_y\text{X}_z$ where X is any halogen species, q ranges from 1 to 4, y, and z, range from 0 to 4, and the values of y and z vary such that each atom has a closed shell of valence electrons.

23. The composition of claim 1, wherein the assistant species comprises CS₂, GeH₄, Ge₂H₆, or B₂H₆.

24. The composition of claim 2, wherein the production of the higher beam current at a power level and a flow rate is 5% or higher in comparison to the beam current generated solely from the dopant source with a diluent at the power level and the flow rate.

25. The composition of claim 2, wherein the production of the higher beam current at a power level and a flow rate is 10% or higher in comparison to the beam current generated solely from the dopant source with a diluent at the power level and the flow rate, and further wherein the TICS of the assistant species is greater than 3 Å².

26. The composition of claim 2, wherein the production of the higher beam current at a power level and a flow rate is 5% or higher in comparison to the beam current generated solely from the dopant source with a diluent at the power level and the flow rate, and further wherein the TICS of the assistant species is greater than 4 Å², and further comprises the lower ionization energy of the assistant species to be at least 5% lower than the ionization energy of the dopant source.

27. The composition of claim 1, wherein the non-carbon target ionic species creates the ion beam current at a level lower than that generated solely from the dopant source.

28. The composition of claim 1, wherein the composition also contains an optional diluent species.

29. The composition of claim 28, wherein the optional diluent species is selected from the group consisting of H₂, N₂, He, Ne, Ar, Kr and Xe.

30. A composition suitable for use in an ion implanter for production of Ge-containing target ionic species to create a Ge-containing ion beam current, said composition comprising:

a dopant source comprising GeF_4 from which the Ge-containing target ionic species are derived; and

an assistant species comprising CH_3F ;

wherein the dopant source and the assistant species occupy the ion implanter and interact therein to produce the Ge-containing target ionic species.

31. The composition of claim 30, wherein the Ge-containing target ionic species creates the Ge-containing ion beam current at a level higher than that generated solely from the dopant source.

32. The composition of claim 30, wherein the Ge-containing target ionic species creates the Ge-containing ion beam current at a level equal to that generated solely from the dopant source.

33. The composition of claim 30, wherein a level of CH_3F ranges from 1 vol%-50 vol% balanced by GeF_4 , based on a total volume of the composition.

34. The composition of claim 30, wherein any atom of the dopant source GeF_4 or the assistant species CH_3F is isotopically enriched to greater than natural abundance levels.

35. The composition of claim 30, wherein the dopant source and/or the assistant species is held in a storage and dispensing assembly in an adsorbed state, a free source state, or a liquefied source state.

36. The composition of claim 30, wherein the Ge-containing target ionic species comprises Ge-containing positively or negatively charged atom or molecular fragment(s) originating from the GeF_4 dopant source that is implanted into the surface of a target substrate.

37. The composition of claim 30, wherein the Ge-containing ion beam current is created at a power level and a flow rate whereby the Ge-containing ion beam current is

5% or higher in comparison to a Ge-containing ion beam current generated solely from the dopant source at the power level and the flow rate.

38. The composition of claim 30, wherein the Ge-containing ion beam current is created at a power level and a flow rate whereby the Ge-containing ion beam current is 10% or higher in comparison to a Ge-containing ion beam current generated solely from the dopant source at the power level and the flow rate.

39. The composition of claim 30, wherein the Ge-containing ion beam current is created at a power level and a flow rate whereby the Ge-containing ion beam current is 20% or higher in comparison to a Ge-containing ion beam current generated solely from the dopant source at the power level and the flow rate.

40. The composition of claim 30, wherein the Ge-containing ion beam current is created at a power level and a flow rate whereby the Ge-containing ion beam current is 25% or higher in comparison to a Ge-containing ion beam current generated solely from the dopant source at the power level and the flow rate.

41. The composition of claim 30, wherein the Ge-containing ion beam current is created at a power level and a flow rate whereby the Ge-containing ion beam current is 30% or higher in comparison to a Ge-containing ion beam current generated solely from the dopant source at the power level and the flow rate.

42. The composition of claim 30, wherein the Ge-containing target ionic species creates the Ge-containing ion beam current at a level lower than that generated solely from the dopant source.

43. The composition of claim 33, wherein the level of CH₃F ranges from 15 vol%-40 vol% balanced by GeF₄, based on a total volume of the composition.

44. The composition of claim 33, wherein the level of CH₃F ranges from 20 vol%-40 vol% balanced by GeF₄, based on a total volume of the composition.

45. The composition of claim 30, wherein the dopant source and the assistant species is pre-mixed in a delivery source.
46. The composition of claim 30, wherein the dopant source and the assistant species are co-flowed into the ion implanter.
47. The composition of claim 30, wherein the dopant source and the assistant species is sequentially flowed to an ion chamber.
48. The composition of claim 30, wherein the composition further comprises an optional diluent species.
49. The composition of claim 48, wherein the optional diluent species is selected from the group consisting of H₂, N₂, He, Ne, Ar, Kr and Xe.
50. A composition suitable for use in an ion implanter for production of B-containing target ionic species to create a B-containing ion beam current, said composition comprising:
a dopant source comprising BF₃ from which the B-containing target ionic species are derived; and
an assistant species comprising Si₂H₆;
wherein the dopant source and the assistant species occupy the ion implanter and interact therein to produce the B-containing target ionic species.
51. The composition of claim 50, wherein the B-containing target ionic species creates the B-containing ion beam current at a level higher than that generated solely from the dopant source.
52. The composition of claim 50, wherein the B-containing target ionic species creates the B-containing ion beam current at a level equal to that generated solely from the dopant source.

53. The composition of claim 50, wherein any atom of the BF_3 or the assistant species Si_2H_6 is isotopically enriched to greater than natural abundance levels.
54. The composition of claim 50, wherein the dopant source and/or the assistant species is held in a storage and dispensing assembly in an adsorbed state, a free source state, or a liquefied source state.
55. The composition of claim 50, wherein the B-containing target ionic species of the dopant source comprises B-containing positively or negatively charged atom or molecular fragment(s) originating from the BF_3 dopant source that is implanted into the surface of a target substrate.
56. The composition of claim 50, wherein the B-containing ion beam current is created at a power level and a flow rate whereby the B-containing ion beam current is 1% or higher in comparison to a B-containing ion beam current generated solely from the dopant source at the power level and the flow rate.
57. The composition of claim 50, wherein the B-containing ion beam current is created at a power level and a flow rate whereby the B-containing ion beam current is 4% or higher in comparison to a B-containing ion beam current generated solely from the dopant source at the power level and the flow rate.
58. The composition of claim 50, wherein the B-containing ion beam current is created at a power level and a flow rate whereby the B-containing ion beam current is 10% or higher in comparison to a B-containing ion beam current generated solely from the dopant source at the power level and the flow rate.
59. The composition of claim 50, wherein the B-containing ion beam current is created at a power level and a flow rate whereby the B-containing ion beam current is 20% or higher in comparison to a B-containing ion beam current generated solely from the dopant source at the power level and the flow rate.

60. The composition of claim 50, wherein the B-containing ion beam current is created at a power level and a flow rate whereby the B-containing ion beam current is 25% or higher in comparison to a B-containing ion beam current generated solely from the dopant source at the power level and the flow rate.

61. The composition of claim 50, wherein the B-containing ion beam current is created at a power level and a flow rate whereby the B-containing ion beam current is 30% or higher in comparison to a B-containing ion beam current generated solely from the dopant source at the power level and the flow rate.

62. The composition of claim 50, wherein the B-containing target ionic species creates the B-containing ion beam current at a level lower than that generated solely from the dopant source.

63. The composition of claim 50, wherein the dopant source and the assistant species are pre-mixed in a delivery source.

64. The composition of claim 50, wherein the dopant source and the assistant species are co-flowed into the ion implanter.

65. The composition of claim 50, wherein the dopant source and the assistant species is sequentially flowed to an ion chamber.

66. The composition of claim 50, wherein the composition further comprises an optional diluent species.

67. The composition of claim 66, wherein the optional diluent species is selected from the group consisting of H₂, N₂, He, Ne, Ar, Kr and Xe.