

PLASMA CVD APPARATUS AND MANUFACTURING METHOD OF MAGNETIC
RECORDING MEDIA

Field of the Invention

5 The present invention relates to a plasma CVD apparatus
and a manufacturing method of magnetic recording media, and
particularly, to a plasma CVD apparatus capable of forming
a high-density and high-hardness thin film on a substrate
by lengthening the distance between the cathode electrode
10 and the substrate.

BACKGROUND OF THE INVENTION

 Fig. 2 is a cross sectional view schematically
illustrating a conventional plasma CVD apparatus. Although
15 the plasma CVD apparatus is capable of forming films on both
sides of a substrate (e.g., disk substrate) 101
simultaneously due to its bilaterally symmetric structure
relative to the substrate 101, only the left side relative
to the substrate 101 is shown in Fig. 2 and the right side
20 is omitted.

 The plasma CVD apparatus includes a chamber 102 in which
a hot cathode (cathode electrode) 103 is formed. Both ends
of the hot cathode 103 are electrically connected to an AC
power supply 105 located outside the chamber 102. One end
25 of the AC power supply 105 is electrically connected to a
ground 106.

 A funnel-shaped horn anode 104 is disposed inside the

chamber 102, the horn anode 104 being electrically connected to a DC power supply 107. The positive potential side of the DC power supply 107 is electrically connected to the horn anode 104, and the negative potential side of the DC power supply 107 is electrically connected to the ground 106.

The substrate 101 is disposed inside the chamber 102. The distance 12 between the hot cathode 103 and the substrate 101 is 163.5 mm.

The substrate 101 is electrically connected to a direct current power supply (DC power supply) 112 as the power supply for ion acceleration. The negative potential side of the DC power supply 112 is electrically connected to the substrate 101, and the positive potential side of the DC power supply 112 is electrically connected to the ground 106.

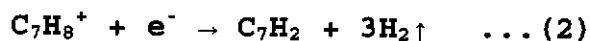
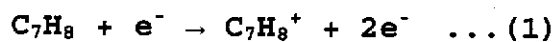
Inside the chamber 102, a plasma wall 108 is disposed so as to cover the space between each of the hot cathode 103 and the horn anode 104 and the substrate 101. The plasma wall 108 is electrically connected to a float potential (not shown). In addition, the plasma wall 108 is cylindrical, and the internal diameter B of the cylinder is in the range of 100 to 200 mm inclusive.

Next, a method of forming a DLC (Diamond Like Carbon) film on the substrate 101 using the plasma CVD apparatus shown in Fig. 2 will be described below.

First, the interior of the chamber 102 is brought into a predefined vacuum state and toluene (C_7H_8) gas, for example, is introduced into the chamber 102 as the film-forming

material gas. After the interior of the chamber 102 has reached a predefined pressure, the hot cathode 103 is heated by supplying alternating current from the AC power supply 105 to the hot cathode 103. In addition, direct current is
 5 supplied from the DC power supply 107 to the horn anode 104 and from the DC power supply 112 to the substrate 101.

By heating the hot cathode 103, a large number of electrons are emitted from the hot cathode 103 to the horn anode 104, whereby glow discharge is initiated between the
 10 hot cathode 103 and the horn anode 104. The toluene gas as the film-forming material gas inside the chamber 102 is ionized by the large number of electrons and brought into a plasma state. On this occasion, a reaction represented by the following equation (1) is occurring. Then, film-forming
 15 material molecules in plasma state are accelerated directly by the negative potential of the substrate 101 to fly toward the direction of the substrate 101 and adhere on the surface of the substrate 101, and whereby a thin DLC film is formed on the substrate 101. On this occasion, a reaction
 20 represented by the following equation (2) is occurring on the surface of the substrate 101.



With the above-mentioned conventional plasma CVD
 25 apparatus, the amount of DLC film formed on the surface of the substrate 101 per unit time can be increased by shortening the distance 12 between the hot cathode 103 and the substrate

101 as much as possible, such as 163.5 mm (see patent documents 1 and 2, for example).

[Patent Document 1]

Japanese Patent No. 3,299,721 (paragraphs 0015 to 0023,
5 Fig. 1)

[Patent Document 2]

Japanese Patent No. 3,930,183 (Fig. 1)

[Disclosure of the Invention]

[Problems to be solved by the invention]

10 With the above-mentioned conventional plasma CVD apparatus, the distance 12 between the cathode electrode 103 and the substrate 101 is shortened as much as possible in order to increase the amount of film formed per unit time.

However, it is difficult to sufficiently increase the
15 hardness of the thin film formed on the substrate if the above-mentioned distance 12 is shortened, and it is impossible to satisfy the needs of forming a high-hardness thin film on the substrate. The reason is that the shortened distance 12 makes the acceleration distance of the ionized
20 film-forming material gas too short to form a high-density thin film on the substrate.

The present invention has been made in consideration of the above-mentioned circumstances, and thus an object of the present invention is to provide a plasma CVD apparatus
25 capable of forming a high-density and high-hardness thin film on a substrate by lengthening the distance between a cathode electrode and the substrate.

SUMMARY OF THE INVENTION

In order to solve the above-mentioned problems, a plasma CVD apparatus according to the present invention
5 comprises: a chamber;

a funnel-shaped anode disposed inside the chamber;

a filament-shaped cathode disposed inside the chamber,
and surrounded by an inner periphery surface of the anode
near the center thereof;

10 a holding member disposed inside the chamber to hold
a substrate which is disposed so as to face the cathode and
the anode;

a plasma wall disposed inside the chamber so as to cover
a space between the substrate held by the holding member and
15 each of the cathode and the anode, the plasma wall having
a float potential;

an AC power supply electrically connected to the
cathode;

a first DC power supply electrically connected to the
20 anode;

a second DC power supply electrically connected to the
substrate held by the holding member;

a gas supply mechanism supplying material gas into the
chamber; and

25 an exhaust mechanism exhausting inside the chamber,
wherein:

the anode has its largest internal diameter side facing

the substrate;

the plasma wall is cylindrical or polygonal and has an internal diameter of the cylinder or polygon in the range of 100 to 200 mm inclusive;

5 a distance between the cathode and the substrate held by the holding member is in the range of 200 to 300 mm inclusive; and

the material gas is turned into plasma by causing discharge between the cathode and the anode.

10 According to the above-mentioned plasma CVD apparatus, if the internal diameter of the cylindrical or polygonal plasma wall is in the range of 100 to 200 mm inclusive, the distance between the filament-shaped cathode and the substrate is lengthened as much as possible, compared with
15 prior-art, to the range of 200 to 300 mm inclusive. In other words, the distance between the cathode and the substrate is lengthened as much as possible in the present embodiment, whereas the distance between the cathode and the substrate is shortened as much as possible according to prior art. In
20 this manner, acceleration distance of the ionized material gas can be lengthened, and whereby the speed of the ionized material gas when colliding with the substrate can be made faster than that with a conventional plasma CVD apparatus. As a result, the thin film formed on the substrate can have
25 a high density and a high hardness.

Additionally, the plasma CVD apparatus according to the present invention further comprises a magnet for

generating magnetic force in a region where the material gas is turned into plasma, wherein the magnet is cylindrical or polygonal, and magnetic force of the magnet center as the center of the internal diameter of the cylinder or polygon is in the range of 50 to 200 Gauss inclusive. In this manner, plasma density can be increased and, as a result, the thin film formed on the substrate can have a higher density and a higher hardness.

Additionally, in the plasma CVD apparatus according to the present invention, it is preferred that the magnet be disposed outside the cathode and the anode so as to surround the cathode and the anode.

Additionally, in the plasma CVD apparatus according to the present invention, the distance between the magnet center and the cathode is preferably within 50 mm, and more preferably, within 35 mm.

Additionally, in the plasma CVD apparatus according to the present invention, it is preferable that the magnet be a neodymium magnet.

A manufacturing method of magnetic recording media according to the present invention is the one using any of the above-mentioned plasma CVD apparatuses, the method comprising the steps of:

holding a film-formed substrate having at least a magnetic layer formed on a non-magnetic substrate at the holding member; and

turning the material gas into a plasma state by electric

discharge between the filament-shaped cathode and the anode which are heated in the chamber under a vacuum condition, and accelerating the plasma to collide on the surface of the film-formed substrate held by the holding member to form a protective layer having carbon as principal component.

Additionally, in the manufacturing method of magnetic recording media according to the present invention, it is preferred that the material gas, which is the material gas for forming a DLC layer on the film-formed substrate as the protective layer, includes gas containing carbon and hydrogen.

[Effect of the Invention]

As thus described, according to the present invention, a plasma CVD apparatus capable of forming a high-density and high-hardness thin film on a substrate by lengthening the distance between a cathode electrode and the substrate can be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a cross sectional view schematically illustrating a plasma CVD apparatus according to an embodiment of the present invention.

Fig. 2 is a cross sectional view schematically illustrating a conventional plasma CVD apparatus.

[Description of Reference Numerals]

1,101 substrate

- 2,102 chamber
- 3,103 cathode electrode (hot cathode)
- 4,104 anode electrode (horn anode)
- 5,105 AC power supply
- 5 6,106 ground power supply
- 7,107 DC power supply
- 8,108 plasma wall
- 8a film thickness correcting plate
- 9 neodymium magnet
- 10 10 magnet center
- 11 internal diameter of cylindrical neodymium magnet
- 12,112 DC power supply

DESCRIPTION OF THE PREFERRED EMBODIMENTS

15 In the following, an embodiment of the present invention will be described, referring to the drawings.

 Fig. 1 is a cross sectional view schematically illustrating a plasma CVD apparatus according to an embodiment of the present invention. Although the plasma CVD
20 apparatus is capable of forming films on both sides of a substrate (e.g., disk substrate) 1 simultaneously due to its bilaterally symmetric structure relative to the substrate 1, only the left side relative to the substrate 1 is shown in Fig. 1 and the right side is omitted.

25 The plasma CVD apparatus includes a chamber 2 in which a filament-shaped cathode electrode (hot cathode) 3 made of tantalum, for example, is formed. Both ends of the hot

cathode 3 are electrically connected to an AC power supply 5 located outside the chamber 2, and the AC power supply 5 is disposed in an insulated state from the chamber 2. As the AC power supply 5, a 0-50 V, 10-50 A (ampere) power supply 5 may be used, for example. One end of the AC power supply 5 is electrically connected to a ground 6.

A funnel-shaped anode electrode (horn anode) 4 is disposed inside the chamber 2 so as to surround the periphery of hot cathode 3, the horn anode 4 having a shape like a speaker. 10 The horn anode 4 is electrically connected to a direct current power supply (DC power supply) 7, and the DC power supply 7 is disposed in an insulated state from the chamber 2. The positive potential side of the DC power supply 7 is electrically connected to the horn anode 4, and the negative 15 potential side of the DC power supply 7 is electrically connected to the ground 6. As the DC power supply 7, a 0-500 V, 0-7.5 A (ampere) power supply may be used, for example.

A substrate 1 is disposed inside the chamber 2 so as to face the hot cathode 3 and the horn anode 4. Specifically, 20 the hot cathode 3 is surrounded by an inner periphery surface of the horn anode 4 near the center thereof, the horn anode 4 being disposed with its largest internal diameter side facing the substrate 1.

It is preferable to lengthen the distance 1 between 25 the hot cathode 3 and the substrate 1 as much as possible, specifically to a range of 200 to 300 mm inclusive. The reason is that the hardness of the thin film formed on the

substrate 1 becomes low if the distance 1 is shorter than 200 mm, whereas the film-forming rate becomes impractically slow if the distance 1 exceeds 300 mm.

The substrate 1 is arranged to be sequentially supplied
5 to the illustrated position by a holder (a holding member) and a transfer device (handling robot or rotary index table), both of which are not illustrated.

The substrate 1 is electrically connected to a DC power supply (direct current power supply) 12 which is the power
10 supply for ion acceleration, and the DC power supply 12 is disposed in an insulated state from the chamber 2. The negative potential side of the DC power supply 12 is electrically connected to the substrate 1, and the positive potential side of the DC power supply 12 is electrically
15 connected to the ground 6. As the DC power supply 12, a 0-1500 V, 0-100 mA (milliampere) power supply may be used, for example.

Inside the chamber 2, a plasma wall 8 is disposed so as to cover the space between each of the hot cathode 3 and
20 the horn anode 4 and the substrate 1. The plasma wall 8 is electrically connected to a float potential (not shown), and disposed in an insulated state from the chamber 2. In addition, the plasma wall 8 is cylindrical or polygonal, and the internal diameter B of the cylinder or the polygon is
25 in the range of 100 to 200 mm inclusive. The reason is that ionization of material gas becomes too high near the horn anode 4 if the internal diameter B is less than 100 mm, which

is undesirable in that it may allow generation of free carbon (i.e., soot). In addition, ionization of material gas becomes too low near the horn anode 4 if the internal diameter B exceeds 200 mm, whereby formation of high-density film on the substrate 1 becomes difficult, and generation of high magnetic field also becomes difficult even if neodymium magnet described below is used.

A film thickness correcting plate 8a is provided at the end of the plasma wall 8 on the side of the substrate 1, the film thickness correcting plate 8a being electrically connected to the float potential. Using the film thickness correcting plate 8a, thickness of the film formed on the outer peripheral of the substrate 1 can be controlled.

A neodymium magnet 9 is disposed outside the chamber 2. The neodymium magnet 9 is cylindrical or polygonal, for example, and it is preferred that the distance A between the internal diameter 11 and the hot cathode 3 is within 50 mm (more preferably, within 35 mm), the internal diameter 11 passing through the center of the cylindrical or polygonal side face along its cylindrical direction. The center of the internal diameter 11 is the magnet center 10, and the magnet center 10 is located so as to face approximately the centers of the hot cathode 3 and the substrate 1, respectively. Preferably, magnetic force at the magnet center 10 of the neodymium magnet 9 is in a range of 50 to 200 G (Gauss) inclusive, and more preferably in a range of 50 to 150 G inclusive. The reason for setting the magnetic force at the

magnet center 10 200 G or less is that this is the manufactural limit of raising the magnetic force at the magnet center 10 of the neodymium magnet up to 200 G. Additionally, the reason why it is more preferable to set the magnetic force at the magnet center 10 150 G or less is that the cost of manufacturing a magnet increases if the magnetic force at the magnet center 10 exceeds 150 G.

In addition, the plasma CVD apparatus includes a vacuum evacuation mechanism (not shown) which vacuum exhaust inside the chamber 2. In addition, the plasma CVD apparatus includes a gas supply mechanism (not shown) which provides film-forming material gas into the chamber 2.

Next, a method of forming a DLC film on the substrate 1 using the plasma CVD apparatus shown in Fig. 1 will be described.

First, the method activates the vacuum evacuation mechanism, brings the interior of the chamber 2 into a predefined vacuum state and, using the gas introduction mechanism, introduces toluene (C_7H_8) gas, for example, into the chamber 2 as the film-forming material gas. After the interior of the chamber 2 has reached a predefined pressure, the hot cathode 3 is heated by supplying alternate current from the AC power supply 5 to the hot cathode 3. In addition, direct current is supplied to the horn anode 4 from the DC power supply 7, and direct current is supplied to the substrate 1 from the DC power supply 12.

By heating the hot cathode 3, a large number of

electrons are emitted from the hot cathode 3 to the horn anode 4, and whereby glow discharge is initiated between the hot cathode 3 and the horn anode 4. The toluene gas as the film-forming material gas inside the chamber 2 is ionized
 5 by the large number of electrons and brought into a plasma state. On this occasion, since a magnetic field is generated in the region where the toluene gas existing near the hot cathode 3 is turned into plasma by the neodymium magnet 9, the plasma can have high density due to this magnetic field,
 10 and whereby ionization efficiency can be enhanced. Then, film-forming material molecules in plasma state are accelerated directly by the negative potential of the substrate 1 to fly toward the direction of the substrate 1 and adhere on the surface of the substrate 1, and whereby
 15 a thin DLC film is formed on the substrate 1. On this occasion, a reaction represented by the following equation (3) is occurring on the surface of the substrate 1.



20 Next, a manufacturing method of magnetic recording media using the plasma CVD apparatus shown in Fig. 1 will be described.

First, the method prepares a film-formed substrate having at least a magnetic layer formed on a non-magnetic
 25 substrate, and lets the holding member hold the film-formed substrate. Then, the method turns the material gas into a plasma state by electric discharge between the hot cathode

3 and the horn anode 4 which are heated in the chamber 2 under a predefined vacuum condition, and accelerates the plasma to collide on the surface of the film-formed substrate held by the holding member. In this manner, a protective layer
5 having carbon as principal component is formed on the surface of the film-formed substrate.

According to the above-mentioned embodiment, when the internal diameter B of the cylindrical or polygonal plasma wall 8 is in the range of 100 to 200 mm inclusive, the distance
10 between the hot cathode 3 and the substrate 1 is lengthened as much as possible. In other words, although the distance between the hot cathode and the substrate is shortened as much as possible according to prior art, the distance between the hot cathode and the substrate is lengthened as much as
15 possible in the present embodiment, specifically in the range of 200 to 300 mm inclusive. In this manner, acceleration distance of the ionized film-forming material gas can be lengthened, and whereby the speed of the ionized film-forming material gas when colliding with the substrate can be made
20 faster than that with a conventional plasma CVD apparatus. As a result, b in the above equation (3) can be reduced in comparison with the DLC film formed by the prior art plasma CVD device. In this manner, the DLC film formed on the substrate can have a high density and a high hardness.

25 Additionally, in the above-mentioned embodiment, the density of the plasma generated between the hot cathode 3 and the horn anode 4 of the present apparatus can be increased

by disposing a neodymium magnet 9 outside the chamber 2. As a result, the DLC film formed on the substrate can have a higher density and a higher hardness.

It should be noted that the present invention is not limited to the above-mentioned embodiment and can be implemented through a variety of modifications without deviating from a gist of the present invention. For example, in above-mentioned embodiment, although the neodymium magnet 9 is disposed outside the chamber 2, the neodymium magnet may be disposed inside the chamber 2, or a magnet made of another material may be disposed in place of the neodymium magnet 9. Moreover, the neodymium magnet 9 is not an essential element, and the present invention may also be implemented without disposing the neodymium magnet 9.

[Example 1]

Next, conditions and results of forming DLC film using the plasma CVD apparatus shown in Fig. 1 (thickness of DLC film, ashing condition of DLC film, and ashing rate) will be described.

(Conditions of film formation)

Internal diameter B of plasma wall: 132 mm

Distance 1 between hot cathode 3 and substrate 1: 238.5 mm

Distance A between hot cathode 3 and magnet center 10: 35 mm

Substrate: Si wafer

Gas: C_7H_8

Gas flow rate: 3.25 sccm

Pressure: 0.3 Pa

Hot cathode 3: tantalum filament

Output of AC power supply 5: 200 W

Current of DC power supply 7: 1650 mA

5 Voltage of DC power supply 12: 250 V

External magnetic field: none

(Results)

Thickness of DLC film: 30 nm

Knoop hardness (Hk) of DLC film: 2680

10 (Ashing conditions and results)

Gas: O₂

Gas flow rate: 50 sccm

Pressure: 30 Pa

Electrode: parallel flat type

15 Frequency of radio frequency wave applied to the electrode:

13.56 MHz

Radio frequency output applied to the electrode: 500 W

Ashing rate: 85 nm/minute

[Comparative example]

20 Next, conditions and results of forming DLC film using
the plasma CVD apparatus shown in Fig. 2 (thickness of DLC
film, ashing condition of DLC film, and ashing rate) will
be described.

(Conditions of film formation)

25 Internal diameter B of plasma wall 108: 132 mm

Distance l2 between hot cathode 103 and substrate 101: 163.5
mm

Substrate: Si wafer

Gas: C_7H_8

Gas flow rate: 3.25 sccm

Pressure: 0.3 Pa

5 Hot cathode 103: tantalum filament

Output of AC power supply 105: 200 W

Current of DC power supply 107: 1650 mA

Voltage of DC power supply 112: 250 V

External magnetic field: none

10 (Results)

Thickness of DLC film: 30 nm

Knoop hardness (Hk) of DLC film: 1800

(Ashing conditions and results)

Gas: O_2

15 Gas flow rate: 50 sccm

Pressure: 30 Pa

Electrode: parallel flat type

Frequency of radio frequency wave applied to the electrode:

13.56 MHz

20 Radio frequency output applied to the electrode: 500 W

Ashing rate: 140 nm/minute

According to the above-mentioned example 1 and the comparative example, acceleration distance of the ionized film-forming material gas can be lengthened by making the distance between the hot cathode and the substrate longer than that of the comparative example. Therefore, the speed of the ionized film-forming material gas when colliding on

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the substrate can be made faster than that with the conventional plasma CVD apparatus. As a result, ashing rate of the formed DLC film can be substantially decreased. Accordingly, it is confirmed that a DLC film with a high density has been formed, implying that the DLC film has a high hardness.

[Example 2]

Next, conditions and results of forming DLC film using the plasma CVD apparatus shown in Fig. 1 (thickness of DLC film, ashing condition of DLC film, and ashing rate) will be described.

(Conditions of film formation)

Internal diameter B of plasma wall: 132 mm
 Distance 1 between hot cathode 3 and substrate 1: 238.5 mm
 Distance A between hot cathode 3 and magnet center 10: 35 mm
 Substrate: Si wafer
 Gas: C_7H_8
 Gas flow rate: 3.25 sccm
 Pressure: 0.3 Pa
 Hot cathode 3: tantalum filament
 Output of AC power supply 5: 200 W
 Current of DC power supply 7: 1650 mA
 Voltage of DC power supply 12: 250 V
 External magnetic field: 50 G

(Results)

Thickness of DLC film: 30 nm

Knoop hardness (Hk) of DLC film: 2740

(Ashing conditions and results)

Gas: O₂

Gas flow rate: 50 sccm

5 Pressure: 30 Pa

Electrode: parallel flat type

Frequency of radio frequency wave applied to the electrode:

13.56 MHz

Radio frequency output applied to the electrode: 500 W

10 Ashing rate: 76 nm/minute

According to the above-mentioned examples 2 and 1, applying an external magnetic field of 50 G during film formation can decrease the ashing rate of the formed DLC film by 9 nm/minute compared with the case where external magnetic
15 field is not applied. Since the DLC film in example 1 has a very high density, the effect of decreasing 9 nm/minute in the example 2 is very large compared with the example 1. Accordingly, it is confirmed that a DLC film with a higher density has been formed, implying that the DLC film has a
20 higher hardness.

[Example 3]

Next, conditions and results of forming DLC film using the plasma CVD apparatus shown in Fig. 1 (thickness of DLC film, ashing condition of DLC film, and ashing rate) will
25 be described.

(Conditions of film formation)

Internal diameter B of plasma wall: 132 mm

Distance 1 between hot cathode 3 and substrate 1: 238.5 mm

Distance A between hot cathode 3 and magnet center 10: 35 mm

Substrate: Si wafer

5 Gas: C_7H_8

Gas flow rate: 3.25 sccm

Pressure: 0.3 Pa

Hot cathode 3: tantalum filament

Output of AC power supply 5: 200 W

10 Current of DC power supply 7: 1650 mA

Voltage of DC power supply 12: 250 V

External magnetic field: 100 G

(Results)

Thickness of DLC film: 30 nm

15 Knoop hardness (Hk) of DLC film: 2770

(Ashing conditions and results)

Gas: O_2

Gas flow rate: 50 sccm

Pressure: 30 Pa

20 Electrode: parallel flat type

Frequency of radio frequency wave applied to the electrode:

13.56 MHz

Radio frequency output applied to the electrode: 500 W

Ashing rate: 74 nm/minute

25 According to the above-mentioned examples 3 and 2, applying an external magnetic field of 100 G during film formation can decrease the ashing rate of the formed DLC film

by 2 nm/minute compared with the case where external magnetic field of 50 G is applied. Since the DLC film in the example 2 has a very high density, the effect of decreasing 2 nm/minute in the example 3 is very large compared with the example 2.

5 Accordingly, it is confirmed that a DLC film with a higher density has been formed, implying that the DLC film has a higher hardness.

6. A manufacturing method of magnetic recording media using a plasma CVD apparatus according to any one of claims 1 to 5, said method comprising the steps of:

holding a film-formed substrate having at least a magnetic layer formed on a non-magnetic substrate at said holding member; and

turning said material gas into a plasma state by electric discharge between said filament-shaped cathode and said anode which are heated in said chamber under a vacuum condition, and accelerating the plasma to collide on the surface of said film-formed substrate held by said holding member to form a protective layer having carbon as principal component.

7. The manufacturing method of magnetic recording media according to claim 6, wherein said material gas, which is the material gas for forming a DLC layer on said film-formed substrate as said protective layer, includes gas containing carbon and hydrogen.