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Alger

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[54] **DEUTERIUM PASS THROUGH TARGET**

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[52] **U.S. Cl.** **250/499;** 250/500

[51] **Int. Cl.**[2] **G21G 4/02**

[58] **Field of Search** 250/499, 500, 501, 502, 250/526

[56] **References Cited**

UNITED STATES PATENTS

3,646,348	2/1972	Detaint	250/499
3,683,190	8/1972	Stark	250/526
3,766,389	10/1973	Fabian	250/499
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[57] **ABSTRACT**

A neutron emitting target for use in neutron generating apparatus including a deuteron source and an accelerator vacuum chamber, comprises a tritium-containing target layer, a deuteron accumulation layer, and a target support containing passages providing communication between the accumulation layer and portions of the surface of the support exposed to the accelerator vacuum chamber. With this arrangement, deuterons passing through the target layer and implanting in and diffusing through the accumulation layer, diffuse into the communicating passages and are returned to the accelerator vacuum chamber. The invention allows the continuous removal of deuterons from the target in conventional water cooled neutron generating apparatus. Preferably, the target is provided with thin barrier layers to prevent undesirable tritium diffusion out of the target layer, as well as deuteron diffusion into the target layer.

13 Claims, 5 Drawing Figures

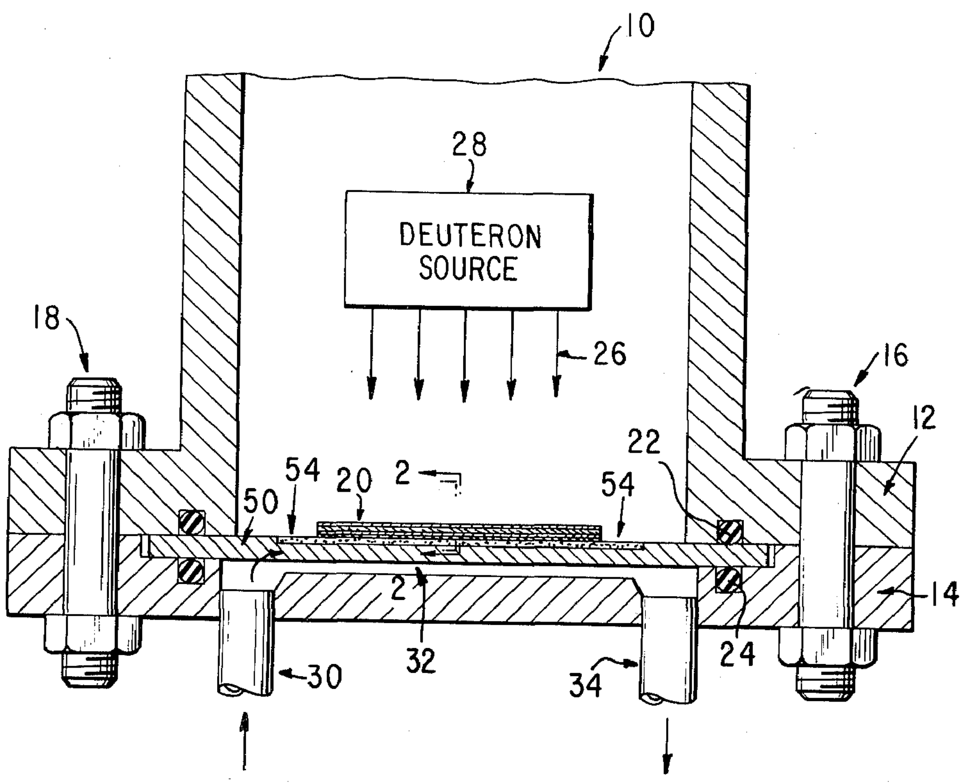


FIG. 1

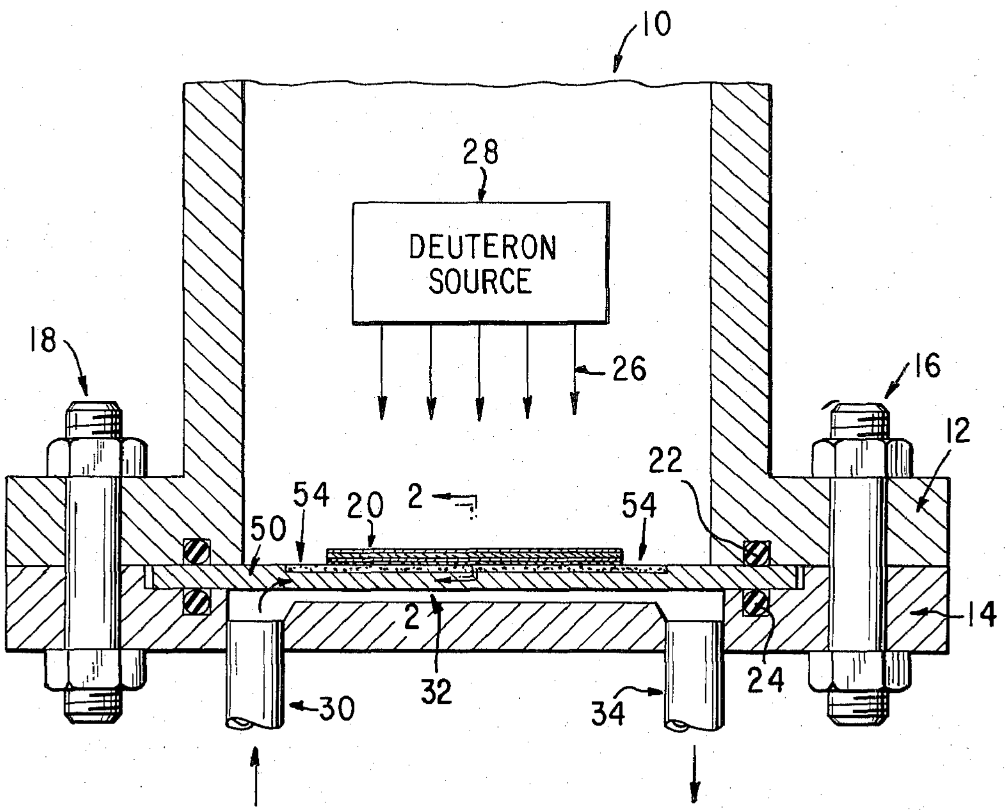


FIG. 2

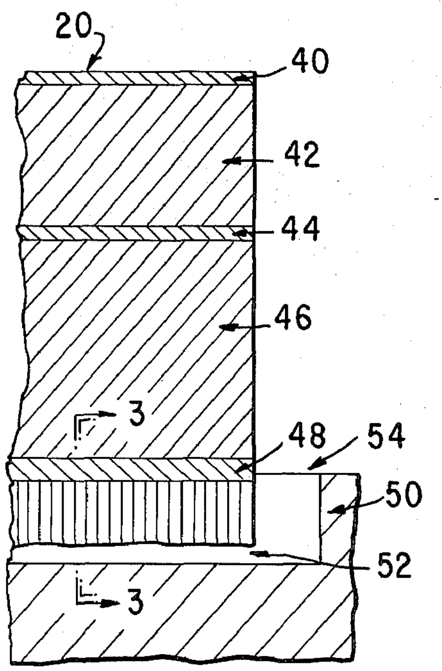


FIG. 3

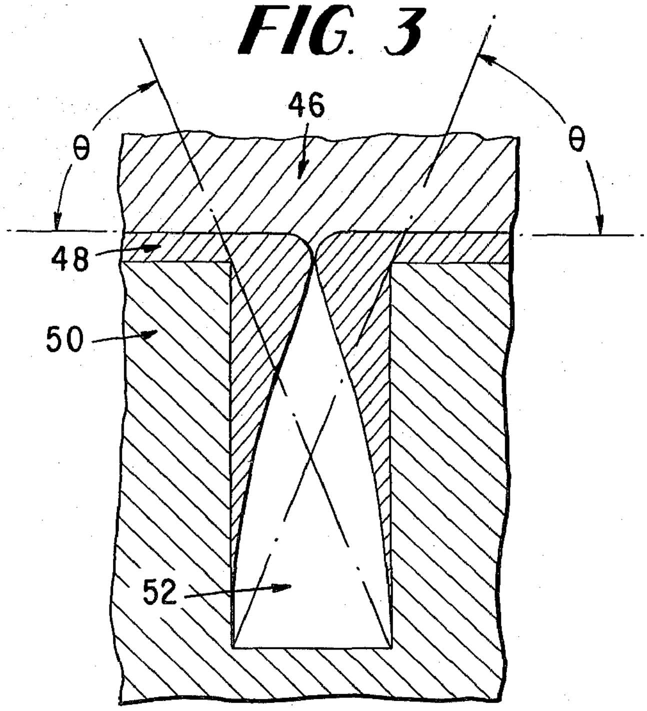


FIG. 4

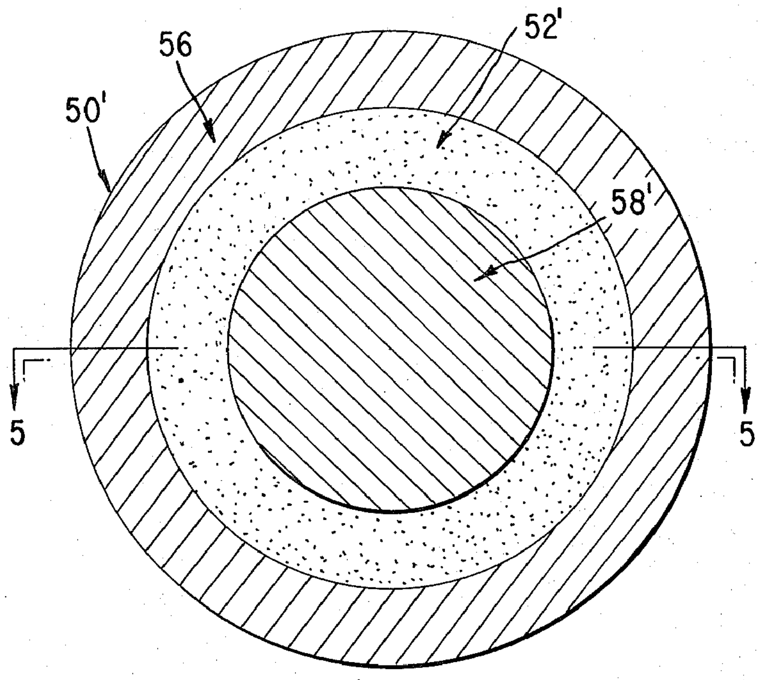
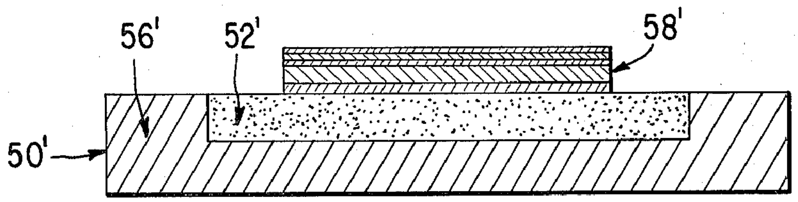


FIG. 5



DEUTERIUM PASS THROUGH TARGET

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention related to neutron emitting targets containing tritium which, when bombarded by an accelerated beam of deuterons, produce fast neutrons by the well-known reaction $T(d,n)^4He$.

2. Description of the Prior Art

Conventional neutron emitting targets of the type referred to above consist of a thin film of a tritiated metal or metal tritide, such as titanium tritide, mounted on a water cooled substrate of a non-hydrogenizeable metal, such as copper. An accelerated beam of a deuterons impinges on the target to produce fast neutrons by the $T(d,n)^4He$ reaction. The cross-section for the $T(d,n)^4He$ reaction is such that only a very few of the impinging deuterons interact with tritium atoms to produce neutrons. The remaining, non-interacting deuterons do not pass through the metal tritide target layer, but implant into the layer and remain there. Since both tritium and deuterium are isotopes of hydrogen, and therefore chemically identical, the deuterons implanted in the target layer continually displace tritium atoms of the metal tritide, which then diffuse to the surface of the target and are lost to the accelerator vacuum chamber. The result is the rapid depletion of the target's tritium, with a corresponding reduction in the useful life of the target.

One attempt to limit the rate at which tritium is displaced in the target layer by deuterons is disclosed in U.S. Pat. No. **3,646,348** (Detaint). As disclosed in the Detaint patent, a neutron emitting target is provided with a thin intermediate diffusion barrier layer between the tritiated target layer and the support. The target and diffusion barrier layers are provided with such thicknesses that the deuterons bombarding the target which do not interact with a tritium atom to produce a fast neutron are not stopped, but penetrate into the support. The barrier layer prevents the return of the deuterons by diffusion back into the target layer. Thus, the rate at which the tritium is displaced is reduced, and a target with a longer useful life is obtained. The deuterons entering the support can remain therein, by the use of an hydrogenizeable support material, or can be removed from the back surface of the support by an auxiliary vacuum system, or by an auxiliary electrochemical or chemical circulating system.

The target disclosed by Detaint suffers several disadvantages. If the target is to be used in conventional water cooled accelerator apparatus, an hydrogenizeable support material must be used to accumulate the deuterons which have penetrated through the target layer. While this allows adequate cooling of the target across the back thereof, hydrogenizeable materials are generally brittle and structurally weak. The result is a fragile target, and one which depends upon the accumulation capability of the support material for its useful life. Further, where the deuterons are continuously removed from the support, as when a stronger nonhydrogenizeable support material is used, or when the accumulation life of an hydrogenizeable support is to be prolonged, the deuterons must be removed from the back surface of the target support by auxiliary equipment with the accompanying additional costs. The use of the back surface of the support for deuteron removal also limits the available target area which can be effectively water cooled to the target perimeter. Inadequate target cooling in turn limits the magnitude of the energy of the deuterons than can be used.

SUMMARY OF THE INVENTION

In accordance with the invention, a neutron emitting target comprises a tritium-containing target layer through which deuterons will penetrate, a deuteron accumulation layer of sufficient thickness to stop the penetrating deuterons, and a non-hydrogenizeable support with means enabling the continuous removal of deuterons from the accumulation layer within conventional neutron generating apparatus.

According to a preferred embodiment of the invention, a neutron emitting target comprises a target layer of a tritiated metal, metal hydride, or mixture of hydrides containing tritium, an accumulation layer of a metal in which hydrogen isotopes diffuse rapidly at the operating temperatures of the target and which has sufficient thickness to stop the deuterons bombarding the target, and a support of a non-hydrogenizeable, good thermal conducting metal, having a larger geometric surface area than the target or accumulation layer, the support including means communicating the surface of the accumulation layer remote from the target layer with the accelerated vacuum chamber through exposed surfaces of the support. With this arrangement, the deuterons which have passed through the target layer, have stopped in the accumulation layer and have diffused through the accumulation layer toward the support, are returned to the accelerator vacuum chamber through exposed portions of the surface area of the support.

In accordance with one embodiment, the accumulation layer contains titanium, and a diffusion enhancing layer is disposed between the accumulation layer and the support to enhance the diffusion of the deuterons from the accumulation layer to vacuum, this diffusion layer comprising a metal selected from the group consisting of palladium, palladium alloys, and mixtures thereof. In a second embodiment, a palladium-containing accumulation layer in direct contact with the support is employed.

The means communicating the accumulation layer with the accelerator vacuum chamber are preferably provided by minute grooves which extend across the face of the support. The accumulation layer and target layer are applied to the support over the grooves so as to leave portions of the grooved support face exposed. In a second preferred embodiment, the support is formed by sintering powdered metal on the face of a solid metal substrate such that a layer or portion of the support face is provided with minute interstices. The subsequent layers are again applied such that portions of the sintered powdered metal face area of the support are left exposed.

Advantageously, the target also contains thin diffusion barrier layers to prevent the tritium from diffusing out of the target layer, and to prevent the deuterons accumulated in the accumulation layer from diffusing back into the target layer.

Other features and advantages of the invention will be set forth in, or apparent from, the detailed description of preferred embodiments thereof found hereinbelow.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic sectional view of a neutron emitting target embodying the invention, mounted in an accelerator vacuum chamber;

FIG. 2 is a diagrammatic sectional view of a detail of the target of FIG. 1 taken generally along line 2—2 of FIG. 1 and illustrating the general relationship of the layers of the target;

FIG. 3 is a diagrammatic sectional view of a detail of the target of FIG. 2 taken generally along line 3—3 of FIG. 2 and illustrating the relationship between the accumulation layer and the support;

FIG. 4 is a diagrammatic plan view of a target according to a second embodiment of the invention; and

FIG. 5 is a diagrammatic sectional view of the target of FIG. 4 taken generally along line 5—5 of FIG. 4.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. **1,** an accelerator vacuum chamber **10** is formed by chamber housings **12,14** secured together by bolts **16,18.** Mounted within the chamber **10** is neutron emitting target generally denoted **20.** Target **20** includes a support **50** which is mounted between housings **12,14** and supports the remaining component layers of the target **20** described hereinbelow. Seals are provided at the target and housing matings by o-rings **22,24.** An accelerated beam of deuterons **26,** produced by a deuteron source **28** mounted within housing **10,** impinges upon target **20** to produce the desired neutrons. Heat generated within the target **20** by the impinging deuterons **26** is removed by the circulation of cooling water through an inlet port **30,** a chamber **32,** and exit port **34,** ports **32,34** being formed in housing **14** and chamber **32** being between housing **14** and target **20,** as illustrated.

Referring to the detailed showing of FIG. **2,** a preferred embodiment of the neutron emitting target of the invention is illustrated. The target **20** comprises a thin first diffusion barrier layer **44,** a deuteron accumulation layer **46,** a deuteron diffusion enhancing layer **48,** and a support **50.** As illustrated, the geometry of support **50** is such that portions **54** thereof extend beyond the other layers and hence are exposed to the vacuum chamber **10.** Support **50** is provided with passages **52** which are described in more detail hereinbelow and which communicate the surface of layer **48** adjacent to support **50** with the accelerator vacuum chamber **10** through exposed portions **54** of the face of support **50.** The arrangement is such that deuterons impinging upon the target **20** and penetrating through barrier layer **40,** target layer **42** and barrier layer **44** will come to rest in accumulation layer **46.** Since the deuterons cannot diffuse through layer **44,** they diffuse through diffusion enhancing layer **48** and enter passages **52.** From passages **52,** the deuterons will be removed from the target **20,** through the exposed portions **54** of the face of support **50,** to the accelerator vacuum chamber **10.** Because the deuterons are removed from the face of the support auxiliary equipment is not necessary. Additionally, the rear surface of the target can be adequately cooled with conventional water coolant.

FIG. **3** depicts the relation of the accumulation layer **46** and diffusion enhancing layer **48** to the communicating passages **52.** To increase the surface area of the diffusion enhancing layer **48** from which deuterons may diffuse into passages **52,** the diffusion enhancing layer **48** is advantageously applied in such a manner that it extends into passage **52.** This may be accomplished by masking the support **50** before deposition of the layer **48** such that the layer material is deposited only within the angles θ, as shown.

According to a first embodiment of the invention, passages **52** are parallel grooves provided across the face of support **50** in a central area of a diameter less than that of the support **50,** but larger than that of the subsequently applied layers. For example, where the support **50** is a disc about **5** centimeters in diameter, and where the subsequent layers, such as layer **48,** are to be applied to a central area about three centimeters in diameter, the central area to which the grooves are applied may be about four centimeters in diameter. The grooves may be formed by any suitable technique, such as chemical etching, electroforming, or ion micromachining, and according to a specific embodiment, are about **2** micrometers wide and **5** micrometers deep and are separated by a distance of about **50** micrometers. *It will be appreciated that other groove sizes* and spacings may be used, but it is noted that if the grooves are too wide, inadequate target cooling will give rise to target "hot-spots," and if the groove spacing is too wide, the deuterons will not adequately diffuse from the accumulation layer **46** to the grooves **52** for subsequent removal back to the vacuum chamber **10.**

Referring to FIGS. **4** and **5,** a second embodiment of the invention is illustrated. This embodiment is similar to that of FIGS. **2** and **3,** and similar elements have been given the same reference numerals with primes attached. According to the embodiment of the invention depicted in FIGS. **4** and **5,** passages **52′** are provided by sintering a layer of powdered metal across the face of support **50′**, or a portion thereof. Advantageously, a solid metal substrate **56′** is machined to produce a recess into which powdered metal is pressed, and then the substrate **56′** is heated to sinterbonding temperature. The surface may then be machined flat before subsequent target layers are applied. The target support **50′** is thus provided with minute interstices which form the communicating passages discussed above.

Target support **50** is advantageously made from a non-hydrogenizeable metal which has good thermal conductivity and in which hydrogen isotopes diffuse slowly at the operating temperature of the target. Exemplary of such a metal is copper. The shape and thickness of support **50** is generally chosen to conform with the neutron generating apparatus used. If a circular disc target shape is chosen, support **50** may be about five centimeters in diameter and about **0.2** centimeters thick.

Accumulation layer **46** comprises a metal in which hydrogen isotopes diffuse rapidly at the operating temperature of the target, and, advantageously, in which the activation energy for diffusion of deuterium is approximately the same as the heat of solution of deuterium in the metal. Exemplary of such a metal is palladium and its alloys, e.g., palladium-silver. When the activation energy for diffusion of deuterium in the metal approximately equals the heat of solution of deuterium in the metal, it is equally probable for the deuterons to leave the metal surface and diffuse into the passages **52,** as it is for the deuterons to diffuse within the metal.

Thus, the metal will allow more efficient removal of deuterons. It will be appreciated that when a metal such as palladium is chosen, the enhancement layer **48** can be eliminated. Where a metal in which the heat of solution of deuterium is greater than the activation energy for diffusion is chosen for the accumulation layer **46**, i.e., a metal such as titanium, zirconium, erbium, and the like, diffusion enhancing layer **48** (which comprises a metal such as palladium and its alloys) is preferably provided between the accumulation layer **46** and the support **50** to increase the rate of deuteron removal from the layer **46** to the passage **52**. The accumulation layer **46** may be applied by any technique consistent with the metal chosen. In the case of palladium, an MRC RF sputtering system may be used. Where titanium is chosen, the palladium diffusion enhancing layer **48** can first be applied by an RF sputtering system, and the titanium accumulation layer **46** then be applied by a vacuum deposition system by sublimination. The accumulation layer **46** must be of sufficient thickness to stop the deuterons bombarding the target. The thickness will thus depend upon the penetration energy of the deuterons of the neutron generating apparatus used.

Target layer **42** may contain tritium in any form desired. In particular, the layer **42** may be a tritiated metal, especially titanium, zirconium, erbium, and the like, a metal hydride, and mixtures thereof containing the material chosen. In the case of a metal tritide, such as titanium tritide, the metal may be applied by a vacuum deposition system by sublimination, the tritium then being absorbed in the metal at elevated temperaturees. For proper operation of the invention, deuterons bombarding the target must pass through the target layer **42** and come to rest in the accumulation layer **46**. Thus, the thickness of the target layer **42** will generally depend upon the penetrating energy of the deuterons of the neutron generating apparatus used. Advantageously, where the accelerated beam of deuterons contains more than one ion specie, e.g., D_1^+, D_2^+, and D_3^+, and a magnetic field is available for application to the beam to deflect the beam into bands according to the species, the target layer **42** may be made into similar bands, each with a thickness tailored to pass the particular specie in the incident beam band.

To prevent loss of tritium from the face of target layer **42** to accelerator vacuum **10**, the diffusion barrier layer **40** is advantageously utilized. Such a diffusion barrier layer **40** will ordinarily comprise a meterial in which hydrogen isotopes diffuse very slowly at the operating temperature of the target, and have a thickness such that the deuterons bombarding the target are not significantly retarded in passing through the barrier layer **40**. Suitable materials for layer **40** may be metals, such as copper, aluminium, gold, and the like, or oxides or nitrides of such metals as titanium, zirconium, erbium, and the like.

To prevent diffusion of tritium from the target layer **42** to the accumulation layer **46**, and thus out of the target, and to prevent deuterons from diffusing back to the target layer **42** from the accumulation layer **46**, a diffusion barrier layer **44** is advantageously disposed between the target layer **42** and the accumulation layer **46**. Diffusion barrier layer **44** can be otherwise similar to the barrier layer **40** discussed above.

EXAMPLE

A neutron emitting target containing six layers, as depicted in FIG. **2**, was prepared for use with a **300**KV positive ion accelerator. Vacuum deposition apparatus required for applying the layered structure were of two varieties, a sputtering system and a vacuum deposition system. The sputtering system was an MRC RF sputtering system using a **6** inch diameter opposed parallel plate cathode and anode mounted in a **24** inch collar. The system was pumped by a turbomolecular pump with an ultimate pressure of 10^{-7} torr. Argon gas, purified by a hot titanium filament to **99.999**% purity, was used for an inert atmosphere. The vacuum deposition system was a Varian Ti-ball subliminator installed in a Varian **360** vacuum system with an ultimate pressure capability of 10^{-10} torr. An electrically insulated and cooled sybstrate holder was used for its capability of withstanding the application to it of the high negative voltages necessary for sputter etch cleaning of substrates. The subliminator and substrate holder were surrounded by cooled getter surfaces. A movable shutter was used to cover the substrate so that a getter layer of titanium could be applied to the getter shield surface prior to deposition on the substrates.

A copper support disc **4.8** cm in diameter and **0.203** cm thick was provided on one surface in a central area **3.8** cm in diameter with parallel micro-grooves **2**μm wide, **5**μm deep and separated by a distance of **50**μm by an electroforming process. The disc was then coated over a central area **2.8**cm in diameter with a palladium diffusion enhancing layer, corresponding to layer **48** of FIG. **2**, by the RF sputtering system. An auxiliary Granville-Phillips sublimation pump of **10,000** liters per second pumping speed was attached by a **4**-inch collar port to reduce ultimate pressure by one more decade to reduce the partial pressure of active gasses in the system. The copper support disc was masked so that both walls of the grooves on the surface of the support were coated simultaneously with palladium striking the substrate within the angles θ shown in FIG. **3**. Prior to deposition, the disc was prepared by swishing in clean acetone, washing in an ultrasonic alcohol bath for **20** minutes, and cleaning for another **15** minutes in an alcohol vapor bath. A jet of freon **12** was sprayed over the disc just prior to putting the disc into the sputtering system. A **35** angstrom thick layer of copper was sputtered from the disc surface and then palladium was sputtered onto the disc, depositing only within the angles θ of FIG. **3**. Palladium was sputtered until the grooves within the **2.8** cm diameter area were completely bridged.

An accumulation layer of titanium, corresponding to layer **46**, was next applied by the vacuum deposition system. Prior to deposition, a **35** Angstrom thick layer of palladium was sputter etched from the palladium layer by application of combined RF/DC voltages to the insulated substrate holder. The etching was followed by sublimination of titanium onto the clean palladium surface in the vacuum deposition system.

To prevent deuteron diffusion from the accumulation layer (layer **46** of FIG. **2**) back to the target layer (layer **42**) a thin barrier layer (corresponding to layer **44**) of titanium nitride (TiN) was applied by the RF sputtering system at **500** watts of RF power in a pure nitrogen atmosphere at a pressure of **10** microns. Prior to deposition of the barrier layer, the accumulation layer was first sputter-etched clean to remove a 35 Angstrom thick layer from the surface, and then TiN was sputtered onto a shutter covering the substrate for 10 minutes. A 1000 Angstrom thick layer of TiN was applied to the accumulation layer.

A titanium tritide target layer, corresponding to layer 42 of FIG. 2, was then formed by deposition of a titanium film in the vacuum deposition system, as was done in the formation of the accumulation layer, followed by tritium absorption at 300°C.

A final thin barrier layer, corresponding to layer 40 of FIG. 2, of titanium nitride was applied in accordance with the procedure used to form the barrier layer described above. This final barrier layer was applied to prevent the loss of tritium from the target layer by diffusion to the vacuum chamber, and by sputtering of the target surface by the incident deuteron beam when the target was used. This final layer was 500 Angstroms thick.

Although the invention has been described relative to specific exemplary embodiments thereof, it will understood by those skilled in the art that variations and modifications can be effected in these exemplary embodiments without departing from the scope and spirit of the invention.

I claim:

1. For use in neutron generating apparatus including a deuteron source and an accelerator vacuum chamber, an improved neutron emitting target comprising a target layer containing tritium for reaction with deuterons from the deuteron source; an accumulation layer for accumulating deuterons which have passed through said target layer, the thickness of said accumulation layer being such that deuterons which have passed through the target layer come to rest therein; and a nonhydrogenizeable metal support on which said target and accumulation layers are supported, said support having at least one portion of one surface thereof exposed to the accelerator vacuum chamber and said support including means for communicating the accumulation layer with said at least one exposed portion of the surface of said support such that deuterons which are accumulated by said accumulation layer are returned to the accelerator vacuum chamber.

2. A neutron emitting target as claimed in claim 1 further comprising a diffusion enhancing layer disposed between said accumulation layer and said support for enhancing the diffusion of the deuterons from said accumulation layer, said diffusion enhancing layer comprising a metal selected from the group consisting of palladium, palladium alloys, and mixtures thereof.

3. A neutron emitting target as claimed in claim 1 wherein said accumulation layer comprises a metal selected from the group consisting of palladium, palladium alloys, and mixtures thereof, said accumulation layer being in direct contact with said support.

4. A neutron emitting target as claimed in claim 1 wherein said communicating means comprises grooves formed in the upper surface of said support in communication with said accumulation layer and said at least one exposed portion of said surface of said support.

5. A neutron emitting target as claimed in claim 1 wherein said support includes a sintered powdered metal and said communicating means comprises interstices formed in said sintered powdered metal.

6. A neutron emitting target as claimed in claim 1 wherein said accumulation layer comprises an hydrogenizeable metal in which hydrogen isotopes diffuse rapidly at the operating temperature of the target.

7. A neutron emitting target as claimed in claim 6 wherein said accumulation layer comprises a metal selected from the group consisting of titanium, palladium, zirconium, erbium, alloys thereof, and mixtures thereof.

8. A neutron emitting target as claimed in claim 1 wherein said target layer comprises a metal selected from the group consisting of tritiated metal, metal hydride, and mixtures of hydrides containing tritium.

9. A neutron emitting target as claimed in claim 1 further comprising hydrogen isotope diffusion barrier layer in contact with said target layer for preventing the diffusion of hydrogen isotopes across the surface of said target layer in contact with said hydrogen isotope diffusion barrier layer.

10. A neutron emitting target as claimed in claim 1 further comprising a first hydrogen isotope diffusion barrier layer disposed on said target layer for preventing the diffusion of tritium atoms from the surface of said target layer, and a second hydrogen isotope diffusion barrier layer disposed between said target layer and said accumulation layer for preventing the diffusion of hydrogen isotopes between said target layer and said accumulation layer.

11. A neutron emitting target which converts bombarding deuterons into neutrons, said target comprising a tritium-containing target layer for reacting with bombarding deuterons to produce neutrons; a titanium-containing accumulation layer for accumulating deuterons which have passed through said target layer, the thickness of said accumulation layer being such that deuterons which have passed through the target layer come to rest therein; a diffusion enhancing layer for enhancing diffusion of deuterons accumulated by said accumulation layer from said accumulation layer, said diffusion enhancing layer comprising a metal selected from the group consisting of palladium, palladium alloys, and mixtures thereof; and a nonhydrogenizeable support comprising a good thermal conducting metal.

12. A neutron emitting target as claimed in claim 11 further comprising an hydrogen isotope diffusion barrier layer in contact with said target layer for preventing the diffusion of hydrogen isotopes across the surface of said target layer in contact with said hydrogen isotope diffusion barrier layer.

13. A neutron emitting target as claimed in claim 11 further comprising a first hydrogen isotope barrier layer disposed on said target layer for preventing the diffusion of tritium atoms from the surface of said target layer, and a second hydrogen isotope diffusion barrier layer disposed between said target layer and said accumulation layer for preventing the diffusion of hydrogen isotopes between said target layer and said accumulation layer.

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