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Tseng et al.

(54) **METHOD FOR PRODUCING A DYNAMIC FLUID BEARING WITH HIGH ROTATION PRECISION AND HIGH HARDNESS**

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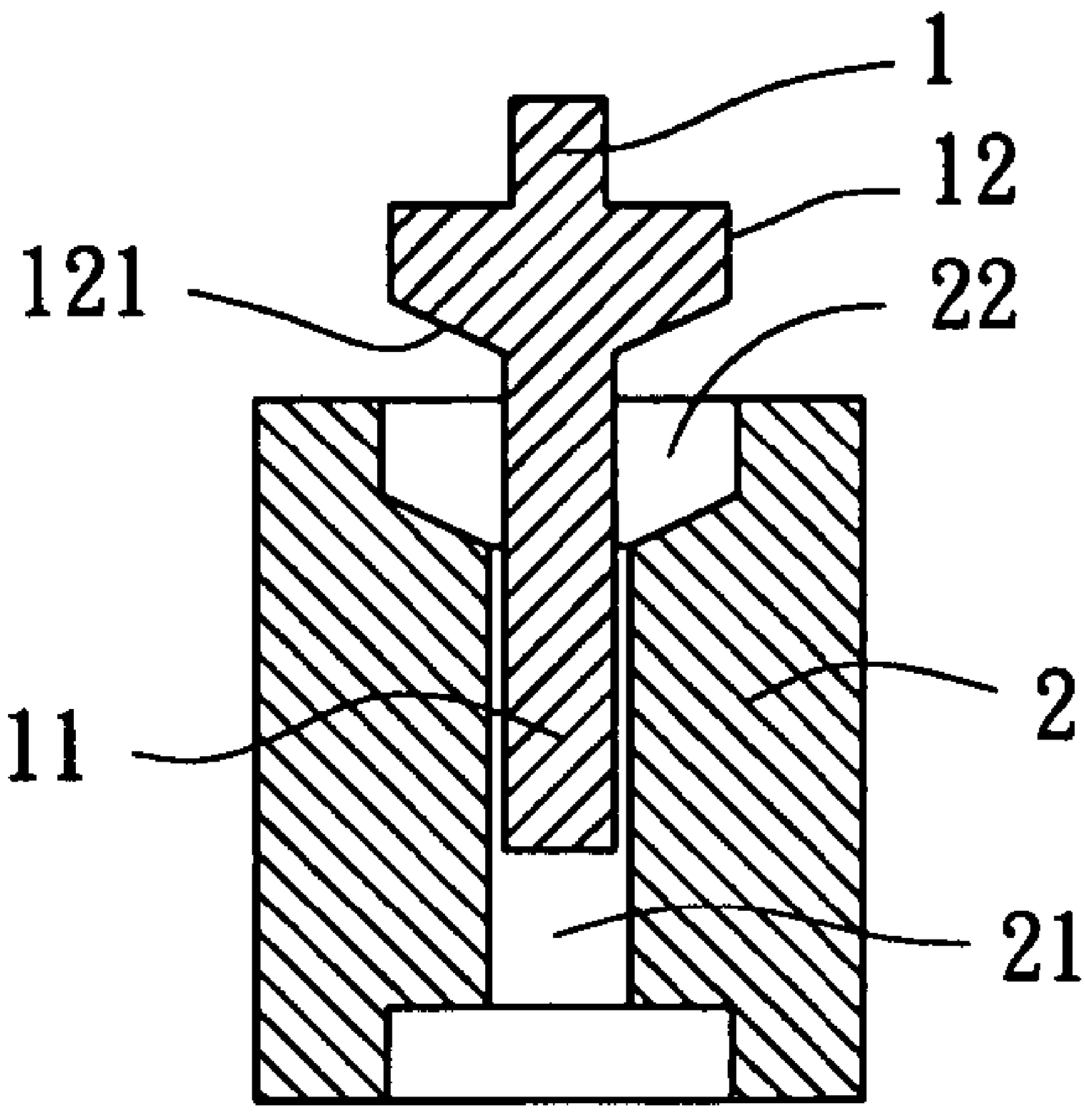
B21K 1/10 (2006.01)

(52) **U.S. Cl.** **29/898.02**

(57) **ABSTRACT**

A method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure comprises the steps of: (1) selecting at least one rotary component provided with a predetermined surface pattern for supporting a distribution of fluid dynamic-pressure; (2) forming an opaque and hard amorphous diamond (DLC, a-D) film (or nano-crystalline diamond film) on the pivotal surface of the component by physical vapor deposition (PVD). Thereby the pivotal surfaces of the rotary component and the pattern thereon can have excellent hardness, wearing resistance, rotational stailbity and durability under repeated urging of dynamic fluid pressure.



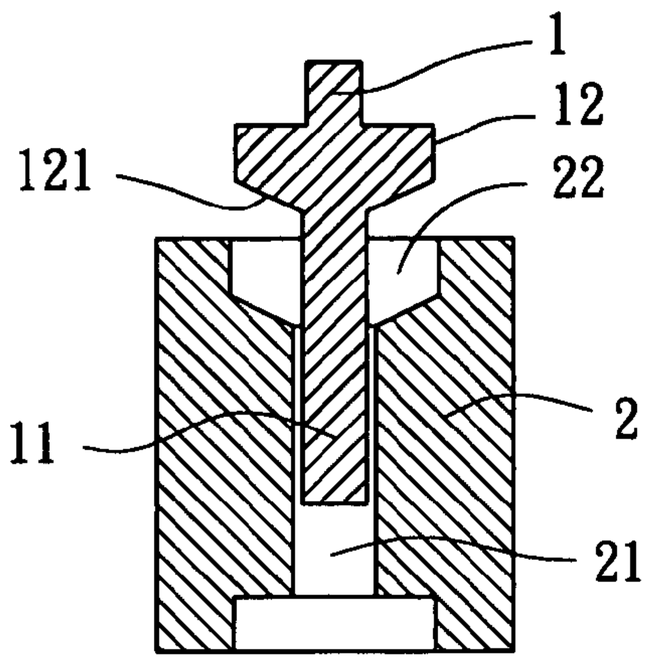


Fig. 1

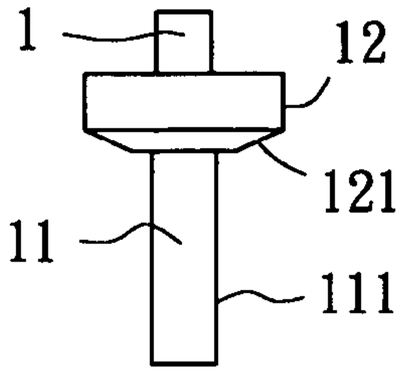


Fig. 1a

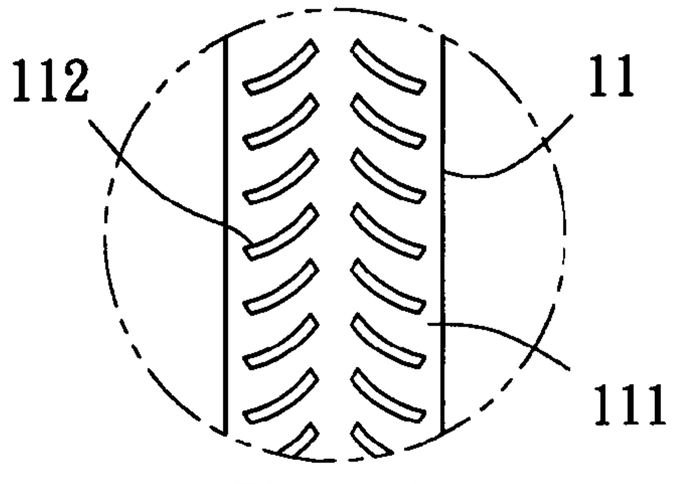


Fig. 1b

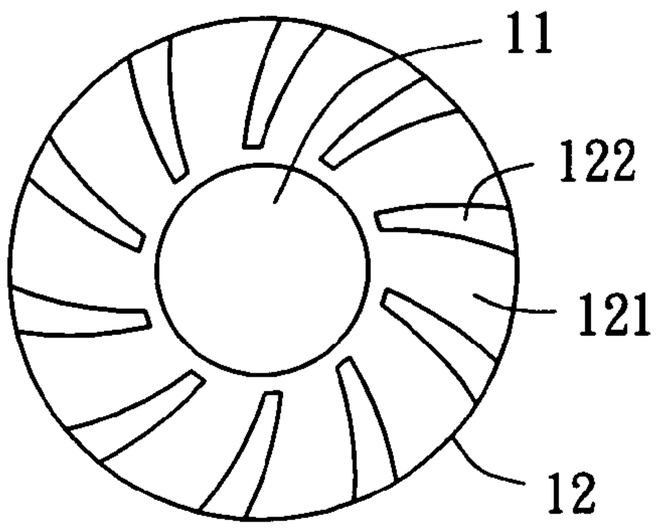


Fig. 1c

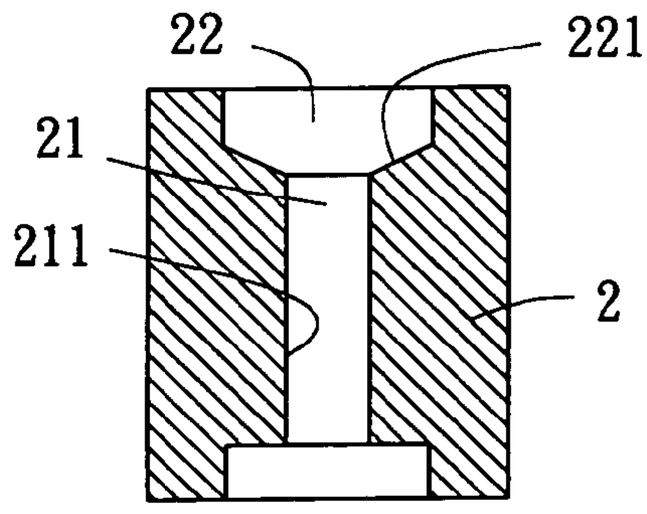


Fig. 1d

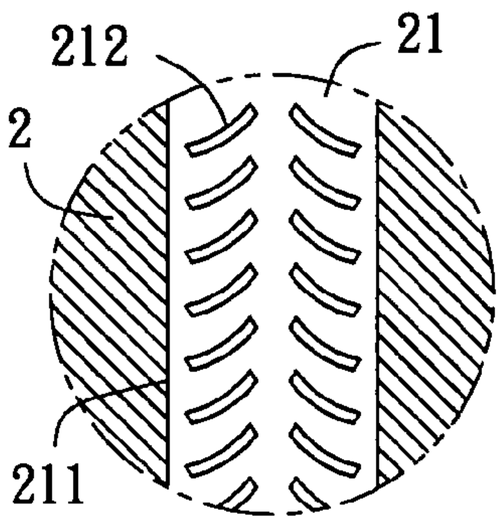


Fig. 1e

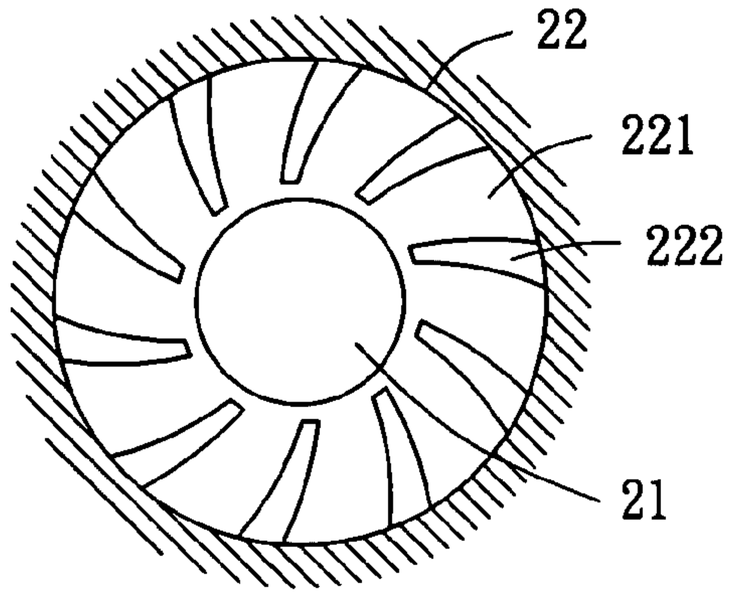


Fig. 1f

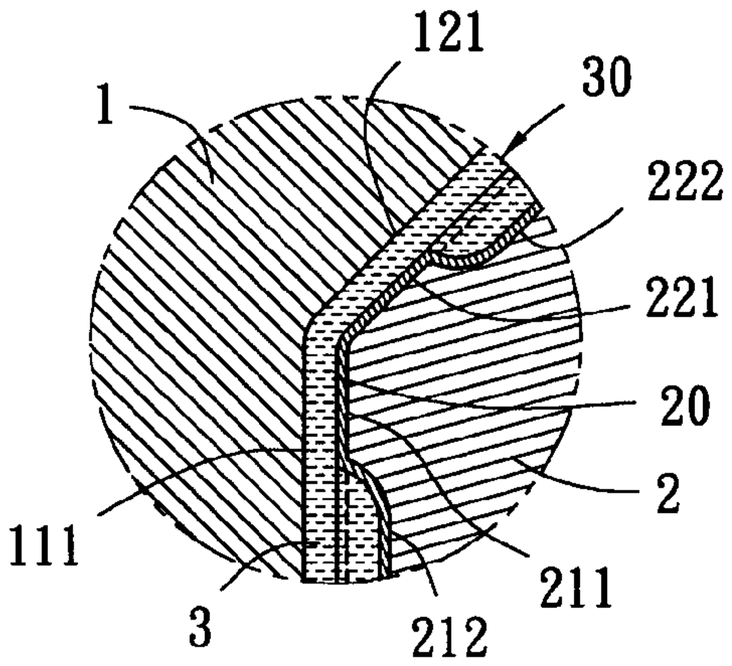


Fig. 1g

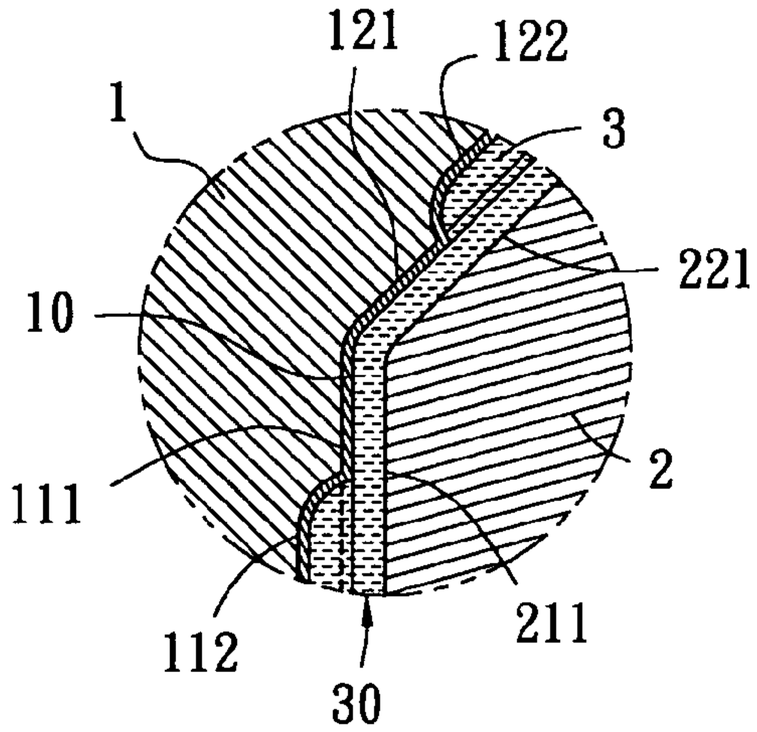


Fig. 1h

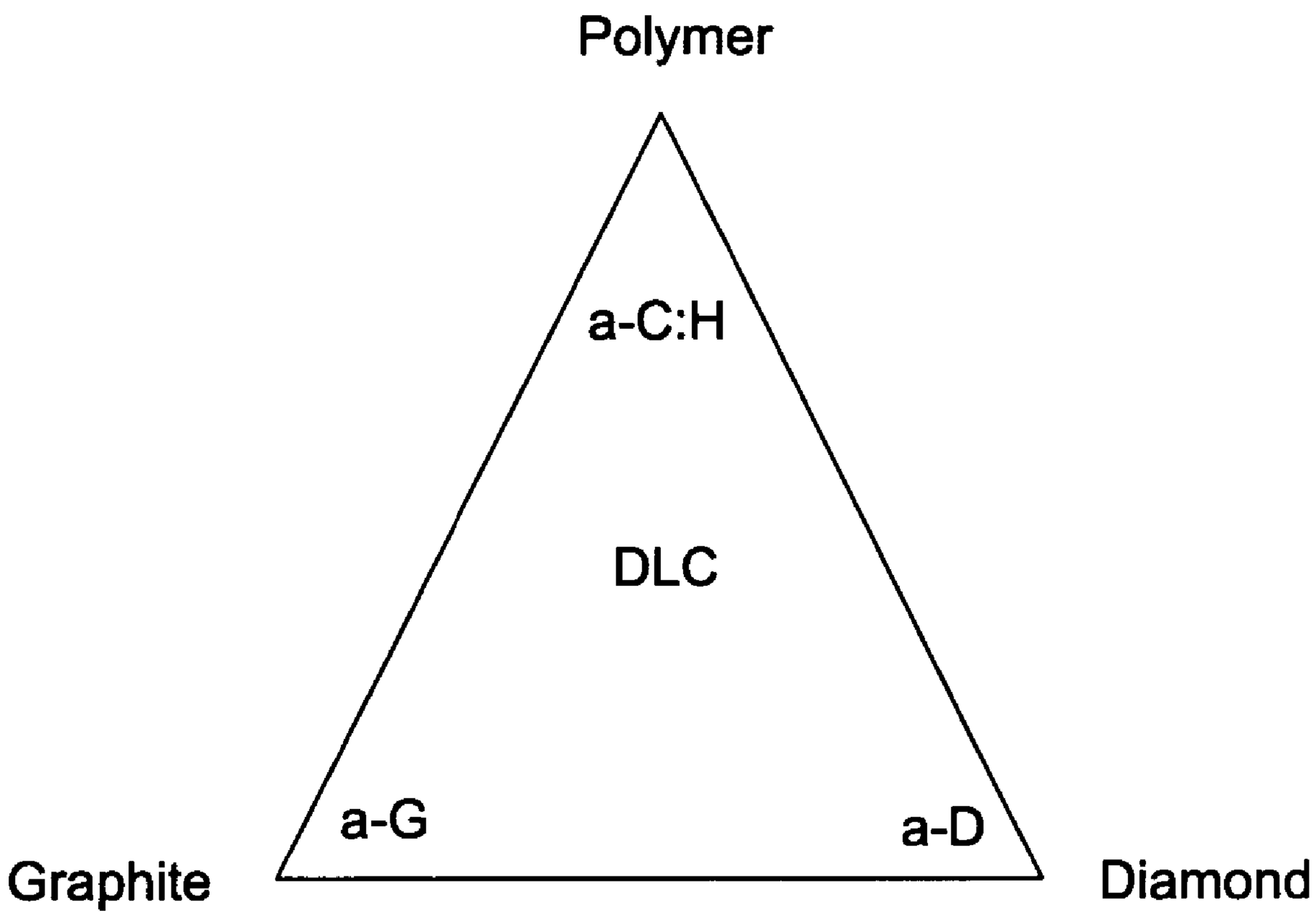


Fig. 2

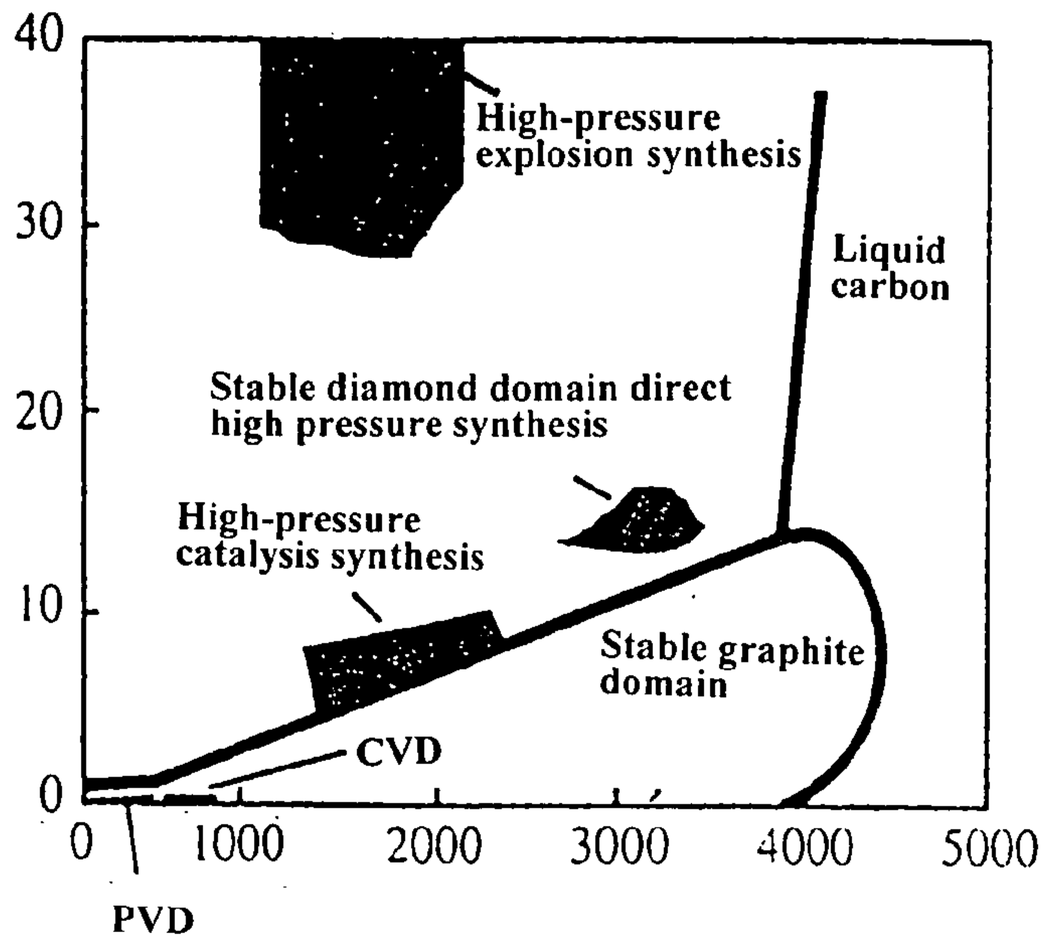

40
30
20
10
0
0
1000
2000
3000
4000
5000
High-pressure explosion synthesis
Liquid carbon
Stable diamond domain direct high pressure synthesis
High-pressure catalysis synthesis
Stable graphite domain
CVD
PVD

Fig. 3

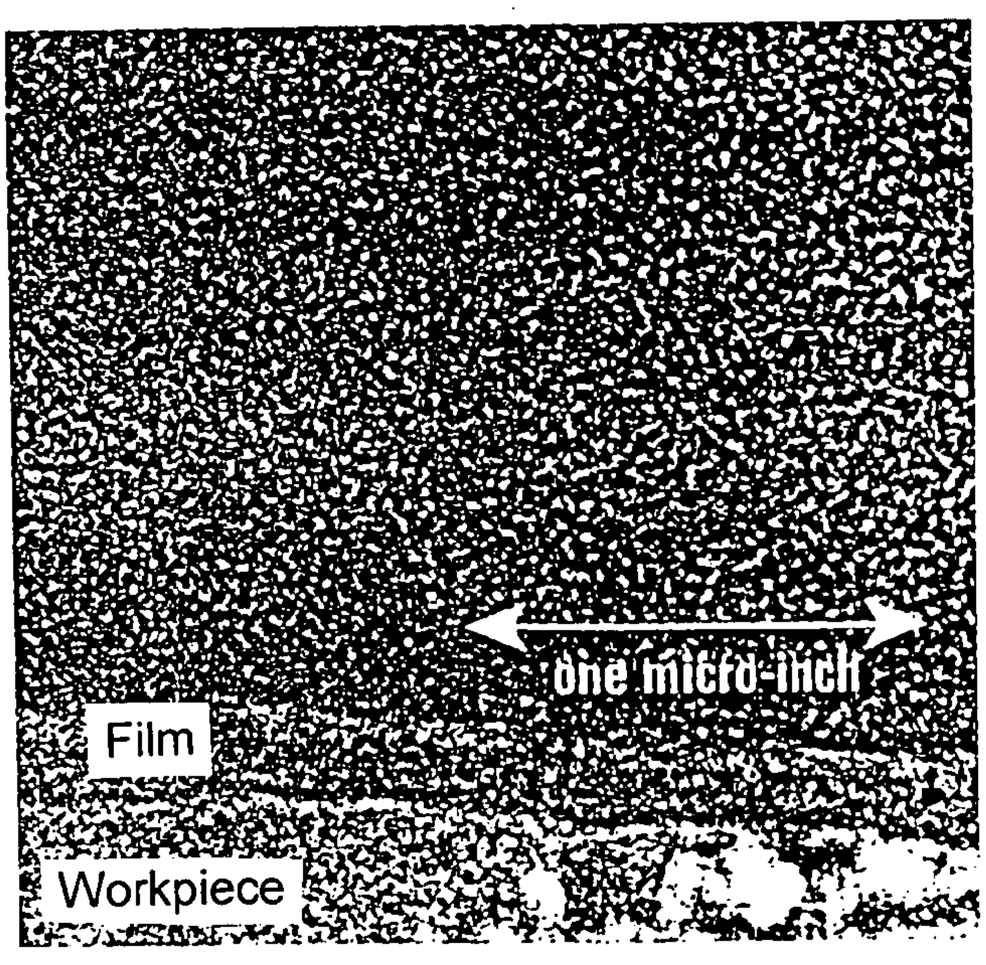

one micro-inch
Film
Workpiece

Fig. 4

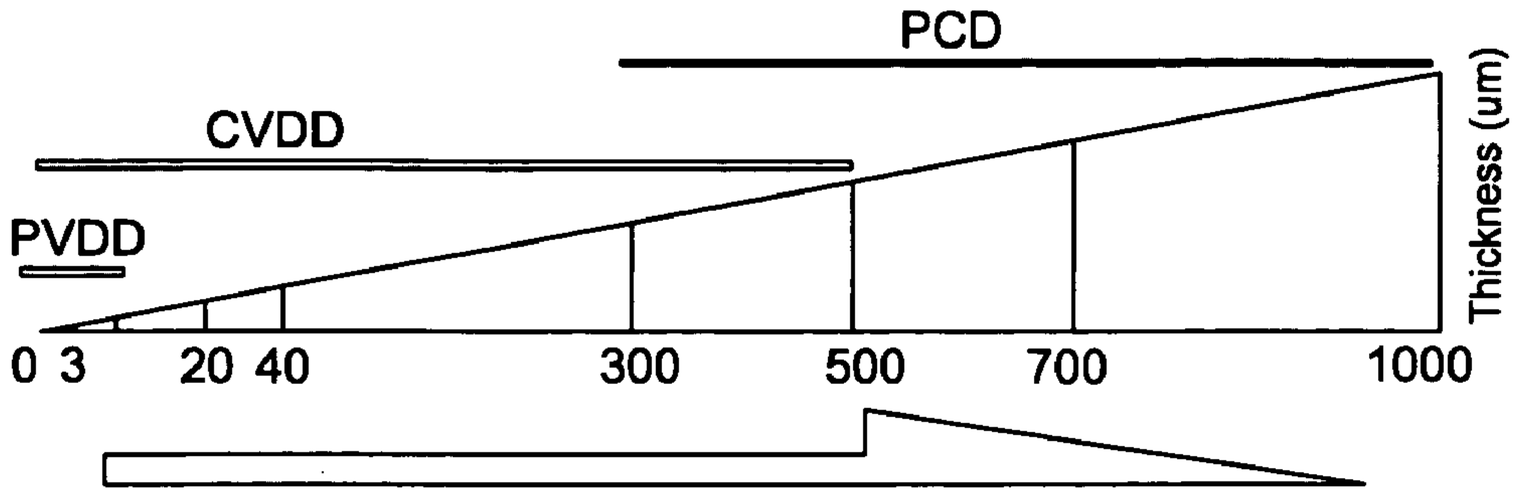


Fig. 5

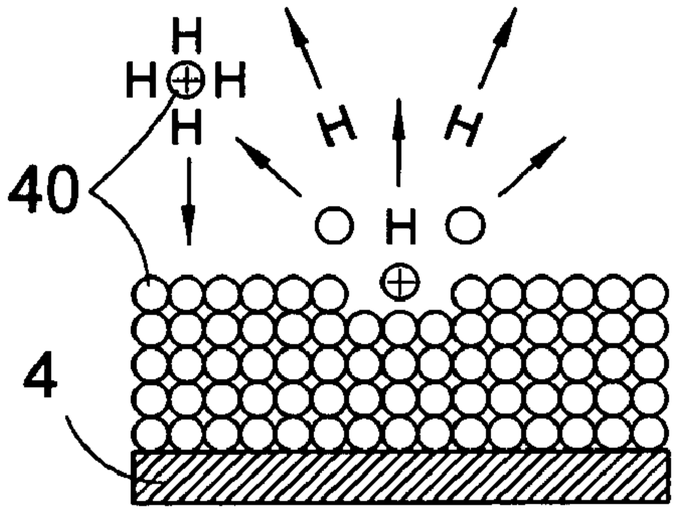


Fig. 6a

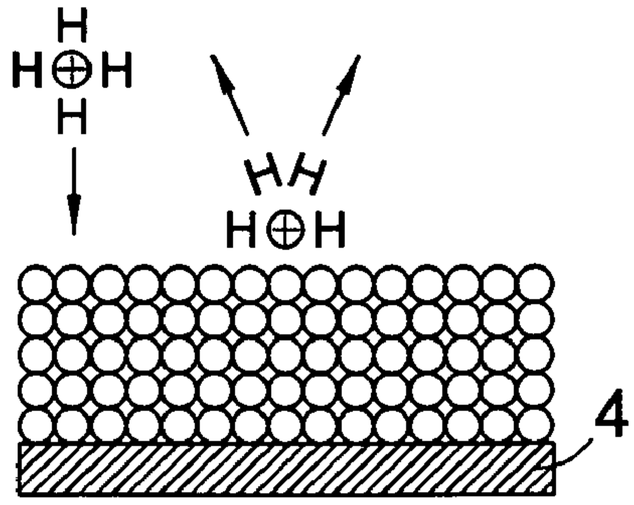


Fig. 6b

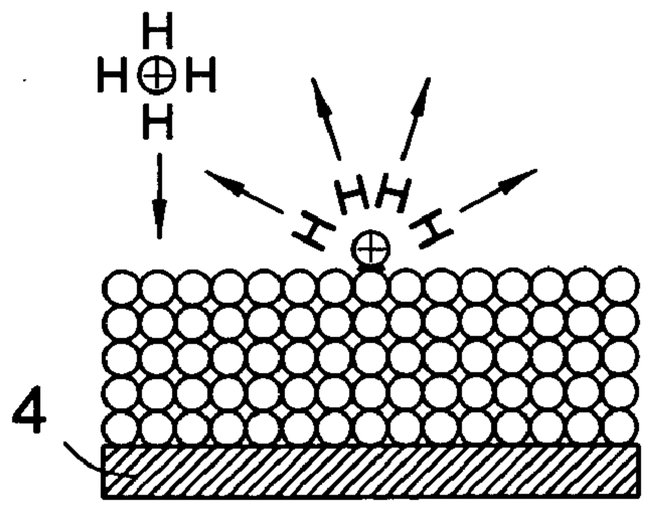


Fig. 6c

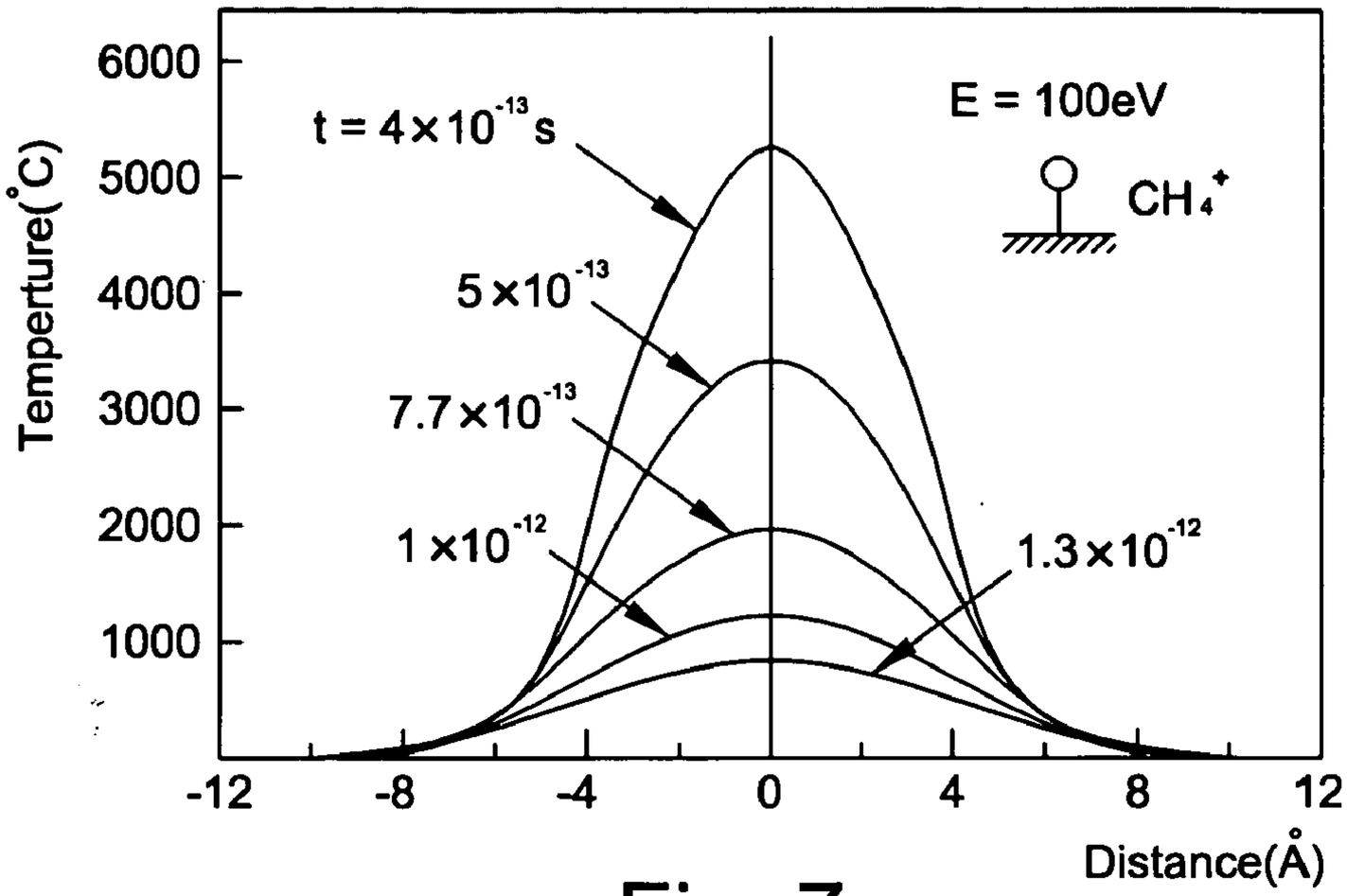

Temperture(°C)
6000
5000
4000
3000
2000
1000
t = 4×10^-13 s
5×10^-13
7.7×10^-13
1×10^-12
1.3×10^-12
E = 100eV
CH4+
-12
-8
-4
0
4
8
12
Distance(Å)

Fig. 7a

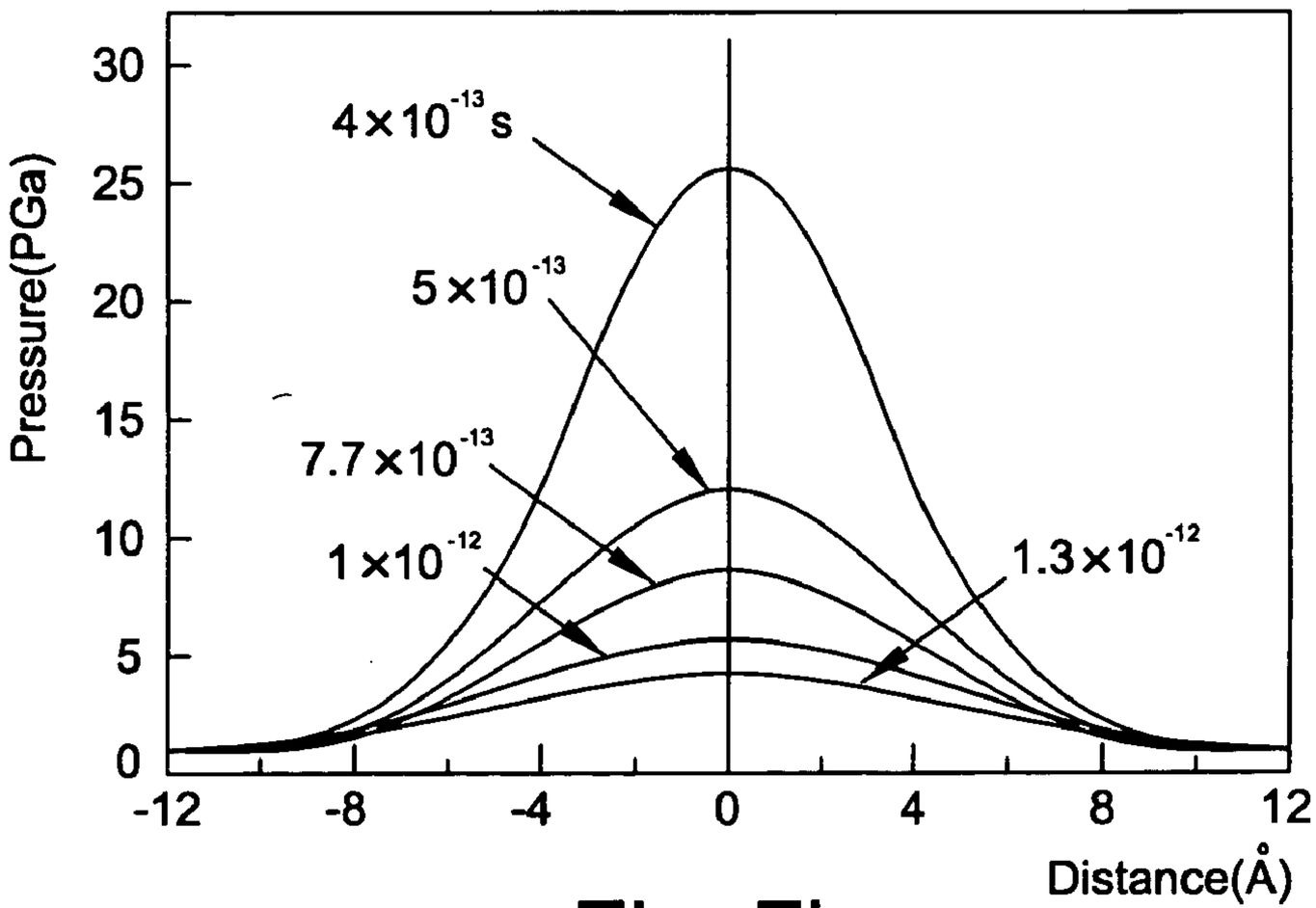

Pressure(PGa)
30
25
20
15
10
5
0
4×10^-13 s
5×10^-13
7.7×10^-13
1×10^-12
1.3×10^-12
-12
-8
-4
0
4
8
12
Distance(Å)

Fig. 7b

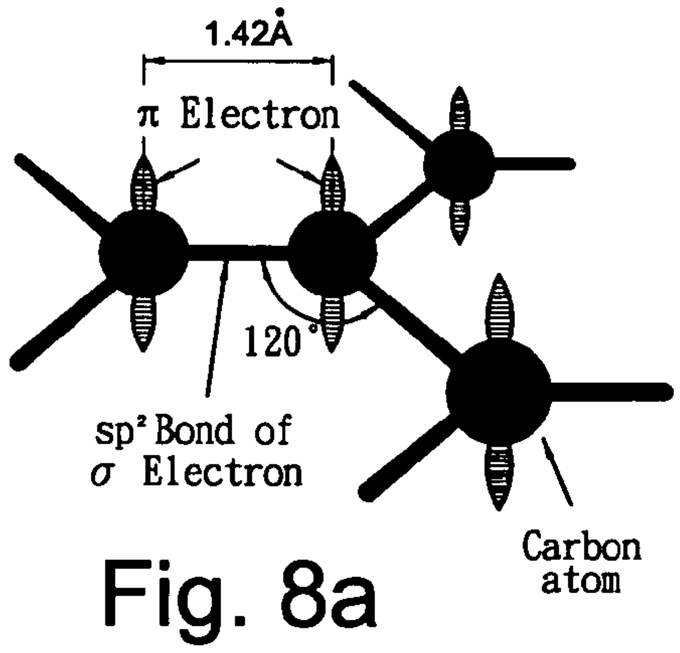


Fig. 8a

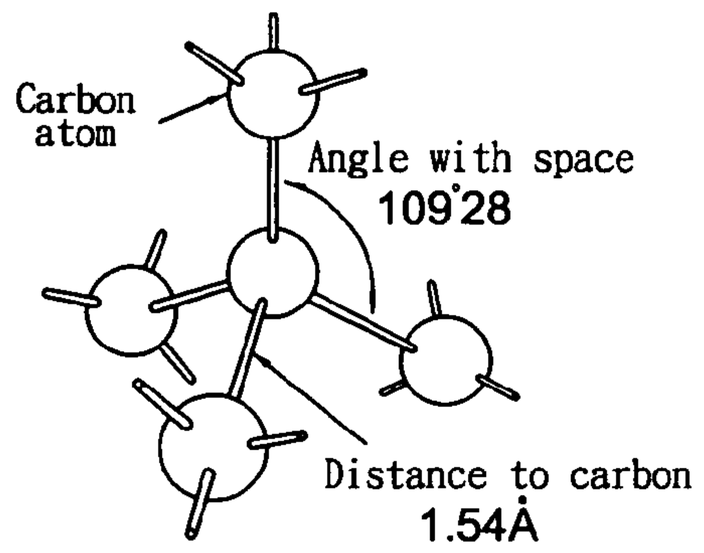


Fig. 8b

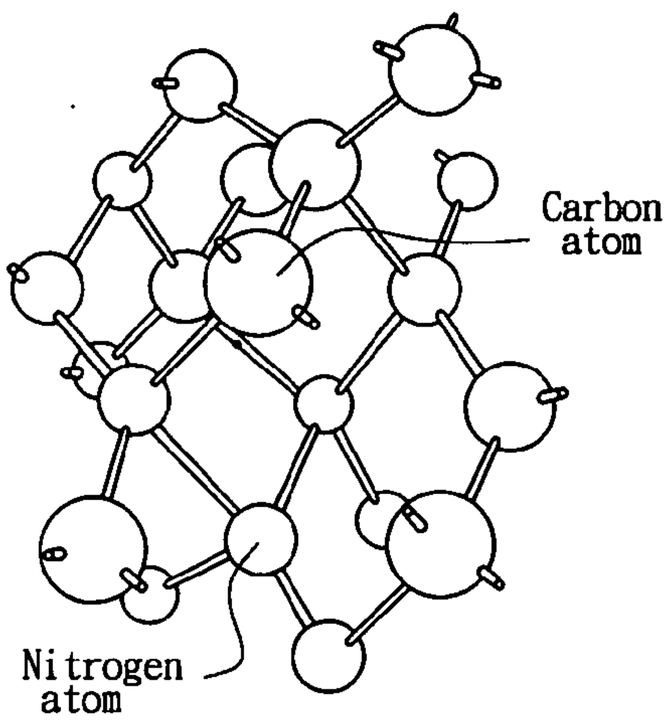


Fig. 8c

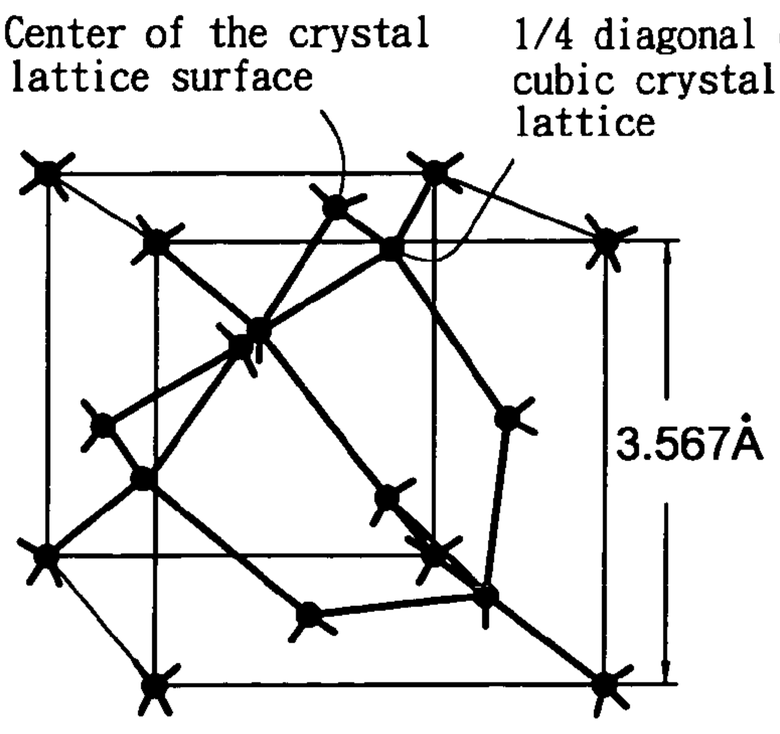


Fig. 8d

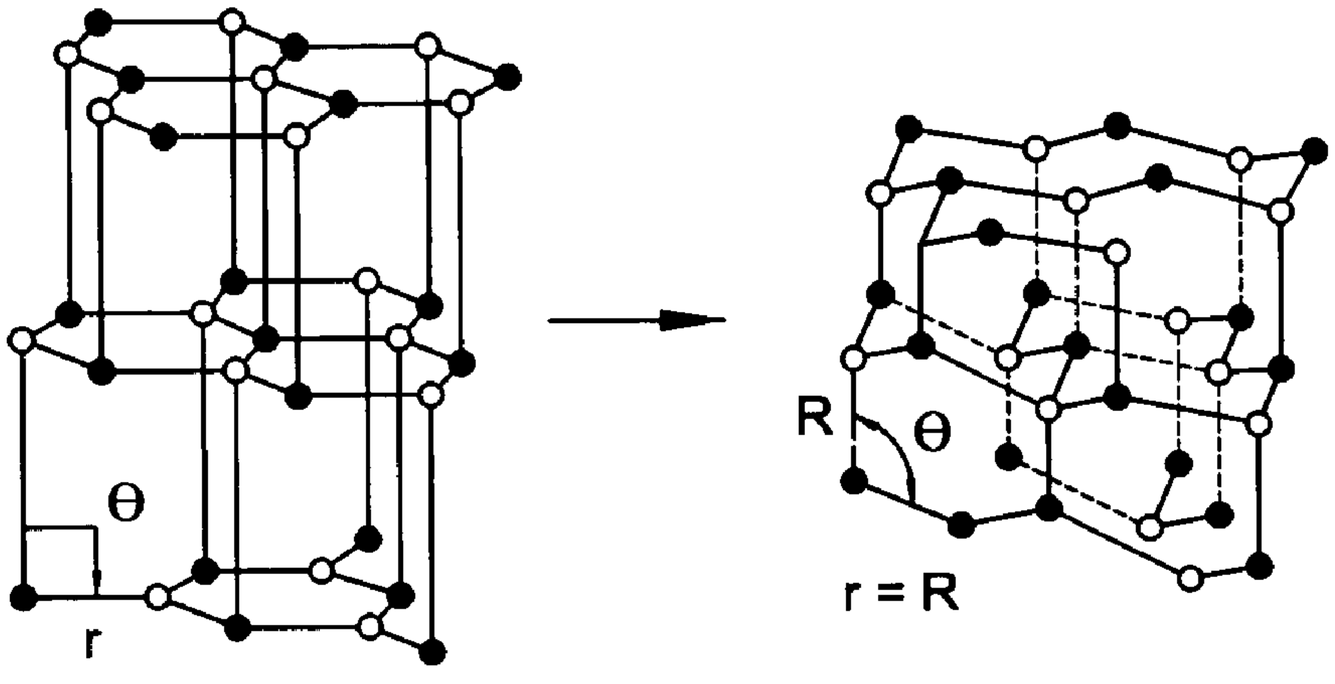


Fig. 9a

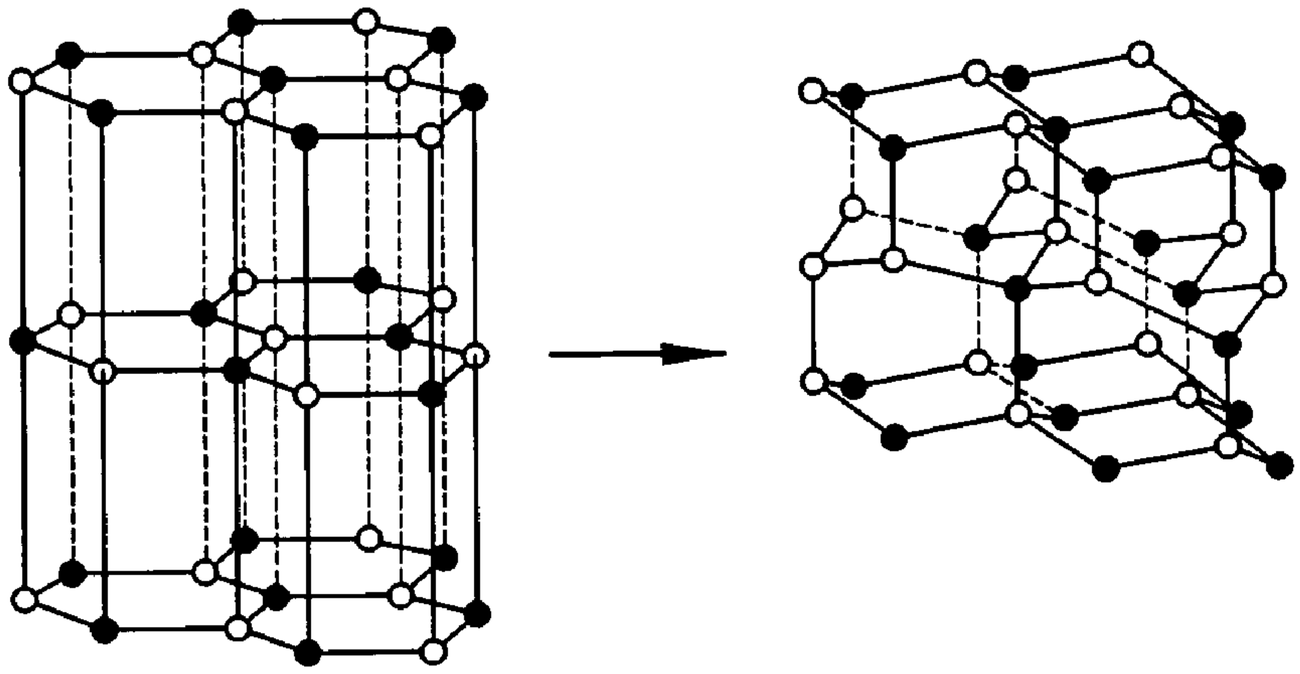


Fig. 9b

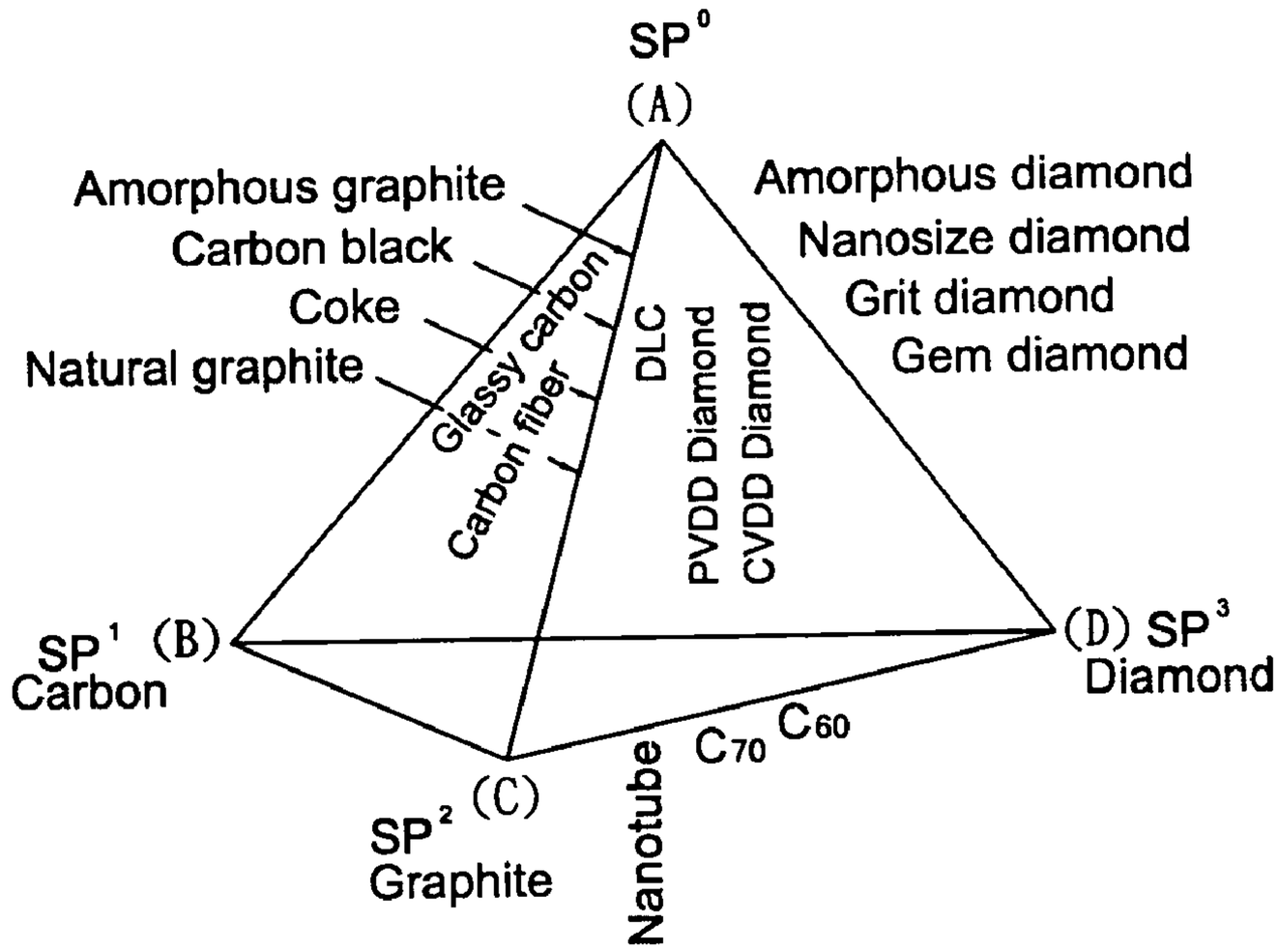

SP0
(A)
Amorphous graphite
Carbon black
Coke
Natural graphite
Glassy carbon
Carbon fiber
DLC
PVDD Diamond
CVDD Diamond
Amorphous diamond
Nanosize diamond
Grit diamond
Gem diamond
SP1 (B)
Carbon
(D) SP3
Diamond
C70
C60
SP2 (C)
Graphite
Nanotube

Fig. 10

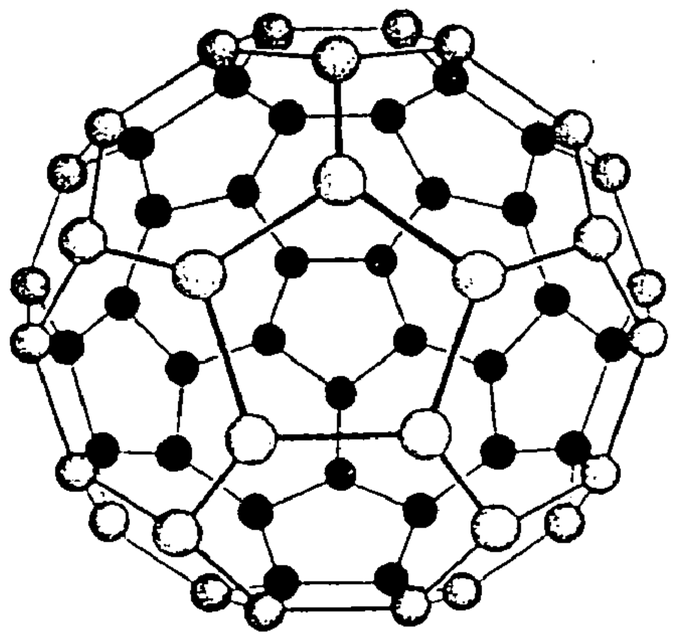


Fig. 11

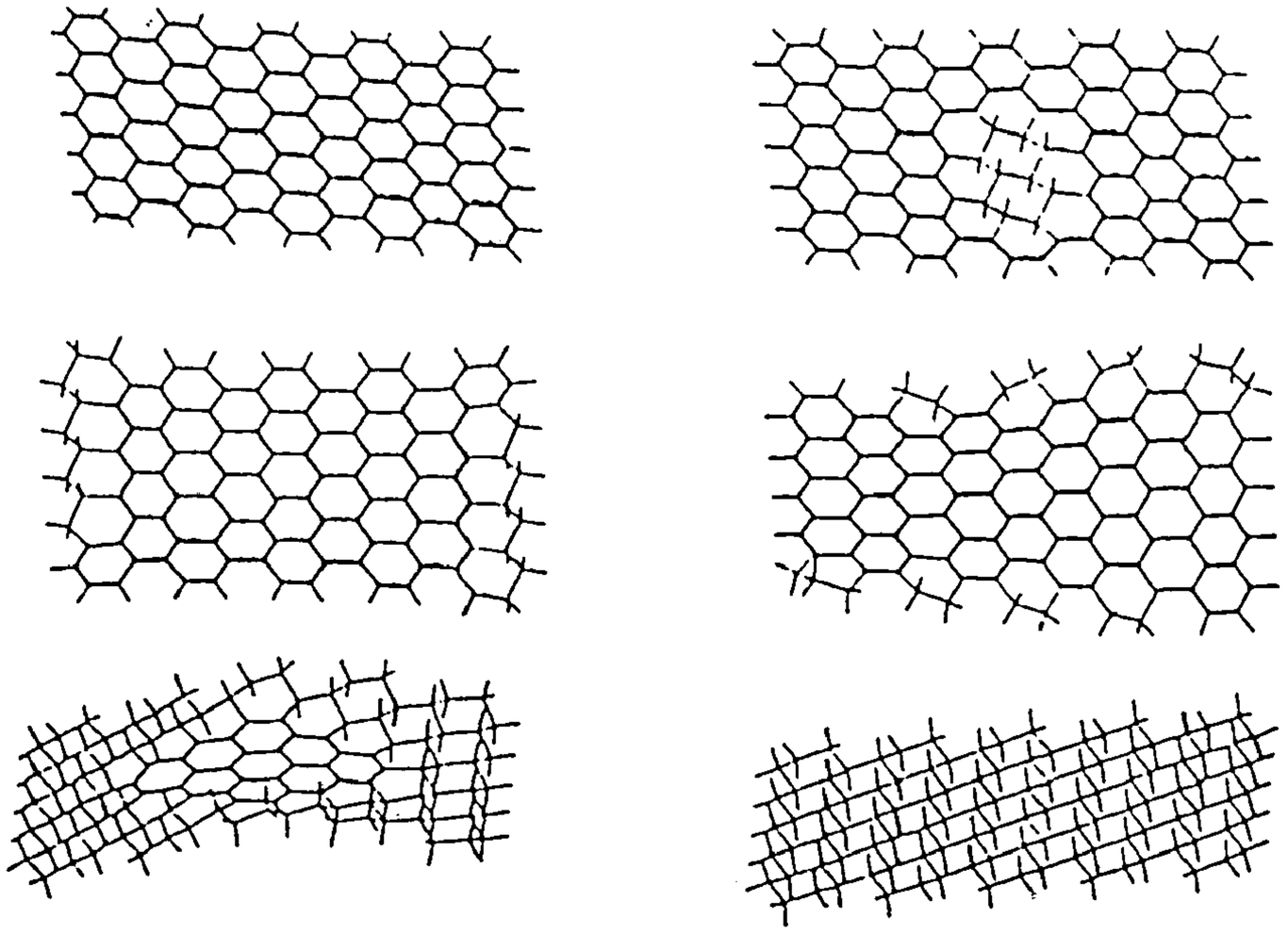


Fig. 12

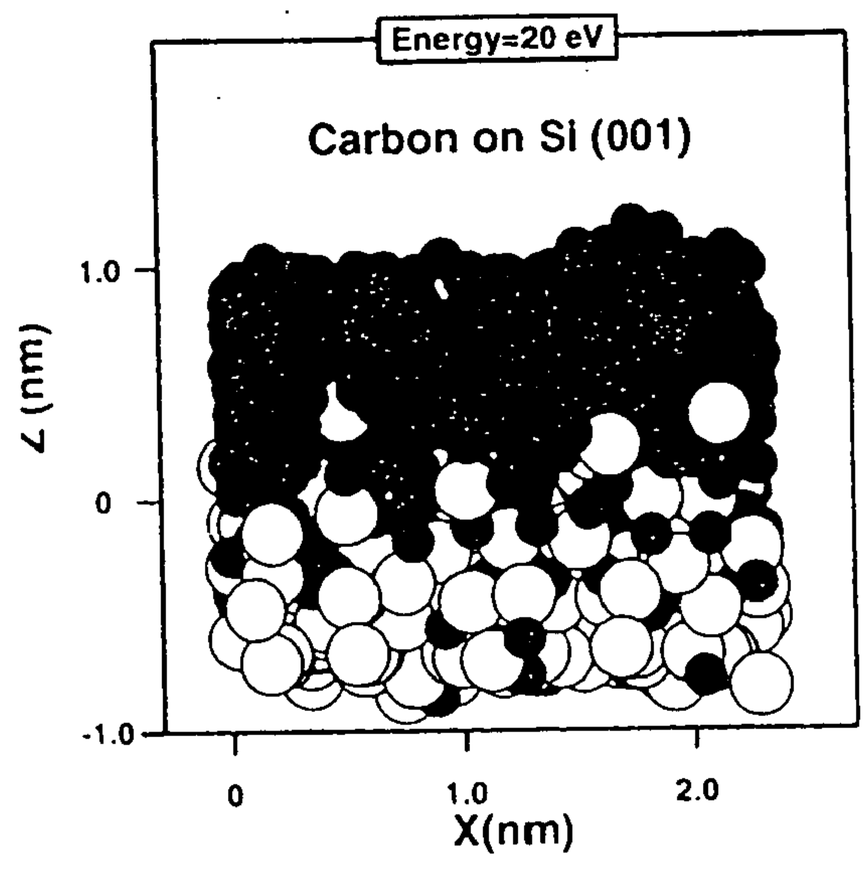


Fig. 13

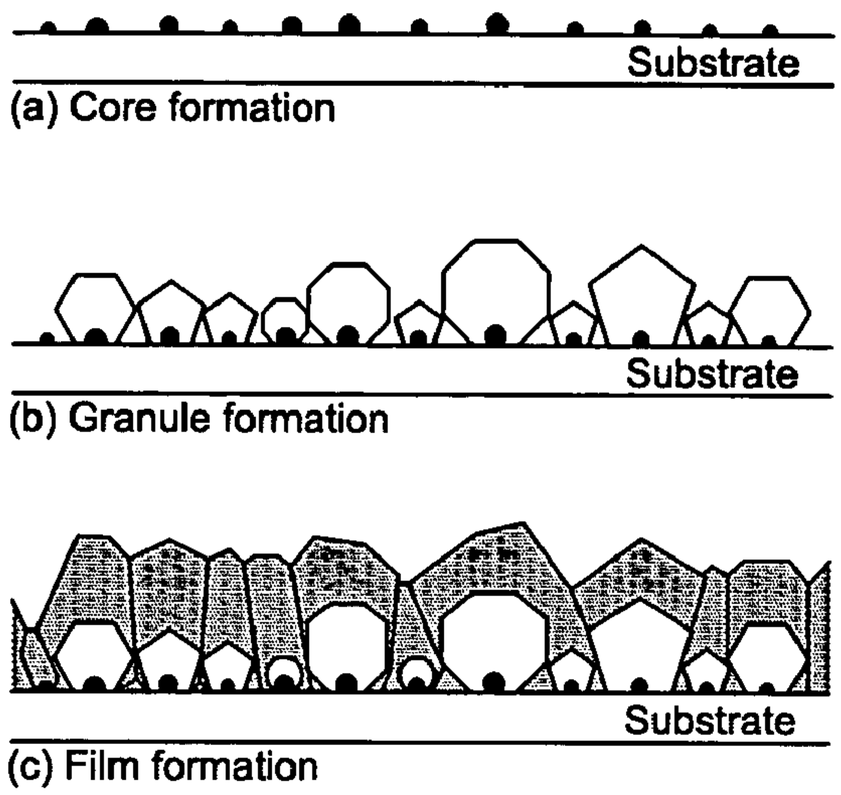


Fig. 14a

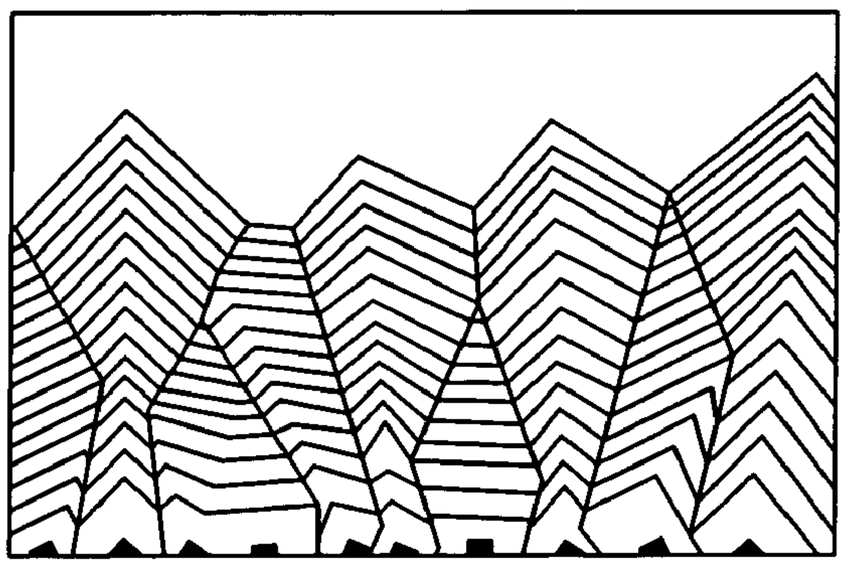


Fig. 14b

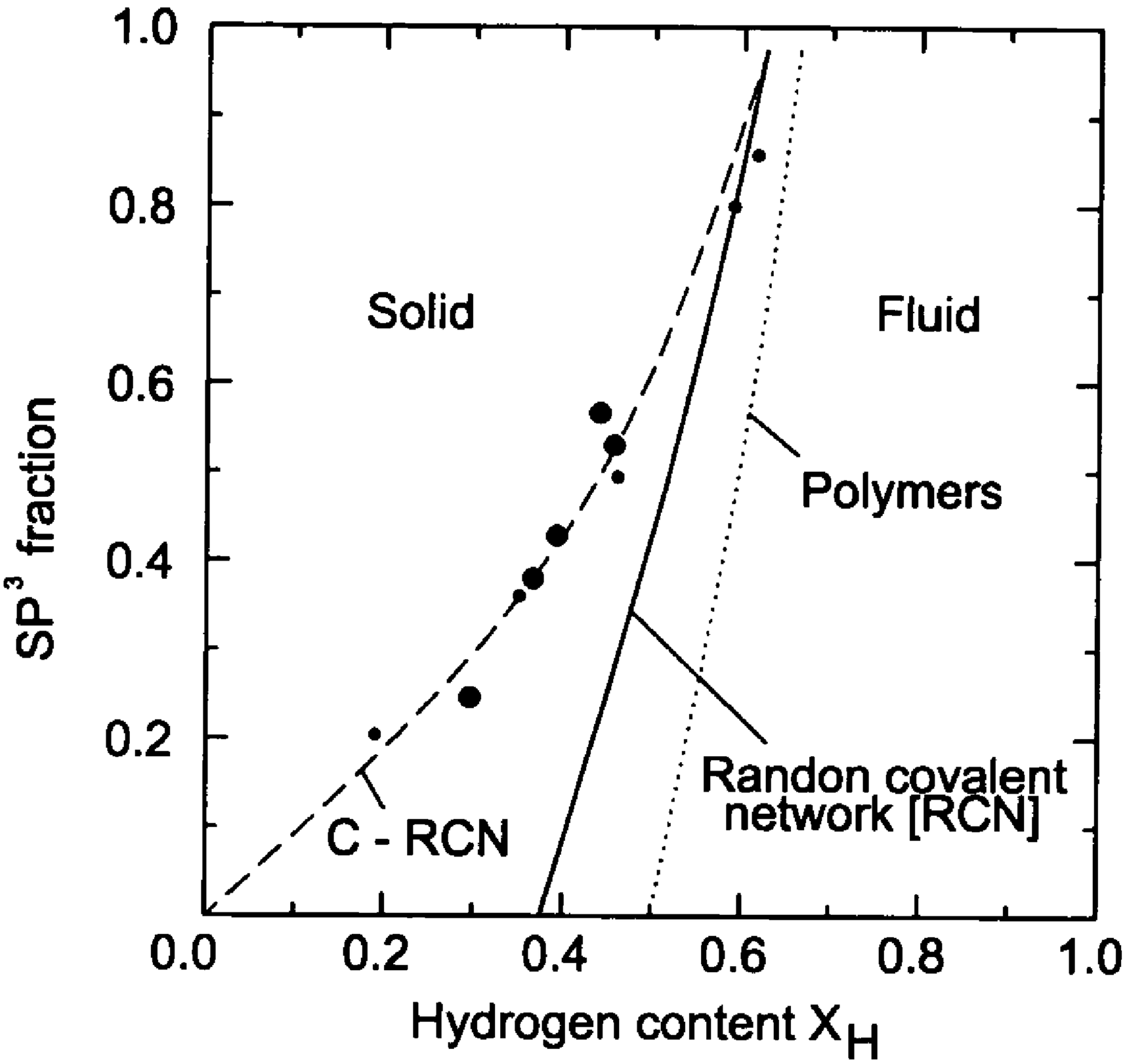

1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0
SP3 fraction
Hydrogen content XH
Solid
Fluid
Polymers
Randon covalent network [RCN]
C - RCN

Fig. 15

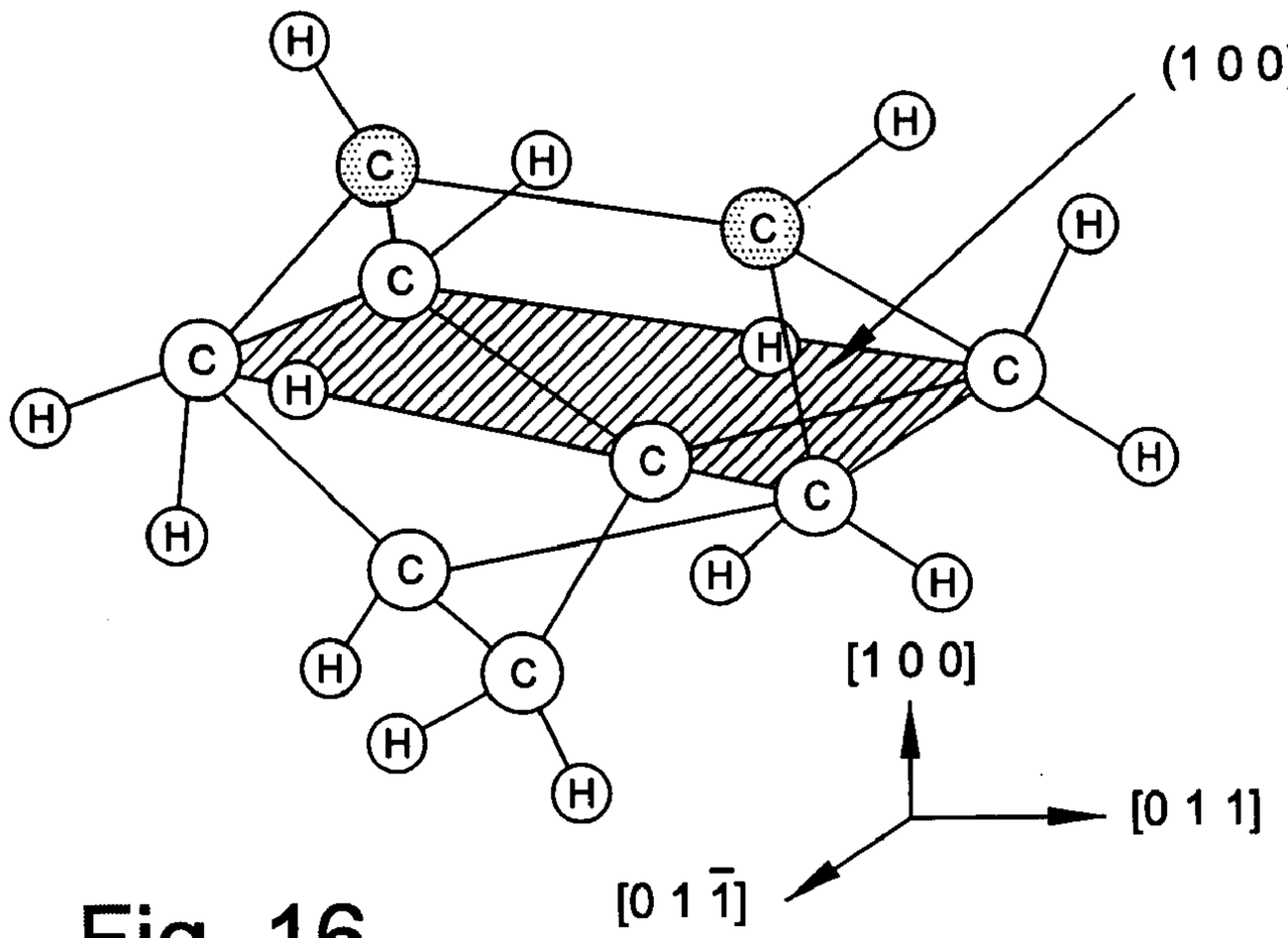


Fig. 16

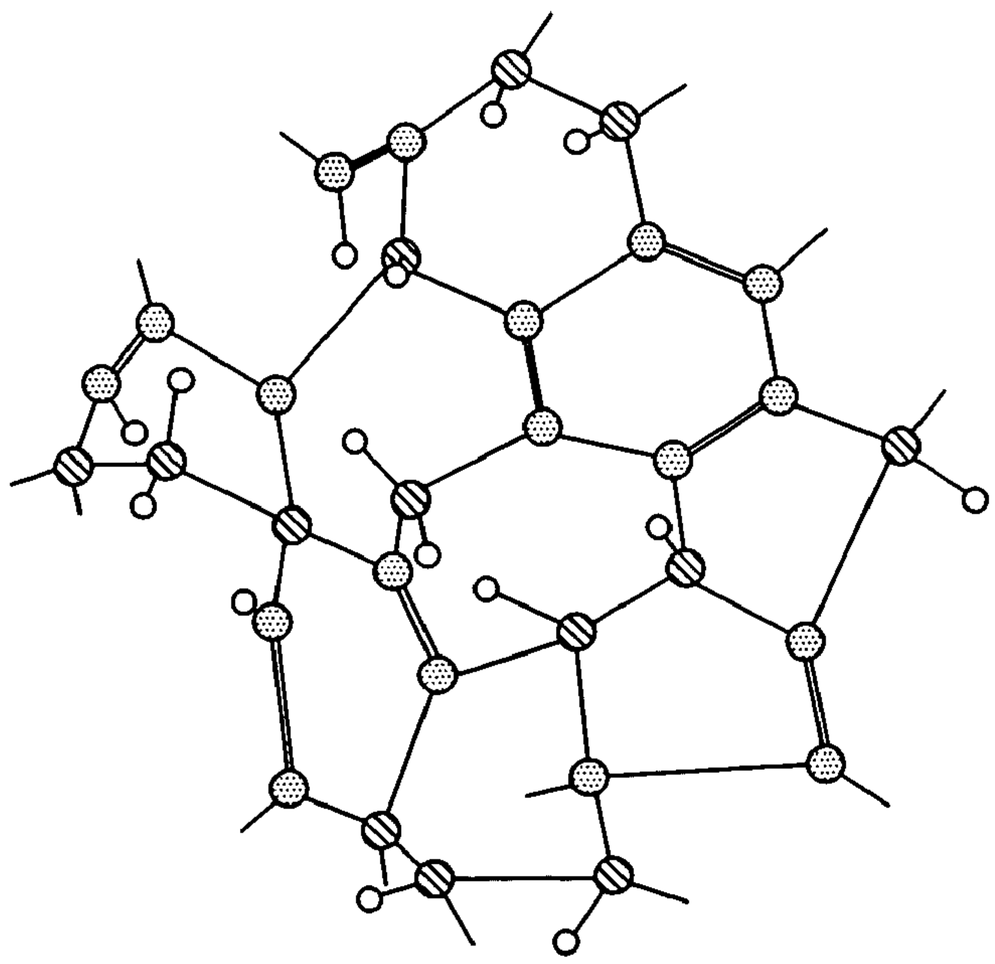


Fig. 17

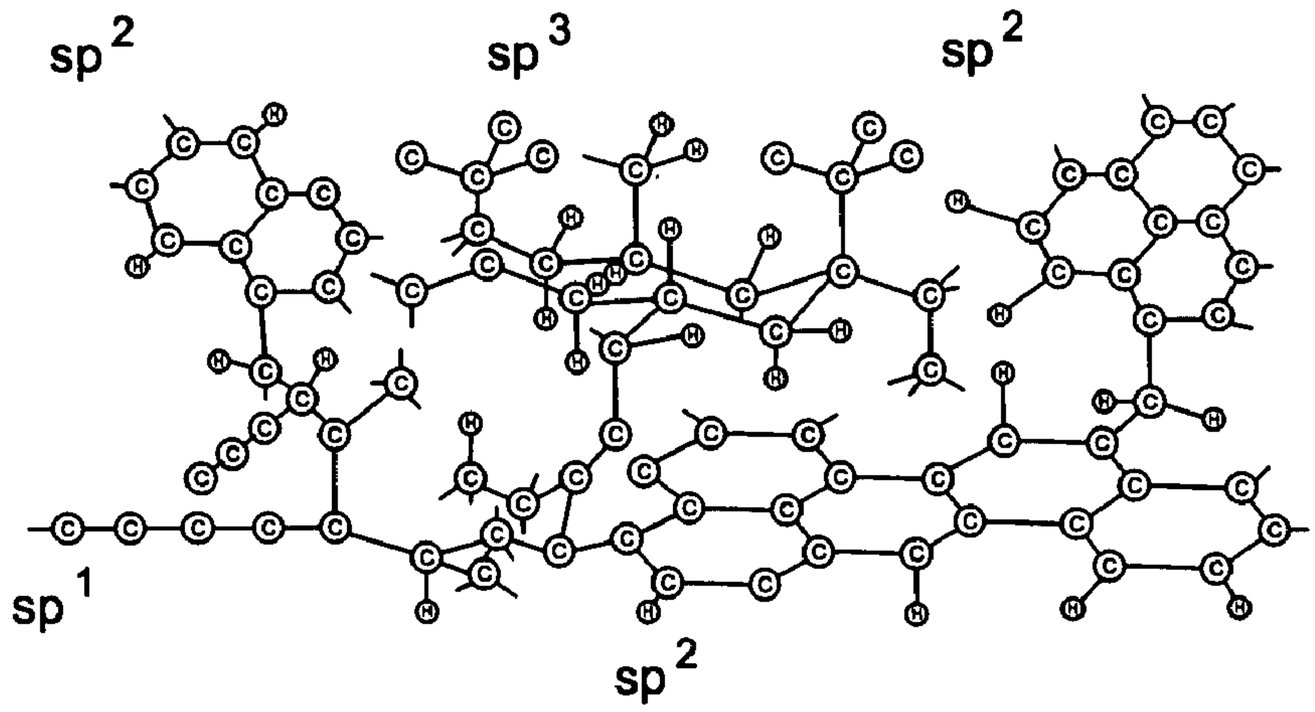

sp 2
sp 3
sp 2
sp 1
sp 2

Fig. 18

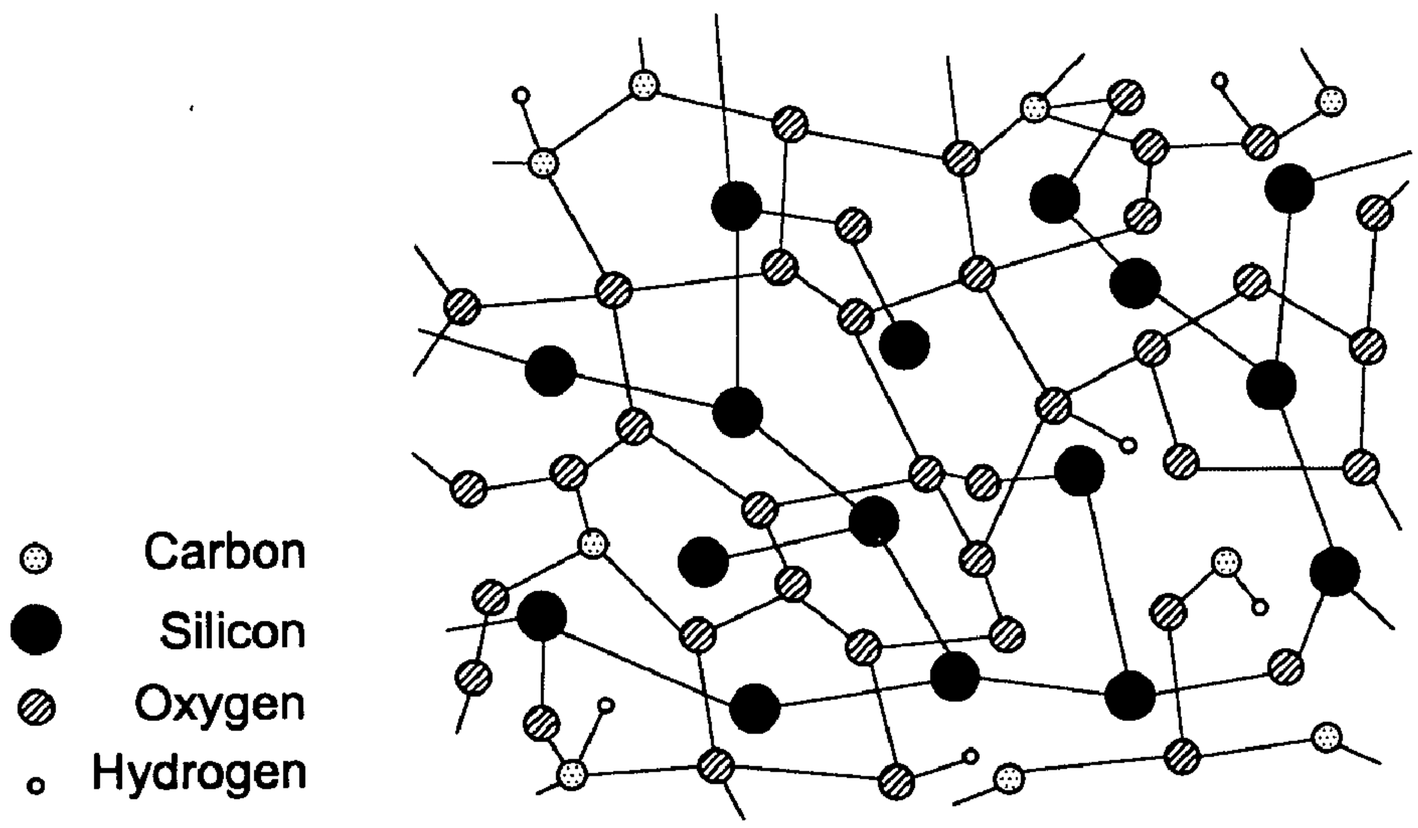

Carbon
Silicon
Oxygen
Hydrogen
a-(C:H0.15)0.7
a-(Si:O0.3)0.3

Fig. 19

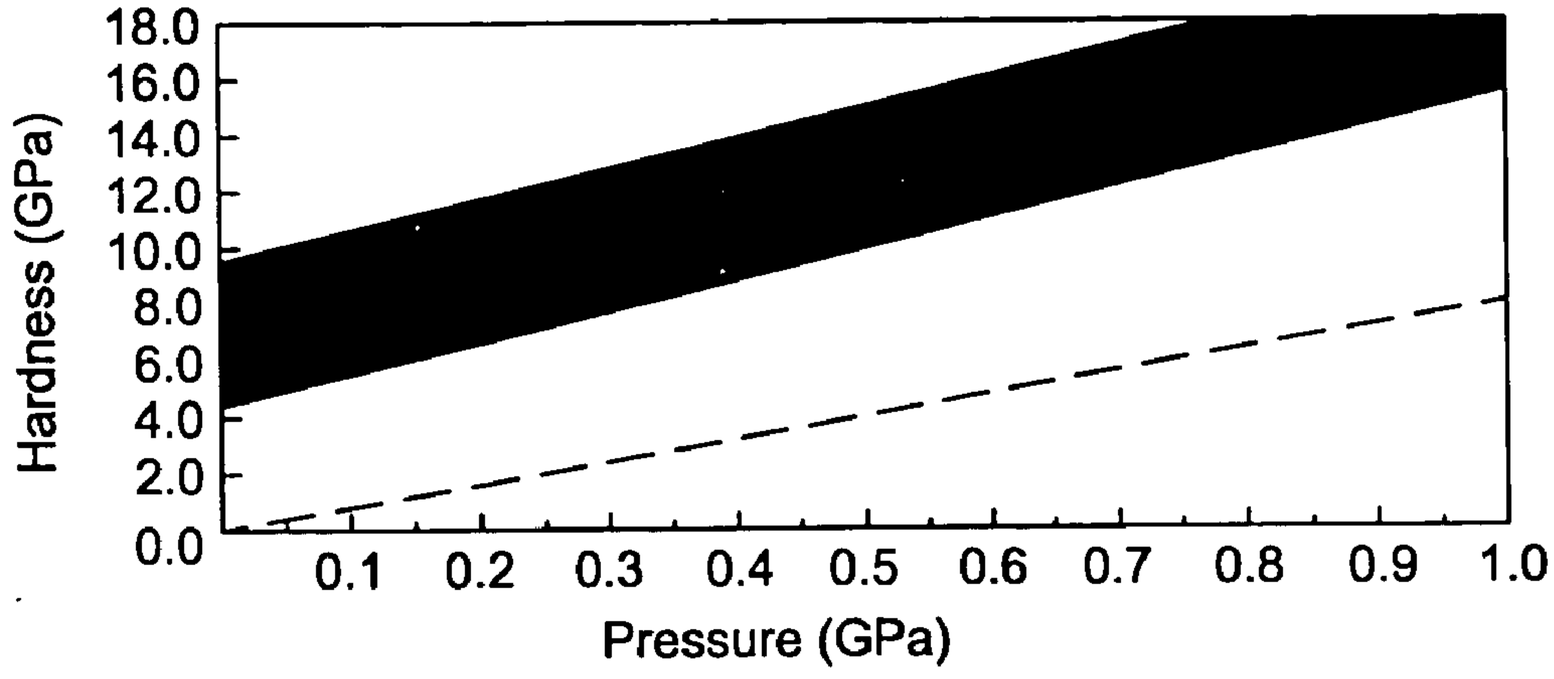

Hardness (GPa)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Pressure (GPa)

Fig. 20

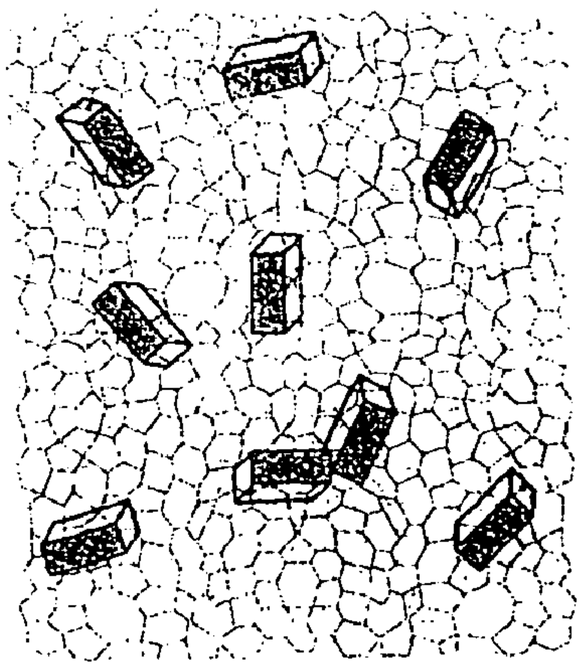


Fig. 21

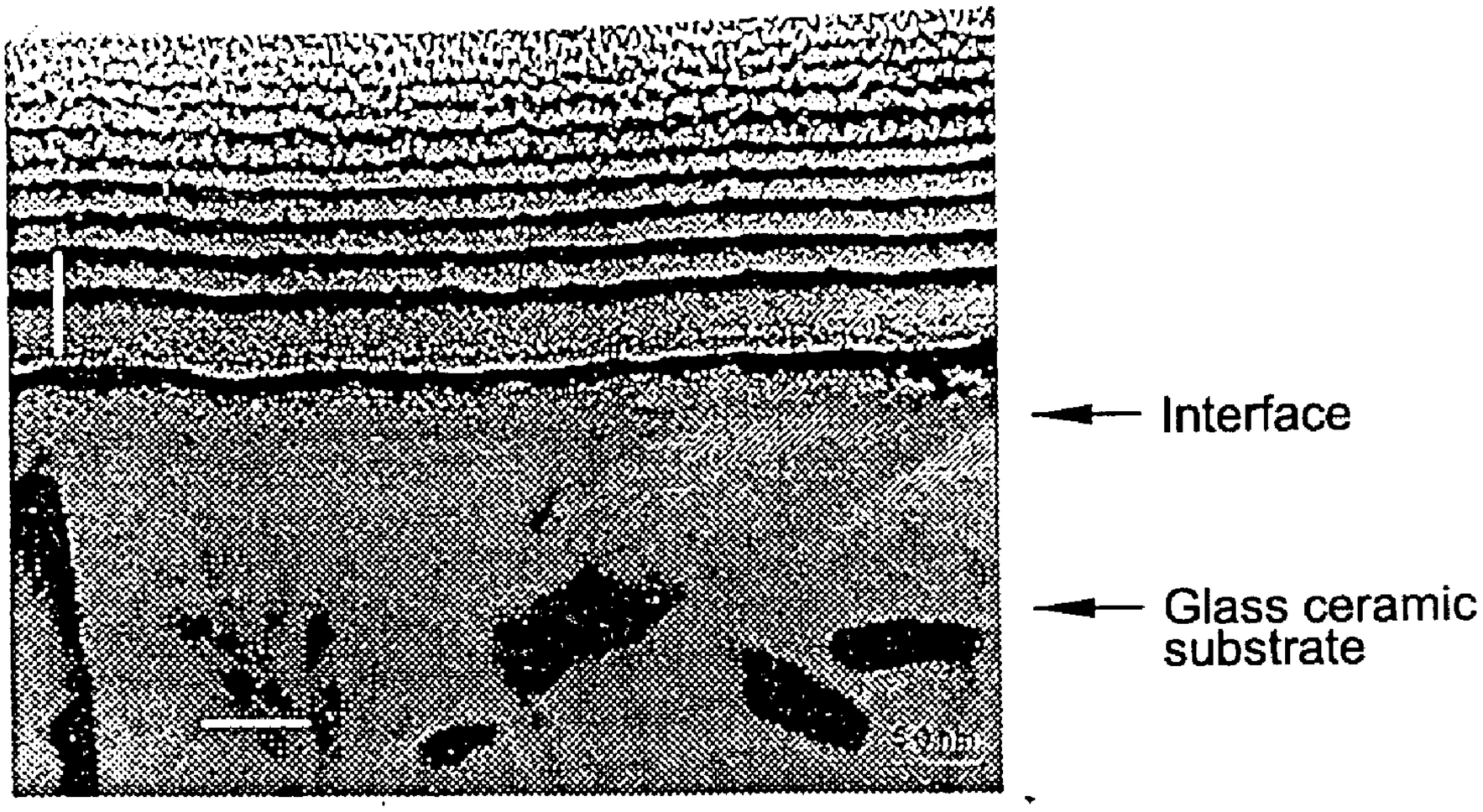


Fig. 22

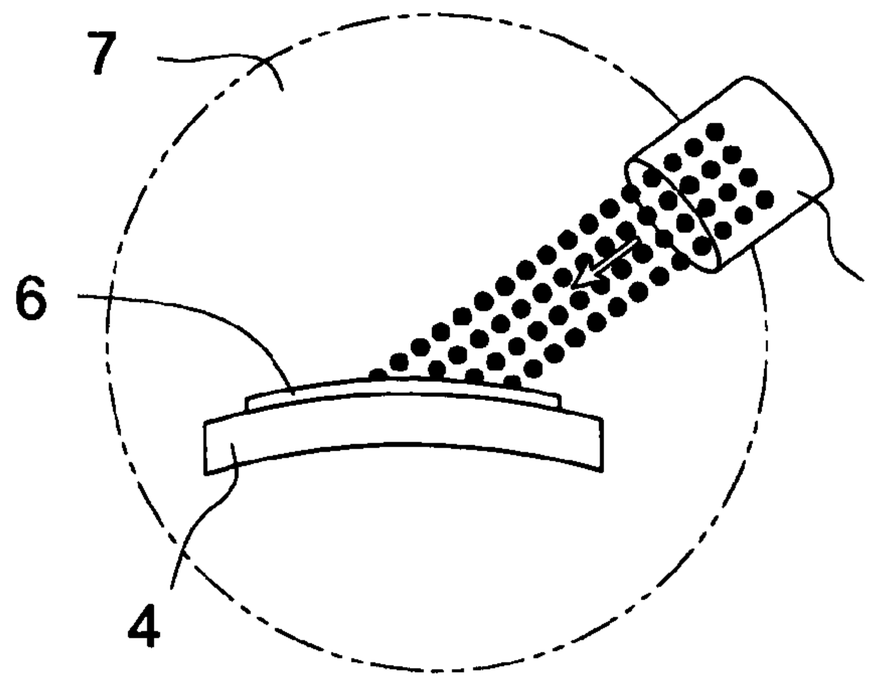


Fig. 23

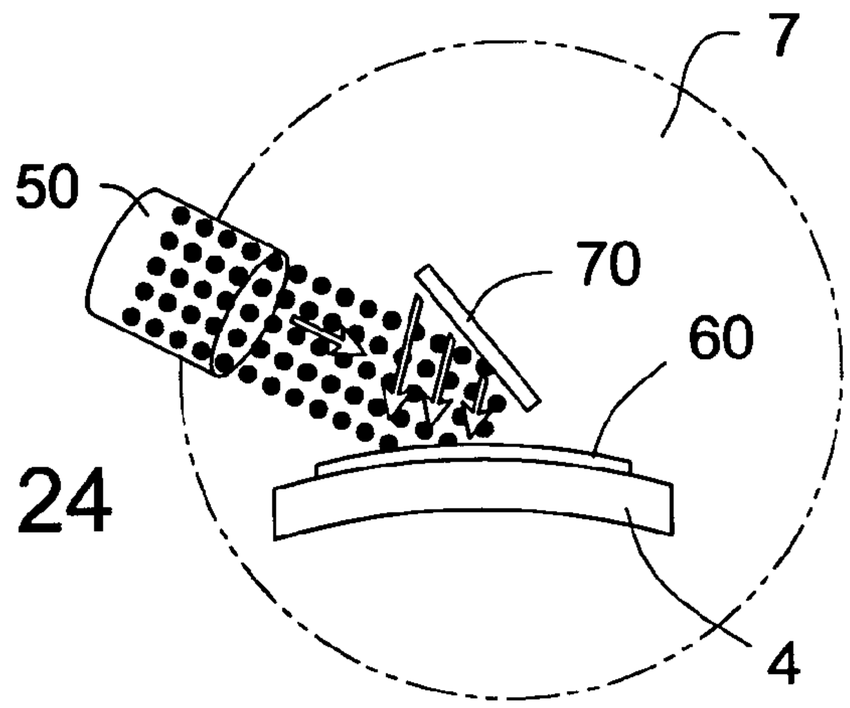


Fig. 24

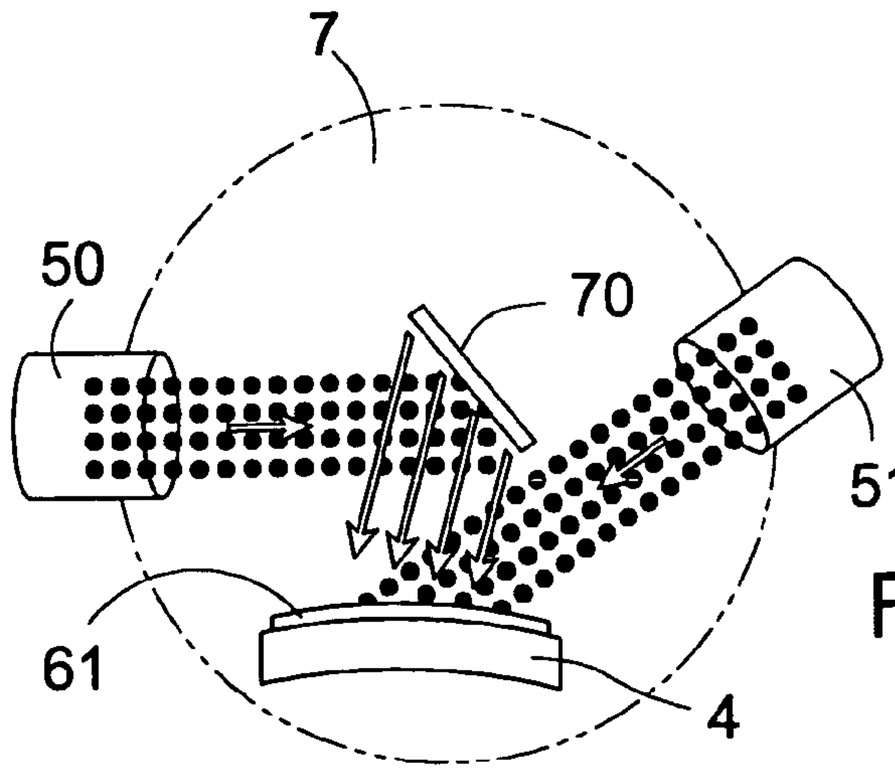


Fig. 25

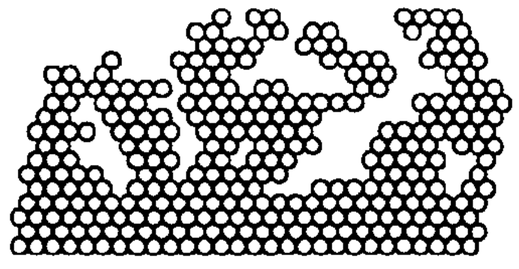


Fig. 26a

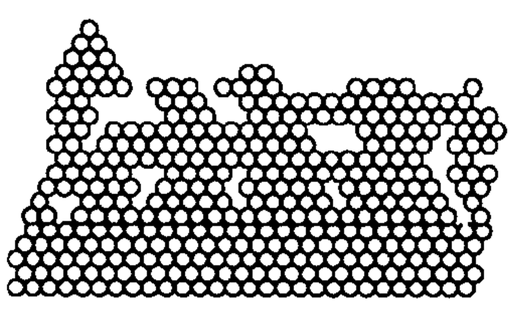


Fig. 26b

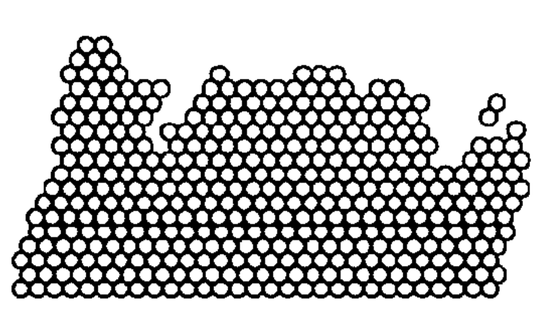


Fig. 26c

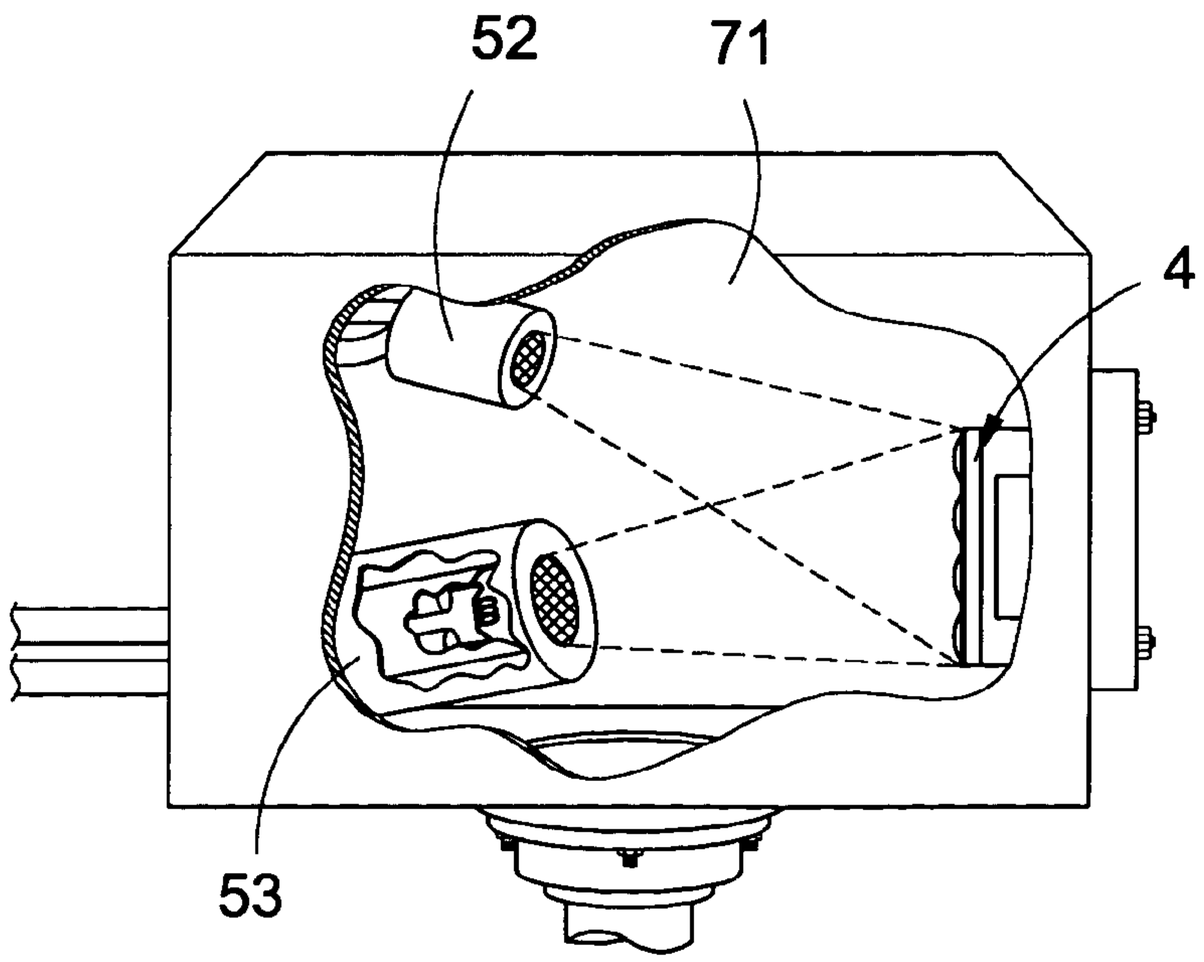


Fig. 27

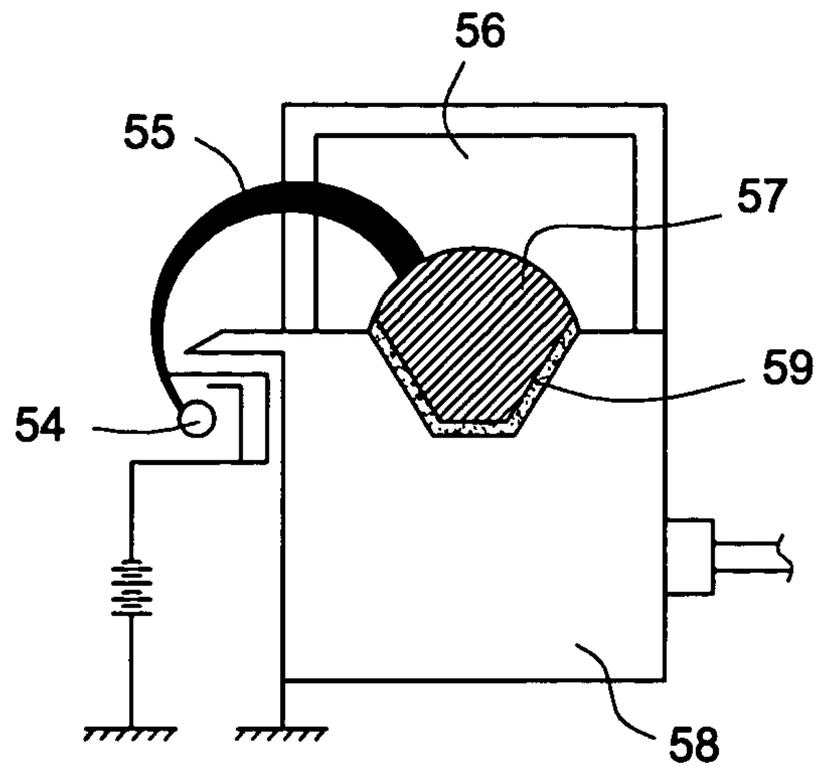


Fig. 28

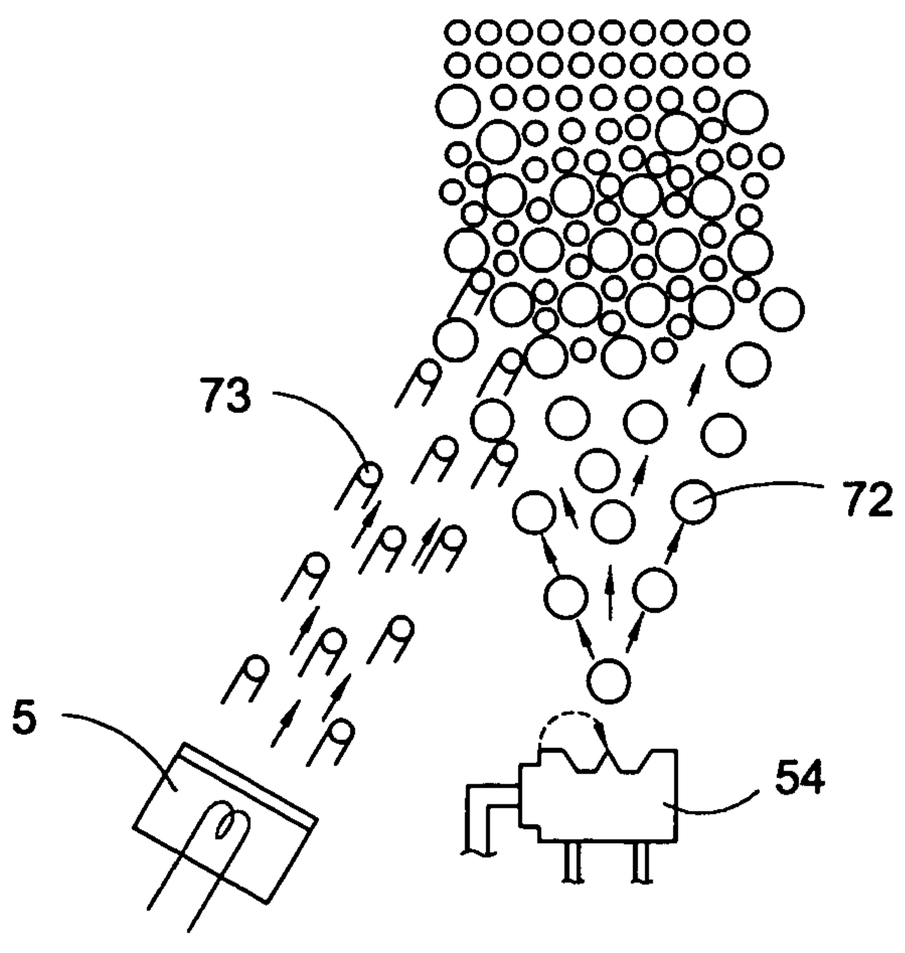


Fig. 29

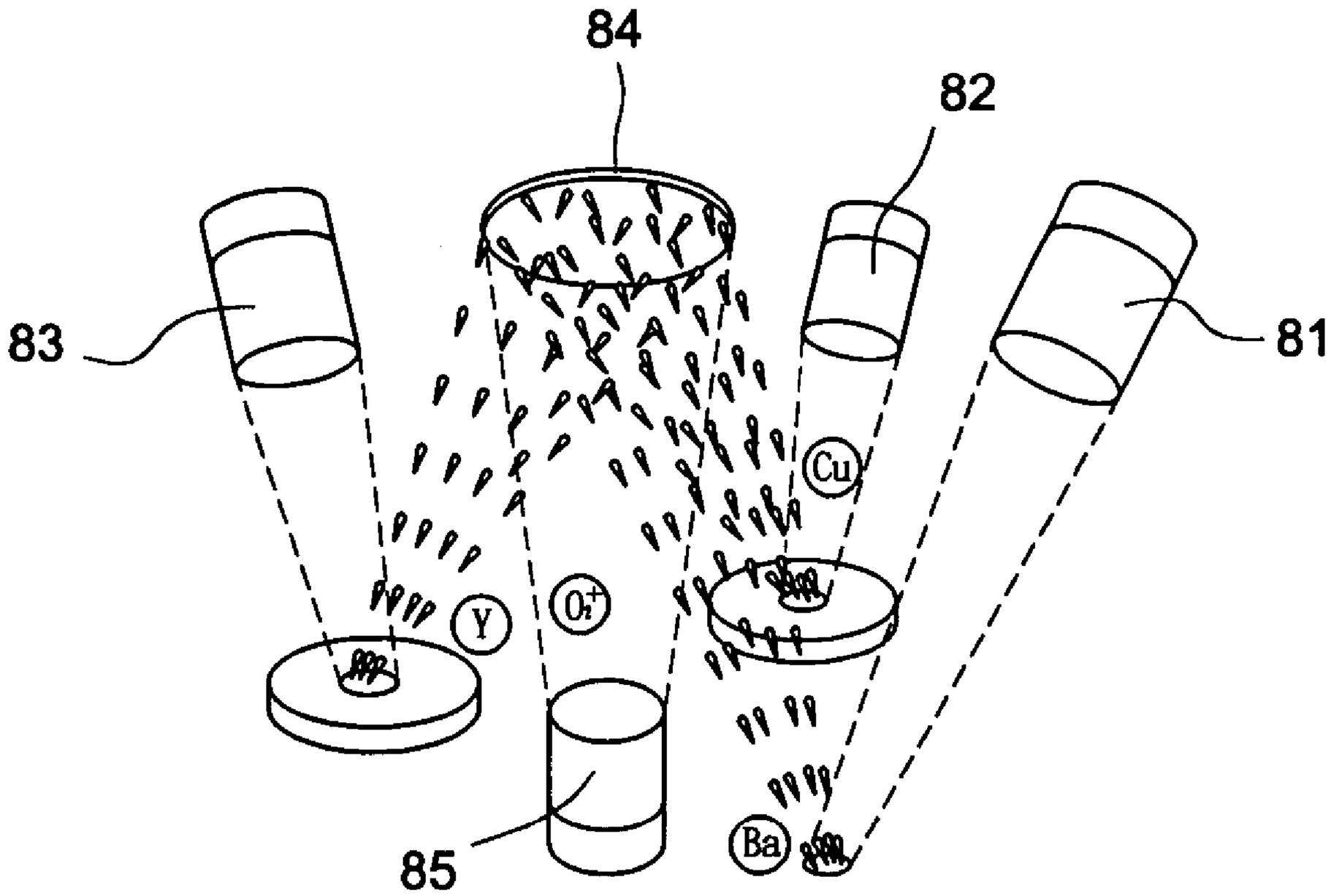


Fig. 30

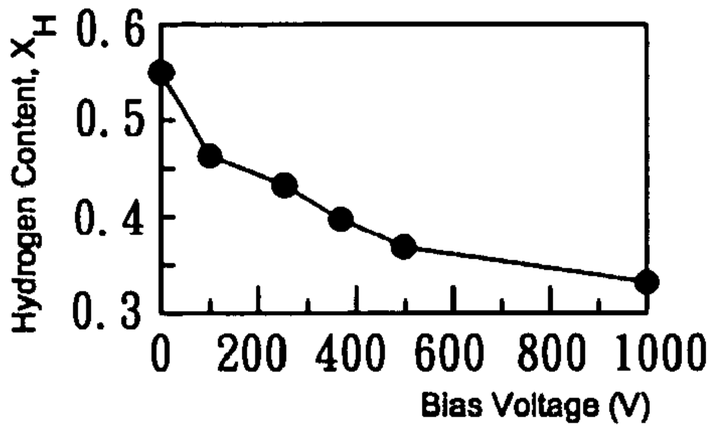


Fig. 31a

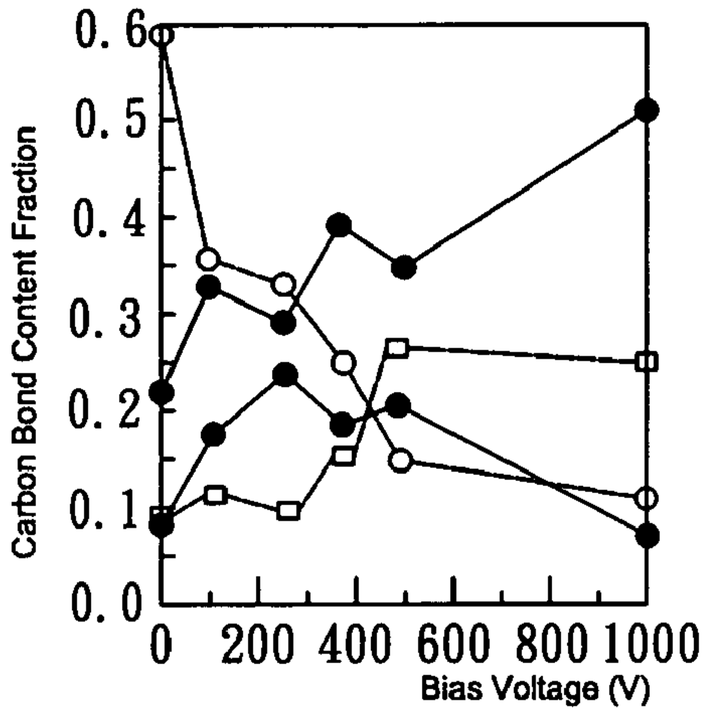


Fig. 31b

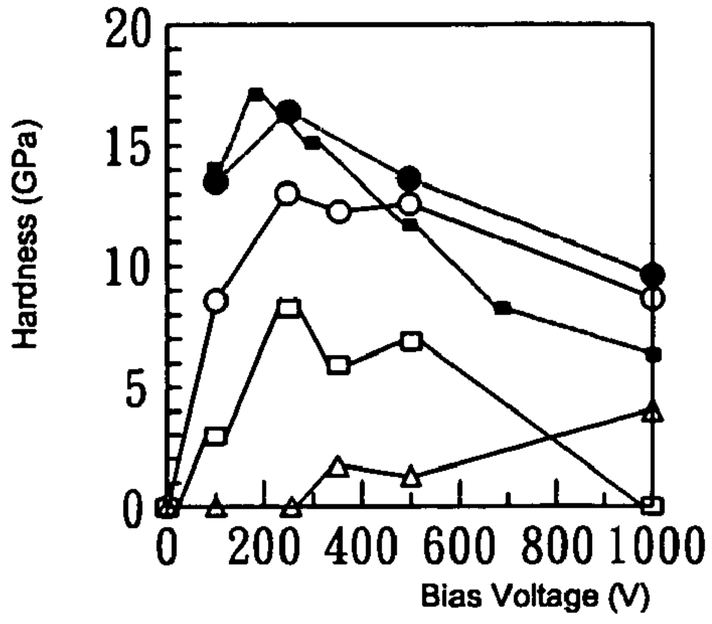


Fig. 31c

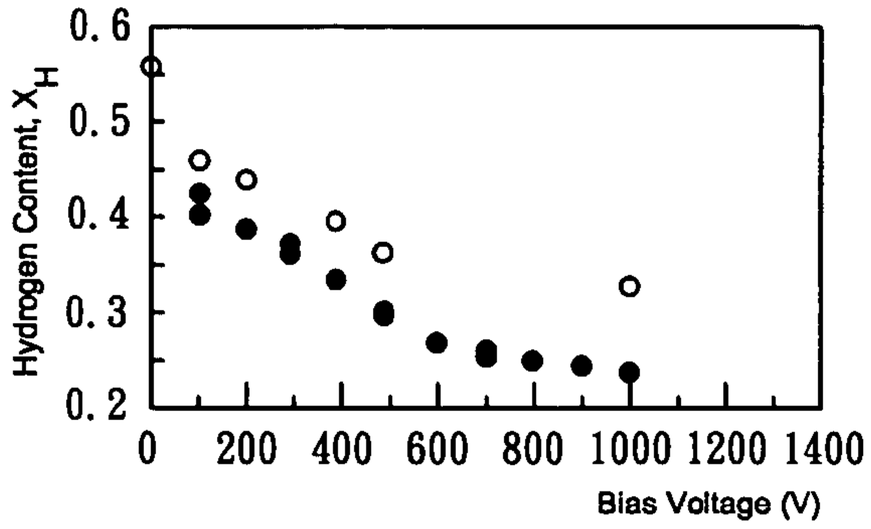


Fig. 32a

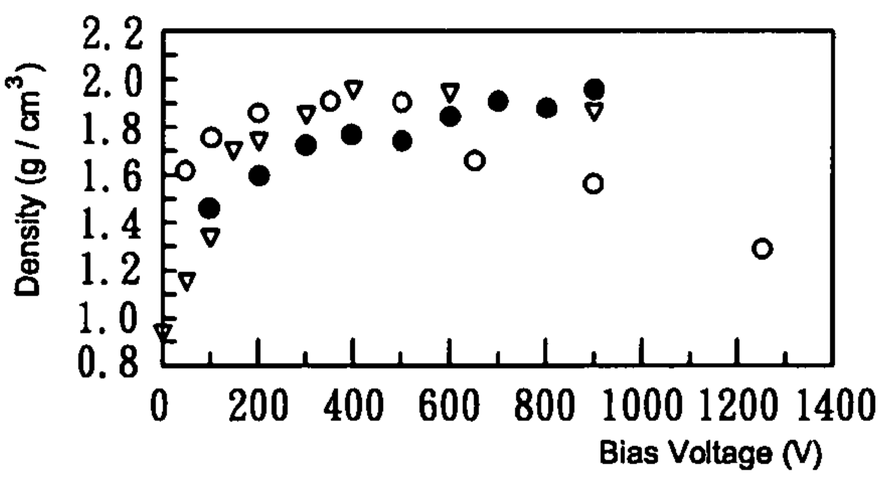


Fig. 32b

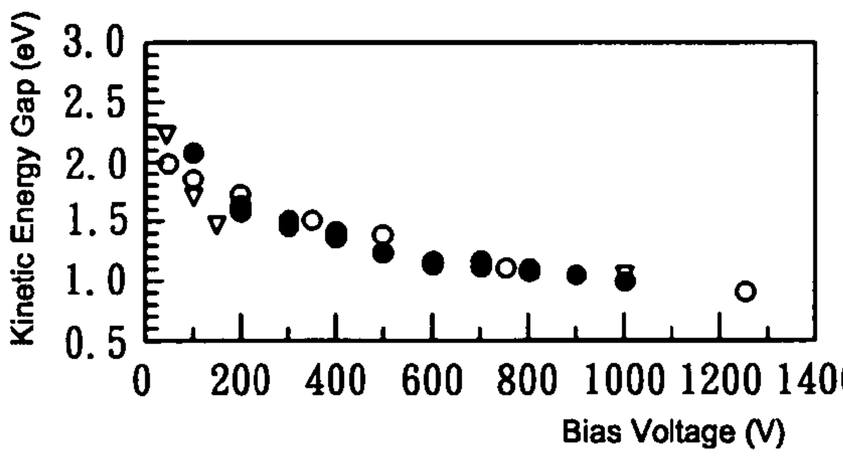


Fig. 32c

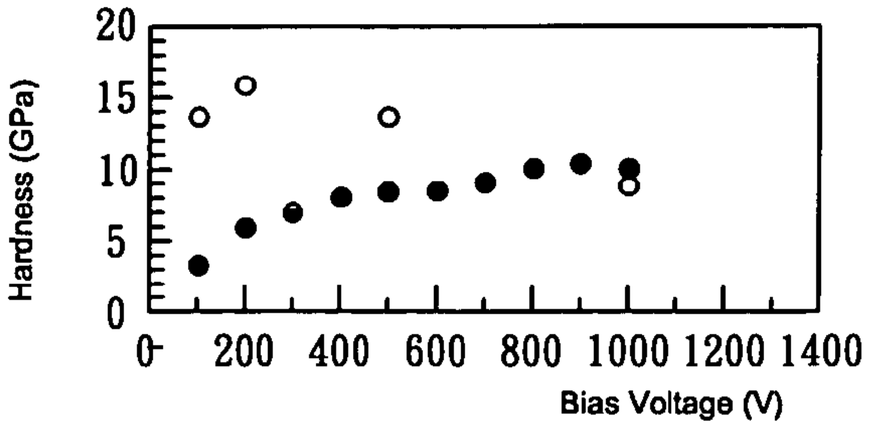


Fig. 32d

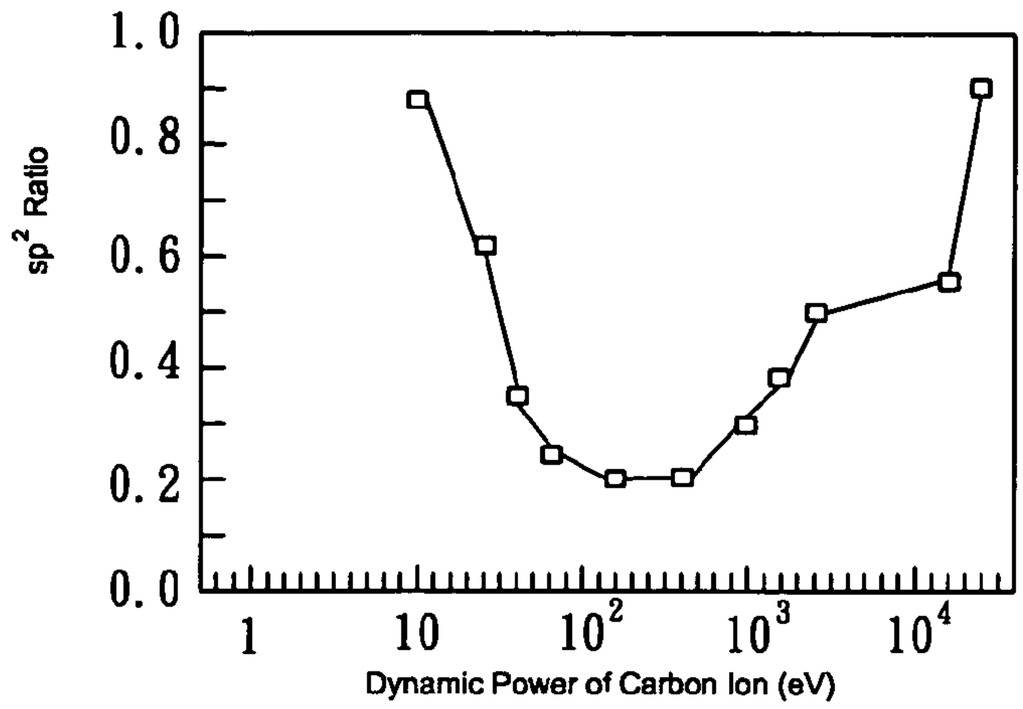


Fig. 33a

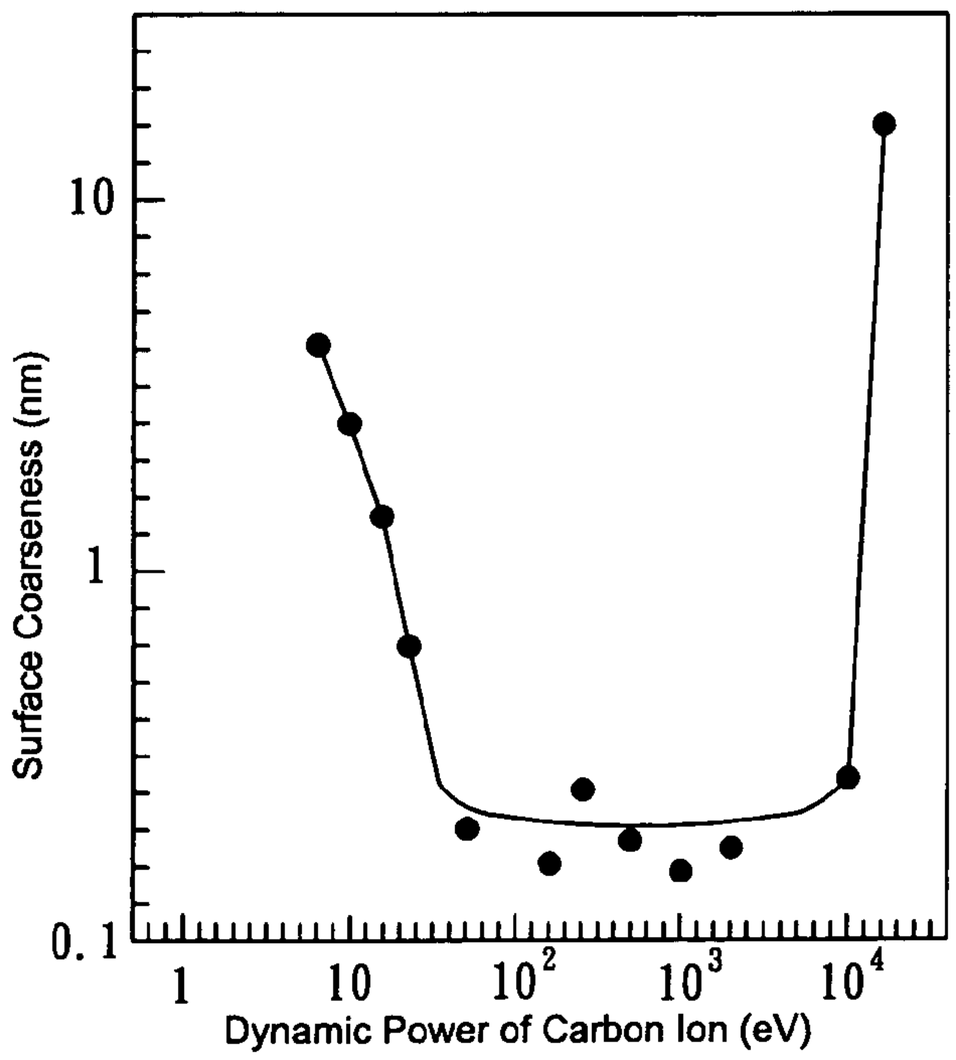


Fig. 33b

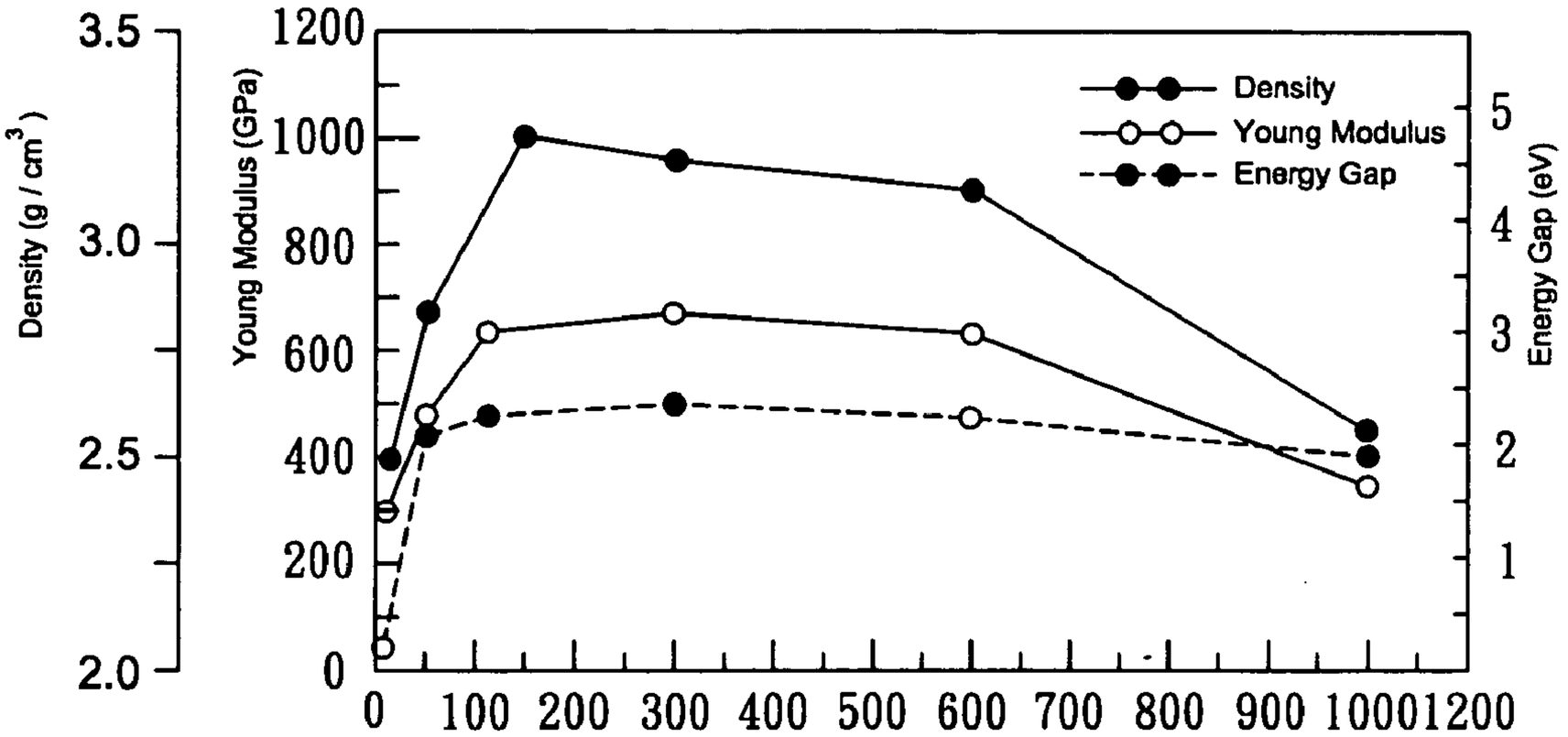


Fig. 33c

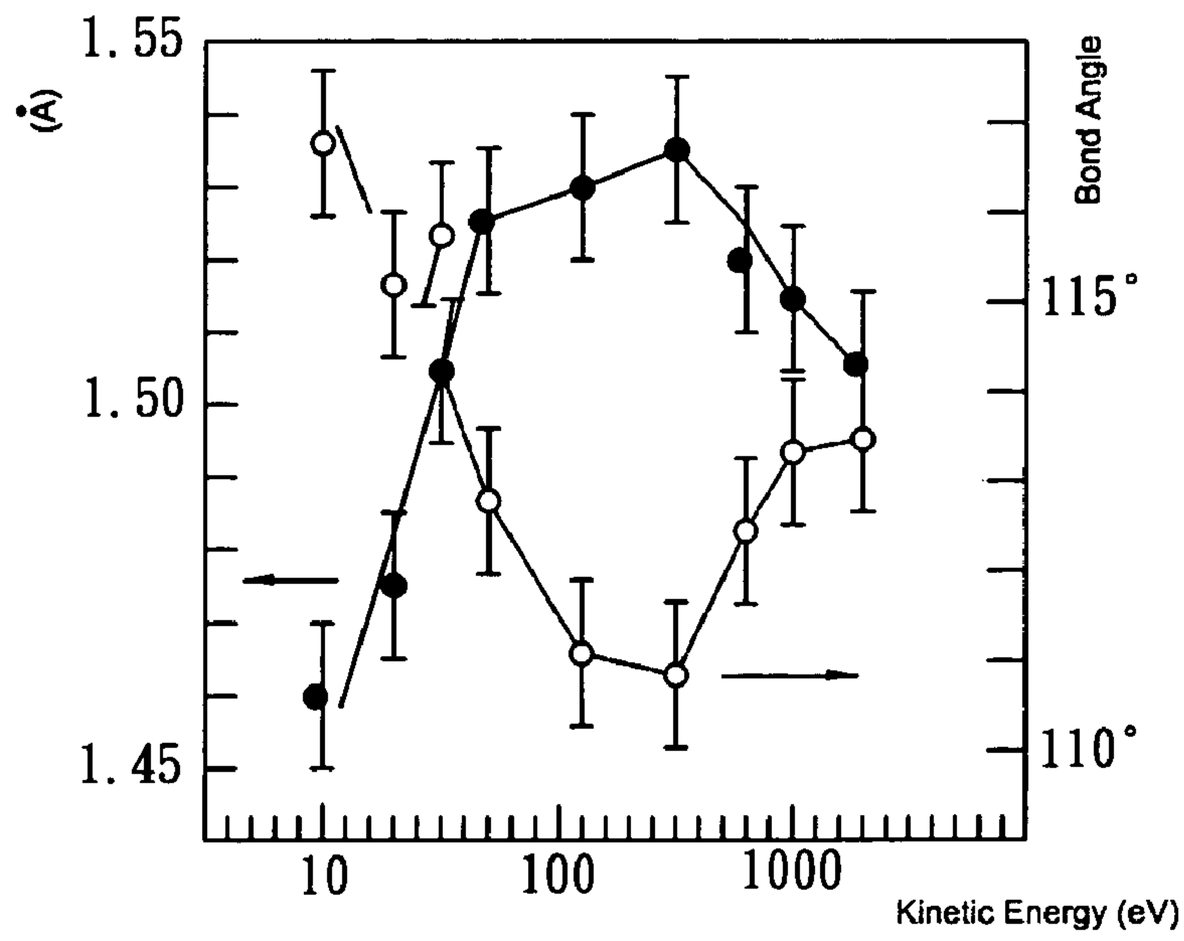


Fig. 33d

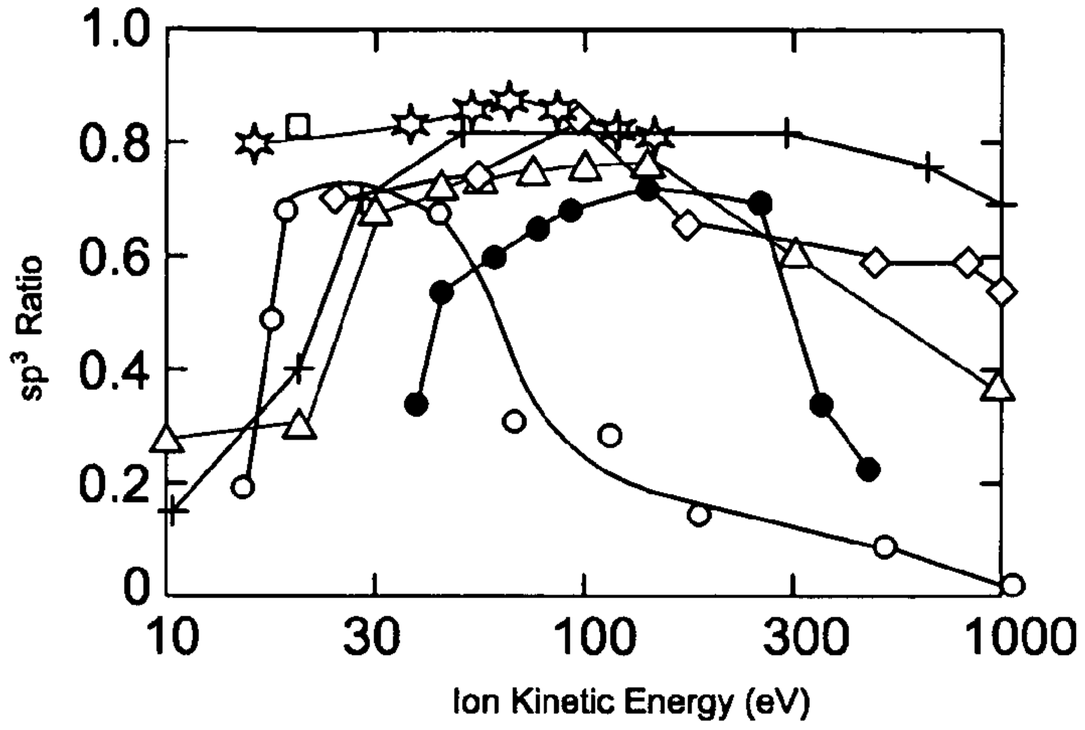

1.0
0.8
0.6
0.4
0.2
0
sp³ Ratio
10
30
100
300
1000
Ion Kinetic Energy (eV)

Fig. 34

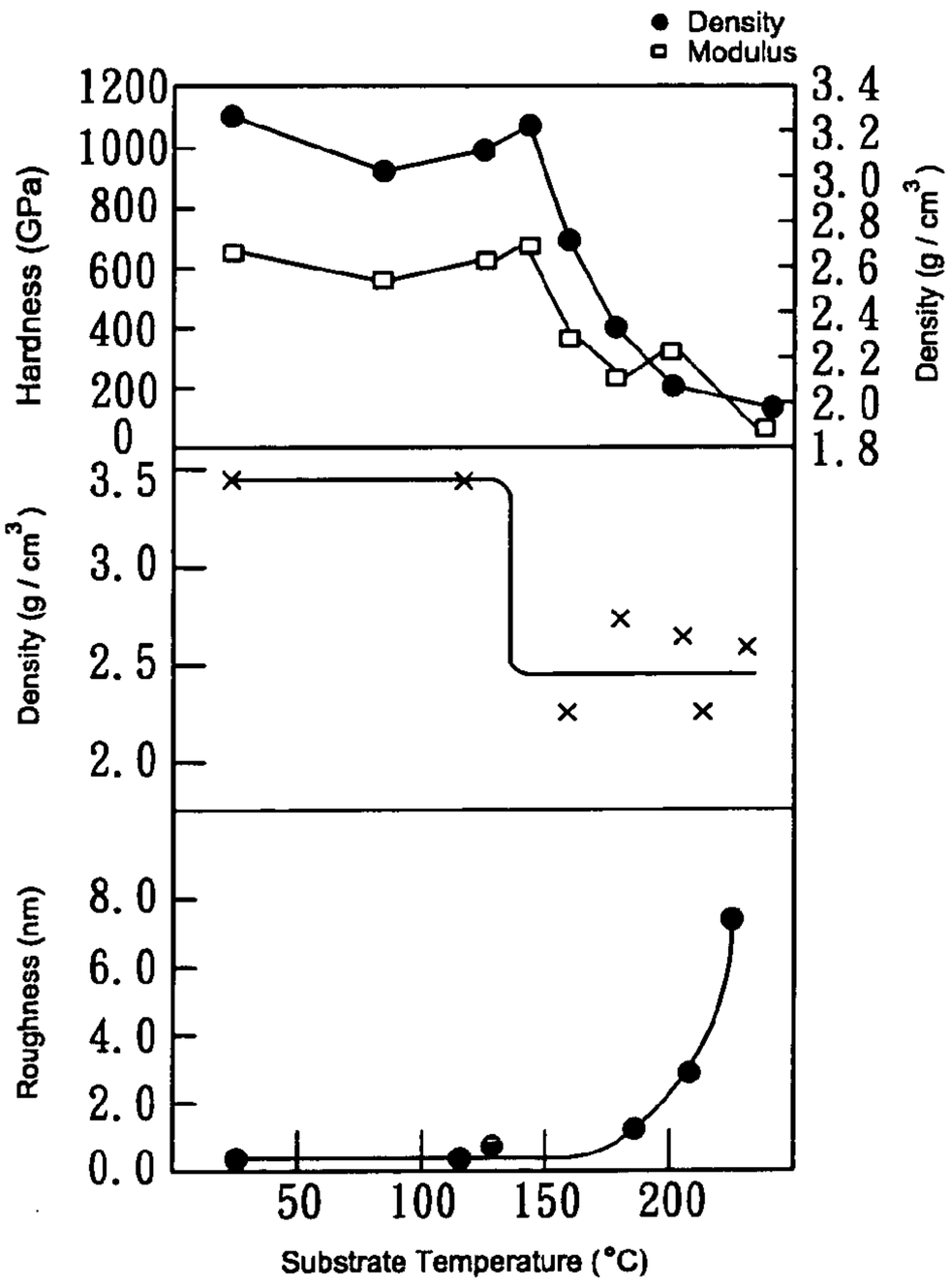

Density
Modulus
1200
1000
800
600
400
200
0
Hardness (GPa)
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
Density (g / cm³)
3.5
3.0
2.5
2.0
Density (g / cm³)
8.0
6.0
4.0
2.0
0.0
Roughness (nm)
50
100
150
200
Substrate Temperature (°C)

Fig. 35

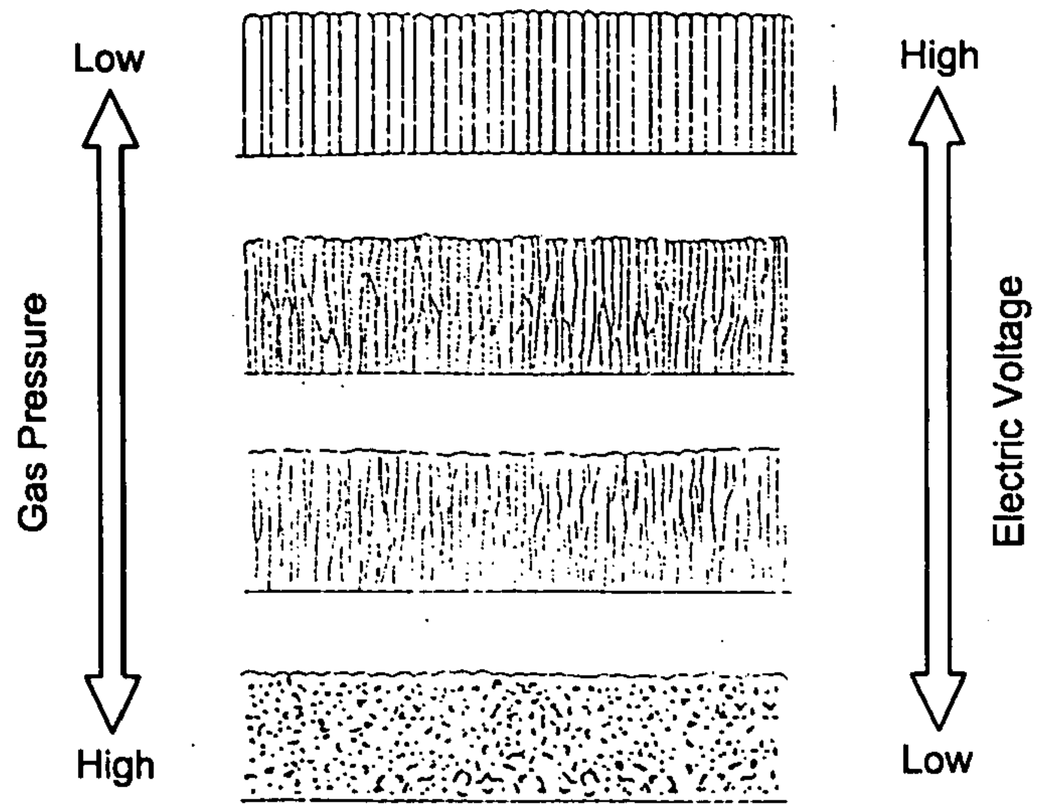

Low
High
Gas Pressure
High
Low
Electric Voltage

Fig. 36

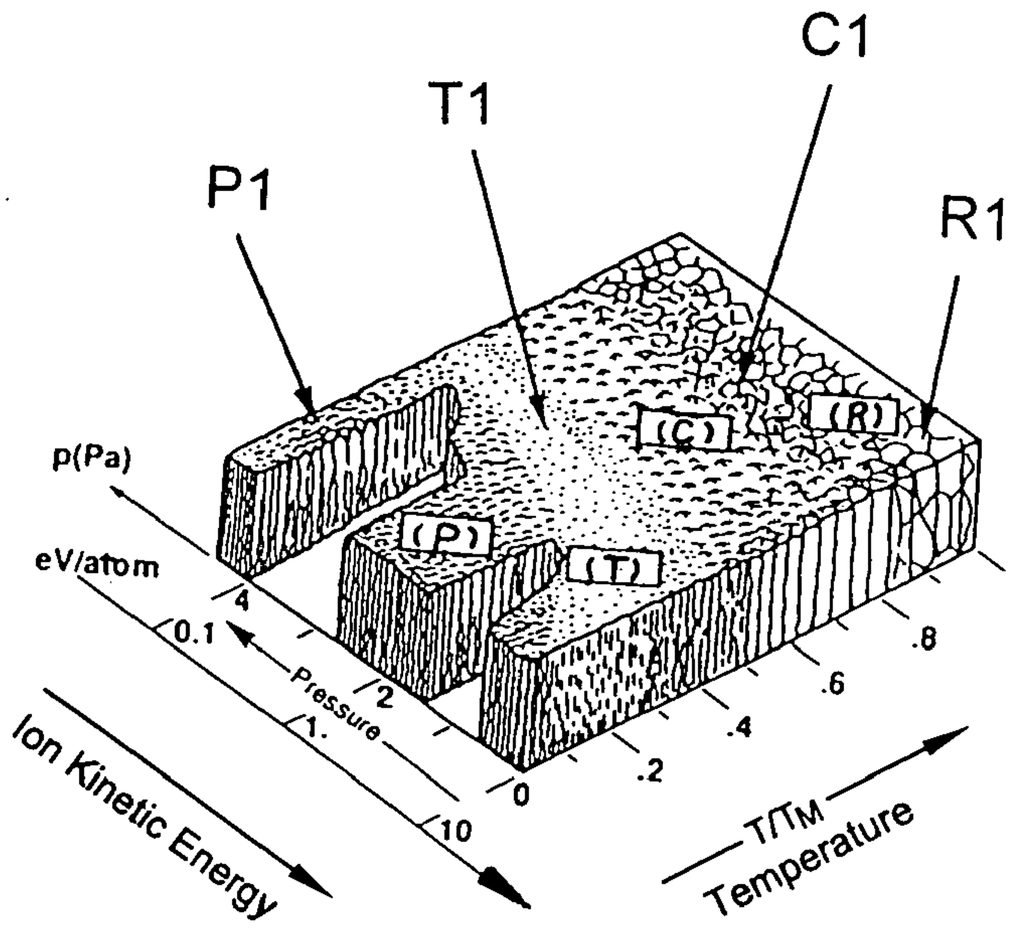

C1
T1
P1
R1
(C)
(R)
(P)
(T)
p(Pa)
eV/atom
4
0.1
Pressure
2
1.
10
0
.2
.4
.6
.8
Ion Kinetic Energy
T/TM
Temperature

Fig. 37

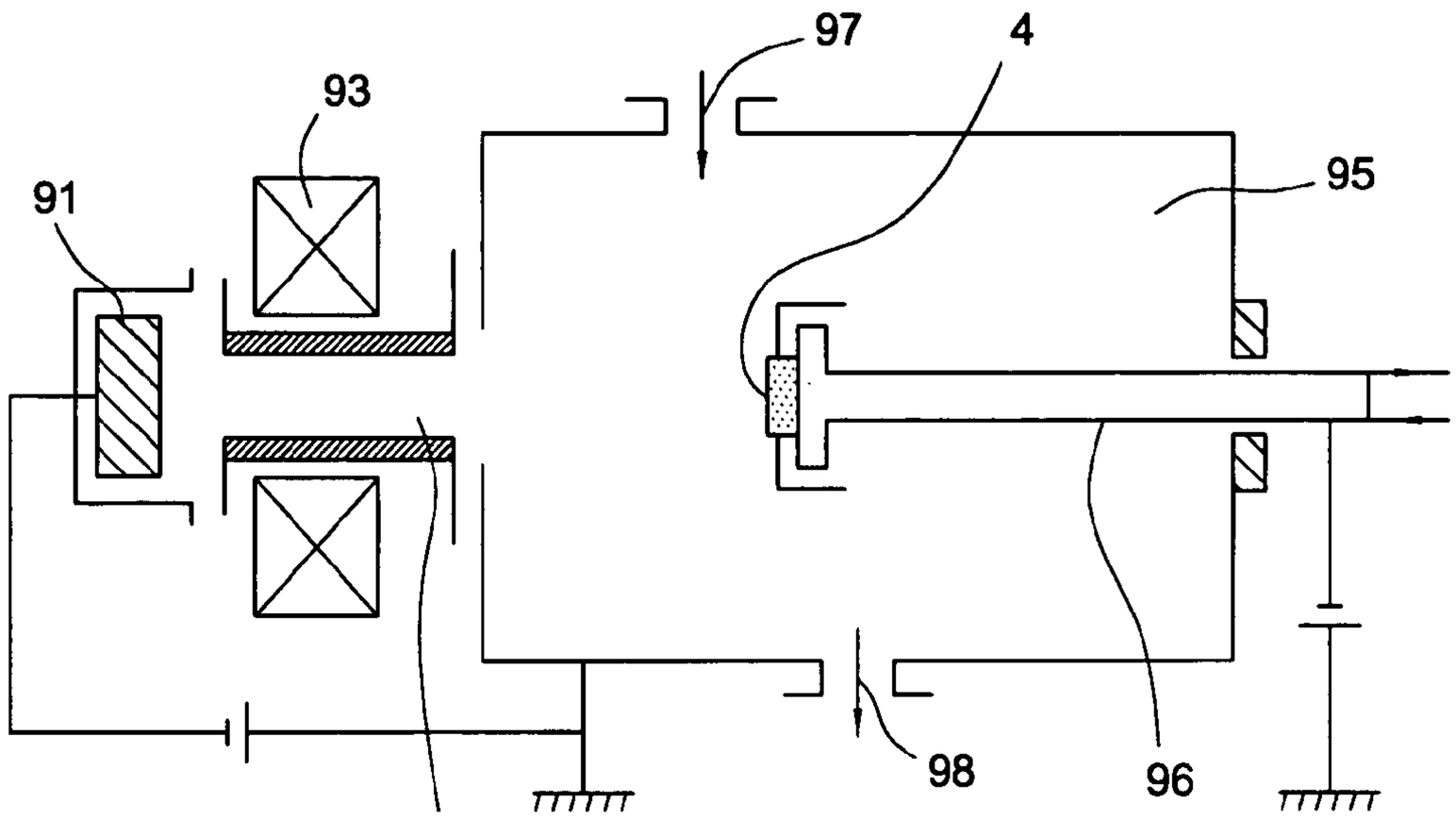


Fig. 38a

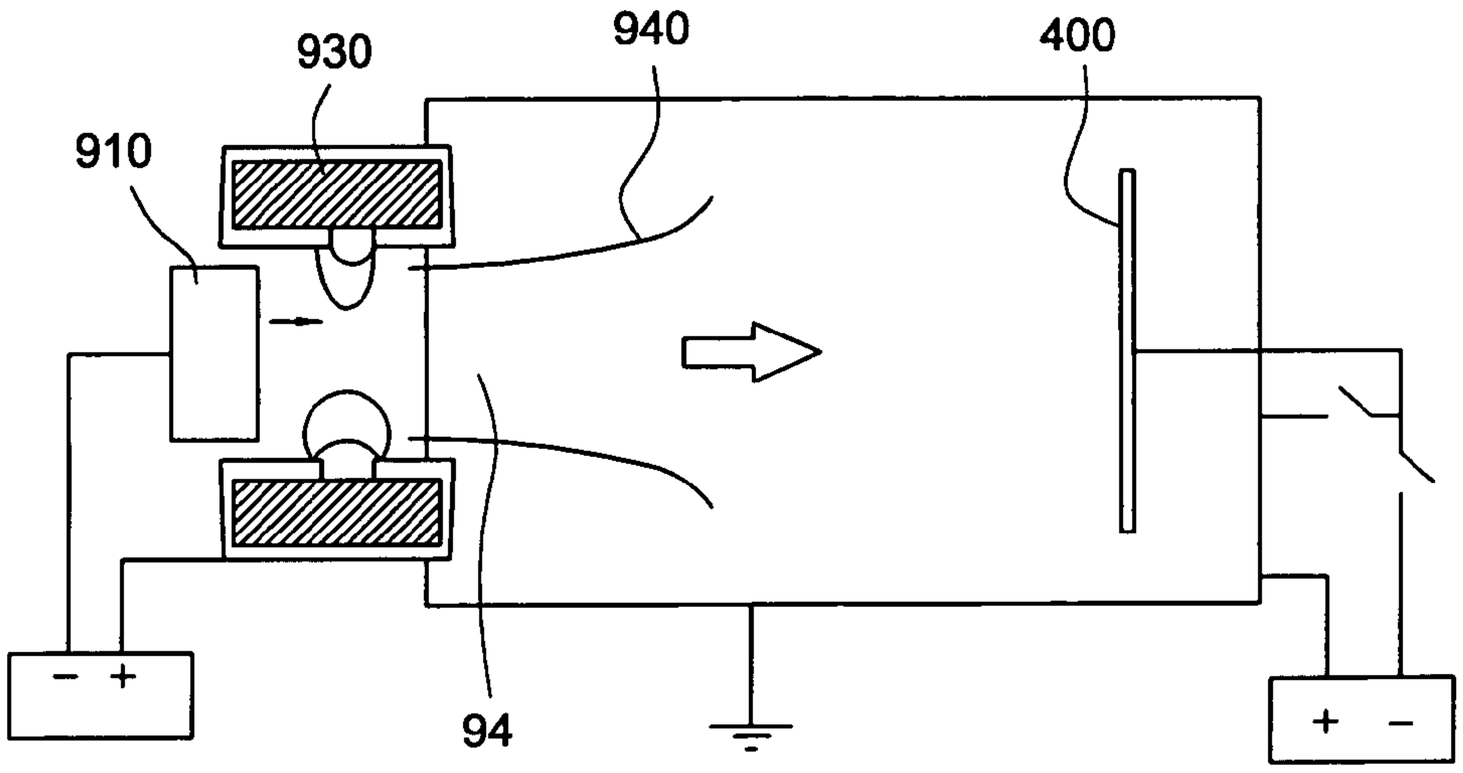


Fig. 38b

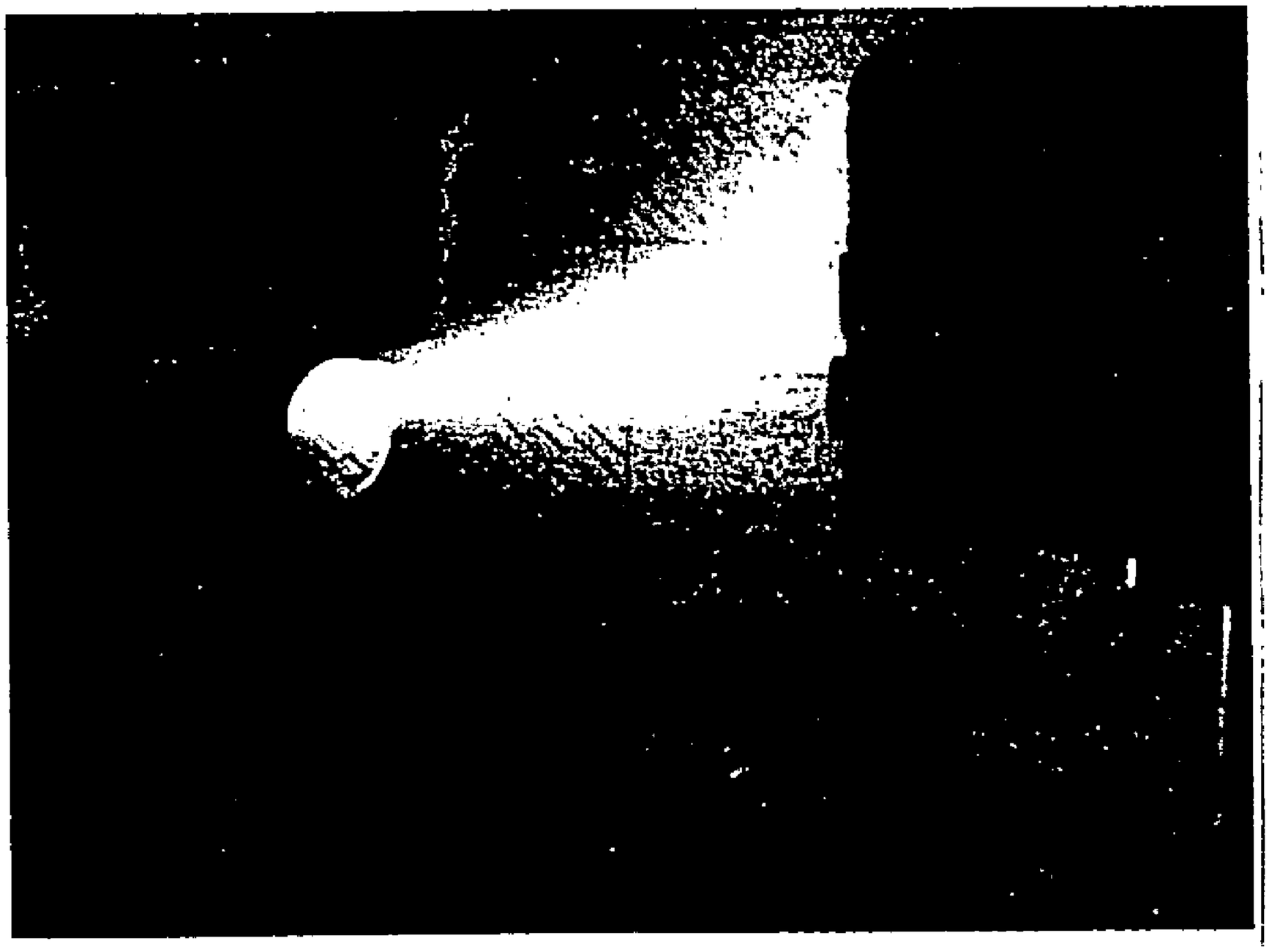


Fig. 39

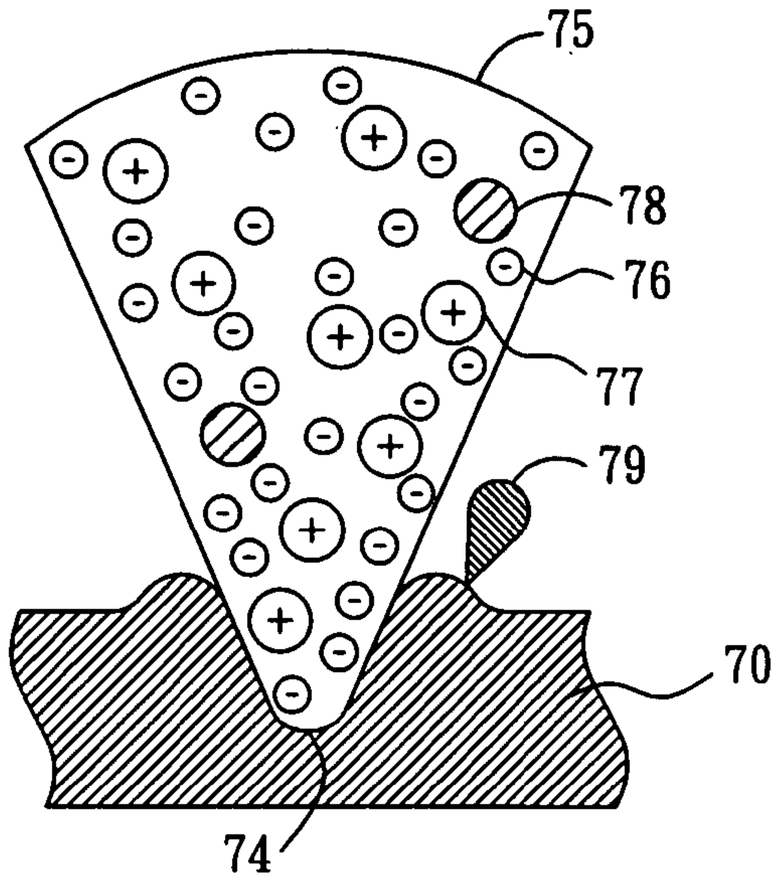


Fig. 40a

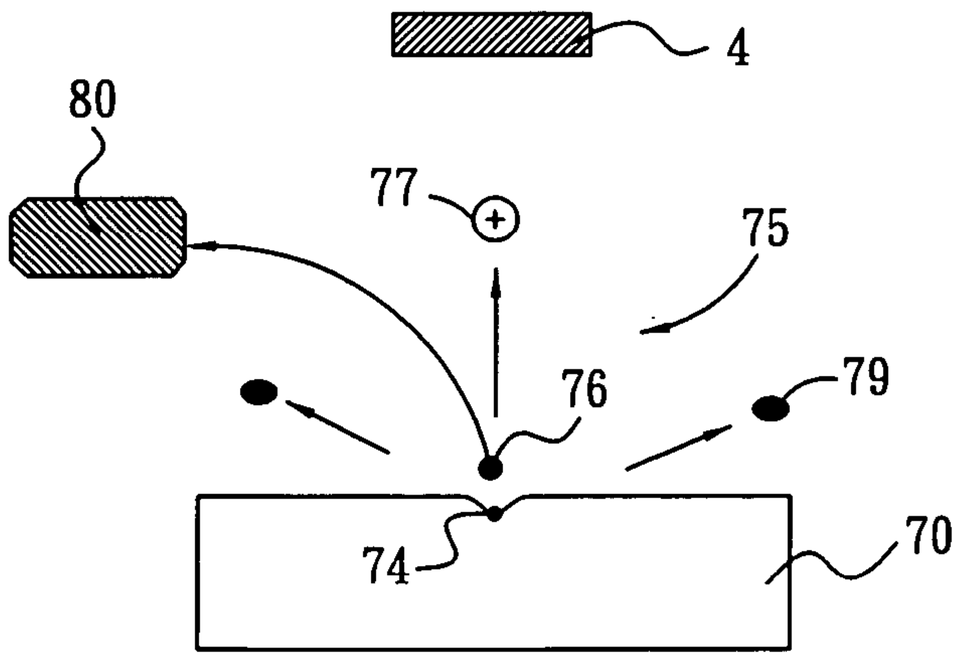
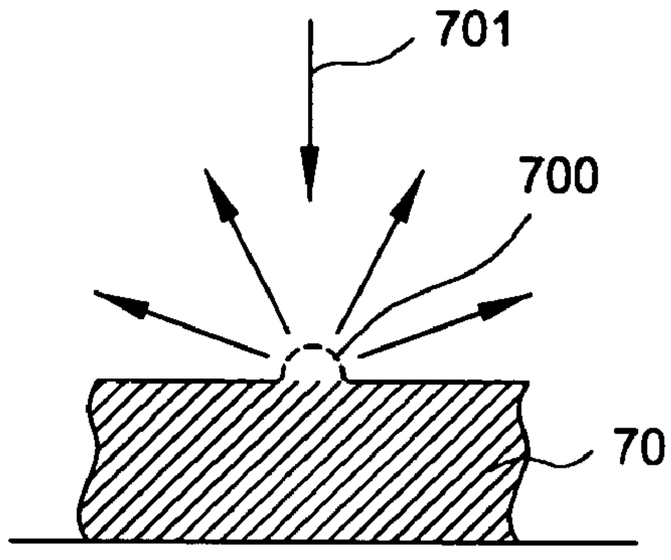
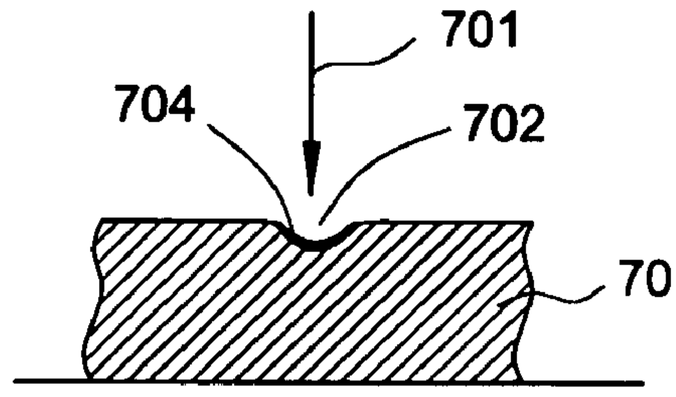


Fig. 40b



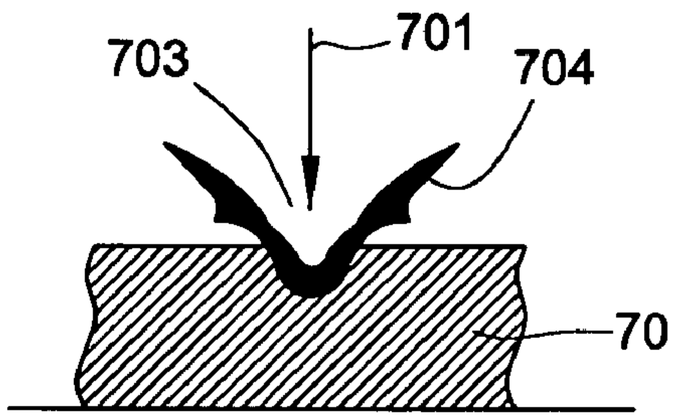
t = 0 - 1 ns

Fig. 41a



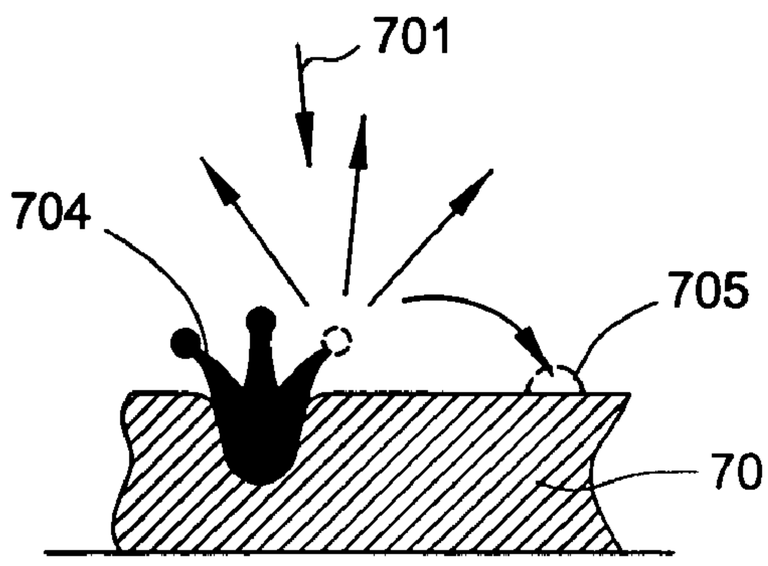
t = 1 - 5 ns

Fig. 41b



t = 5 - 40 ns

Fig. 41c



t = 5 - 40 ns

Fig. 41d

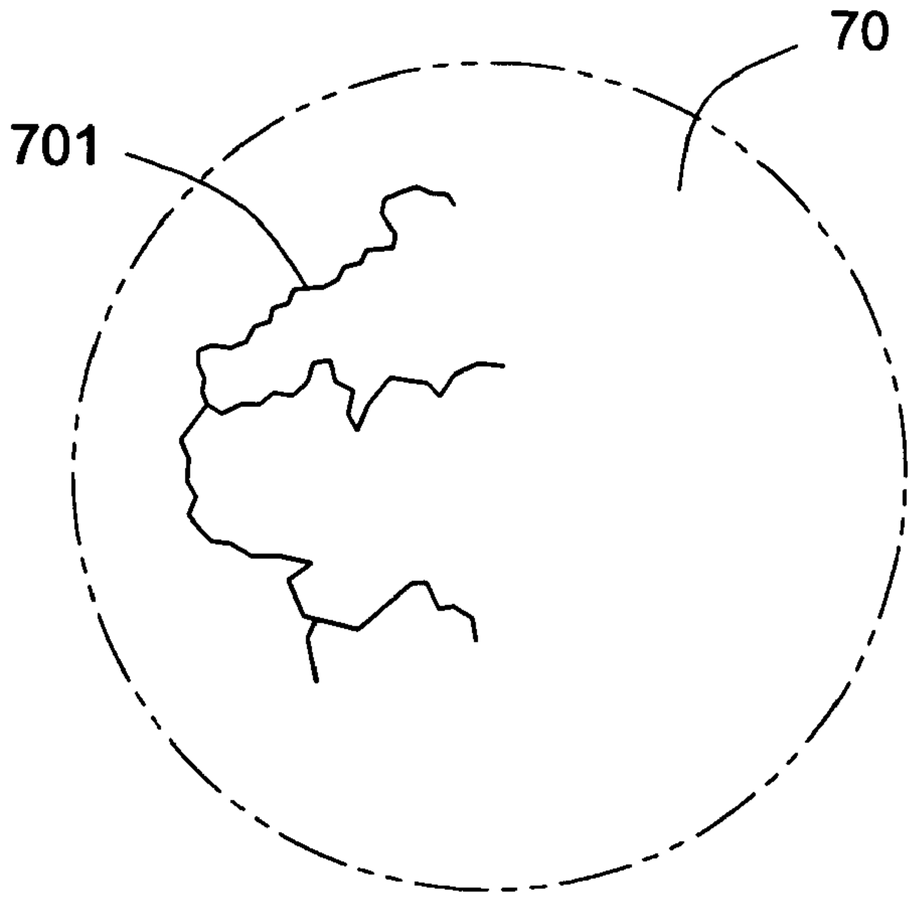


Fig. 42a

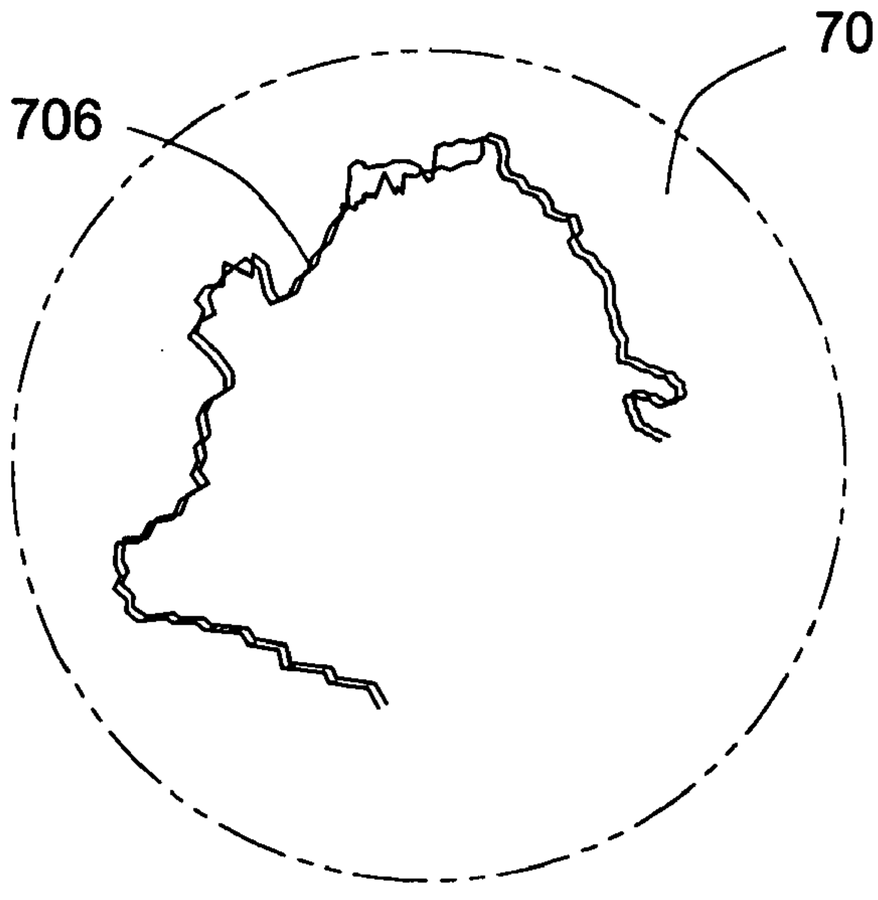


Fig. 42b

METHOD FOR PRODUCING A DYNAMIC FLUID BEARING WITH HIGH ROTATION PRECISION AND HIGH HARDNESS

FIELD OF THE INVENTION

[0001] The present invention relates to methods for manufacturing bearing components supporting fluid dynamic-pressure, more particularly to a method for manufacturing bearing components of high precision and hardness for dynamic pressure fluids, in which physical vapor deposition is utilized to coated an amorphous diamond film of hardness approaching 80-100 GPa over a pivotal interface or a patterned surface on which a fluid pressure is distributed of a bearing component.

BACKGROUND OF THE INVENTION

[0002] Dynamic-pressure fluid bearings are used in high-speed driving units of hard disk drives and CD-ROM, which mainly comprise a sleeve, a spindle and a fluid, such as air and lubricating oil, injected therebetween. The dynamic-pressure fluid bearings of the prior art are categorized into dynamic-pressure fluid radial bearings and dynamic-pressure fluid thrust bearings. According to various necessities, the pivotal interface between the sleeve and the spindle of the bearings is provided with grooved or protrudent patterns of various contours, such as herring bone, tilting pad, foil, step and spiral groove. The grooved or protrudent patterns contribute to respective pressure distributions on the interface between the sleeve and the spindle after a fluid is injected thereon. For example, a radial pattern of herring bone, either on a spindle or on a sleeve, results in the levitation of the spindle by the dynamic pressure produced by the fluid as the sleeve and the spindle undergo a high-speed rotation with respect to each other. To eliminate the vibration of the spindle in ether high-speed rotation or deceleration, the spindle has to be made highly circular, and the spacing between the spindle and the sleeve has to be precisely uniform.

[0003] In the dynamic-pressure fluid bearings of the prior art, the spindle and the sleeve are completely separated in high-speed rotation. However, in the start-up period and in low-speed rotation, the spindle and the sleeve may contact and produce metal powder in the fluid, causing a change in fluid viscosity and therefore degrading the lubricating fluid. The durability and precision of the bearing components may also degrade.

[0004] To overcome the above-mentioned problems, the spindle and the sleeve of the bearings are made of hard metallic materials, such as high-speed steel, tungsten steel, beryllium copper alloy and phosphor bronze. However, the protective effect is not substantial.

[0005] As an alternative, the spindles and sleeves of the prior art are coated with hard films such as hard chromium and Electroless nickel. But, the films have yet to match the industrial requirements of precision, hardness and low cost.

[0006] It is another innovation that diamond like carbon (DLC) films coated via methods of physical vapor deposition (PVD) or chemical vapor deposition (CVD) over the spindle and the sleeve can provide higher hardness. However, the coating methods have a hydrogen problem that enhances water absorptivity of the films, increasing the frictional coefficient and thus decreasing the adhesive force of the films. It is a further defect that, since the diamond-like carbon film containing hydrogen (DLC, a-C:H) has a hydrogen content between 30-60%, as shown in Table 1, and the hardness thereof is below 50 GPa, as shown in **FIGS. 1 and 2**, the durability is good enough.

TABLE 1

comparison of carbon materials

carbon materials	sp^3 (%)	H (%)	density (g/cm^3)	hardness (GPa)
graphite	0	0	2.27	<0.01
carbon glass	0	0	1.3–1.6	2–3
Evaporated carbon	<5	<5	1.9–2.0	2–5
sputtered carbon	5–10	<5	2.2–2.6	10
amorphous diamond(a-D)	>85	<5	2.9–3.4	80–100
hard DLC a-c: H	40–50	30–50	1.6–2.0	10–50
soft DLC a-c: H	50–80	50–60	0.9–1.2	<5
polyethylene	100	66	0.9	0.01
diamond	100	0	3.52	100

SUMMARY OF THE INVENTION

[0007] Accordingly, the primary objective of the present invention is to provide a method for manufacturing bearing components, such as sleeve and spindle, of high precision and hardness supporting fluid dynamic-pressure, which components are hard-wearing and durable so that the space between the spindle and the sleeve can maintain perfectly round after high speed rotation for a long time. And, further, it is convenient to produce such components.

[0008] The method disclosed by the present invention is coating a layer of amorphous diamond over bearing components by physical vapor deposition, whereby the connecting surfaces or the carved pattern of those components may have hardness of 80-100 GPa, density of 3.0-3.2 g/cm^3 and coefficient of friction of 0.1. The hardness of the film can be twice more than that of the diamond like carbon film containing hydrogen (DLC, a-C:H) of the prior art, which is 10-50 GPa as shown in Table 2. Therefore, the film made by the present invention is highly wear-resisting, durable and adhesive, capable of protecting a trough against the dynamic pressure produced by high-speed fluid passing through. And, therefore, the components coated with the film can maintain low vibration, low wiggling, low noise, high durability and perfect roundness even after high-speed rotation for an extended period of time, especially when the components undergo an initial startup or a stall.

[0009] It is a further objective of the present invention that chemical vapor deposition is used to form a film of crystallize diamond of diamond-level hardness, attaining 80-100 GPa (as shown in Table 2). However, the coating temperature of this method should be higher (<600° C.) and therefore is more expansive; this method is suitable for producing thicker films.

[0010] The methods described above are for making bearing components of high precision and hardness supporting fluid dynamic-pressure and therefore suitable for making the sleeves and spindles of the motors used in personal computers, notebook computers, servers, printers, hard disk

drive and CO-ROM. The method disclosed by the present invention can be applied in mass production and therefore of low production cost.

[0011] The present invention provides a method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure, comprising the steps of: selecting at least a first component of a plurality of pivotally connected bearing components supporting fluid dynamic-pressure, said first component having a predetermined surface pattern; forming an opaque and hard amorphous diamond (DLC, a-D) film on the pivotal surface of said first component by physical vapor deposition (PVD) using ion plating, said amorphous diamond film covering said pattern of said first component and/or the corresponding pivotal surface of a second component; and combining said first component coated with an amorphous diamond (DLC, a-D) film and said second component so that the space between said first and second components form a trough for filling a fluid, whereby said pivotal surfaces of said first and second components can be urged with a pressure distribution as a fluid is filled in said trough. The various objects and advantages of the present invention will be more readily understood from the following detailed description when read in conjunction with the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] **FIG. 1** is a cross-sectional view of the bearing components supporting dynamic-pressure fluids referred in a preferred embodiment of the present invention.

[0013] **FIG. 1***a* is a side view of a spindle having smooth surfaces referred in the present invention.

[0014] **FIG. 1***b* is a side view of a spindle having a lateral surface with depressed or bulged fishbone patterns referred in the present invention.

[0015] **FIG. 1***c* is a bottom view of a spindle having a tapered bottom surface with depressed or bulged spiral patterns referred in the present invention.

[0016] **FIG. 1***d* is a lateral cross-sectional view of a sleeve having a smooth inner surface referred in the present invention.

[0017] **FIG. 1***e* is a local enlarged view of the spindle hole of the sleeve having an inner surface with bulged or depressed fishbone pattern.

[0018] **FIG. 1***f* is a bottom view of a sleeve having a tapered surface with depressed or bulged spiral patterns referred in the present invention.

[0019] **FIG. 1***g* is an enlarged cross-sectional view showing the coupling of a spindle with a sleeve referred in another preferred embodiment of the present invention.

[0020] **FIG. 1***h* is an enlarged cross-sectional view showing the coupling of a spindle with a sleeve referred in the third preferred embodiment of the present invention.

[0021] **FIG. 2** illustrates the comparison between the amorphous diamond film of the present invention and diamond-like carbon film having graphite or diamond binding.

[0022] **FIG. 3** is an equilibrium phase diagram showing various artificial diamond making domains.

[0023] **FIG. 4** is a microscopic view of the diamond-like carbon film coated on a steel material.

[0024] **FIG. 5** shows the relation between diamond film thickness and the manufacturing temperature.

[0025] **FIG. 6***a* illustrates methane ion penetrating the surface of a component when it possesses too high a kinetic energy.

[0026] **FIG. 6***b* illustrates methane ion falling off the surface of a component when it possesses too low a kinetic energy.

[0027] **FIG. 6***c* illustrates methane ion attached to the surface of a component to form a diamond film when it possesses a suitable kinetic energy.

[0028] **FIG. 7***a* is a temperature-distribution diagram of the diamond-like carbon film (DLC) produced by physical vapor deposition (PVD).

[0029] **FIG. 7***b* is a pressure-distribution diagram of the diamond-like carbon film (DLC) produced by physical vapor deposition (PVD).

[0030] **FIG. 8***a* shows the atomic arrangement of graphite.

[0031] **FIG. 8***b* shows the atomic arrangement of diamond.

[0032] **FIG. 8***c* shows an atomic arrangement wherein carbon atoms are replaced by nitrogen atoms.

[0033] **FIG. 8***d* shows the diamond structure.

[0034] **FIG. 9***a* illustrates the transition from rhombus graphite to cubic diamond.

[0035] **FIG. 9***b* illustrates the transition from hexagonal graphite to hexagonal diamond.

[0036] **FIG. 10** is a 4-dimensional phase diagram of the carbon structures referred in the present invention.

[0037] **FIG. 11** illustrates the structure of carbon-60 (Bucky Ball).

[0038] **FIG. 12** illustrates the hydrocarbons referred in the present invention may contain graphite or diamond bindings.

[0039] **FIG. 13** shows the microscopic structure of the amorphous diamond (a-D) referred in the present invention.

[0040] **FIG. 14***a* shows the process of growing diamond film on a substrate by chemical vapor deposition (CVD).

[0041] **FIG. 14***b* is a cross-sectional view of a grown thick diamond film by chemical vapor deposition (CVD).

[0042] **FIG. 15** shows the relation between the ratio of sp^3 binding of the hydrocarbons referred in the present invention and the hydrogen content.

[0043] **FIG. 16** illustrates the hydrogen atoms in the diamond-like carbon film containing hydrogen (DLC, a-C:H) referred in the present invention capable of forming a variety of hydrocarbon bindings.

[0044] **FIG. 17** shows the atomic structure of a typical diamond-like carbon film containing hydrogen (DLC, a-C:H) referred in the present invention.

[0045] **FIG. 18** shows a diamond-like carbon film containing hydrogen (DLC, a-C:H) includes atomic groups of a variety of hydrocarbon bindings.

[0046] **FIG. 19** shows an atomic structure with a complex network.

[0047] **FIG. 20** shows the relation between the internal stress of a diamond-like carbon film (DLC) and the hardness thereof.

[0048] **FIG. 21** shows a diamond-like carbon film (DLC) containing granules of nano metal.

[0049] **FIG. 22** is a cross-sectional view of a multi-layer film having a plurality of diamond-like carbon films (DLC).

[0050] **FIG. 23** shows a carbon ion deposition gun directly injecting ions on a surface of a component to form a diamond-like carbon film (DLC, a-C: H).

[0051] **FIG. 24** shows an argon ion source indirectly plating a surface of a component through injecting upon a graphite target first, to form an amorphous diamond film (DLC, a-D) thereon.

[0052] **FIG. 25** shows another argon ion source shooting over a surface of a component already coated with an amorphous diamond film (DLC, a-D), whereby the solidity of the film can be further reinforced.

[0053] **FIG. 26***a* shows the microscopic structure of a diamond-like carbon film (DLC) without sputtering.

[0054] **FIG. 26***b* shows the microscopic structure of a diamond-like carbon film (DLC) with low-energy argon ion sputtering.

[0055] **FIG. 26***c* shows the microscopic structure of a diamond-like carbon film (DLC) with high-energy argon ion sputtering.

[0056] **FIG. 27** shows a solid amorphous diamond (DLC, a-D) film formed by directly plating a component using an argon-ion gun and a methane-ion gun simultaneously.

[0057] **FIG. 28** illustrates an electron gun boils and evaporates a material.

[0058] **FIG. 29** illustrates carbon ions embedded within a diamond-like carbon film (DLC) using an electron-gun evaporating mechanism in company with an ion gun.

[0059] **FIG. 30** illustrates the growing of high-temperature super-conducting YBCO film by sputtering. (after a catalog of Comaonwealth Scientific).

[0060] **FIG. 31***a* shows the variation of the hydrogen content of the diamond-like carbon films (DLC) referred in the present invention against the component bias voltage.

[0061] **FIG. 31***b* shows the variation of the carbon binding content of the diamond-like carbon films (DLC) referred in the present invention against the component bias voltage.

[0062] **FIG. 31***c* shows the variation of the carbon combination hardness of the diamond-like carbon films, (DLC) referred in the present invention against the component bias voltage.

[0063] **FIG. 32***a* shows the variation of the hydrogen content of the diamond-like carbon films (DLC) using two different carbon sources against the component bias voltage.

[0064] **FIG. 32***b* shows the variation of the density of the diamond-like carbon films (DLC) using two different carbon sources against the component bias voltage.

[0065] **FIG. 32***c* shows the variation of the kinetic-energy spacing of the diamond-like carbon films (DLC) using two different carbon sources against the component bias voltage.

[0066] **FIG. 32***d* shows the variation of the hardness of the diamond-like carbon films (DLC) using two different carbon sources against the component bias voltage.

[0067] **FIG. 33***a* shows the influence of the carbon-ion kinetic energy on the sp^2 graphite binding of the film.

[0068] **FIG. 33***b* shows the influence of the carbon-ion kinetic energy on the surface roughness of the film.

[0069] **FIG. 33***c* shows the influence of the carbon-ion kinetic energy on the density of the film.

[0070] **FIG. 33***d* shows the relation between the length of carbon bonds and their angles.

[0071] **FIG. 34** shows the relation between the growth ratio of the sp^3 diamond bindings in a variety of amorphous diamond films (DLC, a-D) and the carbon-ion kinetic energy.

[0072] **FIG. 35***a* shows the influence of the component temperature on the rigidity of a diamond-like carbon film (DLC).

[0073] **FIG. 35***b* shows the influence of the component temperature on the density of a diamond-like carbon film (DLC).

[0074] **FIG. 35***c* shows the influence of the component temperature on the surface roughness of a diamond-like carbon film (DLC).

[0075] **FIG. 36** illustrates variations in gas pressure and in electric voltage producing have opposite effects on the structure of a diamond-like carbon film (DLC).

[0076] **FIG. 37** is a 3D cross-sectional diagram illustrating the relation between ion kinetic energy, pressure and temperature.

[0077] **FIG. 38***a* illustrates the structure of a injection-plating cathode arc instrument for making amorphous diamond (DLC, a-D) films.

[0078] **FIG. 38***b* illustrates the structure of an injection-plating plasma wave instrument for making amorphous diamond (DLC, a-D) films.

[0079] **FIG. 39** is a picture showing carbon ions plating a component using cathode arc injection.

[0080] **FIG. 40***a* shows the formation of plasma on the surface of a cathode graphite target.

[0081] **FIG. 40***b* shows a graphite target emitting positively charged carbon ions toward a component.

[0082] **FIG. 41***a* shows the explosion of a bulge on the surface of a graphite target induced by the shooting of a cathode arc.

[0083] **FIG. 41***b* shows a bulge melting into a small pit by a cathode arc.

[0084] **FIG. 41***c* shows the pit in **FIG. 41***b* growing into an ejection hole.

[0085] **FIG. 41***d* shows the ejection hole in **FIG. 41***c* ejecting liquid metal around to form other bulges.

[0086] **FIG. 42***a* illustrates a random bombardment pattern of a cathode arc on a graphite target without a magnetic field guiding.

[0087] **FIG. 42***b* illustrates a more regular bombardment pattern of a cathode arc on a graphite target with a magnetic field guiding.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0088] The components referred in a method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure according to the present invention are a plurality of pivotally connected rotary units. In the first preferred embodiment they are a sleeve **2** and a spindle **1**; the spindle **1** is pivotally inserted into an axial hole **21** of the sleeve **2**, as shown in **FIG. 1**.

[0089] The spindle **1** comprises a shaft **11** and a bulged ring **12**, which bulged ring **12** further includes an inclined end surface **121**. The inclined end surface **121** and the lateral surface **111** of the shaft **11** form a smooth pivotal interface, as shown in **FIG. 1***a*. The lateral surface **111** and the inclined end surface **121** may be provided with a bulged or carved surface pattern, such as fishbone notches, as shown in **FIGS. 1***b* and **1***c*.

[0090] For stabilizing the rotary spindle **1**, the central portion of the sleeve **2** is provided with an axial hole **21** and a ring receptacle **22**, as shown in **FIG. 1***d*, whereby the shaft **11** can be coupled with the axial hole **21** and the bulged ring **12** can be coupled with the ring receptacle **22**, as shown in **FIG. 22**. Therefore, an inclined surface **221** is also included in the ring receptacle **22** of the sleeve **2**, in correspondence to the inclined end surface **121** of the bulged ring **12**. The inner wall **211** of the axial hole **21** and the inclined surface **221** of the ring receptacle **22** can be a smooth surface, as shown in **FIG. 1***d*, or a surface with a predetermined bulged or carved pattern, as shown in **FIG. 1** *e* and f.

[0091] As the lateral surface **111** of the shaft **11** and the inclined end surface **121** of the bulged ring **12** are smooth, as shown in **FIG. 1***a*, the inner wall **211** of the axial hole **21** of the sleeve **2** and the inclined surface **221** of the ring receptacle **22** can have a predetermined bulged or carved pattern, as shown in **FIG. 1** *e* and *f*.

[0092] As the lateral surface **111** of the shaft **11** and the inclined end surface **121** of the bulged ring **12** have a predetermined bulged or carved pattern, as shown in **FIGS. 1***b* and *c*, the inner wall **211** of the axial hole **21** of the sleeve **2** and the inclined surface **221** of the ring receptacle **22** can be smooth, as shown in **FIG. 1***d*.

[0093] Except for the above two options, wherein one of the bearing components is selected to be provided with a predetermined bulged or carved pattern, both of the spindle **1** (including the lateral surface **111** of the shaft **11** and the inclined end surface **121** of the bulged ring **12**) and the sleeve **2** (including inner wall **211** of the axial hole **21** and the inclined surface **221** of the ring receptacle **22**) can be provided with a predetermined bulged or carved pattern simultaneously.

[0094] To enhance the wearing resistance and the durability of the spindle **1** and the sleeve **2**, at least the lateral surface **111** of the shaft **11** and the inclined end surface **121** of the bulged ring **12** are coated with a film **10** (as shown in **FIG. 1***h*) of amorphous diamond (a-D) or crystalline diamond (c-D). Or select the inner wall **211** of the axial hole **21** and the inclined surface **221** of the ring receptacle **22** to cover with a film **20** of amorphous diamond (a-D) or crystalline diamond (c-D), as shown in **FIG. 1***g*. The films (**10**) and/or (**20**) attach to the pattern of the spindle **1** and the pattern of the sleeve **2** to form a protective layer.

[0095] Thereby, one rotary component, such as a spindle **1**, coated with a film of amorphous diamond (a-D) or crystalline diamond (c-D) can pivotally couple with another rotary component, such as a sleeve **2**, forming a fluid trough **30** therebetween, as shown in **FIGS. 1***g* and **1***h*. A fluid **3** is filled into the fluid trough **30** to form a fluid pressure distribution. In other words, in the aforesaid the preferred embodiment, as the spindle **1** is driven to rotate, the fluid **3** in the fluid trough **30** will produce dynamic pressure distributed over the tracks of the bulged or carved pattern, as shown in **FIGS. 1***g* and **1***h*. Thereby, there exist an axial dynamic pressure between the inclined end surface **121** and the inclined surface **221** that levitates the spindle **1** upward and a radial dynamic pressure between the lateral surface **111** and the inner wall **211** that aligns the spindle **1** along the axial hole **21**. The axial and radial dynamic pressures maintain the stability and precision of the high-speed rotating spindle **1**, especially in the start-up phase and the decelerating phase when the rotational speed is not steady. The above fluid **3** can be air or lubricating oil.

[0096] The amorphous diamond film (a-D) used in the present invention and the diamond-like carbon film containing hydrogen (DLC, a-C:H) of the prior art have different properties. As shown in **FIG. 2**, the diamond-like carbon film (DLC) is polymer having polymer content between graphite and diamond, whereas the amorphous diamond film (a-D) of the present invention is diamond-like carbon film (DLC) with high diamond binding content. The diamond-like carbon film containing hydrogen (DLC, a-C:H) of the prior art is diamond-like carbon film (DLC) with high polymer binding content.

[0097] Further, as shown in Table 1 and 2, the amorphous diamond film (DLC, a-D) of the present invention hardly contains hydrogen (H %<5) but has sp^3 binding above 85%. Therefore, the hardness and the adhesive force are superior to the diamond-like carbon film containing hydrogen (DLC, a-C: H) of the prior art. In other words, the amorphous diamond film (a-D) is close to diamond, and suitable for being coated on a bearing component to enhance its wearing resistance, durability and motion rotational stability.

[0098] Further, the formation of the amorphous diamond (a-D) and the crystalline diamond (c-D) are described as follows.

[0099] Diamond is the high-pressure phase of carbon, and therefore it is formed under a high pressure, as shown in **FIG. 3**. Traditional methods that synthesize diamond include high-pressure explosion, direct forming under high pressure and catalyzed synthesis, all of which expose graphite to an environment of 50,000 ATM, approximately the pressure at the center of the Moon. At the same time, molten metals such as iron, cobalt, nickel and the alloys thereof at

a temperature greater than 1200° C. are used to catalyze the transition. Diamond can also be formed in a half-vacuum say, 40 torr) environment, in which methane (CH_4) or other carbon containing gases may decompose and transit into diamond by chemical vapor deposition (CVD). To avoid forming graphite when the gas pressure is low, the ambient gas is added with an excessive amount of hydrogen molecules, and the molecules are broken into hydrogen atoms by being energized with microwave. The carbon atoms in this circumstance form sp^3 diamond binding, accumulated as a diamond film.

[**0100**] In higher vacuum (ambient pressure 10^{-3} torr or lower), physical vapor deposition (PVD) can be used, by which pure carbon materials of molecules containing carbon atoms, such as methane, are bombarded to form diamond-like carbon films (DLC). A diamond-like carbon film (DLC) can be coated over complex contour of a component, the thickness of which film can be less than <1 μm, as shown in **FIG. 4**. Further, physical vapor deposition (PVD) can focus energy at a small number of bombarded atoms, without affecting other atoms. Therefore, the temperature of the component in the deposition process can maintain low (<300° C.), and therefore the component can be immune form thermal deformation. Therefore, a diamond-like carbon film (DLC) can be plated over a variety of materials, such as metal, ceramic or even plastic.

[**0101**] The above-mentioned physical vapor deposition seems to be performed in vacuum, but the diamond structure therein is still formed by a high-pressure means; only a tiny number of carbon atoms experience a high pressure in a short period of time. Therefore, physical vapor deposition can be interpreted as a principle of leverage, namely, exerting high pressure to carbon atoms a small number at a time. On the other hand, the high-pressure synthesis of the prior art exerts pressure all atoms at a time.

[**0102**] In other words, the low-pressure method needs a long time to form diamond; the growth rate of diamond for CVD is 1-100 μm/hr and for PVD is 0.1-10 μm/hr. While the high-pressure method has a faster growth rate, exceeding 1000 μm/hr or 1 mm/hr. **FIG. 5** shows the relation between synthesis temperature and the thickness of a diamond film, where

[**0103**] PVDD=physical vapor deposited diamond (PVD Diamond);

[**0104**] CVDD=chemical vapor deposited diamond (CVD Diamond);

[**0105**] PCD=Poly-crystallize Diamond;

[**0106**] arrows=representing the tendencies of diamond film properties (including deposition temperature, growth rate, $sp^3/sp^2\pi$, crystal granule roughness, density, hardness, wearing resistance, heat conduction, electric resistance).

[**0107**] Further, when the chemical vapor deposition (CVD) is used to synthesize diamond, four hydrogen atoms will circle around a carbon atom to form a structure similar to that of methane. For a methane molecule, the hydrocarbon binding energy per atom is about 4.6 eV. Table 3 shows the relation between energy density (i.e., pressure) and the temperature,

$$P(\text{pressure}) = F(\text{force})/A(\text{area})$$
$$= F(\text{force}) \times L(\text{distance})/A(\text{area}) \times L(\text{distance})$$
$$= E(\text{energy})/V(\text{volume})$$

[**0108**] E(temperature)=k(Boltzmann constant)×T(absolute temperature).

[**0109**] The 4.6 eV per atom energy density of the hydrocarbon bond is

TABLE 3

comparison of energy density of carbon atoms

Energy (eV)	Temperature (° C.)	Pressure (GPa)
0.1	887	4
0.5	5529	22
1	11331	44
2	22936	88
3	34540	132
4	46145	176
5	57749	219

equivalent to 2 million ATM, which is greater than the pressure attainable in the traditional high-pressure methods (50,000 ATM for static pressurization, 400,000 ATM for explosion pressurization). Therefore, although chemical vapor deposition (CVD) is named low-pressure method, the actual pressure attained is 40 times than that of the high-pressure synthesis methods.

[**0110**] If the methane ions mentioned above that bombard a component surface have an excessively high kinetic energy, the carbon atoms thereof will penetrate the surface and implant into the component, as shown in **FIG. 6***a*. However, if the kinetic energy is too low, the carbon atoms will not attach to the surface and will reflect back to form graphite, as shown in **FIG. 6***b*. Therefore, the kinetic energy has to be just right to form a diamond film on the surface, as shown in **FIG. 6***c*.

[**0111**] Further, when using physical vapor deposition (PVD) to synthesize a diamond-like carbon film (DLC), respective carbon atoms are boosted to a kinetic energy of 10-100 eV. The high-speed carbon atoms, when bombarding a component surface, will produce extremely high temperature and pressure instantaneously at the striking point, as shown in **FIGS. 7***a* and **7***b*. Take a carbon atom of 10 eV kinetic energy as an example, when it collides with another carbon atom, the kinetic energy will transform into heat in several microseconds, and the temperature of the striking point will increase up to several thousand degrees Celsius, equivalent to a pressure of several ten thousand ATM. The kinetic energy dissipated usually will propagate to nearby atoms quickly, and therefore the temperature and pressure at the striking point will soon become normal. Nevertheless, the instantaneous temperature and pressure produced in physical vapor deposition (PVD) is still much greater than the traditional explosion pressurization, as shown in **FIG. 3**. Actually, physical vapor deposition (PVD) can be regarded as a local explosion pressurization. Take a carbon atom of

100 eV kinetic energy as another example, the shock wave it induces can transform 1 million carbon atoms (covering an area of 20 mm diameter) into diamond at a time.

[0112] In summary, the synthesis of diamond must be done under hing pressure and at high temperature. The traditional high-pressure methods can continuously heat and pressurize carbon atoms. The chemical vapor deposition (CVD) is a microscopic high-pressure method that can convert carbon atoms into diamond a small group at a time. Take the formation of an image as an analogy, the high-pressure methods are like taking a picture, which builds up a whole image at once, whereas chemical vapor deposition (CVD) is like painting an image, which is gradually formed by local painting.

[0113] The microscopic and macroscopic versions of the static pressurization have analogies in the explosive pressurization. The traditional explosion method heats up and exerts pressure on whole carbon atoms and transforms them into diamond structure in a moment. PVD is the microscopic version of the explosion method, which uses electric energy to collide a small number of carbon atoms into diamond at a time. The macroscopic version is like bomb explosion, whereas the microscopic version is like machine gun shooting. The comparison of the four diamond synthesis methods is specified in Table 4.

[0114] The four covalent electrons of a carbon atom usually hybridize into $sp^2\pi$ or sp^3 molecular orbits. The $sp^2\pi$ molecular orbit form three covalent bonds (sp^2) and a metallic bond (π); examples are the atomic arrangement of graphite in **FIG. 8***a*, the atomic arrangement of diamond in **FIG. 8***b*, an atomic arrangement wherein carbon atoms are replaced by nitrogen atoms in **FIG. 8***c* and the diamond structure in **FIG. 8***d*. Every carbon atom connects with three adjacent carbon atoms via $sp^2\pi$ bonds to form a planar hexagonal network, as shown in **FIG. 9***a* and **FIG. 9***b*. Diamond can be formed from graphite through puckering, as shown in **FIG. 9***a* and Buckling, as shown in **FIG. 9***b*. Graphite structure is the pileup of those hexagonal networks. In **FIG. 10**, the 4-dimensional phase diagram lists (A) single atom carbon, (B) linear structure, (C) planar structure and (D) stereo structure. If a carbon atom has a sp^3 hybrid orbit, it will connect with four adjacent carbon atoms to form a tetrahedron, which is the standard diamond structure. Since the degree of symmetry of a tetrahedron is higher than that of the planar structure of graphite, the carbon atoms are more compact in a diamond structure.

[0115] The $sp^2\pi$ bond and the sp^3 bond can be mixed to form a intermediate state having a non-integer dimensionality, such as the

TABLE 4

comparison of methods that synthesize diamonds

synthetizing methods	temperature	pressure
high pressure	global, continuous	global, continuous
explosion	global, instantaneous	global, instantaneous
CVD	global, continuous	local, continuous
PVD	local, continuous	local, continuous

structure of carbon 60 (bucky ball) comprises 72% $sp^2\pi$ graphite bonds and 28% sp^3 diamond bonds, as shown in **FIG. 11**. The $sp^2\pi$ bond carbon atoms and the sp^3 bond carbon atoms can coexist with different proportions, such as the full graphite structure, partial graphite partial diamond structure and full diamond structure in **FIG. 12***a* to *f*. These structures are all stable. However, when using physical vapor deposition (PVD) to grow a diamond-like carbon film (DLC), the temperature for forming hydrocarbons is low and therefore the carbon atoms and the hydrogen atoms cannot shift to respective stable positions in time; therefore, part of the carbon atoms are connected by $sp^2\pi$ bonds, and others are connected by sp^3 bonds. This hybrid, disordered structure is called amorphous carbon (a-C). If sp^3 bonds in the amorphous carbon (a-C) make up more than 50% of the population, the amorphous carbon (a-C) is called amorphous diamond (a-D) or nano-crystalline diamond. If sp^3 bonds in the amorphous carbon (a-C) make up less than 50% of the population, the amorphous carbon (a-C) is called amorphous graphite (a-G). **FIG. 13** shows the micro-structure of the amorphous diamond (a-D), wherein the carbon atoms (indicated by black dots) pile up randomly over silicon atoms (white circles) of a workpiece; the carbon kinetic energy is 20 eV, and the crystal surface of the silicon is 001. Compared with diamond-like carbon (DLC), the diamond films produced by chemical vapor deposition (CVD) are crystalline and formed through diamond core formation and growth, as shown in **FIG. 14***a*(*a*) that the diamond core formation is realized on a workpiece substrate, **FIG. 14***a*(*b*) of granulation and **FIG. 14***a*(*c*) of film formation. As shown in **FIG. 14***b*, the cross-section of the thick diamond film produced by chemical vapor deposition (CVD) demonstrates a difference in structure from the diamond-like carbon film (DLC) produced by random piling up.

[0116] A diamond-like carbon (DLC, a-C:H) film may contain a large amount of hydrogen atoms, about ⅓. If the hydrogen content increases to ⅔, the carbon material will approach a polymer substance, as shown in **FIG. 15**. The doted line in **FIG. 15** represents the tendency from polyacetylene to polyethylene, whereas the solid line represents the tendency of random covalent network (RCN). And the dashed line shows the tendency of a random covalent network (RCN) added with graphite lumps, which is also the track of diamond-like carbon (DLC). Therefore, diamond-like carbon (DLC) can be viewed as a combined material of organic matter containing hydrogen, graphite with double bonds and diamond with single bonds, as shown in **FIG. 2**. It will become a-C:H if the amount of hydrogen atoms is high; it will become a-G if the amount of double bonds is high; it will become a-D if the amount of single bonds is high.

[0117] As shown in **FIG. 16**, the hydrogen atoms in a-C:H can interact with carbon atoms to form a variety of hydrocarbon bonds. The structure of C_9H_{12} can be viewed as diamond containing hydrogen. For example, hydrogen may interact with carbon to form polymers or benzene rings; it can further interact with stereo carbon to form cage molecules. **FIG. 17** shows the atomic structure of a typical a-C:H, wherein the fleck-like symbols are carbon atoms with graphite bonds, slashed domains are carbon atoms with diamond bonds and white symbols are hydrogen atoms. Sometimes different portions in an a-C:H may have different combinations, as shown in **FIG. 18**. The atomic groups in a diamond-like carbon (DLC) are very hard, which will produce internal stress as the atomic groups combine. The internal stress will continue to increase as the film thickness

is increased, eventually causing the departure of the film from a workpiece. The addition of hydrogen atoms in a diamond-like carbon (DLC) will lessen the internal stress. However, the introduction of hydrogen also decreases the density and hardness of the diamond-like carbon (DLC). The C—H network in an a-C:H may interlace with Si—O network, as shown in **FIG. 19**. Such substance with complex network (for example, a product called Dylyn) may have a reduced stress after introducing Si therein, but the hardness be lessened at the same time. Diamond-like carbon (DLC, a-C: H) films added with Si—O are more adhesive to a workpiece, and the frictional constants thereof are lower than that of diamond-like carbon (DLC). Sometimes metal atomic groups can be inserted into a-C:H to make it electrically conductive, as shown in **FIG. 21**. **FIG. 22** discloses the cross-section of a multi-layered diamond-like carbon (DLC) film, wherein the each layer can be as thin as 10 Å (about 6 layers of atoms), the content of each layer can be adjusted, and the total thickness is only 0.6 μm.

[**0118**] To grow the diamond granules, a process of core formation and expansion must be activated. An instrument of pressurization is therefore needed. However, direct diamond conversion needs very high temperature and pressure, and an ordinary instrument of pressurization can only make diamonds of small volume, not practical for industrial production. Therefore, it is necessary to use catalytic agents to lower the activation energy of diamond, so that diamond can be grown at lower temperature and pressure.

[**0119**] A catalytic agent must react with graphite, whereby the structure of the graphite becomes loose. However, the catalytic agent should not over-react with graphite, or it will form chemical compounds. Therefore, a suitable catalytic agent must effectively loosen the graphite structure but not react with the graphite.

[**0120**] The catalytic agents commonly used in the synthesis of diamond are transitional elements in a molten state. The d-electron of the transitional elements has a kinetic energy between s- and p-electron, and therefore they can interact with many other elements. If the d-orbit lacks electrons, the element thereof would attract the s- or p-electrons of other elements to form compounds. Therefore, the transitional elements close to the left side of the periodic table, such as Sc, Ti, V, are easy to form hydrides, carbides and oxides. If the d-orbit is filled, such as Cu and Zn, the elements thereof will not interact with hydrogen, carbon, nitrogen and oxygen.

[**0121**] Between these two extremes, the transitional elements such as Cr, Mn, Fe, Co, Ni will interact properly with carbon, resulting in making carbon in a molten state without forming compounds. This is exactly what we want for a suitable catalytic agent.

[**0122**] Further, carbon matter of a single element can be produced by physical vapor deposition (PVD), which is classified into two types as follows.

[**0123**] An arc plating method uses electric arc to gasify graphite, the carbon atoms of which become positive ions. The ions are accelerated by an electric field to shoot on a negatively biased workpiece, forming amorphous diamond or nano-crystalline diamond by mutual collisions.

[**0124**] Another means is a low current, high voltage sputtering method, whereby argon ions bombard a graphite target and eject carbon atoms onto a workpiece **4** to form a diamond-like carbon (DLC, a-C:H) film.

[**0125**] By the straight path of atoms, when arc plating (or called as ion plating) with high current and lower voltage is used, a higher energy is acquired and the current is larger. Meanwhile, since the atoms suffer from larger pressure and higher temperature, the ratio for forming amorphous diamond film of sp^3 or nano-crystallize diamond film is higher to a value of 85%. Moreover the hardness can achieve a value of 80 to 100 GPa which has superior wearing tolerance than the hardness of the DLC, a-C:H which has a hardness below 50 GPa.

[**0126**] On the other hand, when the above-mentioned sputtering method is adopted, the trajectory of the ejected atoms follows a scattering pattern, and the energy and the current are small. Therefore, the carbon atoms on the surface of the workpiece **4** cannot experience sufficient temperature and pressure. The diamond-like carbon (DLC, a-C:H) film thereby formed has a sp^3 ratio less than 50%.

[**0127**] **FIG. 23** shows that, in a vacuum chamber **7**, a carbon ion gun **5** of lower energy ion source directly arc-plates the surface of a workpiece **4** to form a diamond-like carbon (DLC, a-C:H) film. The film thereby formed is of loose structure and the adhesive force thereof is weak, as shown in **FIG. 26***a*.

[**0128**] **FIG. 24** shows that, in a vacuum chamber **7**, an argon ion gun **50** arc-plates a graphite target **70** and then sputters a workpiece **4** to form an amorphous diamond (DLC, a-D) film **60** thereon. The plated layer thereby formed is denser, as shown in **FIG. 26***b*. The best means, as shown in **FIG. 25**, is using an argon ion gun **50** to arc-plate a graphite target **70** in a vacuum chamber **7** and then sputters a workpiece **4** to form an amorphous diamond (DLC, a-D) film **61** thereon, and, at the same time, using another argon ion gun **51** to arc-plate the surface of the amorphous diamond (DLC, a-D) film **61** to make it denser, as shown in **FIG. 26***c*.

[**0129**] For enhancing the solidity of the amorphous diamond (DLC, a-D) film, an argon ion gun **52** and a methane ion gun **53** are used together in a high-vacuum chamber **71** to arc-plate the surface of a workpiece **4** at lower temperature (20-50° C.), as shown in **FIG. 27**.

[**0130**] Further, **FIG. 28** shows the scheme of an evaporation instrument, wherein a crucible **59** is disposed on a cooling water tank **58**. The crucible **59** is for placing a plating material **57**. The instrument is further provided with an electron gun **54** and an electromagnet-guiding device **56**. The electron gun **54** ejects an electron beam **55**, which is bent by the electromagnet-guiding device **56** to form a curved trajectory. The electron beam **55** heats up a plating material **57** such as Si and W, so that it can be evaporated into ions. In this operation, the electron gun **54** equipped with an electromagnet-guiding device **56** can avoid the evaporation sources being contaminated by the heater.

[**0131**] **FIG. 29** shows the combination of electron gun evaporation and carbon ion gun arc plating. That is, the evaporator **54** of the electron gun evaporates for a carbon ion beam **72**, which is then guided to penetrate the diamond-like carbon film (DLC) produced by the ion beam **73** from an ion gun **5**.

[0132] When sputtering is being performed, a plurality of targets of different contents can be used at the same time, and then an ion gun is used to bombard a workpiece. A film thus plated may have a complex content. **FIG. 30** shows three argon ion guns **81**, **82** and **83** respectively ejecting Y, Cu and Ba onto a target **84** and another oxygen ion gun **85** shooting the target **84** to form a high temperature superconducting film of ceramic Y, Cu, Ba and O.

[0133] When making an amorphous diamond (DLC, a-D) film, the kinetic energy of carbon ions has to be kept in a suitable range. If it is less than 100 eV, the carbon ions cannot form polymer substance with high hydrogen content, instead of diamond. If it exceeds 400 eV, the ions are easy to get reflected from the target, and pits will be formed at the striking points. And it is a further effect than the heat produced by excessively high energy ions would transform the amorphous diamond (DLC, a-D) layer already formed into graphite. Therefore, a suitable range of ion kinetic energy is from 100 to 300 eV, preferably close to 150 eV. As the ion kinetic energy is increased from low to high, the hydrogen content of the film becomes lower, and the film structure will transform from transparent soft polymer to opaque hard amorphous diamond (DLC, a-D). However, if the energy is too high, the amorphous diamond (DLC, a-D) will transform into opaque soft graphite.

[0134] **FIGS. 31***a*, **31***b* and **31***c* show the influence of the workpiece bias voltage on the amorphous diamond (DLC, a-D) films, wherein the solid circles represent measured values, the empty circles represent calculated values of the hardness of the sum of total atoms, squares represent the calculated values after the removal of graphite bond atoms and triangles represent the calculated values after the removal of diamond bond atoms. **FIG. 31***a* indicates a decrease of hydrogen content as the workpiece voltage is increased. **FIG. 31***b* indicates the variation in the contents of different carbon bonds as the workpiece voltage is increased. **FIG. 31***c* indicates the variation in carbon hardness as the workpiece voltage is increased. As shown in those figures, the hardness of amorphous diamond (DLC, a-D) films almost solely depends on the sp^3 bond carbon atoms.

[0135] **FIGS. 32***a*, **32***b* and **32***c* show the influence of the carbon sources on the amorphous diamond (DLC, a-D) films, wherein solid circles represent C6H6 gaseous carbon source, empty circles represent CH4 gaseous carbon source and triangles represent C4H10 gaseous carbon source. **FIG. 32***a* indicates a decrease of hydrogen content as the workpiece voltage is increased. **FIG. 32***b* indicates an increase of density as the workpiece voltage is increased. **FIG. 32***c* indicates a decrease of kinetic energy gap as the workpiece voltage is increased. **FIG. 32***d* indicates the variation in hardness as the workpiece voltage is increased. The kinetic energy produced by the bias voltage is about two fifths of the bias voltage.

[0136] **FIG. 33***a* to **33***d* show the influence of the carbon ion kinetic energy on the amorphous diamond (DLC, a-D) films, wherein the workpiece is Si (100), and the plating temperature is room temperature. **FIG. 33***a* shows that the ratio of sp^2 graphite bonds is the lowest as the kinetic energy is increased to 100-150 eV. **FIG. 33***b* shows that the surface roughness is the smoothest as the carbon ion kinetic energy is increased to 100-1000 eV.

[0137] **FIG. 33***c* shows that the density of the amorphous diamond (DLC, a-D) film is the highest (therefore, hardest) as the carbon ion kinetic energy is increased to 100-150 eV. **FIG. 33***d* indicates that the shorter the length of a carbon bond and the upper the associated angle are, the higher the ratio of sp^3 diamond bonds.

[0138] **FIG. 34** shows that, when the kinetic energy of carbon ions is ranged in 30-120 eV, the sp^3 ratio is the highest. **FIGS. 35***a, b* and *c* respectively demonstrate the influence of workpiece temperature on the rigidity, the density and the surface roughness of the amorphous diamond (DLC, a-D) film. When the temperature exceeds 150° C., the rigidity (**35***a*) and the density (**35***b*) will drop drastically, and the surface roughness increases substantially.

[0139] Therefore, besides the ion kinetic energy, gas pressure, temperature and the workpiece material also affect the property of the amorphous diamond (DLC, a-D) film; however, their influences are secondary. For example, as the gas pressure is increased, the kinetic energy of the ions becomes lower, and, as the temperature is increased, the kinetic energy becomes higher. Adopting heavier gaseous carbon source (such as benzene) can accelerate the plating rate. However, since pure carbon ions are smaller than hydrocarbon ions, the ion kinetic energy required for forming diamond is lower, which is 30-80 eV. Because carbon ions do not contain hydrogen atoms, the amorphous diamond (DLC, a-D) thereby formed is of higher density and greater hardness. The amorphous diamond (DLC, a-D) without hydrogen atoms can have an sp^3 bonds ratio as high as 85%. Therefore, it is rather close to natural diamond. Compared with other methods such as sputtering and evaporation plating that produce ions having too low a kinetic energy, the arc plating is the most effective method to form amorphous diamond (DLC, a-D) films.

[0140] The property of the amorphous diamond (DLC, a-D) film can be controlled by carbon sources, gas and workpiece parameters. **FIG. 36** shows the variations in gas pressure and in electric voltage can produce opposite effect on the structure of the amorphous diamond (DLC, a-D) film. **FIG. 37** shows the determination of the structure of the amorphous diamond (DLC, a-D) film by temperature and ion energy in the plating process. The structure of the amorphous diamond (DLC, a-D) film varies from a loose micro-crystal domain P having a plurality of porous substructures **P1** divided by small hollow micro-crystals, a denser fiber domain T formed by crowdedly packed fiber crystal substructures Ti, a solid crystal column domain C consisting of column-like crystal substructures **C1** and a lumped re-crystallization domain R in which multiple crystal granules **R1** are displayed.

[0141] The physical vapor deposition (PVD) adopting cathode arcs is a mature technology and can produce a variety of films, as shown in Table 5.

TABLE 5

Types of Films	
metals	Cu, Al, Ti, Cr, Zr, Ta, W, Mo, Hf
alloys	SS-304, Ti_6Al_4V, High Ni Alloys, Inconel, MCrAly's, Nichrome
nitrides	TiN, ZrN, HfN, Ti_6Al_4VN, TaN, TiZrN, TiAlN
carbides	TiC, RaC, WC, ZrC
hydrocarbon	TiCN, (Ti—Zr)CN, ZrCN, TaCN
oxides	CuO, TiO_2, ZrO_2, Al_2O_3

[0142] The most effective means for making an amorphous diamond film (DLC, a-D) is graphite cathode arc plating. **FIG. 38** shows the structure of a cathode arc plating

instrument, wherein a graphite cathode **91** is capable of providing electric arc. An electromagnet coil **93** is installed close to the arc plating head **92** of the graphite cathode **91**, which can guide the cathode arc to plate a workpiece **4** in a vacuum chamber **95**. The workpiece **4** is located on a water-cooling unit **96** in the vacuum chamber **95** for lowering the working temperature of the workpiece **4**. The workpiece **4** is charged with a cathode current, and the vacuum chamber **95** is further provided with entrance **97** of argon or hydrogen gas. The vacuum chamber **95** further includes an exit **98** for connecting a vacuum pump. **FIG. 38***b* shows a structure of plasma arc plating, wherein a graphite cathode **910** and electromagnet coils **930** are installed to provide a controlled passage for guiding plasma wave **940** to the surface of a workpiece **400**. The workpiece **400** is charged with a cathode current. **FIG. 39** shows cathode arc produced by the structure of **FIG. 38***a* being guided to the workpiece **400**. The power density of the cathode arc can attain 10,000,000 watt per unit area, capable of evaporating graphite quickly and thereby producing a large amount of positive carbon ions for ejection toward a negative charged place. As shown in **FIG. 40***a*, when a cathode arc is directed to a graphite target **70**, a negatively charged point **74** on the surface of the graphite target **70** forms a plasma domain **75** where electrons **76**, ions **77**, neutral atoms **78** and micro-drops **79** coexist. The micro-drops **79** are in a molten state.

[**0143**] The ionization percentage of cathode-arc carbon is as high as 50-100%, and the kinetic energy thereof reaches 10-100 eV. Therefore, the hardness of the amorphous diamond film (a-D) thus formed is close to that of diamond. It is further advantageous that the growth rate of the amorphous diamond film (a-D) plated by cathode arc is fast, attaining 30 μm/hr. If carbon ions are implanted into the surface layer of the component before the arc plating, the adhesive force of the amorphous diamond film (DLC, a-D) with the component surface can be significantly enhanced.

[**0144**] Cathode arc can plate amorphous diamond films (DLC, a-D) on most of conductors (such as Al, Cu, Fe), and the component temperature can be maintained below 150° C. However, when the graphite electrode turns into gas, many micro-particles, lumped groups of carbon atoms, are ejected and may be attached to the component. To prevent such attachments, mass spectrometer is used to form a magnetically controlled passage for turning the positive carbon ions toward the target, leaving micro-particles being collected due to their greater mass. The mass-spectrometer curved magnetic tube assures that the amorphous diamond film (DLC, a-D) contains no micro-particles.

[**0145**] In summary, the method according to the present invention, especially the physical vapor deposition, may plate an amorphous diamond film (a-D) on a bearing component so that the hardness of the film thereof can attain 80-100 GPa, which is twice of the diamond-like carbon film produced by traditional methods. Therefore, the components thus produced are much enhanced in rotational stability and precision, wearing resistance and durability.

[**0146**] The present invention is thus described, and it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the present invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

What is claimed is:

1. A method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure, comprising the steps of:

selecting at least a first component of a plurality of pivotally connected bearing components supporting fluid dynamic-pressure, said first component having a predetermined surface pattern;

forming an opaque and hard amorphous diamond (DLC, a-D) film on the pivotal surface of said first component by physical vapor deposition (PVD) using ion plating, said amorphous diamond film covering said pattern of said first component and/or the corresponding pivotal surface of a second component; and

combining said first component coated with an amorphous diamond (DLC, a-D) film and said second component so that the space between said first and second components form a trough for filling a fluid, whereby said pivotal surfaces of said first and second components can be urged with a pressure distribution as a fluid is filled in said trough.

2. The method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure of claim 1 wherein said first component is a spindle and said pivotal surface thereof consists of a rod surface portion and an inclined surface portion of a bulged round terminal.

3. The method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure of claim 1 wherein said first component is a sleeve and said pivotal surface thereof consists of the inner wall portion of a spindle hole and an inclined inner surface portion of a round terminal indentation.

3. The method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure of claim 1 wherein said surface pattern is selected from a bulged pattern and a notched pattern.

5. The method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure of claim 1 wherein the kinetic energy of said ion plating is gradually increased in a ranged of 150-250 eV.

6. The method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure of claim 1 wherein the sp^3 binding of said amorphous diamond (DLC, a-D) film exceeds 85%.

7. The method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure of claim 1 wherein the hardness of said amorphous diamond (DLC, a-D) film is 80-100 GPa.

8. The method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure of claim 1 wherein said ion plating is directly injecting cathode arc on said components.

9. The method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure of claim 8 wherein said cathode arc is graphite cathode arc.

10. The method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure of claim 8 wherein the temperature of said components are maintained under 150° C.

11. The method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure of claim 8 wherein a catalytic agent is added to react with said graphite in said process of ion plating.

12. The method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure of claim 11 wherein said catalytic agent is selected from the group of molten Cr, Mn, Fe, Co and Ni elements.

13. The method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure of claim 8 wherein said components are selected from metal, ceramic and plastic.

14. The method for manufacturing bearing components of high precision and hardness supporting fluid dynamic-pressure of claim 1 wherein said fluid is selected from air and lubricating oil.

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