1.5 s to 3 s, and may be 2 s. With such configuration, the etching efficiency and the etching quality can be ensured.

[0071] In addition, during the process of the first etching step, the chamber pressure is 1 mTorr to 30 mTorr, such as 3 mTorr to 10 mTorr, and may be 5 mTorr; the upper-electrode center power is 100 W to 1000 W, such as 300 W to 800 W, and may be 600 W; and the upper-electrode edge power is 500 W to 3000 W, such as 1000 W to 2000 W, and may be 1500 W.

[0072] S1320, the second etching step.

[0073] During the process of the second etching step, the lower electrode power is 100 W to 1000 W, such as 200 W to 800 W, or 300 W to 500 W, and may be 400 W. With such configuration, the etching efficiency and the etching quality can be ensured.

[0074] During the process of the second etching step, the flow rate of Ar is 10 sccm to 1000 sccm, such as 30 sccm to 800 sccm, or 50 sccm to 500 sccm, or 80 sccm to 200 sccm, and may be 100 sccm; and the flow rate of the chlorine-containing gas is 20 sccm to 200 sccm, such as 25 sccm to 150 sccm, or 30 sccm to 100 sccm, or 35 sccm to 70 sccm, and may be 40 sccm. With such configuration of the flow rates of the chlorine-containing gas and the inert gas, the etching efficiency and the etching quality can be ensured.

[0075] During the process of the second etching step, the process time is 5 s to 15 s, such as 8 s to 12 s, and may be 10 s. With such configuration, the etching efficiency and the etching quality can be ensured.

[0076] In addition, during the process of the second etching step, the chamber pressure is 1 mTorr to 30 mTorr, and may be 5 mTorr; the upper-electrode center power is 100 W to 1000 W, such as 300 W to 800 W, and may be 600 W; and the upper-electrode edge power is 500 W to 3000 W, such as 1000 W to 2000 W, and may be 1500 W.

[0077] S1330, the volatilization step.

[0078] During the process of the volatilization step, the lower electrode power is 0.5W to 5W, such as 0.8W to 2W, and may be 1 W; the flow rate of Ar is 0.5 sccm to 5 sccm, such as 0.8 sccm to 2 sccm, and may be 1 sccm; and the flow rate of the chlorine-containing gas is 0.5 sccm to 8 sccm, such as 0.8 sccm to 5 sccm, and may be 1 sccm. With such configuration, on the one hand, the by-products can volatilize in time; and on the other hand, during rapid switching between the process steps, the radio frequency does not need to be turned on or turned off, and the gas pipeline valves do not need to be opened or closed, so that frequent on/off of the radio frequency and frequent

opening/closing of the gas pipeline valves can be avoided.

[0079] During the process of the volatilization step, the process time is 0.5 s to 1.5 s, such as 0.8 s to 1.2 s, and may be 1 s. With such configuration, the total process time can be reduced without affecting the etching quality, thereby increasing the etching rate.

[0080] In addition, during the process of the volatilization step, the chamber pressure is 1 mTorr to 30 mTorr, and may be 5 mTorr; the upper-electrode center power is 100 W to 1000 W, such as 300 W to 800 W, and may be 600 W; and the upper-electrode edge power is 500 W to 3000 W, such as 1000 W to 2000 W, and may be 1500 W.

[0081] S1340, the cooling step.

[0082] During the process of the cooling step, the lower electrode power is 0.5 W to 5 W, such as 0.8 W to 2 W, and may be 1 W; the flow rate of Ar is 1 sccm to 15 sccm, such as 8 sccm to 12 sccm, and may be 10 sccm; and the flow rate of the chlorine-containing gas is 0.5 sccm to 8 sccm, such as 0.8 sccm to 5 sccm, and may be 1 sccm. On the one hand, the wafer to be etched can still be cooled in time, and at least part of the by-products can volatilize in time; and on the other hand, during rapid switching between the process steps, the radio frequency does not need to be turned on or turned off, and the gas pipeline valves do not need to be opened or closed, so that frequent on/off of the radio frequency and frequent opening/closing of the gas pipeline valves can be avoided.

[0083] During the process of the cooling step, the process time is 0.5 s to 1.5 s, such as 0.8 s to 1.2 s, and may be 1 s. With such configuration, the total process time can be reduced without affecting the etching quality, thereby increasing the etching rate.

[0084] In addition, during the process of the cooling step, the chamber pressure is 1 mTorr to 30 mTorr, such as 3 mTorr to 10 mTorr, and may be 5 mTorr; the upper-electrode center power is 100 W to 1000 W, such as 300 W to 800 W, and may be 600 W; and the upper-electrode edge power is 500 W to 3000 W, such as 1000 W to 2000 W, and may be 1500 W.

[0085] S1400, the desorption step.

[0086] During the process of the desorption step, the chamber pressure is 10 mTorr to 100 mTorr, such as 30 mTorr to 70 mTorr, and may be 50 mTorr; the upper-electrode center power is 100 W to 1000 W, such as 300 W to 700 W, or 400 W to 600 W, and may be 500 W; the upper-electrode edge power is 100 W to 1000 W, such as 300 W to 700 W, or 400 W to 600 W, and may be 500 W; the lower electrode power is 0; the chlorine-containing gas includes chlorine, the flow rate of chlorine is 10 sccm to 1000 sccm, such as 20 sccm to 500 sccm, or 50 sccm to 200 sccm, and may be 100 sccm; the

in the example of the present disclosure

| process step | chamber pressure/ mTorr | upper-electrode center power/W | upper-electrode edge power/W | lower electrode power/W | flow rate of $BCl_3$/ sccm | flow rate of $Cl_2$/ sccm | flow rate of Ar/ sccm | process time/s |
|---|---|---|---|---|---|---|---|---|
| first etching step | 5 | 600 | 1500 | 600 | 20 | 20 | 100 | 2 |
| second etching step | 5 | 600 | 1500 | 400 | 20 | 20 | 100 | 10 |
| volatilization step | 5 | 600 | 1500 | 1 | 1 | 1 | 1 | 1 |
| cooling step | 5 | 600 | 1500 | 1 | 1 | 1 | 10 | 1 |

[0090] During the above cyclic execution of the main etching process step and the auxiliary etching process step, at least one of the first etching step or the second etching step is selected, and at least one of the volatilization step or the cooling step is selected. For example, the first etching step and the cooling step may be cyclically performed, the second etching step and the cooling step may be cyclically performed, the first etching step and the volatilization step may be cyclically performed, the second etching step and the volatilization step may be cyclically performed, the first etching step, the volatilization step, and the cooling step may be cyclically performed, the second etching step, the volatilization step, and the cooling step may be cyclically performed, the first etching step, the second etching step, and the cooling step may be cyclically performed, or the first etching step, the second etching step, and the volatilization step may be cyclically performed; or all the steps are selected, that is, the first etching step, the second etching step, the volatilization step, and the cooling step are cyclically performed (as shown in Table 2, the main etching process step includes the first etching step and the second etching step, and the auxiliary etching process step includes the volatilization step and the cooling step). $BCl_3$ and the $Cl_2$ may also be replaced with other chlorine-containing gases such as $SiCl_4$. $BCl_3$ and $SiCl_4$ can perform both the etching function and the sidewall protection function, but $Cl_2$ can only perform the etching function. Therefore, when the chlorine-containing gases (such as $BCl_3$ and $SiCl_4$) having the sidewall protection performance are selected, sidewall protection can be achieved during the etching process, so that the anisotropic etching can be realized, and the angle

silicon substrate as an example, an RCA standard cleaning method is adopted, commercially available concentrated sulfuric acid with the concentration of 98% and commercially available hydrogen peroxide with the concentration of 30% are mixed at the volume ratio of 7:3, the silicon substrate is placed in the mixed solution, the mixed solution is heated to 110℃ until bubbles disappear (heated for at least 30 minutes), and the silicon substrate is taken out and rinsed thoroughly with ultrapure water.

[0136] At S302, an AlN buffer layer is grown by Metal-Organic Chemical Vapor Deposition (MOCVD), with a thickness of the AlN buffer layer being 10 nm to 100 nm, such as 40 nm, as shown in FIG. 2b. For example, trimethylaluminum and ammonia are introduced into the reaction chamber, the reaction chamber is heated to 700℃, a growth rate is controlled to 1 nm/min, and an AlN nucleation layer with a thickness of 5 nm is deposited on the substrate 120; then, trimethylaluminum and ammonia are continuously introduced, the temperature in the chamber is raised to 800℃, the growth rate is increased to 5 nm/min, and the AlN buffer layer 130 is formed.

[0137] At S303, based on step S302, the introduction of trimethylaluminum is stopped, trimethylgallium and ammonia are introduced into the reaction chamber, the temperature in the chamber is raised to 1100℃, and a GaN epitaxial layer 110 is deposited on the AlN buffer layer 130, as shown in FIG. 2c. A thickness of the GaN epitaxial layer 110 is 1 μm to 10 μm, such as 3 μm.

[0138] At S304, growth of $Sc_xAl_{1-x}N$ is performed with the MBE method to obtain a barrier layer 200, as shown in FIG. 2d. A thickness of the barrier layer 200 is 0.01 μm to 1 μm, the temperature is 500℃ to 900℃, the flow rate of nitrogen is 0.1 sccm to 10 sccm, the Sc precursor may be obtained by electron beam evaporation, and the Al precursor may be obtained with the filament effusion cell.

[0139] At S305, the photoresist is spin-coated to form a first photoresist layer 310 having a first opening 311, as shown in FIG. 2e. A thickness of the first photoresist layer 310 is 0.5 μm to 10 μm, such as 3 μm. The photoresist is exposed and developed. Design and processing of the mask are performed in advance, such that the first opening 311, i.e., the recess (respectively calculated from two ends of the recess) is kept apart from the source and the drain by a distance of 0.3 μm and a distance of 1 μm, respectively. The exposure time is 3 s to 20 s, such as 6 s; the development time is 45 s to 120 s, such as 75 s; and the fixing time is 60 s to 300 s, such as 120 s. Thus, the photoresist is patterned.

[0140] It should be noted that for a voltage withstanding device, a distance between a gate and a drain can affect a voltage which the device can withstand; and for a radio

layer 110, the buffer layer 130, and the substrate 120 are sequentially arranged from top to bottom to form an epitaxial wafer 100. Referring to FIG. 1, the barrier layer 200 is deposited on the epitaxial layer 110 of the epitaxial wafer 100, the recess 240 is formed in the barrier layer 200 on a side away from the substrate 120, and the source 210 is disposed on the first side of the recess 240; the drain 230 is disposed on the second side of the recess 240, the gate 220 is disposed in the recess 240, the source 210, the gate 220, and the drain 230 are spaced apart from each other by the recess 240, an opening of the recess 240 is away from the epitaxial layer 110, and a bottom of the recess 240 does not reach the epitaxial layer 110, that is, the depth of the recess 240 is smaller than the thickness of the barrier layer 200, and the gate 220 is located in the recess 240; and the barrier layer 200 is the Sc-containing layer. The barrier layer 200 being a $Sc_xAl_{1-x}N$ barrier layer is still taken as an example in the present embodiment.

[0157] A distance h between the bottom of the recess 240 and a side of the Sc-containing layer facing the substrate is 1 nm to 100 nm, such as 2 nm to 20 nm, or 3 nm to 10 nm, and may be 5 nm; the recess 240 has a first edge (i.e., the edge on the first side) and a second edge (i.e., the edge on the second side), which are opposite to each other, the first edge is located between the gate 220 and the source 210, and the second edge is located between the gate 220 and the drain 230; the distance M from the first edge to the source 210 is 0.1 μm to 0.5 μm, and the distance N from the second edge to the drain 230 is 0.5 μm to 5 μm; a length G of the gate 220 is 0.5μm to 5 μm, such as 0.6 μm to 2 μm, and may be 1 μm; a width of the gate 220 is 0.1 mm to 10 mm, such as 1 mm to 5 mm, and may be 3 mm. With such configuration, as shown in FIG. 11a, when a gate voltage is applied to the gate for regulation, a potential well is formed, and a two-dimensional electron gas is generated, so that high electron mobility in the semiconductor device can be realized; as shown in FIG. 11b, when no gate voltage is applied, the potential well for the two-dimensional electron gas disappears, and the semiconductor device is in an off state, that is, the semiconductor device becomes a normally-off semiconductor device, so that safety control performance of the semiconductor device can be realized.

[0158] The thickness H of the barrier layer 200 is 0.01 μm to 1 μm, such as 0.01 μm to 0.5 μm, or 0.01 μm to 0.1 μm, or 0.01 μm to 0.05 μm, and may be 0.03 μm. Taking the epitaxial layer 110 being a GaN epitaxial layer as an example, a thickness of the GaN epitaxial layer is 1 μm to 10 μm, such as 2 μm to 5 μm, and may be 3 μm.

[0159] A length Y of the source 210 is 5 μm to 500 μm, such as 6 μm to 100 μm, or 7 μm to 50 μm, and may be 10 μm. The source 210 includes a Ti layer and an Al layer, and the