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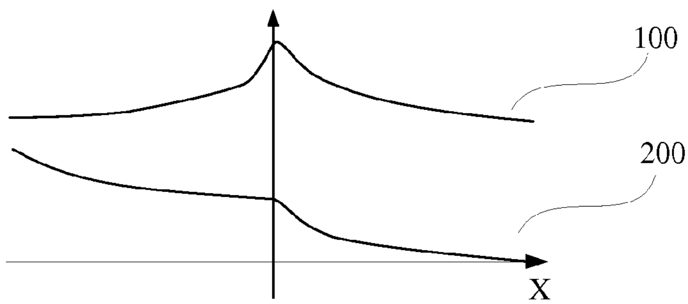

Fig. 3b

(57) Abstract: A light emitting diode is provided, comprising: a p-doped region defining a first end surface and a second end surface opposite to each other; and an n-doped region defining a first end surface and a second end surface opposite to each other, in which the first end surface of the n-doped region is adjacent to the first end surface of the p-doped region to form a PN junction, and a concentration of a p-type impurity decreases gradually in a direction from the second end surface of the p-doped region to the PN junction.

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DIODE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to, and benefits of Chinese Patent Application Serial No. 201010140971.8, filed with the State Intellectual Property Office of P. R. C. on March 31, 2010, the entire contents of which are incorporated herein by reference.

FIELD

The present disclosure relates to semiconductor field, and more particularly, to a diode.

BACKGROUND

The fast recovery diode (FRD) is a new type semiconductor device, which is manufactured using an epitaxial signal crystal silicon wafer through a COMS technology, and has the advantages of high frequency, high voltage, large current, low loss, no electromagnetic interference and so on. The fast recovery diode is not only used as an output rectifier diode, a clamping diode or an absorber diode alone, but also used as a freewheeling diode to cooperate with an insulated gate bipolar transistor (IGBT). The fast recovery diode, the fast recovery diode module, and the module of the fast recovery diode and the insulated gate bipolar transistor are widely applied in industry, medicine and aerospace, such as the motor frequency control, welding machines, various switches and power supplies, inverters and electrostatic induction.

A work cycle of the fast recovery diode includes a forward recovery procedure and an inverse recovery procedure. Nowadays, in a circuit, in order to improve the operation efficiency and the reliability, the fast recovery diode should have a better forward recovery feature and a better inverse recovery feature. The forward recovery feature is that a high transient voltage appears in an initial opening period of the fast recovery diode and then the fast recovery diode is in a stable status after a certain period of time which reflects the forward recovery feature. The inverse recovery feature is that the diode can change from a forward conducting status to an inverse blocking status in a short time. Generally speaking, the fast recovery diode should have fast inverse recovery feature. However, the fast inverse recovery feature leads to a fast current rising ratio (di/dt), which makes the current oscillate in the inverse recovery procedure and causes the problem of electromagnetic interference, so the reliability of the circuit will be affected. Therefore, in a high frequency circuit, a good fast recovery diode not only should have a fast recovery capacity in the inverse recovery procedure, but also should not cause oscillation in the inverse recovery procedure, that is, the good fast recovery diode should have a good inverse recovery feature. Moreover, a good fast recovery diode should also have a good forward recovery feature.

SUMMARY

According to a first aspect of the present disclosure, a diode may be provided, comprising: a p-doped region defining a first end surface and a second end surface opposite to each other; and an n-doped region defining a first end surface and a second end surface opposite to each other, in which the first end surface of the n-doped region is adjacent to the first end surface of the p-doped region to form a PN junction, and a concentration of a p-type impurity decreases gradually in a direction from the second end surface of the p-doped region to the PN junction.

The diode according to the first aspect of the present disclosure has good recovery characteristics.

According to a second aspect of the present disclosure, a diode may be provided, comprising: a first diode structure, and a second diode structure adjacent to the first diode structure in an axial direction. The first diode structure comprises a first p-doped region defining a first end surface and a second end surface opposite to each other; and a first n-doped region defining a first end surface and a second end surface opposite to each other, in which the first end surface of the first n-doped region is adjacent to the first end surface of the first p-doped region to form a first PN junction, a concentration of a p-type impurity decreases gradually in a direction from the second end surface of the first p-doped region to the first PN junction, a concentration of an n-type impurity increases gradually in a direction from the first PN junction to the second end surface of the first n-doped region, a lifetime of a first minority carrier in the first p-doped region increases gradually in the direction from the second end surface of the first p-doped region to the first PN junction, and a lifetime of a second minority carrier in the first n-doped region decreases gradually in the direction from the first PN junction to the second end surface of the first n-doped region. The second diode

structure comprises a second p-doped region defining a first end surface and a second end surface opposite to each other; and a second n-doped region defining a first end surface and a second end surface opposite to each other, in which the first end surface of the second n-doped region is adjacent to the first end surface of the second p-doped region to form a second PN junction, a concentration of a p-type impurity decreases gradually in a direction from the second end surface of the second p-doped region to the second PN junction, a concentration of an n-type impurity decreases gradually in a direction from the second PN junction to the second end surface of the second n-doped region, a lifetime of a first minority carrier in the second p-doped region decreases gradually in the direction from the second end surface of the second p-doped region to the second PN junction, and a lifetime of a second minority carrier in the second n-doped region increases gradually in the direction from the PN junction to the second end surface of the second n-doped region.

The diode according to the second aspect of the present disclosure comprises the first diode structure having good forward recovery feature and the second diode structure having good inverse recovery feature, thus improving both forward recovery feature and inverse recovery feature of the diode.

Additional aspects and advantages of the embodiments of present disclosure will be given in part in the following descriptions, become apparent in part from the following descriptions, or be learned from the practice of the embodiments of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features and advantages of the disclosure will be better understood from the following detailed descriptions taken in conjunction with the accompanying drawings, in which:

Fig. 1 shows a structure of the diode and the curve of the concentration of the impurity in the diode in the prior art;

Fig. 2 shows an energy band of the diode in Fig. 1;

Fig. 3a is a schematic structural view of the diode according to a first embodiment of the present disclosure;

Fig. 3b is a diagram showing a curve of the concentration of the impurity and a lifetime distribution of the minority carrier in a diode according to the first embodiment of the present disclosure;

Fig. 4a is a schematic structural view of the diode according to a second embodiment of the present disclosure; and

Fig. 4b is a diagram showing a concentration of the impurity and a lifetime distribution of the minority carrier according to the second embodiment of the present disclosure.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Reference will be made in detail to embodiments of the present disclosure. The embodiments described herein with reference to the drawings are explanatory, illustrative, and used to generally understand the present disclosure. The embodiments shall not be construed to limit the present disclosure.

The present disclosure relates generally to the field of light emitting diode. It should be understood that the following disclosure provides different embodiments, or examples, for implementing different features of the disclosure. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, of course, merely illustrative and are not intended to limit the present disclosure. In addition, the present disclosure may repeatedly refer to numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself denote a relationship between the various embodiments and/or configurations under discussion. Moreover, the formation of a first feature over or on a second feature described below may include embodiments in which the first and second features are in direct contact, and may also include embodiments in which additional features may be formed interposing the first and second features, such that the first and second features may not be in direct contact.

In some embodiments of the present disclosure, the concentration of the impurity in the p-doped region and the n-doped region and the lifetime of the minority carrier are changed according to the direction of the current density during the forward recovery procedure and the inverse recovery procedure, the relationship between the concentration of the p-type impurity and the effective value of the concentration of the p-type impurity, and the relationship between the concentration of the n-type impurity and the effective value of the concentration of the n-type impurity so as to improve the forward recovery feature and the inverse recovery feature of the diode.

In the description of the present disclosure, a transverse direction refers to the horizontal direction in Fig. 3a and an axial direction refers to the vertical direction in Fig. 3a.

The determinative factors of the current of the fast recovery diode will be analyzed with reference to Fig. 1 and Fig. 2. As shown in Figs. 1 and 2, a diode comprises a p-doped region, and an n-doped region adjacent to the p-doped region. A PN junction is formed between the p-doped region and the n-doped region. In the p-doped region, the minority carrier is electron, and in the n-doped region, the minority carrier is hole. A one-dimensional coordinate system is established by using a point in the PN junction as the origin, and by using the direction from the p-doped region to the n-doped region as the positive direction of the x axis. The diode further comprises a depletion layer disposed between -xp0 and xn0.

Two coordinate systems are redefined as follows. One coordinate system is defined by using a point xn0 of the boundary of the depletion layer near the n-doped region as the origin and using the direction from the depletion layer to the n-doped region as the positive direction of the x axis, where xn means that the distance from a point to xn0 is xn units. Another coordinate system is defined by using a point xp0 of the boundary of the depletion layer near the p-doped region as the origin and using the direction from the depletion layer to the p-doped region as the positive direction of the x axis, where xp means that the distance from a point to xp0 is xp units.

According to a principle of the semiconductor, the following may be obtained:

the electron current density in the p-doped region is $J_n = q\mu_n n(x)\dfrac{d(F_n/q)}{dx}$;

the hole current density in the n-doped region is $J_p = q\mu_p p(x)\dfrac{d(F_p/q)}{dx}$;

according to the formula $n(x_p) = n_i \exp\{(F_n(x_p) - E_i)/kT\} = n_p + \Delta n_p e^{-x_p/L_n}$,

the formula $F_n(x_p) = E_i + kT\ln\dfrac{\Delta n_p}{n_i} - \dfrac{kT}{L_n}x_p$, ($0 \le x_p < L_n$) may be obtained; and according to the formula $p(x_n)=n_i \exp\{(E_i - F_p(x_n))/kT\} = p_n + \Delta p_n e^{-x_n/L_p}$,

the formula $F_p(x_n) = E_i - kT \ln\frac{\Delta p_n}{n_i} - \frac{kT}{L_p}x_n$, ($0 \le x_n < L_p$) may be obtained;

in which E is the electric field intensity, q is the electron charge, μ_n is the moving rate of the electron, μ_p is the moving rate of the hole, F_n is the quasi-fermi level of the electron, F_p is the quasi-fermi level of the hole, and k is the boltzmann constant.

According to the formulas mentioned above, the electron current density is relevant to the quasi-fermi level F_n and in direct ratio with the differential (gradient) of F_n, and the hole current density is relevant to the quasi-fermi level F_p and in direct ratio with the differential (gradient) of F_p. The quasi-fermi level is relevant to the concentration of the p-type impurity or the n-type impurity. In a semiconductor device, for the majority carrier, because the concentration thereof is large, the gradient of the quasi-fermi level is small; and for the minority carrier, because the concentration thereof is small, the gradient of the quasi-fermi level is large.

In a space charge region of a PN junction, when the majority carrier in a region becomes the minority carrier in another region, the value of the quasi-fermi level changes to a certain degree, but not obviously. In Fig. 2, Ecp is the conduction band of the hole, Evp is the valence band of the hole, EFp is the quasi-fermi level of the hole, Ecp is the conduction band of the electron, Evn is the valence band of the hole, and EFn is the quasi-fermi level of the electron. The difference of the two quasi-fermi levels is qVf, and the difference of the two conduction bands is q（V0-Vf）. Outside the space charge region of a PN junction, the quasi-fermi level of the minority carrier changes linearly according to the distance from the boundary of the space charge region and finally overlaps with the quasi-fermi level of the majority carrier. In the region where the quasi-fermi level changes linearly, the concentration of the minority carrier, i.e., the hole, in the position far from the boundary of the space charge region in the n-doped region may be reduced to p(xn)=pn. Actually, in the position far from the boundary of the space charge region in the n-doped region, excess carrier dose not exist, so F_n and F_p overlap at the EF position.

If considering from the average algorithm, F_n changes obviously from the position x=-xp0 to the position x=-xp0-Ln, and F_p changes obviously from the position x=xn0 to the position x=xn0-Lp. If the concentration of the impurity in the p-doped region and the n-doped region are constant, at the same voltage, the quasi-fermi levels EF_n and EF_p in the p-doped region and the n-doped region are constant. In this case, for the same energy difference, the longer the distance, the smaller the energy change in a unit distance is, so that the wider the thickness of the depletion layer (i.e., the space charge region) needed to be reduced, the more slowly the current changes.

According to this principle, an embodiment of the present invention provides a diode. The diode comprises: a p-doped region defining a first end surface and a second end surface opposite to each other; and an n-doped region defining a first end surface and a second end surface opposite to each other, in which the first end surface of the n-doped region is adjacent to the first end surface of the p-doped region to form a PN junction, and a concentration of a p-type impurity decreases gradually in a direction from the second end surface of the p-doped region to the PN junction so as to adjust recovery characteristics of the diode. In some embodiments of the present disclosure, a concentration of an n-type impurity increases gradually in a direction from the PN junction to the second end surface of the n-doped region. In some embodiments of the present disclosure, a lifetime of a first minority carrier in the p-doped region increases gradually in the direction from the second end surface of the p-doped region to the PN junction, and a lifetime of a second minority carrier in the n-doped region decreases gradually in the direction from the PN junction to the second end surface of the n-doped region.

Fig. 3a is a schematic structural view of the diode according to a first embodiment of the present disclosure and Fig. 3b a diagram showing a curve of the concentration of the impurity and a lifetime distribution of the minority carrier in a diode according to the first embodiment of the present disclosure. In Fig. 3a, the diode comprises a p-doped region and an n-doped region adjacent to the p-doped region. A concentration of a p-type impurity in the p-doped region decreases gradually in the direction from the second end surface of the p-doped region to the PN junction, and a concentration of an n-type impurity in the n-doped region increases gradually in the direction from the PN junction to the second end surface of the n-doped region. In Fig. 3b, a Cartesian coordinate system is established by using a point in the PN junction as the origin and using the direction from the p-doped region to the n-doped region as the positive direction of the x axis. The curve 200 is the hole concentration curve, which reflects that the concentration of a p-type impurity in the p-doped region decreases gradually in the direction from the second end surface of the p-doped region to the PN junction, and the concentration of an n-type impurity in the n-doped region increases gradually in the direction from the PN junction to the second end surface of the n-doped region. According to the curve 200, the minority carrier concentrations near the PN junction in both the p-doped region and the n-doped region are highest, that is, in this embodiment, the width of the space charge region is larger than that of a conventional diode. As mentioned above, the wider the thickness of the depletion layer (i.e., the space charge region) needed to be reduced, the more slowly the current changes, that is, the current changes slowly in the forward recovery procedure. So the diode in this embodiment has a soft turn-on feature. The curve 100 is the lifetime distribution curve of the minority carrier. According to the curve 100, the lifetimes of the minority carriers near the PN junction in both the p-doped region and the n-doped region are longest. The longer the lifetime of the minority carrier, the more the minority carriers reaching the space charge region are, which means that in the space charge region, the recombination chance of the minority carrier is large. The more rapidly the width of the space charge region is reduced, the shorter the forward turn-on time of the diode is. So the diode in this embodiment has a good soft turn-on feature and a fast turn-on feature.

Because the conductivity and the effective mass of the hole are larger than those of the electron respectively, the mobility of the hole is less than that of the electron. Under the same electric field, the directional moving rate and the kinetic energy of the hole are smaller than those of the electron respectively, so a breakdown may not be caused. Therefore, in some embodiments of the present disclosure, an average concentration of a p-type impurity in the p-doped region is higher than that of an n-doped impurity in the n-doped region. In some embodiments of the present disclosure, the concentration of the p-type impurity at the second end surface of the p-doped region is about E16/cm^3-E20/cm^3, the concentration of the p-type impurity at the first end surface of the p-doped region is about E14/cm^3-E17/cm^3, the concentration of the n-type impurity at the second end surface of the n-doped region is about E16/cm^3-E20/cm^3, and the concentration of the n-type impurity at the first end surface of the n-doped region is about E12/cm^3-E14/cm^3, thus achieving a compromise between the cost and the forward recovery feature.

In the first embodiment of the present disclosure, the hole concentration and the lifetime of the minority carrier change according to an exponential function. Two formulas for the hole concentration and the lifetime are provided respectively as follows:

$$N(x) = \begin{cases} f\exp(a1x/Lp) & x \leqslant 0 \\ f\exp(a2x/Lp) & x \geqslant 0 \end{cases} \qquad \text{Formula (1)}$$

$$\tau(x) = \begin{cases} g\exp(-b1x/Lp) & x \leqslant 0 \\ g\exp(-b2x/Lp) & x \geqslant 0 \end{cases} \qquad \text{Formula(2)}$$

in which $N(x)$ is the concentration of the hole, $\tau(x)$ is the lifetime of the minority carrier, f is a maximum value of the concentration of the hole, g is a maximum value of the lifetime of the minority carrier, each of $a1$, $a2$, $b1$ and $b2$ is a constant, and Lp is a diffusion length of the hole. Each of $a1$, $a2$, $b1$ and $b2$ is in a range of from -20 to 20. In some embodiments of the present disclosure, $a1$ is -0.3, $a2$ is -0.35, $b1$ is -0.4, and $b2$ is 0.45.

In some embodiments of the present disclosure, the concentration of the impurity in the p-doped region and the n-doped region is controlled by a diffusion technology, and the lifetime distribution of the minority carrier may be changed by: (1) doping a heavy metal such as platinum; (2) using an electron irradiation method, which comprises the steps of: putting the semiconductor device in an irradiation field; and bombarding the semiconductor device by using high energy electron to make the silicon atom in the semiconductor device break away from the normal lattice position, so as to form oxygen vacancy, phosphorus vacancy, bivacancy and so on, and so as to form a variety of deep level recombination centers in the silicon forbidden band, in which the electron irradiation method is characterized in that the lifetime of the minority carrier is controlled by adjusting the injection quantity of the electron; and (3) using the light ion injection technology such as the helion injection technology and the neutron irradiation technology, in which the principle of the light ion injection is similar to that of the electron irradiation, but the volume of the light ion is larger than that of the electron, so the depth, that the light ion with certain energy may reach in the silicon, may be confirmed and consequently the lifetime of the minority carrier may be controlled by adjusting the injection quantity of the light ion. In some embodiments of the disclosure, the light ion injection technology is used to change the lifetime distribution of the minority carrier. In some embodiments of the present disclosure, the lifetime of the minority carrier is about 1E-8-5E-6s.

During the inverse recovery procedure of the conventional diode, the junction capacitance Cj tends to increase with the extension of the depletion layer. During most time of the inverse recovery procedure, the diffusion capacitance Cs is larger than the junction capacitance Cj, but at the end of the inverse recovery procedure, the diffusion capacitance Cs decreases because of the disappearance of excess holes and electrons and even is far less than the junction capacitance Cj, so the current or voltage oscillation may be caused easily at the end of the inverse recovery procedure.

In a second embodiment of the present disclosure, a diode with a better inverse recovery feature is provided. The diode comprises: a p-doped region defining a first end surface and a second end surface opposite to each other; and an n-doped region defining a first end surface and a second end surface opposite to each other, in which the first end surface of the n-doped region is adjacent to the first end surface of the p-doped region to form a PN junction, and a concentration of a p-type impurity decreases gradually in a direction from the second end surface of the p-doped region to the PN junction so as to adjust recovery characteristics of the diode. In some embodiments of the present disclosure, a concentration of an n-type impurity decreases gradually in a direction from the PN junction to the second end surface of the n-doped region. In some embodiments of the present disclosure, a lifetime of a first minority carrier in the p-doped region decreases gradually in the direction from the second end surface of the p-doped region to the PN junction, and a lifetime of a second minority carrier in the n-doped region increases gradually in the direction from the PN junction to the second end surface of the n-doped region.

Fig. 4a is a schematic structural view of the diode according to the second embodiment of the present disclosure, and Fig. 4b is a diagram showing a concentration of the impurity and a lifetime distribution of the minority carrier according to the second embodiment of the present disclosure.

In Fig. 4a, the diode comprises a p-doped region and an n-doped region adjacent to the p-doped region. A concentration of a p-type impurity in the p-doped region decreases gradually in the direction from the second end surface of the p-doped region to the PN junction, and a concentration of an n-type impurity in the n-doped region decreases gradually in the direction from the PN junction to the second end surface of the n-doped region. In Fig. 4b, a Cartesian coordinate system is established by using a point in the PN junction as the origin and using the direction from the p-doped region to the n-doped region as the positive direction of the x axis. The curve 400 is the hole concentration curve, which reflects that the concentration of a p-type impurity in the p-doped region decreases gradually in the direction from the second end surface of the p-doped region to the PN junction, and the concentration of an n-type impurity in the n-doped region decreases gradually in the direction from the PN junction to the second end surface of the n-doped region. According to the curve 400, the concentration of the p-type impurity Nd in a part of the p-doped region near the PN junction is lower than that in the other part of the p-doped region, and the concentration of the n-type impurity Na in a part of the n-doped region near the PN junction is larger than that in the other part of the n-doped region. So the junction capacitance Cj is smaller than that of the conventional diode. According to the curve 300, the lifetime of the minority carrier at two end surfaces of the diode far away from the PN junction is longer than that of the minority carrier in the other part of the diode near the PN junction. At the end of the inverse recovery procedure, the mount of the minority carrier at the two end surfaces of the diode in this embodiment is larger than that of the conventional diode. According to the property of the capacitance, the diffusion capacitance Cs of the diode in this embodiment is larger than that of the conventional diode at the end of the inverse recovery procedure. The small junction capacitance Cj and the large diffusion capacitance Cs may reduce the difference between the junction capacitance Cj and the diffusion capacitance Cs at the end of the inverse recovery procedure, so the probability and the times of the current and voltage oscillation is reduced at the end of the inverse recovery procedure. The distributions of the concentration of the p-type impurity in the p-doped region, the lifetime of the minority carrier in the p-doped region, the concentration of the n-type impurity in the n-doped region and the lifetime of the minority carrier in the n-doped region make the hole and the electron recombine evenly, so the reliability of the diode in the inverse recovery procedure may be further improved. The shorter the lifetime of the minority carrier near the PN junction, the faster the space charge region extends, that is, the inverse recovery time is shorter. So the diode in this embodiment has a good inverse recovery property.

Because the conductivity and the effective mass of the hole are larger than those of the electron, the mobility of the hole is less than that of the electron. Under the same electric field, the directional moving rate and the kinetic energy of the hole are smaller than those of the electron, so a breakdown may not be caused easily. Therefore, in some embodiments of the present disclosure, an average concentration of a p-type impurity in the p-doped region is greater than that of an n-doped impurity in the n-doped region. In some embodiments of the present disclosure, the concentration of the p-type impurity at the second end surface of the p-doped region is about E16/cm^3-E20/cm^3, the concentration of the p-type impurity at the first end surface of the p-doped region is about E14/cm^3-E17/cm^3, the concentration of the n-type impurity at the first end surface of the n-doped region is about E16/cm^3-E20/cm^3, and the concentration of the n-type impurity at the second end surface of the n-doped region is about E12/cm^3-E14/cm^3, so as to achieve a compromise between the cost and the reverse recovery feature.

In the second embodiment of the present disclosure, the hole concentration and the lifetime of the minority carrier change according to an exponential function respectively. Two formulas for the hole concentration and the lifetime are provided respectively as follows:

$$N(x) = \begin{cases} h\exp(c1x/Lp) & x \leqslant 0 \\ h\exp(c2x/Lp) & x \geqslant 0 \end{cases} \qquad \text{Formula (3)}$$

$$\tau(x) = \begin{cases} l\exp(-d1x/Lp) & x \leqslant 0 \\ l\exp(-d2x/Lp) & x \geqslant 0 \end{cases} \qquad \text{Formula(4)}$$

in which $N(x)$ is the concentration of the hole, $\tau(x)$ is the lifetime of the minority carrier,

h is a maximum value of the concentration of the hole, l is a maximum value of the lifetime of the minority carrier, each of c1, c2, d1 and d2 is a constant, and Lp is a diffusion length of the hole. Each of c1, c2, d1 and d2 is in a range of from -20 to 20. In some embodiments of the present disclosure, c1 is -0.25, c2 is 0.35, d1 is 0.15, and d2 is -0.20.

In some embodiments of the present disclosure, the concentration of the impurity in the p-doped region and the n-doped region is controlled by the diffusion technology, and the lifetime distribution of the minority carrier may be changed by: (1) doping a heavy metal such as platinum; (2) using an electron irradiation method, which comprises the steps of: putting the semiconductor device in an irradiation field; and bombarding the semiconductor device by using high energy electron to make the silicon atom in the semiconductor device break away from the normal lattice position, so as to form oxygen vacancy, phosphorus vacancy, bivacancy and so on, and so as to form a variety of deep level recombination centers in the silicon forbidden band, in which the electron irradiation method is characterized in that the lifetime of the minority carrier is controlled by adjusting the injection quantity of the electron; and (3) using the light ion injection technology such as the helion injection technology and the neutron irradiation technology, in which the principle of the light ion injection is similar to that of the electron irradiation, but the volume of the light ion is larger than that of the electron, so the depth, that the light ion with certain energy may reach in the silicon, may be confirmed and consequently the lifetime of the minority carrier may be controlled by adjusting the injection quantity of the light ion. In some embodiments of the disclosure, the light ion injection technology is used to change the lifetime distribution of the minority carrier. In some embodiments of the present disclosure, the lifetime of the minority carrier is about 1E-8-5E-6s.

In a third embodiment of the present disclosure, a diode is provided. The diode comprises a first diode structure, and a second diode structure adjacent to the first diode structure in an axial direction. The first diode structure comprises a first p-doped region defining a first end surface and a second end surface opposite to each other; and a first n-doped region defining a first end surface and a second end surface opposite to each other, in which the first end surface of the first n-doped region is adjacent to the first end surface of the first p-doped region to form a first PN junction, a concentration of a p-type impurity decreases gradually in a direction from the second end surface of the first p-doped region to the first PN junction, a concentration of an n-type impurity increases gradually in a direction from the first PN junction to the second end surface of the first n-doped region, a lifetime of a first minority carrier in the first p-doped region increases gradually in the direction from the second end surface of the first p-doped region to the first PN junction, and a lifetime of a second minority carrier in the first n-doped region decreases gradually in the direction from the first PN junction to the second end surface of the first n-doped region. The second diode structure comprises a second p-doped region defining a first end surface and a second end surface opposite to each other; and a second n-doped region defining a first end surface and a second end surface opposite to each other, in which the first end surface of the second n-doped region is adjacent to the first end surface of the second p-doped region to form a second PN junction, a concentration of a p-type impurity decreases gradually in a direction from the second end surface of the second p-doped region to the second PN junction, a concentration of an n-type impurity decreases gradually in a direction from the second PN junction to the second end surface of the second n-doped region, a lifetime of a first minority carrier in the second p-doped region decreases gradually in the direction from the second end surface of the second p-doped region to the second PN junction, and a lifetime of a second minority carrier in the second n-doped region increases gradually in the direction from the PN junction to the second end surface of the second n-doped region.

The diode according to the third embodiment comprises the first diode structure having good forward recovery feature and the second diode structure having good inverse recovery feature, thus obtaining both good forward recovery feature and good inverse recovery feature. An axial area ratio of the first diode structure to the second diode structure (that is the ratio of the axial area of the first diode structure in the vertical direction in the drawings to that of the second diode structure in the vertical direction in the drawings) reflects whether good forward recovery feature or good inverse recovery feature of the diode in the third embodiment predominates. In some embodiments of the present disclosure, the axial area ratio of the first diode structure to the second diode structure is about 1:0.1 to about 1:10. In some embodiments of the present disclosure, because the inverse recovery feature of the diode is paid more attention, the axial area ratio of the first diode structure to the second diode structure is about 1:1 to about 1:5. In an embodiment of the present disclosure, the axial area ratio of the first diode structure to the second diode structure is about 1:2, so that the whole feature of the diode may meet the practical application requirements and the inverse recovery feature may predominate. In another embodiment of the present disclosure, the axial area ratio of the first diode structure to the second diode structure is about 1:3, so that the whole feature of the diode may meet the practical application requirements and the inverse recovery feature may further predominate.

In some embodiments of the present disclosure, in the first diode structure, a function of a concentration of a hole in the first p-doped region is $f\exp(a1x/Lp)$ in the direction from the second end surface of the first p-doped region to the first PN junction, a function of the lifetime of the first minority carrier in the first p-doped region is $g\exp(-b1x/Lp)$ in the direction from the second end surface of the first p-doped region to the first PN junction, a function of a concentration of a hole in the first n-doped region is $f\exp(a2x/Lp)$ in the direction from the first PN junction to the second end surface of the first n-doped region, and a function of the lifetime of the second minority carrier in the first n-doped region is $g\exp(-b2x/Lp)$ in the direction from the first PN junction to the second end surface of the first n-doped region, in which each of $a1$, $a2$, $b1$ and $b2$ is a constant, Lp is a diffusion length of the hole, f is a maximum value of the concentration of the hole, and g is a maximum value of the lifetime of the minority carrier. Each of $a1$, $a2$, $b1$ and $b2$ is in a range of from -20 to 20. In some embodiments of the present disclosure, $a1$ is -0.3, $a2$ is -0.35, $b1$ is -0.4, and $b2$ is 0.45. In the second diode structure, a function of a concentration of a hole in the second p-doped region is $h\exp(c1x/Lp)$ in the direction from the second end surface of the second p-doped region to the second PN junction, a function of the lifetime of the first minority carrier in the second p-doped region is $l\exp(-d1x/Lp)$ in the direction from the second end surface of the second p-doped region to the second PN junction, a function of a concentration of a hole in the second n-doped region is $h\exp(c2x/Lp)$ in the direction from the second PN junction to the second end surface of the second n-doped region, and a function of the lifetime of the second minority carrier in the second n-doped region is $l\exp(-d2x/Lp)$ in the direction from the second PN junction to the second end surface of the second n-doped region, in which each of $c1$, $c2$, $d1$ and $d2$ is a constant, Lp is a diffusion length of the hole, h is a maximum value of the concentration of the hole, and l is a maximum value of the lifetime of the minority carrier. Each of $c1$, $c2$, $d1$ and $d2$ is in a range of from -20 to 20. In some embodiments of the present disclosure, $c1$ is -0.25, $c2$ is 0.35, $d1$ is 0.15, and $d2$ is -0.20.

Because the conductivity and the effective mass of the hole are larger than those of the electron, the mobility of the hole is less than that of the electron. Under the same electric field, the directional moving rate and the kinetic energy of the hole are smaller than those of the electron, so a breakdown may not be caused easily. Therefore, in some embodiments of the present disclosure, an average concentration of a p-type impurity in the first p-doped region is greater than that of an n-doped impurity in the first n-doped region, and an average concentration of the p-type impurity in the second p-doped region is greater than that of the n-doped impurity in the second n-doped region.

Although explanatory embodiments have been shown and described, it would be appreciated by those skilled in the art that changes, alternatives, and modifications can be made in the embodiments without departing from the spirit and principles of the disclosure. Such changes, alternatives, and modifications all fall into the scope of the claims and their equivalents.

WHAT IS CLAIMED IS:

1. A diode, comprising:

a p-doped region defining a first end surface and a second end surface opposite to each other; and

an n-doped region defining a first end surface and a second end surface opposite to each other,

wherein the first end surface of the n-doped region is adjacent to the first end surface of the p-doped region to form a PN junction, and a concentration of a p-type impurity decreases gradually in a direction from the second end surface of the p-doped region to the PN junction.

2. The diode of claim 1, wherein a concentration of an n-type impurity increases gradually in a direction from the PN junction to the second end surface of the n-doped region.

3. The diode of claim 2, wherein a lifetime of a first minority carrier in the p-doped region increases gradually in the direction from the second end surface of the p-doped region to the PN junction.

4. The diode of claim 3, wherein a lifetime of a second minority carrier in the n-doped region decreases gradually in the direction from the PN junction to the second end surface of the n-doped region.

5. The diode of claim 4, wherein a function of a concentration of a hole in the p-doped region is $f\exp(a1x/Lp)$ in the direction from the second end surface of the p-doped region to the PN junction, in which $a1$ is a constant, Lp is a diffusion length of the hole, and f is a maximum value of the concentration of the hole.

6. The diode of claim 4, wherein a function of the lifetime of the first minority carrier in the p-doped region is $g\exp(-b1x/Lp)$ in the direction from the second end surface of the p-doped region to the PN junction, in which $b1$ is a constant, Lp is a diffusion length of the hole, and g is a maximum value of the lifetime of the first minority carrier.

7. The diode of claim 4, wherein a function of a concentration of a hole in the n-doped region is $f\exp(a2x/Lp)$ in the direction from the PN junction to the second end surface of the n-doped region, in which $a2$ is a constant, Lp is a diffusion length of the hole, and f is a maximum value of the concentration of the hole.

8. The diode of claim 4, wherein a function of the lifetime of the second minority carrier in the n-doped region is $g\exp(-b2x/Lp)$ in the direction from the PN junction to the second end surface of the n-doped region, in which $b2$ is a constant, Lp is a diffusion length of the hole, and g is a maximum value of the lifetime of the second minority carrier.

9. The diode of claim 4, wherein the concentration of the p-type impurity at the second end surface of the p-doped region is about E16/cm^3-E20/cm^3, and the concentration of the p-type impurity at the first end surface of the p-doped region is about E14/cm^3-E17/cm^3.

10. The diode of claim 4, wherein the concentration of the n-type impurity at the second end surface of the n-doped region is about E16/cm^3-E20/cm^3, and the concentration of the n-type impurity at the first end surface of the n-doped region is about E12/cm^3-E14/cm^3.

11. The diode of claim 1, wherein a concentration of an n-type impurity decreases gradually in a direction from the PN junction to the second end surface of the n-doped region.

12. The diode of claim 11, wherein a lifetime of a first minority carrier in the p-doped region decreases gradually in the direction from the second end surface of the p-doped region to the PN junction.

13. The diode of claim 12, wherein a lifetime of a second minority carrier in the n-doped region increases gradually in the direction from the PN junction to the second end surface of the n-doped region.

14. The diode of claim 13, wherein a function of a concentration of a hole in the p-doped region is $h\exp(c1x/Lp)$ in the direction from the second end surface of the p-doped region to the PN junction, in which $c1$ is a constant, Lp is a diffusion length of the hole, and h is a maximum value of the concentration of the hole.

15. The diode of claim 13, wherein a function of the lifetime of the first minority carrier in the p-doped region is $l\exp(-d1x/Lp)$ in the direction from the second end surface of the p-doped region to the PN junction, in which $d1$ is a constant, Lp is a diffusion length of the hole, and l is a maximum value of the lifetime of the first minority carrier.

16. The diode of claim 13, wherein a function of a concentration of a hole in the n-doped region is $h\exp(c2x/Lp)$ in the direction from the PN junction to the second end surface of the n-doped region, in which $c2$ is a constant, Lp is a diffusion length of the hole, and h is a maximum

value of the concentration of the hole.

17. The diode of claim 13, wherein a function of the lifetime of the second minority carrier in the n-doped region is $l\exp(-d2x/Lp)$ in the direction from the PN junction to the second end surface of the n-doped region, in which $d2$ is a constant, Lp is a diffusion length of the hole, and l is a maximum value of the lifetime of the second minority carrier.

18. The diode of claim 13, wherein the concentration of the p-type impurity at the second end surface of the p-doped region is about E16/cm^3-E20/cm^3, and the concentration of the p-type impurity at the first end surface of the p-doped region is about E14/cm^3-E17/cm^3.

19. The diode of claim 13, wherein the concentration of the n-type impurity at the first end surface of the n-doped region is about E16/cm^3-E20/cm^3, and the concentration of the n-type impurity at the second end surface of the n-doped region is about E12/cm^3-E14/cm^3.

20. A diode, comprising:

a first diode structure comprising:

a first p-doped region defining a first end surface and a second end surface opposite to each other; and

a first n-doped region defining a first end surface and a second end surface opposite to each other, in which the first end surface of the first n-doped region is adjacent to the first end surface of the first p-doped region to form a first PN junction, a concentration of a p-type impurity decreases gradually in a direction from the second end surface of the first p-doped region to the first PN junction, a concentration of an n-type impurity increases gradually in a direction from the first PN junction to the second end surface of the first n-doped region, a lifetime of a first minority carrier in the first p-doped region increases gradually in the direction from the second end surface of the first p-doped region to the first PN junction, and a lifetime of a second minority carrier in the first n-doped region decreases gradually in the direction from the first PN junction to the second end surface of the first n-doped region; and

a second diode structure adjacent to the first diode structure in an axial direction comprising:

a second p-doped region defining a first end surface and a second end surface opposite to each other; and

a second n-doped region defining a first end surface and a second end surface opposite to each other, in which the first end surface of the second n-doped region is adjacent to the first end surface of the second p-doped region to form a second PN junction, a concentration of a p-type impurity decreases gradually in a direction from the second end surface of the second p-doped region to the second PN junction, a concentration of an n-type impurity decreases gradually in a direction from the second PN junction to the second end surface of the second n-doped region, a lifetime of a first minority carrier in the second p-doped region decreases gradually in the direction from the second end surface of the second p-doped region to the second PN junction, and a lifetime of a second minority carrier in the second n-doped region increases gradually in the direction from the PN junction to the second end surface of the second n-doped region.

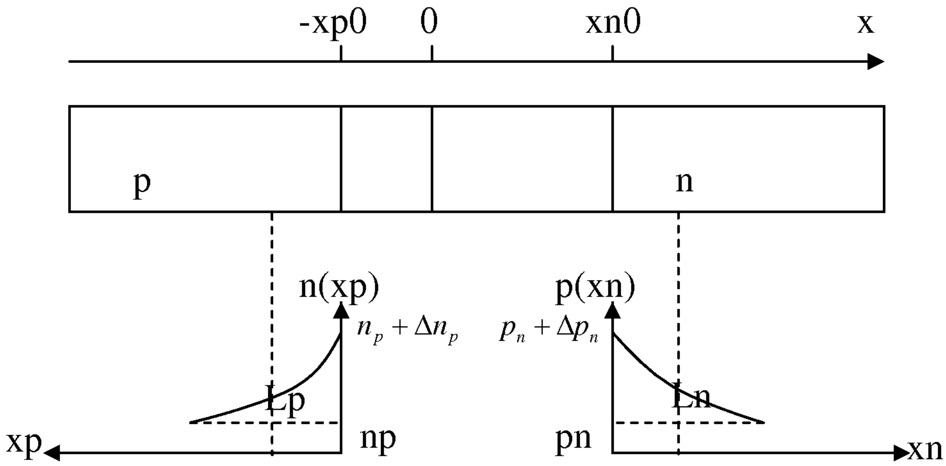
21. The diode of claim 20, wherein an axial area ratio of the first diode structure to the second diode structure is about 1:0.1 to about 1:10.

22. The diode of claim 21, wherein the axial area ratio of the first diode structure to the second diode structure is about 1:1 to about 1:5.

23. The diode of claim 20, wherein an average concentration of a p-type impurity in the first p-doped region is greater than that of an n-doped impurity in the first n-doped region, and an average concentration of the p-type impurity in the second p-doped region is greater than that of the n-doped impurity in the second n-doped region.

24. The diode of claim 20, wherein a function of a concentration of a hole in the first p-doped region is $f\exp(a1x/Lp)$ in the direction from the second end surface of the first p-doped region to the first PN junction, a function of the lifetime of the first minority carrier in the first p-doped region is $g\exp(-b1x/Lp)$ in the direction from the second end surface of the first p-doped region to the first PN junction, a function of a concentration of a hole in the first n-doped region is $f\exp(a2x/Lp)$ in the direction from the first PN junction to the second end surface of the first n-doped region, and a function of the lifetime of the second minority carrier in the first n-doped region is $g\exp(-b2x/Lp)$ in the direction from the first PN junction to the second end surface of the first n-doped region, in which each of $a1$, $a2$, $b1$ and $b2$ is a constant, Lp is a diffusion length of the hole, f is a maximum value of the concentration of the hole, and g is a maximum value of the lifetime of the minority carrier; and

a function of a concentration of a hole in the second p-doped region is $h\exp(c1x/Lp)$ in the direction from the second end surface of the second p-doped region to the second PN junction, a function of the lifetime of the first minority carrier in the second p-doped region is $l\exp(-d1x/Lp)$ in the direction from the second end surface of the second p-doped region to the second PN junction, a function of a concentration of a hole in the second n-doped region is $h\exp(c2x/Lp)$ in the direction from the second PN junction to the second end surface of the second n-doped region, and a function of the lifetime of the second minority carrier in the second n-doped region is $l\exp(-d2x/Lp)$ in the direction from the second PN junction to the second end surface of the second n-doped region, in which each of $c1$, $c2$, $d1$ and $d2$ is a constant, Lp is a diffusion length of the hole, h is a maximum value of the concentration of the hole, and l is a maximum value of the lifetime of the minority carrier.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Lp
Ln
xp
np
pn
xn

Fig. 1

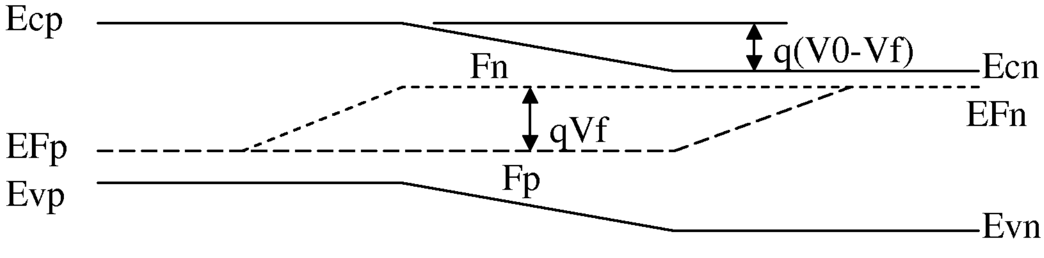
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Fig. 2

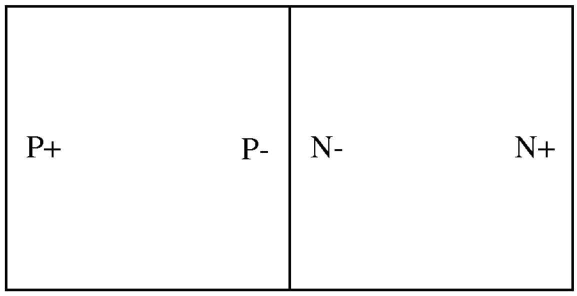

Fig. 3a

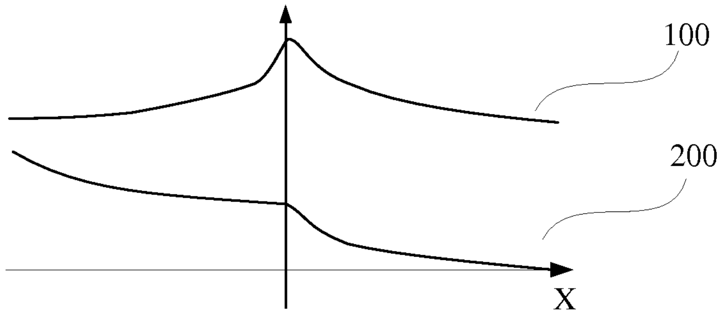

Fig. 3b

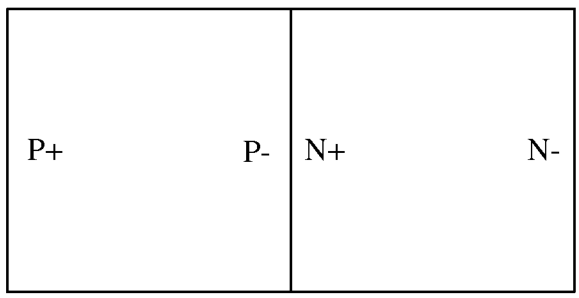

Fig. 4a

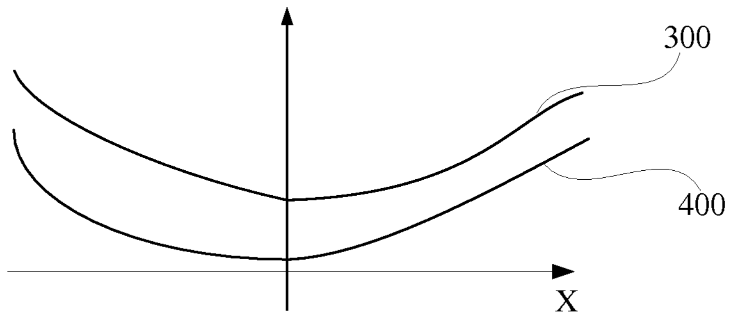

Fig. 4b

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2011/070221

A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: H01L29/-; H01L21/-

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC, CPRS, CNKI: impurity, concentration, decrease, increase, density, P, N

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US5811873 A (SOEJIMA) 22 September 1998 (22.09.1998) column 19 line 43- column 20 line 5; figures 12(b), 12(b')	1-2
A		3-24
X	JP2-072675 A (SEMIKRON ELEKTRONIK GMBH) 12 March 1990 (12.03.1990) columns 8-12; figures 2a-2b	1
A		2-34
X	US4594602 A (IIMURA ET AL.) 10 June 1986 (10.06.1986) column 2 line 37- column 3 line 18; figures 1a-1b	1
A		2-34

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim (S) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&"document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 February 2011 (25.02.2011)	**14 Apr. 2011 (14.04.2011)**

Name and mailing address of the ISA/CN	Authorized officer
The State Intellectual Property Office, the P.R.China 6 Xitucheng Rd., Jimen Bridge, Haidian District, Beijing, China 100088 Facsimile No. 86-10-62019451	WANG,Xin Telephone No. (86-10)62411567

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2011/070221

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
US5811873 A	22.09.1998	EP0749166 B1	23.08.2000
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		EP0122598 A3	24.10.1984
		EP0122598 B2	04.04.1990

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2011/070221

Continuation of : A. CLASSIFICATION OF SUBJECT MATTER

H01L 29/861 (2006.01) i
H01L 21/329 (2006.01) i