

MAGNETRON AND MAGNETRON SPUTTERING DEVICE

Field of the Invention

The present invention relates to the field of sputtering deposition technology, and in particular relates to a magnetron and a magnetron sputtering device.

Background of the Invention

Physical vapor deposition technology or sputtering deposition technology, which generally refers to a thin-film preparation process employing a physical method to prepare a thin film, is a most widely used type of thin-film fabrication technology in the semiconductor industry. Physical vapor deposition technology is applicable to many process areas, such as copper interconnection technology, through-silicon via technology in the packaging field, and the like.

Fig. 1 is a schematic diagram of a structure of a typical magnetron sputtering device. The device mainly includes: a process chamber 1, an electrostatic chuck 3 provided inside the process chamber 1 and used for bearing a substrate, a target material 2 and a magnetron 4 provided above the process chamber 1, and a magnetron driving motor 5. There is an air pumping device 13 attached onto a lower end or a sidewall of the process chamber 1. In a magnetron sputtering process, process gas (e.g. argon, or the like) used for generating plasma is fed into the process chamber 1, and under the combined effect of an electric field and a magnetic field inside the chamber, electrons are bounded by the magnetic field generated by the magnetron, the range of motion of the electrons is limited, and moving tracks of the electrons are elongated, which causes the electrons to be ionized to the greatest extent. A part of the ions react on a surface of the target material to form a compound, and another part of the ions, which are attracted by a negative voltage of the target material, bombard the surface of the target material 2, and cause a part of the atoms on the surface of the target material 2 to fall off and be deposited onto a surface of a substrate to be processed, thereby forming a desired film layer.

Fig. 2a is a radial cross-sectional diagram of a magnetron of the prior art, and Fig. 2b is a target material corrosion curve of the target material corroded by the magnetron in Fig. 2a. Please refer to Figs. 2a and 2b together. The magnetron includes an outer magnetic pole 102 and an inner magnetic pole 104, both of which have a spiral ring

shape and are nested within each other, and in the outer magnetic pole 102 and the inner magnetic pole 104, magnets 108 with opposite polarities are uniformly distributed along the profiles of respective magnetic poles, to form a magnetic field that can bound plasma at a surface of the target material. Further, a constant gap 106 having a spiral ring shape is formed between the outer magnetic pole 102 and the inner magnetic pole 104. The constant gap 106 is used to define a region with a high density of plasma, which is adjacent to a front face of the target material, and form a closed current loop in the plasma to maintain the plasma. During the process, the magnetron performs a rotary scanning on the surface of the target material by taking an inner end 14 of the inner magnetic pole 104 as a center of rotation. The above magnetron is able to realize full target corrosion, and the utilization ratio of the target material is very high.

However, as illustrated in Fig. 2b, Fig. 2b is a target material corrosion curve of the target material corroded by the magnetron in Fig. 2a. It can be seen from the figure that a thickness of the thin film obtained by deposition employing the above magnetron has a poor uniformity. The reason is that: since particles sputtered from positions at different radii of the target material fly to the substrate at different angles, and specifically, an overall angle at which particles sputtered from a periphery of the target material arrive at the substrate is smaller than an overall angle at which particles sputtered from a center of the target material arrive at the substrate, causing the thin film deposited on the surface of the substrate to be thick in the center and thin on the periphery in its radial direction. The uniformity of the thickness of the entire film is greater than 3%, which is poor. Also, because of a relatively long path of a track formed by the gap 106, a relatively large glow voltage is required, and the relatively large glow voltage may cause damage to the surface of a P-GaN substrate in a subsequent ITO thin-film deposition process.

Fig. 2c is a radial cross-sectional diagram of another magnetron of the prior art. As illustrated in Fig. 2c, the magnetron, with a shape similar to a kidney, includes an outer magnetic pole 62 and an inner magnetic pole 64 with opposite polarities to each other, and a gap 66 having a fixed width is formed therebetween. A track of such a kidney-shaped magnetron 60 does not completely cover a center of a target material (i.e. a center of rotation 14), and does not cover a periphery of the target material either, and thus cannot realize full target scanning. Also, the track of the magnetron defines substantially the same radians in a central region and a peripheral region of the target material, and thus for a short range sputtering, the problem that a deposited thin film is

thick in the center and thin on the periphery will occur in the end.

In view of the above-described two types of defects in the prior art, the question challenging those skilled in the art is: how to provide a magnetron capable of increasing the uniformity of the thickness of the thin film.

Summary of the Invention

Based on this, it is necessary to provide a uniformly sputtering magnetron and a magnetron sputtering device including the same.

A magnetron of the present invention comprises an inner magnetic pole and an outer magnetic pole with opposite polarities, wherein the inner magnetic pole and the outer magnetic pole are each formed of a plurality of spiral lines, the spiral lines of the inner magnetic pole are surrounded by those of the outer magnetic pole, and a gap is provided between the inner magnetic pole and the outer magnetic pole; and the gap has different widths at different positions from a spiral center to a spiral periphery; and

the spiral lines of the outer magnetic pole and the spiral lines of the inner magnetic pole satisfy the following polar coordinate equation:

$$r = a \times \theta^n + b \times (\cos \theta)^m + c \times (\tan \theta)^k + d$$

where r and θ are polar coordinates; a , b , c , d are constants; $0 \leq n \leq 2$, $0 \leq m \leq 2$, $c = 0$ or $k = 0$.

Optionally, the width of the gap gradually decreases or gradually increases from the spiral center to the spiral periphery.

Optionally, the width of the gap ranges from 10mm to 60mm.

Optionally, quantities of the spiral lines forming the inner magnetic pole and the outer magnetic pole are both three.

Optionally, the width of the gap gradually decreases from a spiral intermediate part to the spiral center, and the width of the gap gradually decreases from the spiral intermediate part to the spiral periphery as well; or the width of the gap gradually increases from a spiral intermediate part to the spiral center, and the width of the gap gradually increases from the spiral intermediate part to the spiral periphery as well.

Optionally, polar coordinate equations for the three spiral lines of the inner magnetic pole are, respectively:

$$r = 4.875 \times \theta^{1.701} + 1.46 \times (\cos \theta)^{1.244} - 26.72, \text{ where } 1.5\pi \leq \theta \leq 2.6\pi;$$
$$r = 8.31 \times \theta^{1.235} + 10.84 \times (\cos \theta)^{1.362} + 39.02, \text{ where } 1.72\pi \leq \theta \leq 3.14\pi;$$

$$r = 4.64 \times \theta^2 + 35.84 \times (\cos \theta)^{1.695} - 48.52, \text{ where } 1.1\pi \leq \theta \leq 1.72\pi;$$

polar coordinate equations for the three spiral lines of the outer magnetic pole are:

$$r = 4.75 \times \theta^{1.92} + 1.25 \times (\cos \theta)^{1.56} + 32.49, \text{ where } 0.25 \leq \theta \leq 2\pi;$$

$$r = 17.54 \times \theta^{0.78} + 5.45 \times (\cos \theta)^{1.12} + 179.42, \text{ where } 0 \leq \theta \leq 1.15\pi;$$

$$r = 6.42 \times \theta^{1.98} + 1.88 \times (\cos \theta)^{1.95} + 45.41, \text{ where } 0.3 \leq \theta \leq 1.14\pi.$$

Optionally, the magnetron is applicable to a standard chamber; in the standard chamber, a distance from a target material to a substrate is smaller than 80mm.

Optionally, among the three spiral lines of the outer magnetic pole, two spiral lines correspond to a position at which a periphery of the gap is located, and ends of the two spiral lines are connected end-to-end by an arc line.

Optionally, the arc line satisfies the following polar coordinate equation:

$$\rho^2 + 303 \times \rho \times \cos \theta + 140 \times \rho \times \sin \theta + 25872 = 0, \text{ where } \rho \text{ and } \theta \text{ are polar coordinates; } 1.2\pi \leq \theta \leq 2.2\pi.$$

As another implementation, the present invention further provides a magnetron sputtering device, comprising a magnetron chamber, a vacuum process chamber, a target material, a substrate and a tray, and further comprising any one of the magnetrons provided by the present invention; wherein the tray is provided in the vacuum process chamber, an upper surface of the tray used as a bearing surface for bearing the substrate; the magnetron is provided in the magnetron chamber; the target material is provided between the magnetron chamber and the vacuum process chamber, a back surface of the target material facing the magnetron chamber.

Optionally, a distance from the target material to the substrate is 50-80mm, when the magnetron sputtering device is used for deposition of metal hard mask TiN.

Optionally, a distance from the target material to the substrate is 30-90mm, when the magnetron sputtering device is used for deposition of other nitride than TiN or metal.

Optionally, the gap passes through a center and a periphery of the target material, during a scanning performed on the target material by the magnetron.

Compared to the prior art, beneficial effects of the present invention are as follows:

The magnetron provided by the present invention includes an inner magnetic pole and an outer magnetic pole with opposite polarities, a gap is formed between the adjacent inner magnetic pole and the outer magnetic pole, and the gap has different widths at different positions from a spiral center to a spiral periphery, so that in-plane

intensity distribution of a magnetic field tends to be uniform, thereby enhancing the uniformity of the thickness of the thin film. Meanwhile, the gap between the inner magnetic pole and the outer magnetic pole of the magnetron provided by the present invention is approximately in a spiral shape, and the number of cycles of the spiral shape is relatively few, so that a relatively short path of plasma can be obtained, and further a glow voltage of the plasma can be lowered, thereby preventing a surface of a P-GaN substrate from being damaged during a subsequent ITO thin-film deposition process.

As a preferable embodiment, the width of the gap gradually decreases from the spiral center to the spiral periphery. At this time, the spiral-shaped magnetron generates a relatively weak magnetic field at the center of the target material, and a relatively strong magnetic field at the periphery of the target material, so that quantities of particles deposited at different positions on the substrate are substantially equal in a radial direction, thereby increasing the uniformity of the film thickness. The uniformity of the thickness of the thin film obtained by deposition applying the magnetron provided by the present embodiment is less than 3%.

Brief Description of the Drawings

Fig. 1 is a schematic diagram of a structure of a conventional magnetron sputtering device.

Fig. 2a is a radial cross-sectional diagram of a magnetron of the prior art.

Fig. 2b is a target material corrosion curve of the target material corroded by the magnetron in Fig. 2a.

Fig. 2c is a radial cross-sectional diagram of another magnetron of the prior art.

Fig. 3 is a schematic diagram of a magnetron provided by an embodiment of the present invention.

Fig. 4 is a target material corrosion curve of a magnetron sputtering device provided by an embodiment of the present invention.

Detailed Description of the Embodiments

In order to address the problem of poor uniformity of a thickness of a thin film, there is proposed a magnetron and a magnetron sputtering device to obtain a thin film with a uniform thickness.

Above and other technical features and advantages of the present invention will be

described in further detail below in conjunction with the drawings.

Referring to Fig. 3, which is a schematic diagram of a magnetron of the present invention, a magnetron 100 includes an inner magnetic pole 120 and an outer magnetic pole 130 with opposite polarities to each other, the inner magnetic pole 120 and the outer magnetic pole 130 are each formed of a plurality of spiral lines, the spiral lines of the inner magnetic pole 120 are surrounded by the spiral lines of the outer magnetic pole 130, and the spiral lines of the inner magnetic pole 120 and the outer magnetic pole 130 both satisfy the following polar coordinate equation:

$$r = a \times \theta^n + b \times (\cos \theta)^m + c \times (\tan \theta)^k + d,$$

where a coordinate origin 110 is the center of the spiral, r and θ are polar coordinates; a , b , c , d are constants.

Let $c = 0$ or $k = 0$; $0 \leq n \leq 2$; $0 \leq m \leq 2$.

The coordinate origin 110 is the spiral center of the spiral lines of the inner magnetic pole 120, and the spiral lines of the inner magnetic pole 120 are around the coordinate origin 110; the coordinate origin 110 is also the spiral center of the spiral lines of the outer magnetic pole 130.

Specifically, as illustrated in Fig. 3, quantities of the spiral lines forming the inner magnetic pole 120 and the outer magnetic pole 130 are both three. The spiral lines forming the inner magnetic pole 120 are a first inner spiral line 122, a second inner spiral line 124 and a third inner spiral line 126; the spiral lines forming the outer magnetic pole 130 are a first outer spiral line 132, a second outer spiral line 134 and a third outer spiral line 136.

In the present embodiment, polar coordinate equations for the first inner spiral line 122, the second inner spiral line 124, and the third inner spiral line 126 forming the inner magnetic pole 120 are as follows, respectively:

- (1) $r = 4.875 \times \theta^{1.701} + 1.46 \times (\cos \theta)^{1.244} - 26.72$, where $1.5\pi \leq \theta \leq 2.6\pi$;
- (2) $r = 8.31 \times \theta^{1.235} + 10.84 \times (\cos \theta)^{1.362} + 39.02$, where $1.72\pi \leq \theta \leq 3.14\pi$;
- (3) $r = 4.64 \times \theta^2 + 35.84 \times (\cos \theta)^{1.695} - 48.52$, where $1.1\pi \leq \theta \leq 1.72\pi$.

Polar coordinate equations for the first outer spiral line 132, the second outer spiral line 134, and the third outer spiral line 136 forming the outer magnetic pole 130 are as follows, respectively:

- (1) $r = 4.75 \times \theta^{1.92} + 1.25 \times (\cos \theta)^{1.56} + 32.49$, where $0.25 \leq \theta \leq 2\pi$;

$$(2) \quad r = 17.54 \times \theta^{0.78} + 5.45 \times (\cos \theta)^{1.12} + 179.42, \text{ where } 0 \leq \theta \leq 1.15\pi;$$

$$(3) \quad r = 6.42 \times \theta^{1.98} + 1.88 \times (\cos \theta)^{1.95} + 45.41, \text{ where } 0.3 \leq \theta \leq 1.14\pi.$$

In the present embodiment, ends of two spiral lines of the outer magnetic pole 130 corresponding to a periphery of a gap 140 are connected end-to-end with one another by an arc line, that is, the second outer spiral line 134 and the third outer spiral line 136 are connected using an arc line 138 therebetween. A center of a circle where the arc 138 is located is at a position (-151.5, -70) of the coordinate system, a radius of the arc 138 is 44.5mm, and a curve equation for the arc 138 is:

$\rho^2 + 303 \times \rho \times \cos \theta + 140 \times \rho \times \sin \theta + 25872 = 0$, where ρ and θ are polar coordinates; $1.2\pi \leq \theta \leq 2.2\pi$.

In addition to the arc 138 connecting the second outer spiral line 134 and the third outer spiral line 136, arc lines are used also for connections between the three spiral lines of the inner magnetic pole 120, and between the rest of the adjacent ends of the three spiral lines of the outer magnetic pole 130, so that the three spiral lines forming the inner magnetic pole 120 and the three spiral lines forming the outer magnetic pole 130 form respective smooth curves, to form a closed gap 140.

For a magnetron provided by an embodiment of the present invention, a gap between the inner magnetic pole and the outer magnetic pole obtained by following the above polar coordinate equations is approximately in a spiral shape, and the number of cycles of the spiral shape is relatively few (the gap 140 can be seen as two tracks spirally wound in parallel for one round), so that a relatively short plasma path can be obtained, and further a glow voltage of the plasma can be lowered, thereby preventing a surface of a P-GaN substrate from being damaged during a subsequent ITO thin-film deposition process.

In addition, the gap 140 has different widths at different positions from the center to the periphery of the spiral. Specifically, as illustrated in Fig. 3, the gap 140 is in a closed ring shape, and the ring shape is bent in a spiral manner, and has one end close to a center of the spiral of the inner magnetic pole 120 or the outer magnetic pole 130, and the other end spirally extending outwards around the center of the spiral; the different positions of the gap 140 from the center to the periphery of the spiral refer to different positions of the gap 140 from an end thereof close to the center of the spiral to an end thereof far from the center of the spiral. The larger the width of the above gap 140, the smaller the intensity of the magnetic field at the gap 140; otherwise, the smaller the

width of the above gap 140, the greater the intensity of the magnetic field at the gap 140. Thus, in-plane intensity distribution of the magnetic field may be controlled by changing a magnitude of the width of the gap 140 at different positions from the center to the periphery of the spiral, thereby increasing a uniformity of a thickness of a thin film.

Preferably, the gap 140 is divided into three parts successively from an end thereof close to the center of the spiral to an end thereof far from the center of the spiral, which are a spiral center, a spiral intermediate part, and a spiral periphery, respectively. And, depending on a difference in distribution of a thickness of a thin film on a surface of a substrate in its radial direction, the width of the gap 140 may gradually decrease or gradually increase from the spiral center to the spiral periphery; or, the width of the gap 140 may gradually decrease from the spiral intermediate part to the spiral center, and gradually decrease from the spiral intermediate part to the spiral periphery; or, the width of the gap 140 may gradually increase from the spiral intermediate part to the spiral center, and gradually increase from the spiral intermediate part to the spiral periphery, so that the thickness of the thin film tends to be uniform in the end. Preferably, the width of the gap 140 ranges from 10mm to 60mm.

For example, if there is a problem that the thin film is thick in the center and thin on the periphery, then the width of the gap 140 may gradually decrease from the spiral center to the spiral periphery, that is, $d_1 > d_2 > d_3$, which causes the magnetic field of the magnetron 100 at the spiral center to be weak, and the magnetic field at the spiral periphery to be strong, and also reduces a quantity of particles sputtered from the center by a certain extent, while increasing a quantity of particles sputtered from the periphery, so that the thickness of the thin film tends to be uniform in the end. Preferably, the width of the gap 140 at the spiral center $d_1 (=40\text{nm})$ is progressively decreased to the width of the gap 140 at the spiral periphery $d_3 (=30\text{nm})$. The uniformity of the thickness of the thin film obtained by deposition applying the magnetron provided by the present embodiment is less than 3%. But the present invention is not limited thereto. If there is a problem that the thin film is thin in the center and thick on the periphery, then the width of the gap 140 may gradually increase from the spiral center to the spiral periphery of the magnetron, that is, $d_1 < d_2 < d_3$. Further, in order to better refine the control, the width of the gap 140 may gradually decrease from the spiral intermediate part to the spiral center of the magnetron, and the width of the gap 140 may gradually decrease from the spiral intermediate part to the spiral periphery as well, that is, $d_2 > d_1$ and $d_2 > d_3$; or, the width

of the gap 140 may gradually increase from the spiral intermediate part to the spiral center of the magnetron 100, and the width of the gap 140 may gradually increase from the spiral intermediate part to the spiral periphery as well, that is, $d_2 < d_1$ and $d_2 < d_3$.

Preferably, please refer to Fig. 4, which is a target material corrosion curve of a magnetron sputtering device of the present invention. The center of the spiral of the spiral lines of the inner magnetic pole 120 is the coordinate origin 110 of the spiral-shaped magnetron 100, the coordinate origin 110 passes through the center of the target material in a vertical direction, and the spiral lines of the outer magnetic pole 130 cover the periphery of the target material, so that a path of plasma passes through the center and the periphery of the target material, to realize uniform corrosion of the entire target.

The magnetron provided by an embodiment of the present invention can not only improve a uniformity of a thickness of a thin film, but also improve a uniformity of a sheet resistance of a metal hard mask. Specifically, in the sputtering deposition technology, deposition of metal (e.g. copper, titanium, tantalum and the like) or reactive sputtering of metal compound (e.g. tantalum nitride) is performed, the sheet resistance and the thickness of them are substantially the same throughout a wafer, and the product of these two parameters, i.e. resistivity is substantially the same throughout the wafer. However, for the reactive sputtering of hard metals (such as TiN, AlN, Ti and the like), because there are multiple forms of TiN, if one of the two process characteristics, i.e. the uniformity of the thickness and the uniformity of the sheet resistance of the thin film, becomes good, the other becomes poor. From this perspective, when a hard metal is sputtered, if a path of plasma of the magnetron is too short, the sheet resistance uniformity of the thin film would be poor; otherwise, if a path of plasma of the magnetron is too long, although the sheet resistance uniformity may be improved, a high glow voltage is required, which may cause damage to a surface of a P-GaN substrate in a subsequent ITO thin film deposition process. Thus, an appropriate path of plasma of the magnetron must be chosen, for the purpose of improving the sheet resistance uniformity while keeping the glow voltage low. As for the magnetron provided by an embodiment of the present invention, compared to the prior art, the path of plasma thereof is shorter than that of the magnetron illustrated in Fig. 1, and longer than that of the magnetron illustrated in Fig 2a, so that the sheet resistance uniformity can be improved while keeping the glow voltage low. Meanwhile, the magnetron provided by an embodiment of

the present invention can control in-plane intensity distribution of a magnetic field by changing a magnitude of the width of the gap 140 at different positions from the spiral center to the spiral periphery, and thus improve the uniformity of the thickness of the thin film, so not only the thickness uniformity and the sheet resistance uniformity of the thin film, but also the uniformity of the resistivity can be improved.

It is indicated by experimental data that when performing deposition of hard metal using the magnetron provided by the present embodiment, for a thin film obtained at high temperature and high pressure ($>5\text{mT}$), the sheet resistance uniformity is less than 5%, and the thickness uniformity is less than 3%; for a thin film obtained at room temperature and high pressure ($>5\text{mT}$), the sheet resistance uniformity is less than 3%, and the thickness uniformity is less than 6%. Both satisfy the process requirements of the present stage. Further, the magnetron provided by the present embodiment not only is suitable for reactive sputtering deposition of hard metal, but also can obtain a hard metal thin film with a sheet resistance uniformity less than 3% through sputtering deposition.

As another embodiment of the present invention, a magnetron sputtering device is also provided by the present invention. The magnetron sputtering device includes a magnetron chamber, a vacuum process chamber, a target material, a substrate, a tray, and the above magnetron 100.

The tray is provided in the vacuum process chamber, an upper surface of the tray is used as a bearing surface for bearing the substrate; the magnetron 100 is provided in the magnetron chamber; the target material is provided between the magnetron chamber and the vacuum process chamber, a back surface of the target material faces the magnetron chamber.

To improve the sputtering efficiency, the magnetron 100 is placed on the back surface of the target material. The magnetron 100 includes magnets with opposite polarities, that is, one or more magnets with opposite polarities form the inner magnetic pole 120 and the outer magnetic pole 130, respectively, to form a spiral-shaped inner track and a spiral-shaped outer track, respectively.

The magnets forming the inner magnetic pole 120 and the outer magnetic pole 130 are located on respective tracks of the spiral lines of the inner magnetic pole 120 and the spiral lines of the outer magnetic pole 130, and the magnets are bounded by the tracks and generate a magnetic field within a range of the chamber close to the magnets.

The inner magnetic pole 120 of the magnetron 100 is surrounded by the magnets

with an opposite polarity of the outer magnetic pole 130.

For the purpose of uniform sputtering, the magnetron 100 is driven by a motor and performs a uniform scanning on the surface of the target material. The rotation speed of the motor is 60-100rpm.

The gap passes through a center and a periphery of the target material during the scanning of the target material by the magnetron, so that a spiral center of the spiral lines of the inner magnetic pole 120 is the coordinate origin 110 of the spiral-shaped magnetron 100. The coordinate origin 110 passes through the center of the target material in a vertical direction, and the spiral lines of the outer magnetic pole 130 cover the periphery of the target material, so that a path of plasma passes through the center and the periphery of the target material, to realize uniform corrosion of the entire target.

As one possible implementation, when the magnetron sputtering device is used for deposition of metal hard mask TiN, a process pressure may be 2-15mT, a power may be no greater than 20kW, and a distance between the target material and the substrate may be 50-80mm.

As one possible implementation, when the magnetron sputtering device is used for deposition of other nitride than TiN or metal, such as AlN, Cu, Ti and the like, a process pressure may be 1-20mT, a power may be no greater than 40kW, and a distance between the target material and the substrate may be 30-90mm.

In the above cases, an excellent sputtering deposition effect can be obtained. The magnetron 100 and the magnetron sputtering device are also suitable for sputtering depositions under various process conditions, and have a wide application range.

The above-described embodiments merely illustrate several implementations of the present invention, and are described in detail, which, however, cannot be construed as limiting the patentable scope of the present invention. It should be noted that, for those of ordinary skill in the art, various variations and improvements can be made without departing from the concept of the present invention, and these variations and improvements shall fall into the protection scope of the present invention.

CLAIMS:

1. A magnetron, comprising an inner magnetic pole and an outer magnetic pole with opposite polarities, wherein the outer magnetic pole are formed of three spiral lines, which are respectively a first outer magnetic pole spiral line, a second outer magnetic pole spiral line and a third outer magnetic pole spiral line, the second outer magnetic pole spiral line is the farthest spiral line from a spiral center, and an open gap is provided between the first outer magnetic pole spiral line and the third outer magnetic pole spiral line, the spiral lines of the inner magnetic pole are surrounded by the spiral lines of the outer magnetic pole, and a gap is provided between the inner magnetic pole and the outer magnetic pole; and the gap has different widths at different positions from a spiral center to a spiral periphery; and

the spiral lines of the outer magnetic pole and the spiral lines of the inner magnetic pole satisfy the following polar coordinate equation:

$$r = a \times \theta^n + b \times (\cos \theta)^m + c \times (\tan \theta)^k + d$$

where r and θ are polar coordinates; a, b, c, d are constants; $0 \leq n \leq 2$, $0 \leq m \leq 2$, $c = 0$ or $k = 0$.

2. The magnetron according to claim 1, wherein the width of the gap gradually decreases or gradually increases from the spiral center to the spiral periphery.

3. The magnetron according to claim 1, wherein the width of the gap gradually decreases from a spiral intermediate part to the spiral center, and the width of the gap gradually decreases from the spiral intermediate part to the spiral periphery as well; or

the width of the gap gradually increases from a spiral intermediate part to the spiral center, and the width of the gap gradually increases from the spiral intermediate part to the spiral periphery as well.

4. The magnetron according to claim 1, wherein the width of the gap ranges from 10mm to 60mm.

5. The magnetron according to any one of claims 1 to 4, wherein quantities of the spiral lines forming the inner magnetic pole are three.

6. The magnetron according to claim 5, wherein polar coordinate equations for the three spiral lines of the inner magnetic pole are, respectively:

$$r = 4.875 \times \theta^{1.701} + 1.46 \times (\cos \theta)^{1.244} - 26.72, \text{ where } 1.5\pi \leq \theta \leq 2.6\pi;$$

$$r = 8.31 \times \theta^{1.235} + 10.84 \times (\cos \theta)^{1.362} + 39.02, \text{ where } 1.72\pi \leq \theta \leq 3.14\pi;$$

$$r = 4.64 \times \theta^2 + 35.84 \times (\cos \theta)^{1.695} - 48.52, \text{ where } 1.1\pi \leq \theta \leq 1.72\pi; \text{ and}$$

polar coordinate equations for the three spiral lines of the outer magnetic pole are:

$$r = 4.75 \times \theta^{1.92} + 1.25 \times (\cos \theta)^{1.56} + 32.49, \text{ where } 0.25 \leq \theta \leq 2\pi;$$

$$r = 17.54 \times \theta^{0.78} + 5.45 \times (\cos \theta)^{1.12} + 179.42, \text{ where } 0 \leq \theta \leq 1.15\pi;$$

$$r = 6.42 \times \theta^{1.98} + 1.88 \times (\cos \theta)^{1.95} + 45.41, \text{ where } 0.3 \leq \theta \leq 1.14\pi.$$

7. The magnetron according to any one of claims 1 to 4, wherein the magnetron is applicable to a standard chamber; and

in the standard chamber, a distance from a target material to a substrate is smaller than 80mm.

8. The magnetron according to claim 5, wherein among the three spiral lines of the outer magnetic pole, two spiral lines correspond to a position at which a periphery of the gap is located, and ends of the two spiral lines are connected end-to-end by an arc line.

9. The magnetron according to claim 8, wherein the arc line satisfies the following polar coordinate equation:

$$\rho^2 + 303 \times \rho \times \cos \theta + 140 \times \rho \times \sin \theta + 25872 = 0,$$

where ρ and θ are polar coordinates; $1.2\pi \leq \theta \leq 2.2\pi$.

10. A magnetron sputtering device, comprising a magnetron chamber, a vacuum process chamber, a target material, a substrate and a tray, and further comprising the magnetron according to any one of claims 1 to 9; wherein

the tray is provided in the vacuum process chamber, an upper surface of the tray used as a bearing surface for bearing the substrate;

the magnetron is provided in the magnetron chamber;

the target material is provided between the magnetron chamber and the vacuum process chamber, a back surface of the target material facing the magnetron chamber.

11. The magnetron sputtering device according to claim 10, wherein a distance from the target material to the substrate is 50-80mm, when the magnetron sputtering device is

used for deposition of metal hard mask TiN.

12. The magnetron sputtering device according to claim 10, wherein a distance from the target material to the substrate is 30-90mm, when the magnetron sputtering device is used for deposition of other nitride than TiN or metal.

13. The magnetron sputtering device according to claim 10, wherein the gap passes through a center and a periphery of the target material, during a scanning performed on the target material by the magnetron.