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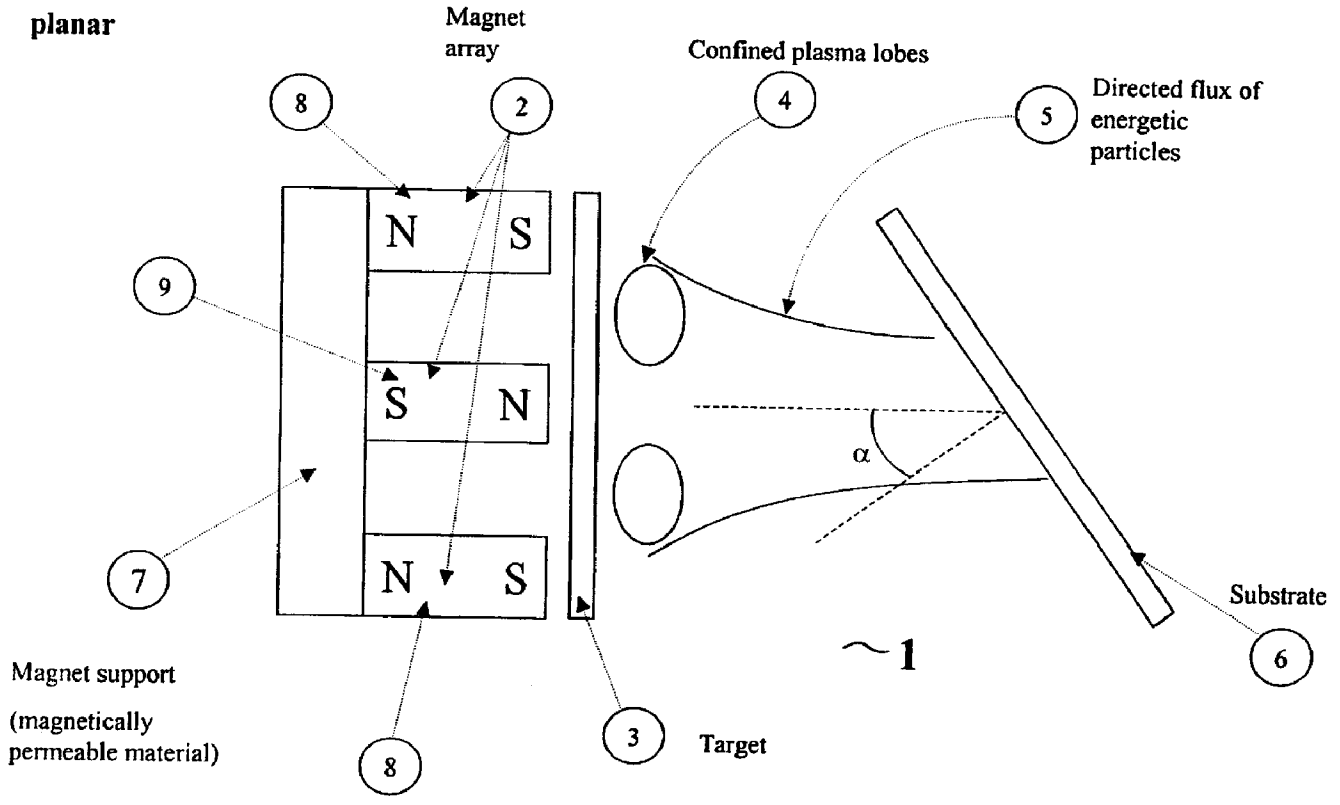
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(54) Titre : PROCEDE ET APPAREIL POUR DEPOSER DES REVETEMENTS A TEXTURE BIAXIALE
(54) Title: METHOD AND APPARATUS FOR DEPOSITION OF BIAXIALLY TEXTURED COATINGS



(57) Abrégé/Abstract:
A deposition method and apparatus is described for manufacture of biaxially textured coatings where the biaxial texturing is induced by bombardment during deposition by energetic particles under a specifically controlled angle. The method for deposition of biaxially textured coatings onto a substrate (6) utilizes one or more magnetron sputtering devices (1) generating both a flux of material to be deposited and a flux (5) of energetic particles with a controllable direction and thereby controllable angle of incidence on the substrate (6). The magnetron sputter source (1) generates a beam (5) of energetic particles together with material to be

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(57) Abrégé(suite)/Abstract(continued):
deposited, said source being adapted so that said beam (5) is directed towards a substrate (6) under an angle controlled in such a way that a biaxially textured coating is deposited on the substrate (6).

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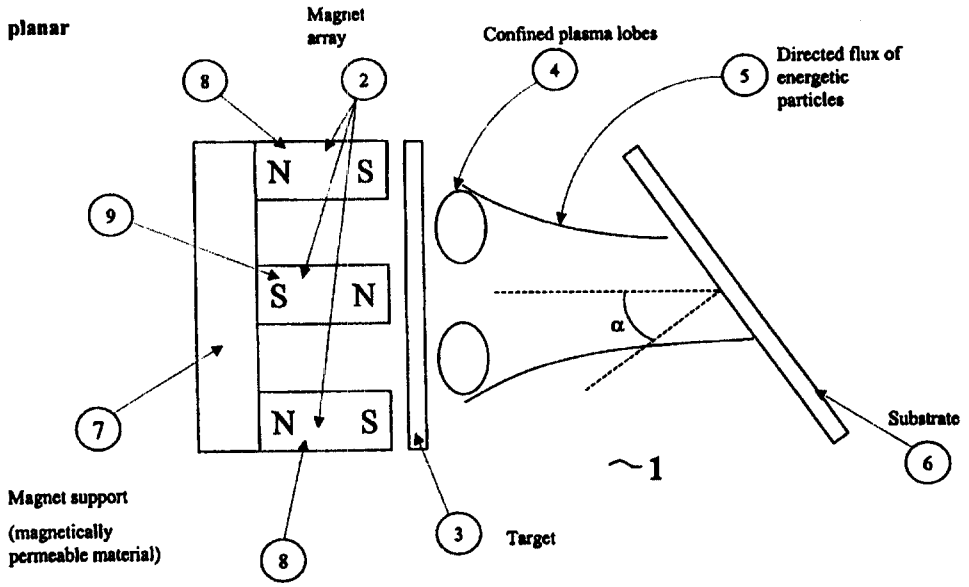
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(54) Title: METHOD AND APPARATUS FOR DEPOSITION OF BIAXIALLY TEXTURED COATINGS



(57) Abstract

A deposition method and apparatus is described for manufacture of biaxially textured coatings where the biaxial texturing is induced by bombardment during deposition by energetic particles under a specifically controlled angle. The method for deposition of biaxially textured coatings onto a substrate (6) utilizes one or more magnetron sputtering devices (1) generating both a flux of material to be deposited and a flux (5) of energetic particles with a controllable direction and thereby controllable angle of incidence on the substrate (6). The magnetron sputter source (1) generates a beam (5) of energetic particles together with material to be deposited, said source being adapted so that said beam (5) is directed towards a substrate (6) under an angle controlled in such a way that a biaxially textured coating is deposited on the substrate (6).

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METHOD AND APPARATUS FOR DEPOSITION OF BIAXIALLY TEXTURED COATINGS

BACKGROUND

This invention relates to deposition methods of bi-axially textured coatings where the bi-axial texturing is induced by bombardment during deposition by energetic particles under a specifically controlled angle.

A bi-axially textured coating is a coating in which two crystallographic directions are parallel in adjacent grains. It is a known fact that a flux of energetic particles directed, during deposition, under an angle less than 90^0 with respect to the substrate surface can induce bi-axial texturing in a coating. It is also known that, depending on the crystal structure of the material to be deposited, there will be an optimal angle of incidence for the energetic particles which will result in the highest degree of bi-axial texturing, L.S. Yu, J.M. Harper, J.J. Cuomo and D.A. Smith, J. Vac. Sci. Technol. A 4(3), p. 443, 1986, R.P. Reade, P. Berdahl, R.E. Russo, S.M. Garrison, Appl. Phys. Lett. 61(18), p. 2231, 1992, N. Sonnenberg, A.S. Longo, N.J. Cima, B.P. Chang, K.G. Ressler, P.C. McIntyre, Y.P. Liu, J. Appl. Phys. 74(2), p. 1027, 1993, Y. Iijima, K. Onabe, N. Futaki, N. Tanabe, N. Sadakate, O. Kohno, Y. Ikeno, J. Appl. Phys. 74(3), p. 1905, 1993, X.D. Wu, S.R. Foltyn, P.N. Arendt, D.E. Peterson, High Temperature Superconducting Tape Commercialization Conference, Albuquerque, New Mexico, July 5-7, 1995.

Several deposition methods have been described for the preparation of bi-axially textured coatings. An important draw-back of these deposition methods is the fact that the supply of the material to be deposited and the flux of energetic particles are generated by distinct sources. This requires that both sources are in the same vacuum chamber. This may result in incompatibility between the sources requiring some compromises on operation ranges to achieve compatible working. Generally an ion source is used to generate a flux of energetic ions directed under a controlled angle towards the substrate and the coating growing on it. Different deposition apparatus (e.g. ion beam sputtering, pulsed laser deposition, e-beam deposition, magnetron sputtering, see the above references) have been used to

generate the material to be deposited. This need for two distinct sources for the generation of the material to be deposited and the flux of energetic particles, makes the deposition method more difficult to master, more difficult to control, less suited for large scale application and more expensive.

Effective ways for depositing material with energetic particle bombardment (e.g. by ions) during deposition using plasma assisted deposition methods have been described. These plasma assisted deposition or ion assisted deposition methods are widely used for increasing density of coatings, increasing hardness of coatings, controlling stress in coatings, influencing optical properties in coatings, etc. The use of magnetron sputtering apparatus for these purposes has also been described. It has also been described that the efficiency of the magnetron sputtering source can be greatly influenced by changing the magnet field configuration. W. D. Sproul for example has described a method for increasing the density of energetic particles at the substrate by changing the magnet field configuration in Material Sciences and Engineering, vol. A136, page 187, (1993). Savvides and Katsaros in Applied Physics letters, vol. 62, page 528 (1993) and S. Gnanarajan et. alia in Applied Physics Letters, vol. 70, page 2816, (1997) describe a way of decreasing the energetic particle bombardment in the substrate and the growing coating. In all these methods, however, no control of the direction of the energetic particles and the angle of incidence on the substrate is described and are, therefore, not suitable for biaxial texturing

The use of an unbalanced magnetron for ion assisted deposition has been described for different applications, see B. Window, J. Vac. Sci. Technol. A 7(5), p. 3036, 1989, and B. Window, G.L. Harding, J. Vac. Sci. Technol. A 8(3), p. 1277, 1990.

There remains therefore a need for a deposition method and apparatus for biaxially textured coatings which involves simpler equipment. Such a method and apparatus should ideally be easy to master and control and well suited for large scale application. Prior to the present invention, no such method or apparatus for biaxial texturing existed using a single source for the material to be deposited and

the flow of energetic particles.

Accordingly, it is the object of this invention to provide a method for depositing bi-axially textured coatings which is simpler to carry out and control as well as an apparatus for carrying out the method.

SUMMARY OF THE INVENTION

The present invention provides a method for deposition of bi-axially textured coatings onto a substrate using one or more magnetron sputtering devices as a source of both the particles to be deposited and a directed flux of energetic particles inducing the bi-axial texturing.

The present invention also includes use of an unbalanced magnetron including a sputter gas and a target for sputtering target material onto a substrate, to generate an ion beam by ambipolar diffusion, said ion beam consisting essentially of ions of the sputter gas.

The present invention also provides a method for deposition of bi-axially textured coatings onto a substrate utilising one or more magnetron sputtering devices generating both a flux of material to be deposited and a flux of energetic particles with a controllable direction and thereby controllable angle of incidence on the substrate.

The present invention also includes a magnetron sputter source generating a beam of energetic particles together with material to be deposited directed towards a substrate under an angle controlled in such a way that a bi-axially textured coating is deposited on the substrate.

By using a single source for the ion beam used for texturing the coating on the substrate and also for depositing the particles onto the substrate to form the coating, the problems with incompatibility between different sources in one vacuum chamber for these two different beams is eliminated.

The dependent claims define further independent embodiments of the present invention. The present invention will now be described with reference to the following drawings.

In one broad aspect, there is provided a method for deposition of bi-axially textured coatings onto a substrate using a magnetron sputtering device as a source of both the particles to be deposited and a directed flux of energetic particles directed against the substrate inducing the bi-axial texturing, wherein the magnetron sputtering device includes a target and further comprising the step of unbalancing the magnetron so that the magnetic flux generated at an outer portion of the target differs from the magnetic flux generated at an inner portion of the target thereby generating ambipolar diffusion of the flux of energetic particles, the directed flux of energetic particles comprising electrons and the electron energy being controlled so that they do not initiate or support a plasma at the surface of the substrate sufficient to disturb the directionality of the directed flux of energetic particles, and controlling the direction and thereby controlling the angle of incidence onto the substrate of the directed flux of energetic particles, the flux of energetic particles being free of a target material.

In another broad aspect, there is provided a magnetron sputter source generating a beam comprising a directed flux of energetic particles together with material to be deposited, said source being adapted so that said beamflux is directed towards a substrate under an angle controlled in such a way that a bi-axially textured coating is deposited on the substrate, the source further comprising a target and a magnet assembly including one magnet array located towards an inner portion of the target and generating a magnetic field of one magnet pole and a further magnet array located towards an outer portion of the target and generating a magnetic field of the other pole, said magnet assembly being adapted so that magnetic field lines

generated by the outer magnet array cut the substrate and an ambipolar flow of energetic particles is directed against the substrate, and the directed flux of energetic particles comprising electrons and the electron energy being controlled so that they do not initiate or support a plasma at the surface of the substrate sufficient to disturb the directionality of the directed flux of energetic particles, and the magnetron sputter source furthermore comprising means for controlling the direction and thereby controlling the angle of incidence onto the substrate of the directed flux of energetic particles, the flux of energetic particles being free of a target material.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic representation of a planar magnetron sputtering source in accordance with one embodiment of the present invention.

Fig. 2 is a schematic representation of a rotating cathode magnetron sputtering source in accordance with one embodiment of the present invention.

Figs. 3a and b are schematic representations of the magnetic field lines of a planar and a rotating magnetron sputtering source in accordance with the present invention.

Figs. 4a - d are schematic representations of electrostatic deflection shields which may be used with any of the embodiments of the present invention.

Figs. 5 and 6 are schematic representations of multiple planar and rotating cathode sputtering sources in accordance with an embodiment of the present invention.

Fig. 7 is a schematic representation of a planar magnetron sputtering source in accordance with another embodiment of the present invention.

DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

The present invention will be described with reference to certain specific embodiments and certain drawings but the present invention is not limited thereto but only by the claims.

The method for the deposition of bi-axially textured coatings according to the present invention, that will be explained in detail below, may be used for coating stationary substrates, rotating substrates, batches of substrates and in continuous coating processes. The magnetron sputter device or devices used, may be any suitable sputtering magnetron, e.g. magnetrons with planar circular targets or planar rectangular targets, or rotatable devices. General aspects of the substrate mounting and/or substrate movement, of the sputtering devices and other components required to construct and operate a deposition system, such as the vacuum chamber, apparatus for mounting and cooling the target, apparatus for

electrically connecting the target cathode to the power supply, ground shields to prevent unwanted sputtering of certain parts of the sputtering device and to prevent arcing, etc. are well known to persons having skill in the art. Therefore, these components are not described herein in detail. Persons skilled in the art will also recognise the need for cleaning the substrate before deposition, e.g. by sputter cleaning, exposure to a glow discharge, exposure to an Electron Cyclotron Resonance plasma or a plasma generated in another way, heating in vacuum, etc.

As shown schematically in Fig. 1 for a planar sputtering magnetron 1, a target material 3 is located in a vacuum chamber (not shown) with a magnet assembly 2 on one side thereof and a substrate 6 to be sputter coated located on the other side thereof. The atmosphere of the vacuum chamber may include sputtering gases such as argon and may also include reactive gases such as oxygen or nitrogen when reactive sputtering is to be carried out. Substrate 6 may be a stationary plate or a moving strip of material. The target material 3 may be cooled, e.g. by a water circuit (not shown) which is not accessible from the vacuum chamber. The negative pole of an electrical supply (not shown) is connected to the target 3. The combination of the crossed electric and magnetic fields above the target 3 generate a plasma 4 above the target 3. The plasma 4 is generally in areas of high magnetic field generated by poles 8, 9 of the magnet assembly 2. As shown the magnet assembly 2 may include a central magnet array 9 which has one pole directed towards the target 3 (either north or south) and outer magnet arrays 8 which have the other pole (south or north) directed towards the target 3. If the target 3 is circular, the magnet arrays 8 and 9 may also be circular. The poles 8, 9 may be located on a soft magnetic material keeper 7, e.g. soft iron.

Fig. 2 is a schematic representation of a rotating cathode sputtering magnetron 1 in accordance with the present invention. A generally cylindrical target 3 is provided in a vacuum chamber (not shown) with sputtering gas or gasses as previously described. A magnet assembly 2 is provided within the target 3 and a means for generating relative motion between the target 3 and magnet assembly 2 is also provided. Usually the target 3 is rotated and the magnet assembly 2 is held

still. An electric supply (not shown) holds the target 3 at a negative potential. The poles 8, 9 of the magnet assembly 2 are located close to the inner surface of target 3 and generate magnet fields above the target 3. These magnet fields with the crossed electric field generate a plasma 4 usually in the form of a "race-track" above the surface of the target 3. Opposite the target 3 and in the vacuum chamber a substrate 6 is located. Substrate 6 may be a stationary plate or a moving strip of material.

In order to obtain the object of the invention, described above, the magnetron sputter device 1 and the substrate 6 may be configured as schematically represented in Figs. 1 or 2, with a flux 5 of energetic particles, coming from the magnetron sputter device 1, directed toward the substrate 6 under a specific angle α that will give the maximum degree of bi-axial texturing. The angle α depends on the material to be deposited. For a cubic material in the coating, for instance, α will be approximately equal to 54.74^0. The flux 5 of energetic particles is substantially only generated by the sputtering device 1 which provides not only this flux 5 but also sputters the coating onto the substrate 6 which is to be textured. The flux 5 may be substantially free of any ions from the target material. The flux 5 may consist substantially of ionised gas atoms or molecules, e.g. from the sputter gas.

The directed flux 5 of energetic particles from a magnetron sputter device is obtained in accordance with the present invention by using an unbalanced magnet configuration 2 that causes secondary electrons emitted at the target 3 and electrons generated in the plasma 4 to move along the magnetic field lines toward the substrate 6, resulting, through ambipolar diffusion, in a directed flux 5 of energetic ions toward the substrate 6. In a balanced magnetron most of the field lines leaving one pole of the magnet assembly are collected on the opposite pole of the magnet assembly. In an unbalanced magnetron some of the magnetic filed lines from one pole are not collected on the other pole. Unbalancing may be achieved in a variety of ways, e.g. by using magnets of different strengths, by using magnets of different sizes, by weakening part of the magnet assembly by placing magnets of opposed polarity close to one of the poles of the assembly, by locating a competing

electromagnet close to one of the poles. As shown schematically in Figs. 3a or b, the magnet assembly 2 of the magnetron sputter device 1, either planar (Fig. 3a) or rotating cathode (Fig. 3b), in accordance with the present invention is configured in such a way that a substantial number of magnetic field lines 11 emanating from the outer magnet array 8 in the magnet assembly 2, cross the substrate surface. This can be achieved by considerably stronger outer magnets 8 compared with inner magnets 9. The result of unbalancing the magnetron 1 in this way is to produce a three dimensional volume 12 which is defined by the field lines 11 of the outer magnets 8 which do not collect on the inner magnets 9. Some electrons from the plasma 4 follow the field lines 11 thereby also "dragging" with them a flow of high energy positive ions, typically ions of the surrounding gasses. Such a flow may be called an ambipolar flow. The flux 5 is directed towards the substrate 6 within and around the volume 12 and can texturise the coating which is being sputtered onto the substrate 6 by normal sputtering action. Hence, in accordance with the present invention the flux 5 has a definable direction.

In accordance with any embodiment of the present invention, the energy of the electrons following the field lines 11 towards the substrate is preferably not such as to cause significant ionisation. In particular, it is preferred if the electrons in the flux 5 do not initiate nor support a significant plasma at, or close to the surface of the substrate 6. By a significant plasma is meant a plasma which may disturb the directionality of the high energy ions in the flux 5 which induce the surface texturing of the coating. It is this directionality and its relationship to the crystal structure of the deposited coating which allows texturing of this coating. Hence, the ion beam 5 generated in accordance with the present invention should impinge on the substrate 6 at a defined angle. It is anticipated that the electron energy in the flux 5 should preferably be greater than 30 eV, more preferably greater than 50 eV and most preferably between 50 and 70 eV. If a disturbing plasma develops at the substrate surface, its effects may be reduced by changing the degree of unbalance of the magnetron 1 so that the energy of the particles, particularly the electrons in the flux 5 is reduced.

As shown schematically in Figs. 4a - d, the directed flux 5 of energetic particles from an unbalanced magnetron sputter device 1 can be enhanced by using electrostatic deflection shields 13 that increase the number of electrons reaching the substrate 6 by moving along the magnetic field lines 11. The deflection shields 13 are preferably held at a negative potential in order to repel electrons. The deflections shields 13 should preferably not extend too deeply into the region 12 otherwise they may start to trap positive ions in the flux 5. Some examples of such deflection shield configurations are schematically shown in Fig. 4 in cross-section for a planar magnetic configuration. For example, in Fig. 4a straight shields 13 may be used which are oriented perpendicular to the target 3. If the target 3 is a circular target, the shields 13 may be in the form of a cylinder. In Figs. 4b and c the shields 13 are "V" shaped in cross-section or inclined inwards towards the substrate, respectively. Such shields 13 may assist in channelling any electrons with a wide trajectory towards the substrate 6. Alternatively, the shields may be inclined outwardly as shown schematically in Fig. 4d, thus concentrating the electron flow close to the target 3. The deflection shields 13 shown in Figs. 4a to d can also be used with rotatable magnetron devices.

Any inhomogeneity of the coating deposition on the substrate 6 in the configurations schematically shown in Fig. 1 and in Fig. 2 may be overcome by using multiple unbalanced magnetron sputter devices 1 within the same vacuum chamber. The flux 5 of energetic particles from each of these devices is preferably directed so that it reaches the substrate 6 at the same angle α to the substrate 6 in order to avoid competing texturing processes. An embodiment of the present invention with two unbalanced magnetron devices 1 is shown schematically in Fig. 5 for a planar magnetron and in Fig. 6 for a rotating cathode magnetron.

In this configuration the normal to the substrate surface and the two normals to the targets 3 in the magnetron sputter devices 1 are in the same plane. When more than two unbalanced magnetron devices 1 are used, the configuration will be determined by the crystal structure of the material of the growing coating on the substrate 6 and the desired bi-axially textured structure. With four devices e.g. for a

cubic material where bi-axially texturing with the (100) axis perpendicular to the substrate normal and another crystallographic axis (e.g. (111) or (110)) parallel in adjacent grains, two unbalanced magnetron devices may be added to the above configuration of Fig. 5 or 6, with the plane formed by the normals to the surfaces of the target 3 and the substrate 6 being perpendicular to the corresponding plane of the two original devices.

For material with a cubic crystallographic structure e.g. it is known that the optimal angle of incidence with respect to the substrate surface normal for energetic particles is equal to the inverse tangent of the square root of 2, which approximately equals 54.74^0, in order to obtain bi-axial texturing with the crystallographic (100) plane of all the grains in the coating perpendicular to the substrate surface and another crystallographic direction (e.g. (111)) parallel in adjacent grains in the coating.

A further embodiment of the present invention is shown schematically in Fig. 7, in which an additional magnet 10 is positioned behind the substrate 6 in order to influence the flux of energetic particles 5 directed towards the substrate 6. Using the configuration shown in Fig. 7, field lines emanating at the outer magnet array 8 behind the target 3 will arrive at the magnet 10 behind the substrate 6 and the magnetic field will be more focussed. This will result in a focussing of the plasma flux and a better control of the direction of the plasma flux. The addition of a magnet 10 behind the substrate 6 in this configuration will result in an increase of the magnetic field at the substrate 6. This increase in magnetic field will result in an increased gyrating speed of the electrons and because of conservation of energy in a decreased speed parallel to the field lines. This may also result in a decrease in the number of energetic ions being dragged along by ambipolar diffusion. The energy of these ions may also be reduced. Depending the amount of energetic particles needed and the energy needed for achieving bi-axial texturing of a specific coating, such an additional magnet 10 behind the substrate 6 may be used to fine-tune the biaxial texturing in accordance with the present invention. The magnet 10 may be a controllable electromagnet.

Experiments have been performed with the flux of energetic particles from an unbalanced magnetron sputter device in accordance with the present invention. During the experiments, a sputter source similar to that shown in Fig. 1 was used. The magnet array was configured in such a way that the magnetic flux of the outside magnet 8 was much higher than the magnetic flux of the inside magnet 9. In this way a strongly unbalanced magnetron was achieved with magnetic field lines emanating at the outside magnet 8 crossing the substrate 6. As described below, this magnetic field configuration generated a flux of energetic particles towards the substrate 6. Three different magnet arrays were examined: one with a ratio of the outside magnetic flux to the inside magnetic flux of 9/1, one with a ratio of 4/1 and one with a ratio of 2/1.

The electrons generated at the target 3 and in the plasma 4 gyrate around field lines and are directed along these field lines toward the substrate 6. By ambipolar diffusion, ions are dragged along and a directed flux of ions and neutral particles (resulting from neutralisation of ions) is generated. From measurements with a Faraday cup in an Electron Cyclotron Resonance plasma, that is also based on ambipolar diffusion, it is known that depending on the gradient of the magnetic fields and the total gas pressure these ions (and neutral particles) can achieve energies from 10 eV to 70 eV. Similar to visual observations with ECR plasmas, a luminous plasma flux could be observed with the unbalanced magnetron. The form of this plasma flux clearly corresponded with the magnetic field line pattern and for the three different magnet arrays three different shapes were observed.

With a highly unbalanced magnetron (ratio 9/1) a directed flux of energetic particles was achieved and the electrons travelling along the fields did more than just ionise the gas atoms. The influence of the total gas pressure on the lateral distribution of the deposition speed of metallic Zr+Y layers with different compositions was examined. During these experiments RF sputtering was performed with an input power of 100 Watt, a target - substrate distance of 50 mm, an Ar-pressure between 0,2 Pa and 0,7 Pa, and without substrate heating or substrate cooling. For these experiments glass substrates were used. In the

configuration with a ratio of 2/1 for the magnetic flux, the deposition speed was somewhat reduced (~ 10%) by reducing the total gas pressure from 0,7 Pa to 0,2 Pa. The lateral distribution didn't change as a function of the gas pressure. In the case of the configuration with magnetic flux ratio of 9/1 however the deposition speed was much more reduced by reducing the pressure in the centre of the substrate (~ 35%) than at the edges of the substrate (~ 15%). This indicates that at the centre, resputtering of the growing film is occurring. The area with the strongest resputtering correspond with the area where the directed plasma flux reaches the substrate 6. These experiments show that the energy of the particles in the plasma flux is high enough (probably >50eV) to cause resputtering.

Due to the directionality of the flux of energetic particles, the incidence of energetic particles on a growing film under a controlled angle could be examined. These experiments were performed with both DC and RF sputtering with an input power between 50 and 25 Watt. The target-substrate distance was varied between 6,5 cm and 13,5 cm. A gas mixture of about 150 sccm Ar and 10 sccm O_2 was used at a total gas pressure of about 0,4 Pa. Yttria Stabilised Zirconia layers were deposited by sputtering from a metallic Zr+Y target with different compositions (from Zr/Y = 85/15 to Zr/Y = 55/45) in a reactive process. Most of the layers were deposited with an angle of 55° between the plasma flux and the substrate normal. From X-Ray Diffraction pole figure measurements, bi-axial texturing occurred on both metallic (NiFe, Ti, Fecralloy™) and glass substrates. With a magnetic flux ratio of 9/1 Full Width at Half Maximum values of ~ 11° for the psi-angle (characteristic for out of plane orientation) and ~ 22° for the phi-angle (characteristic for the in plane orientation) were obtained on glass substrates. With the 9/1 ratio and metallic substrates less bi-axial texturing was observed (FWHM psi ~ 25° / FWHM phi ~ 30°=, which might be caused by the higher surface roughness compared to glass. At a magnetic flux ratio of 4/1 the bi-axial texturing was somewhat reduced, but still clearly present.

Decreasing the target substrate distance resulted in an increased energetic particle bombardment. Using RF sputtering instead of DC sputtering also

resulted in an increased particle bombardment. At small target substrate distances and with high power RF sputtering, such a severe particle bombardment could be obtained that the layer being deposited was completely sputter etched, resulting in a negative deposition speed.

These experiments demonstrate that bi-axial texturing is produced by directing the energetic particle flux generated by ambipolar diffusion in a strongly overbalanced sputter source under a controlled angle towards the substrate. By tuning the different parameters involved, it is possible to optimise the process and obtain a high degree of bi-axially texturing with a reasonably high deposition speed as well as a scalable process.

CLAIMS:

1. A method for deposition of bi-axially textured coatings onto a substrate using a magnetron sputtering device as a source of both the particles to be deposited and a directed flux of energetic particles directed against the substrate inducing the bi-axial texturing, wherein the magnetron sputtering device includes a target and further comprising

the step of unbalancing the magnetron so that the magnetic flux generated at an outer portion of the target differs from the magnetic flux generated at an inner portion of the target thereby generating ambipolar diffusion of the flux of energetic particles, the directed flux of energetic particles comprising electrons and the electron energy being controlled so that they do not initiate or support a plasma at the surface of the substrate sufficient to disturb the directionality of the directed flux of energetic particles, and

controlling the direction and thereby controlling the angle of incidence onto the substrate of the directed flux of energetic particles, the flux of energetic particles being free of a target material.

2. The method according to claim 1, characterized in that the ratio of the magnetic flux at the outer portion of the target to the inner portion is at least 4 to 1.

3. The method according to any of claims 1 to 2, wherein the magnetron includes a sputter gas and the directed flux of energetic particles consists essentially of ions from the sputter gas.

4. The method according to any of claims 1 to 2, wherein the electrons in the flux are directed towards the substrate by following lines of force of the magnetic field of the unbalanced magnetron.

5. The method according to any of claims 1 to 4, wherein the flux of energetic particles directed towards the substrate is controlled by a magnet on the side of the substrate remote from the target or by electrostatic shields.

6. The method according to any of claims 1 to 5, further comprising the step of generating the plasma discharge above the target.

7. The method according to claim 6, wherein the plasma discharge is generated by crossed magnetic and electric fields.

8. A magnetron sputter source generating a beam comprising a directed flux of energetic particles together with material to be deposited, said source being adapted so that said beamflux is directed towards a substrate under an angle controlled in such a way that a bi-axially textured coating is deposited on the substrate,

the source further comprising a target and a magnet assembly including one magnet array located towards an inner portion of the target and generating a magnetic field of one magnet pole and a further magnet array located towards an outer portion of the target and generating a magnetic field of the other pole, said magnet assembly being adapted so that magnetic field lines generated by the outer magnet array cut the substrate and an ambipolar flow of energetic particles is directed against the substrate, and the directed flux of energetic particles comprising

electrons and the electron energy being controlled so that they do not initiate or support a plasma at the surface of the substrate sufficient to disturb the directionality of the directed flux of energetic particles, and

the magnetron sputter source furthermore comprising means for controlling the direction and thereby controlling the angle of incidence onto the substrate of the directed flux of energetic particles, the flux of energetic particles being free of a target material.

9. The magnetron sputter source according to claim 8, the means for controlling comprising at least one electrostatic shield located around said beam of energetic particles.

10. The magnetron sputter source according to any of claims 8 to 9, the means for controlling comprising a magnet located on the side of the substrate remote from the target for influencing the directed flux of energetic particles.

11. The magnetron sputter source according to claim 8 to 10, wherein said source is a planar or a rotating cathode magnetron.

12. The magnetron sputter source according to any of claims 8 to 11, further comprising a sputter gas and the directed flow of energetic particles consists essentially of ions from the sputter gas.

13. The magnetron sputter source according to any of claims 9 to 12, further comprising a means for generating the plasma discharge above the target.

14. The magnetron sputter source according to

claim 13, wherein the means for generating a plasma discharge comprises a means for generating crossed magnetic and electric fields for generating the plasma discharge.

SMART & BIGGAR

OTTAWA, CANADA

PATENT AGENTS

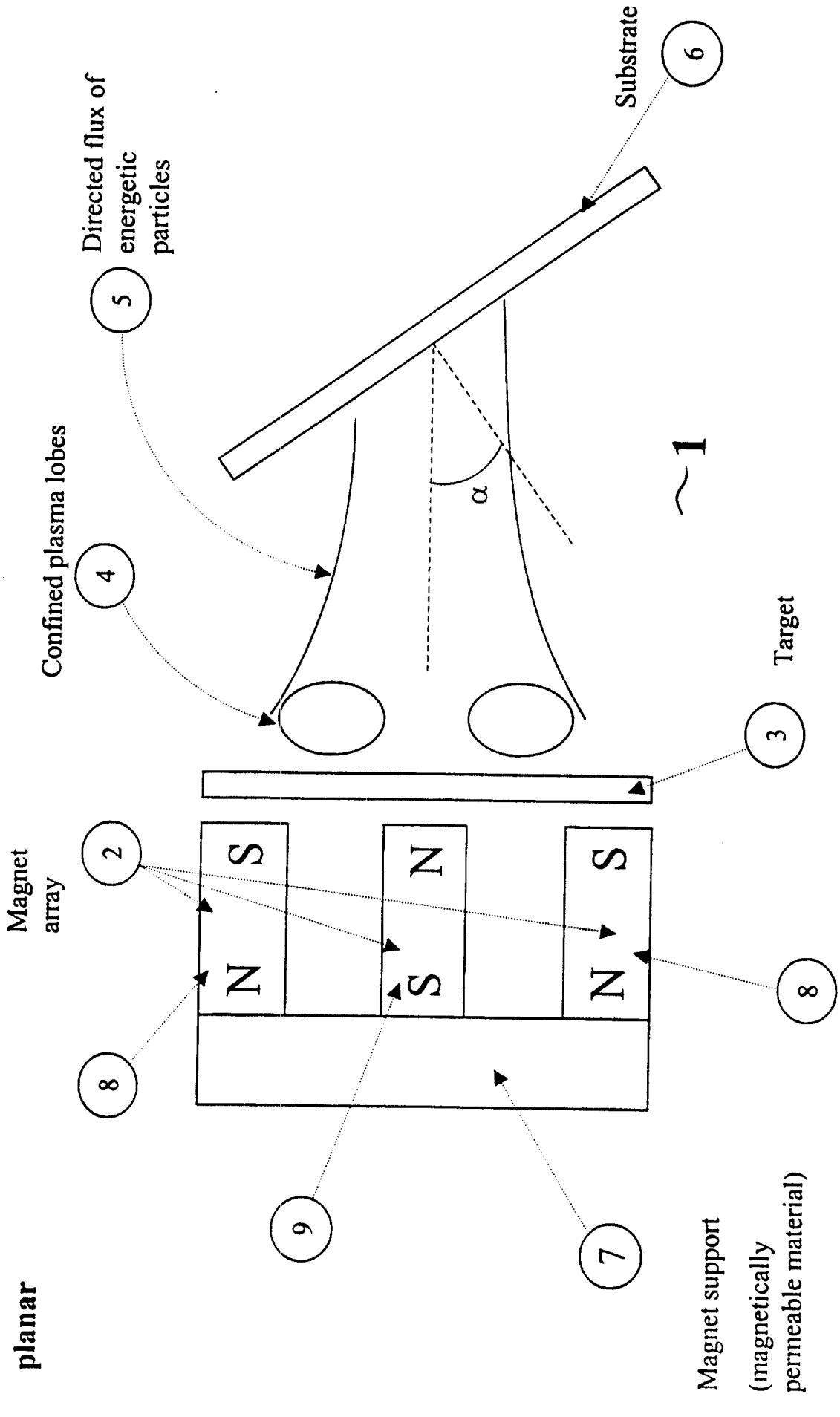

Substrate
6
Directed flux of energetic particles
5
Confined plasma lobes
4
α
~ 1
Target
3
Magnet array
2
S
N
N
S
N
S
8
8
9
7
Magnet support
(magnetically permeable material)

Fig.1
planar

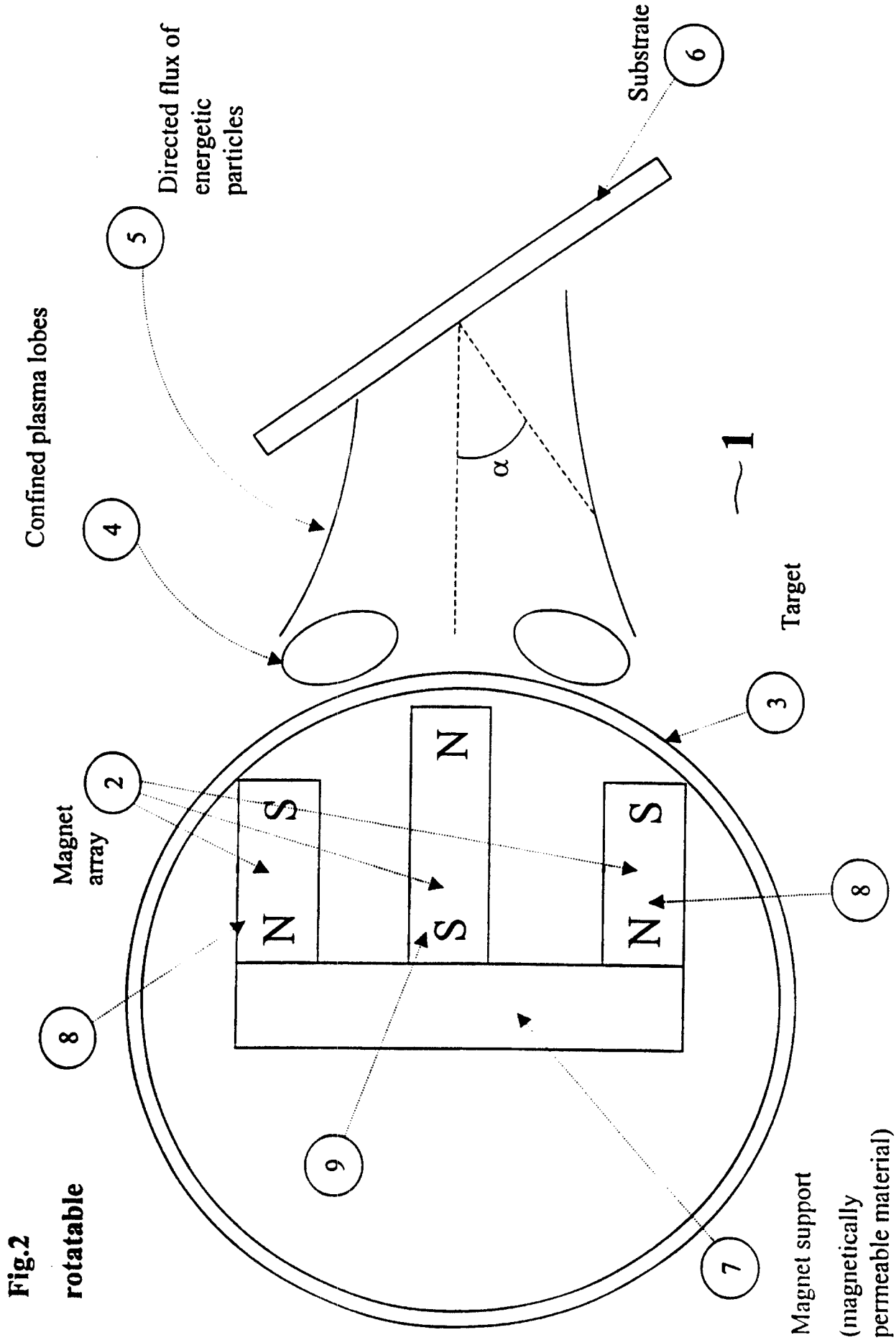
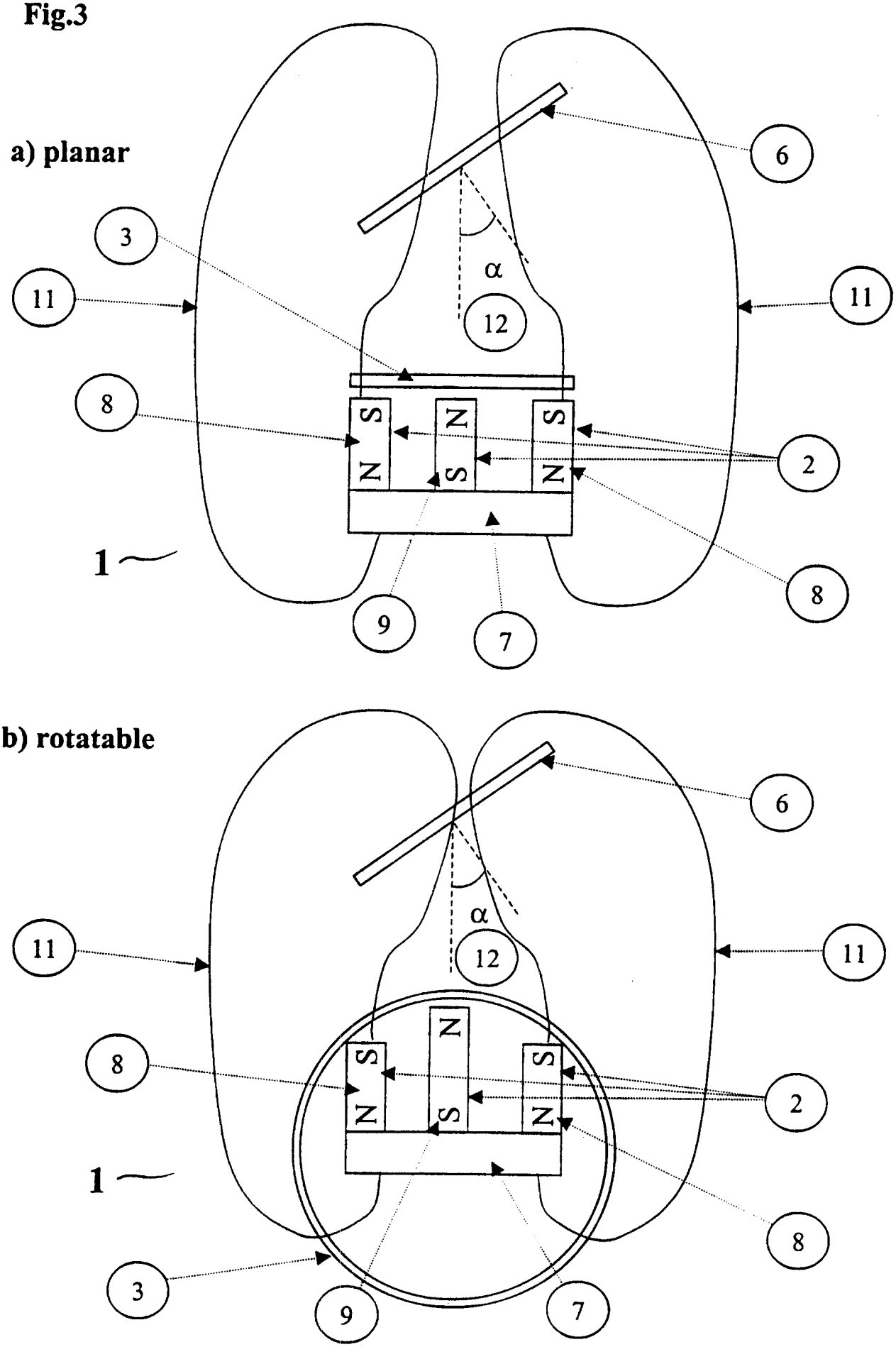

Substrate
6
Directed flux of energetic particles
5
Confined plasma lobes
4
α
1
Target
3
Magnet array
2
S
N
N
S
S
N
8
8
9
7
Magnet support (magnetically permeable material)
rotatable

Fig.2

Fig.3


a) planar
6
3
11
α
12
11
8
S
N
N
S
S
N
2
1
8
9
7
b) rotatable
6
11
α
12
11
8
S
N
N
S
S
N
2
1
8
3
9
7

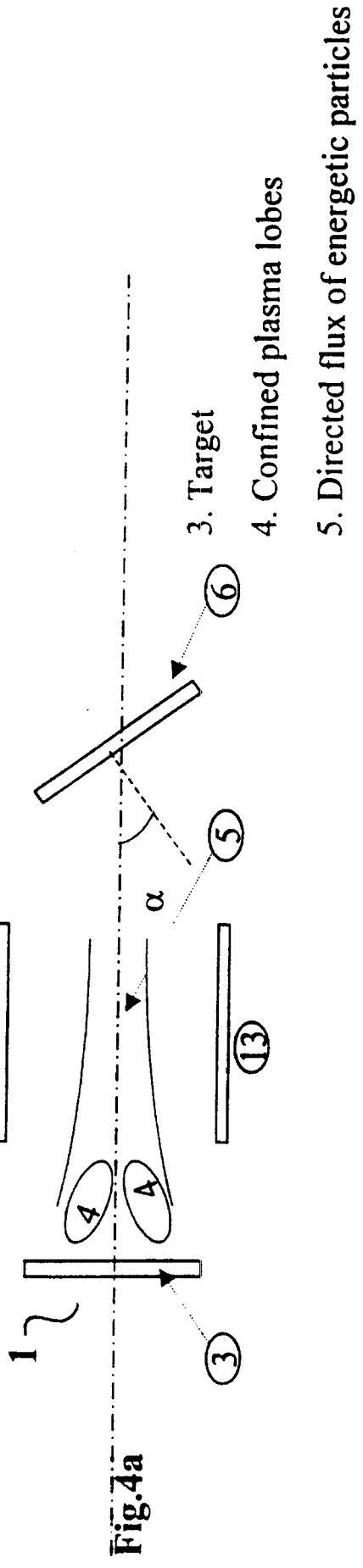

3. Target
4. Confined plasma lobes
5. Directed flux of energetic particles
6. Substrate
13. Deflection shield at negative potential
α
1
3
4
5
6
13

Fig.4a

Fig.4b

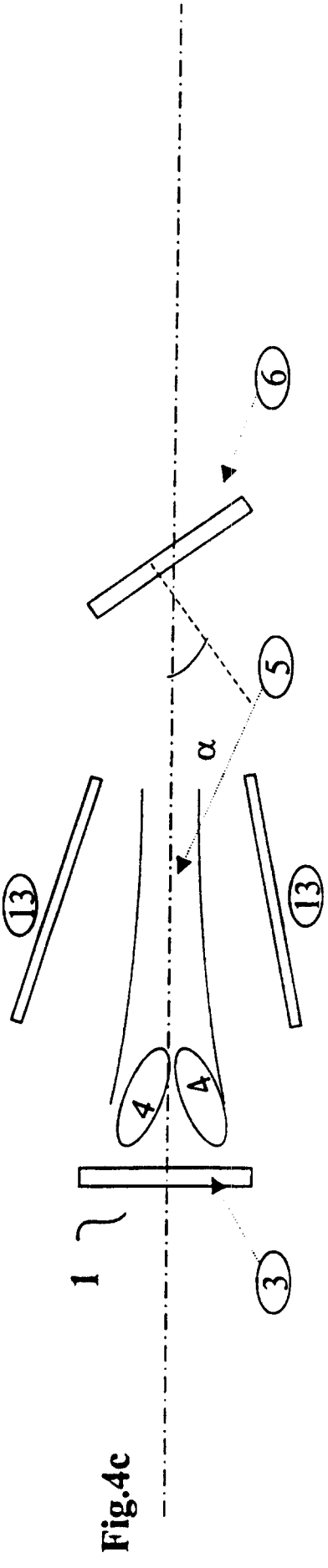


Fig.4c

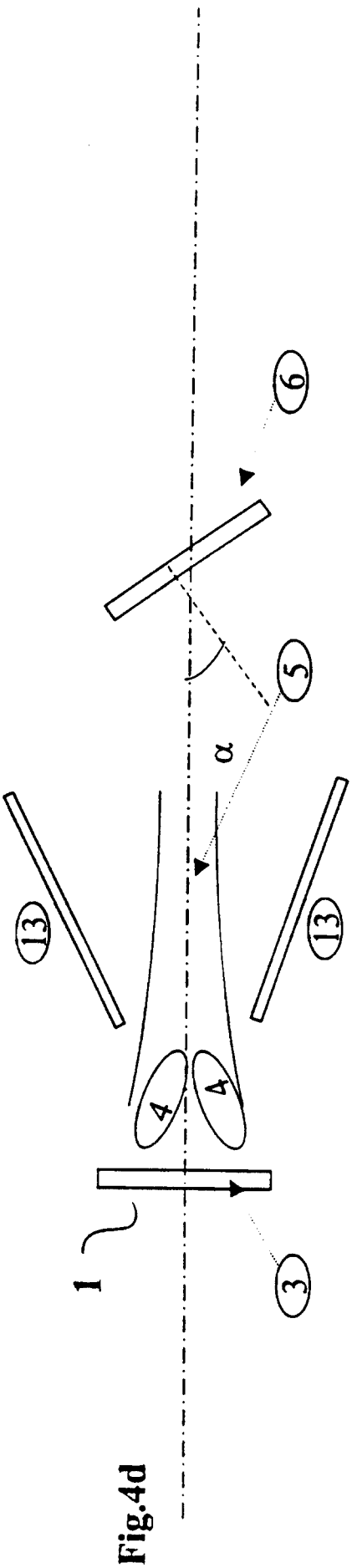


Fig.4d

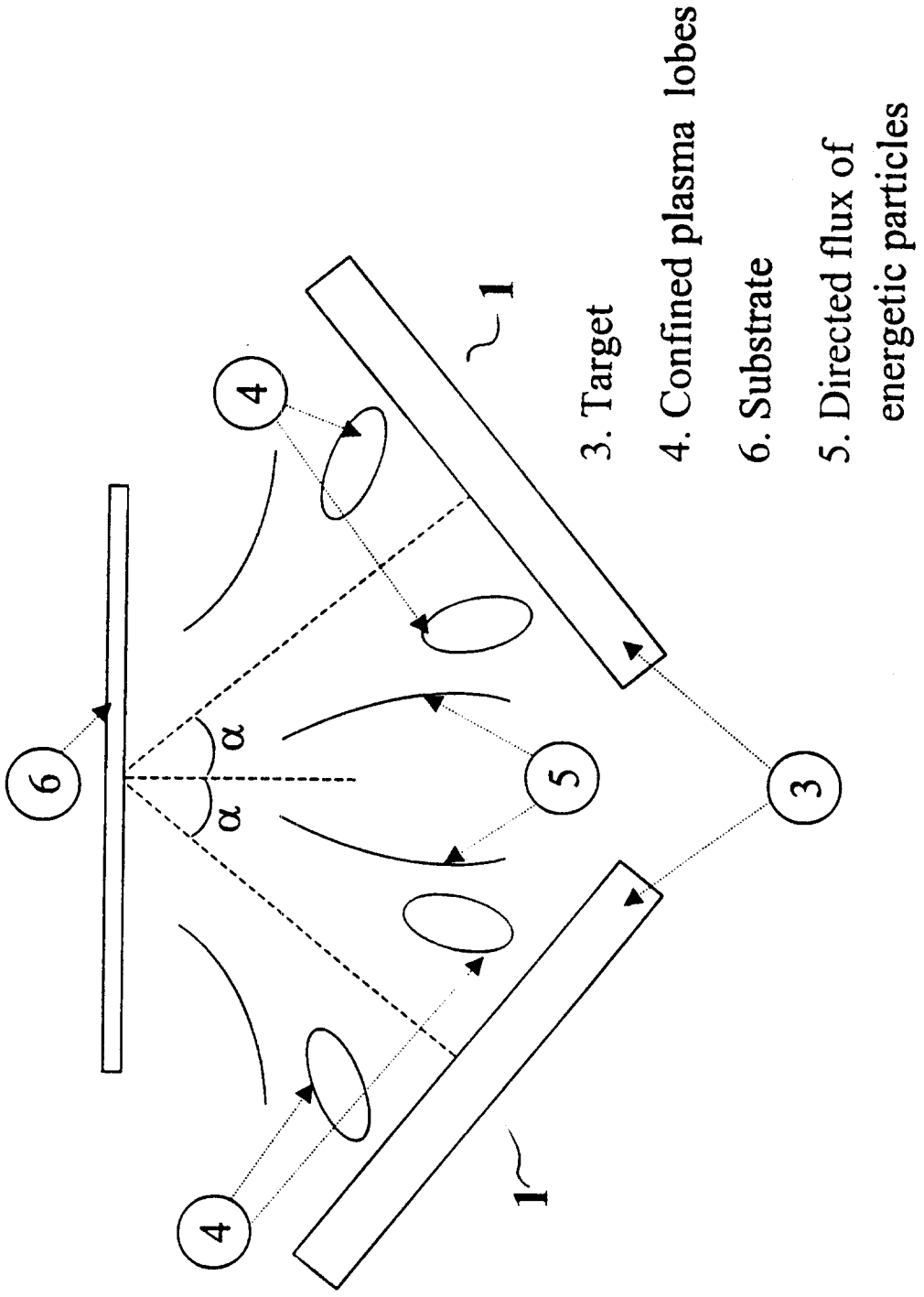

1
3. Target
4. Confined plasma lobes
6. Substrate
5. Directed flux of energetic particles
α
α
1
3
4
4
5
6

Fig. 5 planar

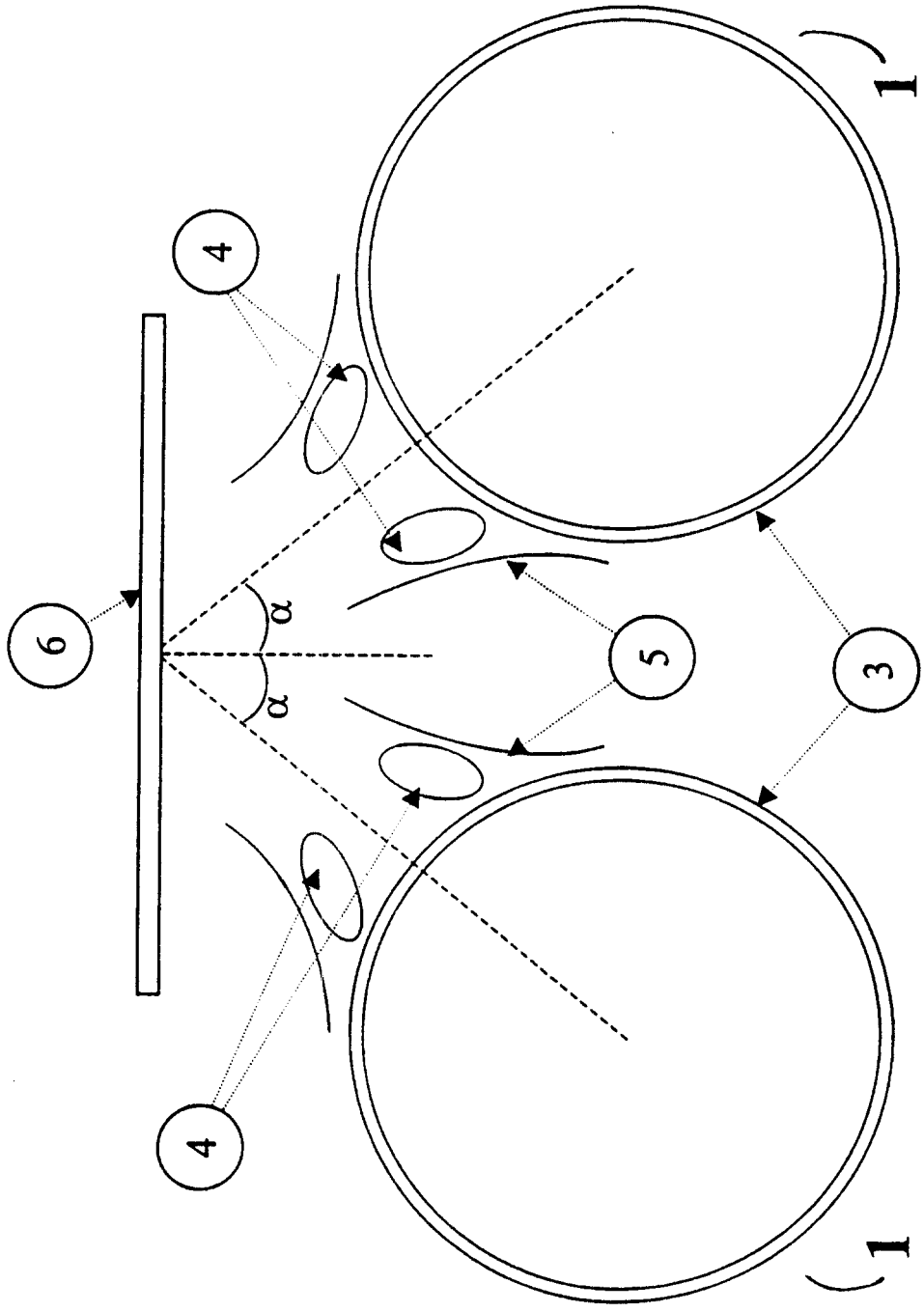


Fig. 6 rotatable

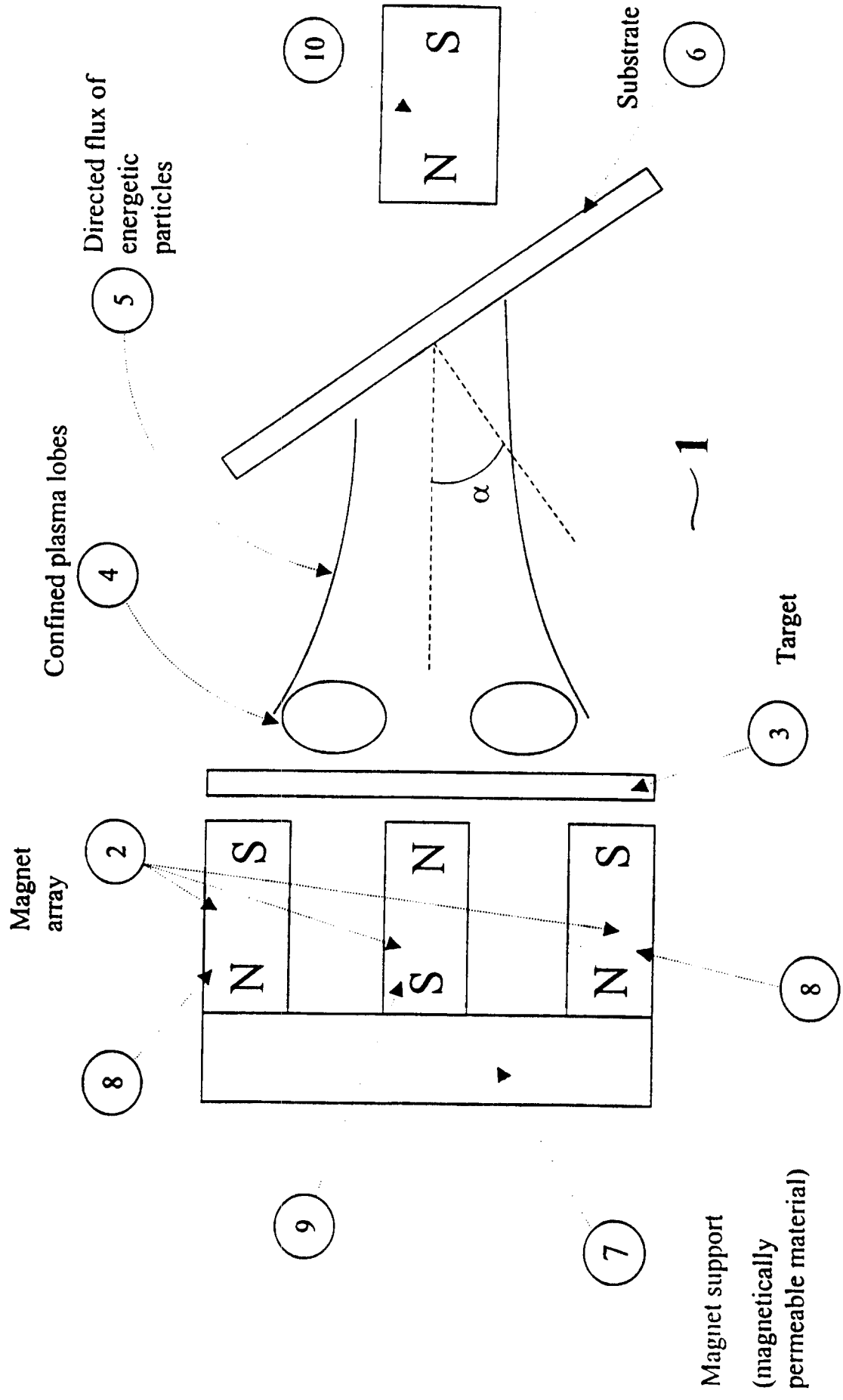
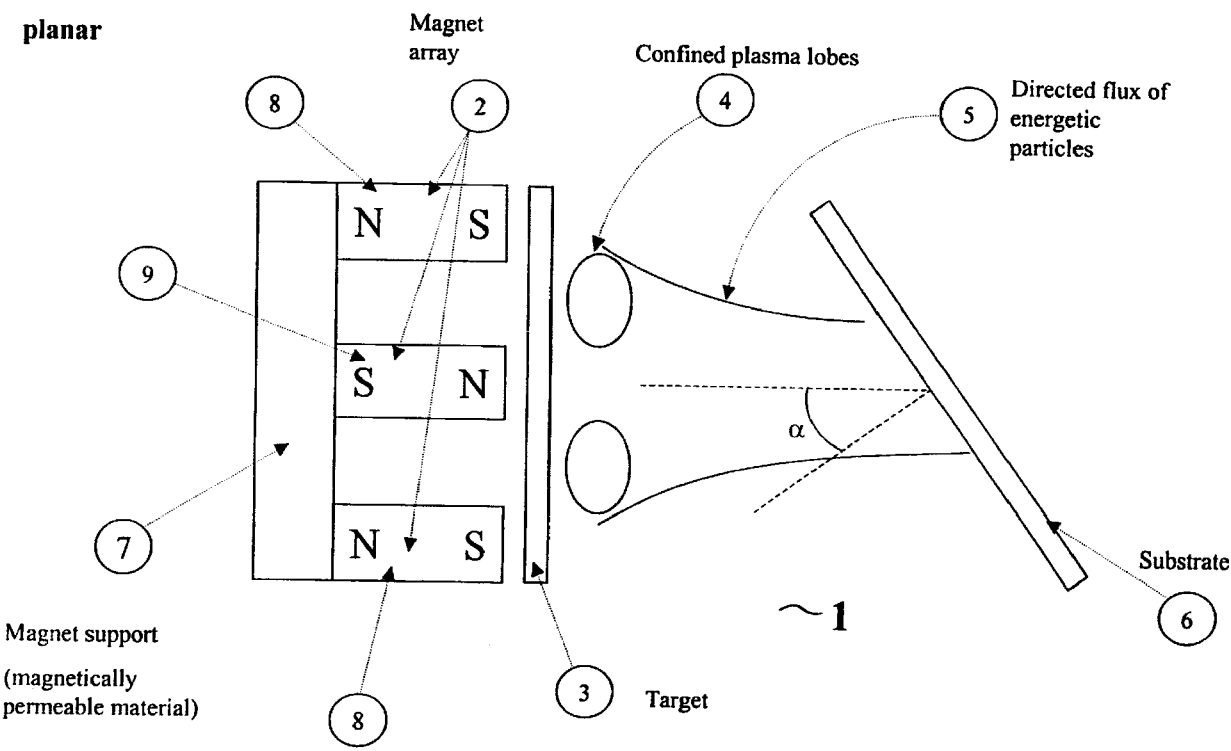

Directed flux of energetic particles
5
Confined plasma lobes
4
Magnet array
2
8
8
9
7
Magnet support (magnetically permeable material)
10
S
N
Substrate
6
α
1
Target
3
8
S
N
S
N
S
N

Fig.7


planar
Magnet array
Confined plasma lobes
Directed flux of energetic particles
8
2
4
5
N
S
9
S
N
α
7
N
S
Substrate
~1
6
Magnet support
(magnetically permeable material)
8
3
Target