

(19)



(11)

EP 3 979 407 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:

06.04.2022 Bulletin 2022/14

(51) International Patent Classification (IPC):

H01Q 1/00 (2006.01)

H01P 1/08 (2006.01)

H01P 1/14 (2006.01)

(21) Application number: **20199656.8**

(52) Cooperative Patent Classification (CPC):

H01Q 1/002; H01P 1/08; H01P 1/14

(22) Date of filing: **01.10.2020**

(84) Designated Contracting States:

**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**

Designated Extension States:

BA ME

Designated Validation States:

KH MA MD TN

(71) Applicant: **European Space Agency**

2201 AZ Noordwijk (NL)

(72) Inventor: **ESPANA, Cesar Miguel**

2201 AZ Noordwijk (NL)

(74) Representative: **D Young & Co LLP**

120 Holborn

London EC1N 2DY (GB)

(54) **DEVICE AND METHOD FOR IMPROVED MULTIPACTOR PERFORMANCE**

(57) There is disclosed a method of modifying a dielectric, ferrite or metallic surface, the method comprising the steps of causing a flow of particles to collide with the surface at a predetermined angle and energy so as to

cause microscopic discontinuities or modifications extending into the surface by virtue of inelastic collisions of the particles and the surface..

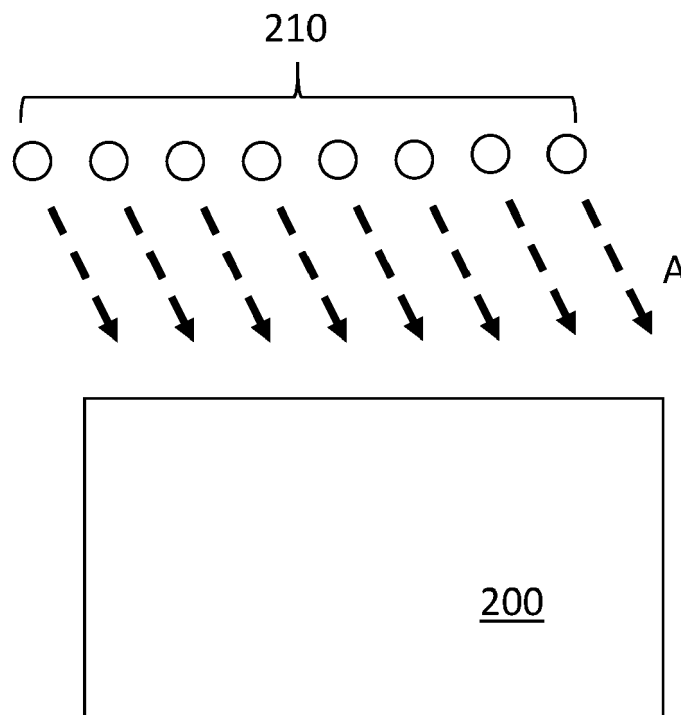


Figure 2A

EP 3 979 407 A1

Description

Field

[0001] The present disclosure relates to a device and method for improved multipactor performance.

Description of the Prior Art

[0002] The "background" description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description which may not otherwise qualify as prior art at the time of filing, are neither expressly or impliedly admitted as prior art against the present disclosure.

[0003] The multipactor performance of a material includes the secondary electron yield of the material. The secondary electron yield relates to the response of the material as a result of absorbing incident electrons and then subsequently re-emitting electrons. In practice, a number of high energy electrons are absorbed and a greater number of lower energy electrons are re-emitted from the material. In this way, the number of electrons exiting the surface is greater than the number incident on the surface.

[0004] The use of materials, in particular dielectric materials, in high power radio frequency (RF) designs is growing due to the benefits gained in terms of mass and size. Currently, the multipactor performance of materials, in particular dielectric or ferrite materials, may be a blocking point preventing the achievement of higher RF power capabilities.

[0005] As such, consideration of the multipactor performance may be seen as important in the improvement of the production of high power RF designs. High power RF designs are increasingly important in modern communication and therefore efforts in this area may yield novel and inventive techniques for improvements for these designs.

[0006] Efforts to date have focussed on improvement of materials, such as by the layering of additional material over the material for use in the high power RF device. Other attempts have investigated chemical deposition of additional material.

[0007] Herein, we present a novel and inventive approach to providing benefits in this area.

SUMMARY OF THE INVENTION

[0008] In a first aspect of the disclosure there is provided a method of modifying a dielectric, ferrite or metallic surface, the method comprising the steps of causing a flow of particles to collide with the surface at a predetermined angle and energy so as to cause microscopic discontinuities or modifications extending into the surface by virtue of inelastic collisions of the particles and the

surface.

[0009] This method provides a surface that has been treated so as to have an improved multipactor performance. This method provides discontinuities and/or modifications extending into the surface such that incident electrons which might otherwise be absorbed and then re-emitted are absorbed and then ultimately retained in the structure of the surface. As such, the method provides a reduction in the total number of re-emitted electrons that are successfully released from the surface (i.e. released and not then re-absorbed). In this way, an improved multipactor performance can be provided. This process can be performed on a surface of a device, which may be a part of a larger fully constructed product. Therefore, after the device (or surface) is designed and produced this device/surface can be treated according to the method described herein, without changing or impacting the other properties of the device/surface (of course, the multipactor properties are changed). As such, this present method is advantageous over present systems which require treatments to be applied prior to the construction of the device, or which impact other properties of the device or product and so need to be accounted for. This improved multipactor performance is also provided without the requirement for additional layering of materials on the surface. An improved multipactor performance may be considered as including an improved secondary electron yield, where the secondary electron yield decreases as an improvement. This process is therefore operationally less intensive than present methods.

[0010] In an example, the particles are individual atoms or molecules. Such particles have impact effects (from their mass and energy levels etc) which are particularly effective in producing microscopic discontinuities and or modifications extending into the surface which can capture incident electrons. "Capture" here means reduce the likelihood of subsequently re-emitted electrons being successfully released from the surface as described in detail below.

[0011] In an example, the particles are oxygen particles. In particular, the particles may be oxygen atoms. Oxygen particles have been found to be effective at providing discontinuities and/or modifications that are able to capture incident electrons as described herein.

[0012] In an example, the flow of particles is movable relative to the surface during the method. Control over the flow of particles enables a greater control over the discontinuities and modifications that can be produced by the impacting particles. With greater control over the resulting discontinuities and/or modifications, the user of the method can tailor the discontinuities and/or modifications to provide a higher electron retention (i.e. reabsorption after re-emission) likelihood. Furthermore the user can decide to treat a portion of the surface and move the beam to treat another portion or not as would be most effective in the specific situation.

[0013] In an example, the predetermined angle and

the energy is continuous across the surface or changes in response to desired collisions. As above, control over the angle and energy of particles enables a greater control over the discontinuities and modifications that can be produced by the impacting particles. With greater control over the resulting discontinuities and/or modifications, the user of the method can tailor the discontinuities and/or modifications to provide a higher electron retention (i.e. reabsorption after re-emission) likelihood.

[0014] In a second aspect of the disclosure there is provided a high power RF device comprising a surface against which in use electrons may collide, the surface comprising one or more regions having been exposed to a flow of particles so as to collide therewith and to create microscopic discontinuities or modifications extending into the surface by virtue of inelastic collisions of the particles and the surface. The surface of the device therefore has an improved multipactor performance by virtue of the microscopic discontinuities and/or modifications present in the surface.

[0015] In a third aspect of the disclosure there is provided a device, comprising: a surface, wherein the surface comprises a series of impact artefacts formed on the surface, the device arranged to provide an improved multipactor performance.

[0016] The presently disclosed system provides a device with a surface that has impact artefacts such that an improved multipactor performance is provided to the device. Surface artefacts may be discontinuities and/or modifications in the surface. This improved multipactor performance is therefore provided without the requirement for additional layering of materials on the surface. An improved multipactor performance may be considered as including an improved secondary electron yield, where the secondary electron yield decreases as an improvement.

[0017] As such, this invention advantageously enables a device to be constructed from materials which have been selected for use with the device and which have had the performance enhancing treatment applied to it. Therefore, there is no need for modifications to the designs as is often the case in presently available solutions.

[0018] The term "impact artefact" is intended to refer to a geometrical change to an otherwise substantially uniform surface. Specifically, but not exclusively, the term is intended to refer to the resulting indentation or indentations in a surface as a result of multiple impact/s from specifically selected particles under specific parameters.

[0019] In an example, the series of impact artefacts are formed by impaction of particles on the surface. Advantageously the impact artefacts can be produced on the surface by impaction of particles on the surface. Use of particles, as opposed to conventional manufacturing techniques, provides a less operationally intensive method for providing impact artefacts on the surface. As described further herein, the particular impact surface treatment approach provides other performance benefits in addition to the manufacturing benefits.

[0020] In an example, the impaction of particles on the surface is a controlled impaction of particles on the surface. A controlled impaction of particles allows for a more uniform distribution of the series of impact artefacts on the surface. The uniform distribution can be achieved by specific control over the formation of the impacts. Parameters of control that may advantageously be adapted to achieve the desired impact surface profile include, but are not limited to, impact energy, impact particle size and also the angle of incidence of the particles against the surface being modified.. A controlled impaction of particles may also allow a surface geometry to be achieved according to a predetermined desired profile.

[0021] In an example, the impact artefacts are arranged on at least a minimum area of the surface. Covering the minimum area of the surface advantageously allows for particularly effective improvement in the multipactor performance of the device. Indeed, covering the minimum area significantly reduces the propensity of minor imperfections leading to high re-emission of electrons. The minimum area being covered reduces the likelihood of the multipactor performance from a small untreated portion of the device undermining the improved multipactor performance of the device from the remaining treated portion. Aspects of inventions disclosed herein may apply to the devices above, and other similar devices, embodying surface modifications by surface modification techniques as explained herein.

[0022] In an example, the secondary electron yield (SEY) of the surface is improved by a factor of from around 1.1 to around 10. Improvement in this context may be taken to mean that, if a blank surface typically re-emits X electrons when impacted with electrons of energy E, the impacted surface re-emits from X/10 to X/1.1 electron(s) when the impacting electron also has an energy E. Clearly, this is a significant and advantageous improvement in the multipactor performance of the surface.

[0023] In an example, the series of impact artefacts have an average depth and an average width, the average depth being greater in magnitude than the average width. This arrangement has been found to be advantageous in improving the multipactor performance of a surface. Indeed, the absorbing and re-emission of electrons decreases in an arrangement wherein the average depth is greater than the average width.

[0024] In an example, the series of impact artefacts have an aspect ratio of above around 1:2. In this way, the average depth of an artefact may be twice as great (or more) in distance than the average width. This may reduce the SEY of a surface more than other arrangements wherein the aspect ratio is less. Herein, reduction of the SEY means reduction of the "effective" SEY, as the SEY of a material is a property intrinsic to the material, however the effective SEY of the material can be reduced, as disclosed herein.

[0025] A surface treatment approach as described herein has many applications for RF components, devic-

es and systems, particularly where the uncontrolled release of low energy electrons might inhibit performance. One such application is to an antenna. The proposed technique is effective in many telecommunications devices or the like. The proposed technique is particularly effective for high power RF devices including antennae. The proposed technique may also be particularly effective for devices including an RF switch, an isolator/circulator, RF ferrite devices, RF loads and attenuators, RF transmission lines, RF power combiners or dividers and travelling wave tubes. The proposed technique may also be particularly effective in particle accelerators.

[0026] In a fourth aspect of the disclosure there is provided a method of treatment of a surface for improving multipactor performance of the surface, comprising: forming a series of impact artefacts extending into the surface.

[0027] The method proposed herein is less operationally intensive than present methods for providing an improvement in multipactor performance. Furthermore, the method proposed herein can be a treatment provided to a device pre or post construction without requiring the user to further consider the impact of the treatment on the device. In this way, the proposed method is less detrimental to other considerations of the user than present methods.

[0028] Additionally the surface modification provided by the present disclosure can be applied post device manufacture i.e. as the last step in manufacture. A high quality surface may therefore be provided which might otherwise be damaged during device manufacture.

[0029] In an example, forming a series of impact artefacts comprises impacting the surface with particles. Advantageously the impact artefacts can be produced on the surface by impaction of particles on the surface. Use of particles, rather than say via manufacture methods, provides a less operationally intensive method for providing impact artefacts on the surface.

[0030] Further aspects are provided in accordance with the claims.

[0031] It is to be understood that both the foregoing general summary of the disclosure and the following detailed description are exemplary, but are not restrictive, of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032] A more complete appreciation of the disclosure and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

- Figures 1A and 1B schematically show longitudinal cross-sectional views of a device;
- Figures 2A and 2B schematically show views of examples of a method according to the present inven-

tion;

- Figures 3A and 3B schematically show views of examples of a device according to the present invention;
- Figure 4 schematically shows a longitudinal cross-sectional view of an example of a device;
- Figure 5 schematically shows a longitudinal cross-sectional view of an example of a device;
- Figure 6 schematically shows a top-down view of an example of a device;
- Figure 7 schematically shows a longitudinal cross-sectional view of an example of a device being treated; and,
- Figure 8 schematically shows an example of an arrangement for performing a method according to an example.

DESCRIPTION OF THE EMBODIMENTS

[0033] A device with improved multipactor performance and a method of treatment of a surface for improving multipactor performance of the surface are disclosed. In the following description, a number of specific details are presented in order to provide a thorough understanding of the embodiments of the present disclosure. It will be apparent, however, to a person skilled in the art that these specific details need not be employed to practice embodiments of the present disclosure. Conversely, specific details known to the person skilled in the art are omitted for the purposes of clarity where appropriate.

[0034] As described above, the present disclosure relates to provision of improvements in the multipactor performance of surfaces and devices. Throughout the following description the term "multipactor performance" is sometimes used but this term may be used alongside secondary electron yield (SEY) or similar. The result is the same, that of a reduced production of lower energy emitted electrons from a surface having absorbed a higher energy electron. The term "improved" may be used herein in relation to multipactor performance or SEY. Improved is to be taken to mean made more beneficial in the circumstances. So, in a specific example, an "improved" SEY would mean a reduced SEY rather than an increased SEY. Furthermore, although this will not be repeated in each example, the multipactor performance of a surface is for an incident electron of a given energy E. Therefore, a surface will have one multipactor performance for an incident electron of a first given energy E1, and a second multipactor performance for a different incident electron of a second given energy E2.

[0035] The re-emission of lower energy electrons by surfaces as a response to the absorption of a higher energy electron can be detrimental in high power RF devices. Such devices may be antennae, RF filters, RF switches, isolator or circulators or the like. These are a small number of the devices that can benefit from improved multipactor performance. Development of devices with improved multipactor performance goes hand in

hand with development of advantageous methods of treatment for multipactor performance. As such, the disclosure herein relates to both a device with an improved multipactor performance, the device having an improved multipactor performance by virtue of the application of a treatment method which is disclosed herein.

[0036] Referring now to the drawings, wherein like reference numerals designate identical or corresponding parts throughout the several views, Figure 1A is a schematic diagram of device 100. The device 100 has a surface and a body. The term surface is used herein to refer to an outwardly facing portion of the device 100. The surface does not have a set thickness, but is that which would be reasonably considered as the thickness of a surface. The surface is not infinitesimally small but is not overly deep either. The surface may be formed of the same material as the device, and may be integral with the body of the device. The surface is a term which is used as the element which is affected by the presently disclosed method for improving multipactor performance.

[0037] In the example of Figure 1A, the device 100 has a surface. Incident on the device 100 is an electron 120. The electron 120 is incident on the device along a direction of travel indicated by arrow I. The electron 120 is of an energy level such that the electron 120 is absorbed by the device 100 of Figure 1A when the electron 120 reaches the device 100 and interacts with the device 100 (and therefore also the surface of the device 100).

[0038] After the electron 120 is absorbed by the device 100, the electron 120 may be emitted from the device 100 as a greater number of lower energy electrons. This is shown schematically in Figure 1B. The higher energy electron 120 has been absorbed and is emitted from the device 100 as a greater number of lower energy electrons 130, 132, 134. In the specific example shown, the electron 120 has been re-emitted as three electrons 130, 132, 134. Each electron 130, 132, 134 has a specific re-emission direction as shown by the three arrows R1, R2, R3. In this example, the device 100 has an SEY of 3, given the material of the device 100, the energy of the incident high energy electron 120 and the incidence angle of the high energy electron 120 travelling along direction I.

[0039] As can be seen from the example of a device in Figures 1A and 1B, the device 100 has absorbed one electron, of a given energy E, and re-emitted three. Therefore the secondary electron yield performance for this device 100, for an electron of that same given energy E, is 3. This means that there is a danger of a release of significant amounts of electrons from the surface which may interrupt and interfere with RF activities of the device 100. Indeed, detrimental effects may be noticed if released electrons enter an RF EM (electromagnetic) field area of the device 100. As such, methods described herein have been developed to reduce this effect. The secondary electron yield may vary with material selection of the device 100 and therefore approaches exist which analyse the material and utilise addition to the device 100

of layers of different materials with different SEY performances. Although such layering may be beneficial for SEY it can impact the device in other unforeseen ways, and make optimisation of the device more operationally intensive. We disclose a method herein which does not consider materials, and is therefore beneficial for ease of construction of devices as well as for optimisation of devices.

[0040] Referring now to Figures 2A and 2B, there are schematically shown views of examples of a method according to the present invention. Figure 2A shows a device 200 with a surface. The surface may be a dielectric, ferrite or metallic surface. Incident on the device 200 (and therefore the surface of the device 200) are a group of particles 210. The flow of particles are incident with a predetermined angle and energy so as to cause microscopic discontinuities and/or modifications extending into the surface by virtue of inelastic collisions of the particles and the surface. In an example, the particles 210 are atoms and/or molecules. The particles 210 are incident on the device 200 as indicated by the dashed arrows A. The particles 210 are of a sufficient energy to impact the device 200 and form a series of impact artefacts on the surface of the device 200. Impact artefacts on a surface may be microscopic discontinuities and/or modifications which extend into the surface.

[0041] The impact artefacts may be formed in the surface of the device 200 in a similar manner to asteroid collisions, and in a similar way while the artefact is formed from an impact, material from the surface may be ejected from the surface in solid or liquid form and landed elsewhere on the surface. Such molten or solid material may be easily removed from the surface via gentle cleaning or abrasion of the surface as some of the material will likely not adhere strongly to the surface.

[0042] Referring specifically to Figure 2B, there is shown a device 200 and an impacting element 212. The impacting element 212 may move in a direction substantially indicated by arrow B. The element 212 moves with a sufficient energy to impact the device 200 and form a series of impact artefacts on the surface of the device 200. Although the element 212 of Figure 2B is shown as moving perpendicular to the device 200 there is no requirement for this to be the case. Other techniques for forming a series of artefacts on a surface may include additive or subtractive manufacturing. The technique can be performed by a method which can result in a similar topology change on the surface of the device 200.

[0043] Referring now to Figures 3A and 3B, schematically show views of examples of a device according to the present invention. Figure 3A shows a device 300 with an impact artefact 302 in the surface 304 of the device 300. The device 300 has a surface 304 and a body 306. The body 306 is of some undefined length as shown in the Figure. The device 300 has been treated with an impaction method as of the type shown in the specific examples of Figures 2A and 2B. The impaction has formed a series of impact artefacts 302 on the surface 304 of the

device 300, though only one is shown in the Figure. In Figure 3A, there is an incident higher energy electron 320. The direction of travel of the electron 320 is shown by arrow I. As in the example of Figure 1A, the electron 320 will be absorbed by the device 300.

[0044] In the example of Figure 3B, the higher energy electron 320 has been absorbed and re-emitted as three lower energy electrons 330, 332, 334. As previously discussed, the number of re-emitted electrons will not be three for every device, but three is used herein to illustrate the invention. Lower energy electron 330 is re-emitted in direction R1. Lower energy electron 332 is re-emitted in direction R2. Lower energy electron 334 is re-emitted in direction R3. Lower energy electron 332 travels out from the impact artefact 302 and out from the device 300. Lower energy electrons 330, 334 travel along directions R1 and R3, but these directions lead into the side walls of the artefact 302 in the surface 304. Therefore, lower energy electrons 330, 334 are reabsorbed and are therefore not released from the device 300.

[0045] In this way, compared to the example of Figures 1A and 1B, the present method may provide an improved multipactor performance. In this specific example, which is merely an example and schematic, the multipactor performance has been improved by a factor of 3. This factor 3 comes from the SEY of the example of Figures 1A and 1b being 3 (three lower energy electrons being released for one higher energy incident electron) while the SEY of the example of Figures 3A and 3B is 1 (one lower energy electron being released for one higher energy incident electron). The factor 3 as discussed above presumes that the example shown in Figure 3B is not representing one particular impact-and-re-emission event but rather the average in the example wherein the device 300 contains a large number of artefacts 302 and is impacted by a large number of electrons, i.e. across a statistically significant number of impact-and-re-emission events.

[0046] Improvements will be dependent, by their very nature, on the materials selected and the surface artefacts formed in those materials. Improvements should be easily obtained by factors of from around 1.1 to around 10.

[0047] Referring now to Figure 4, there is shown a schematic view of a device 400 with a surface 404 and a body 406. The device 400 has a series of impact artefacts 402 on the surface 404. The term "on the surface" includes the term "in the surface" an impact artefact may appear as a crater in the device 400 and as such the term on the surface must also mean in the surface.

[0048] In the example, one particular impact artefact 402A has a maximum depth D and a maximum width W. As a whole, the series of artefacts 402 will have an average maximum depth and an average maximum width. By "maximum depth" it is meant the depth at the deepest point of the artefact. By "maximum width" it is meant the width at the widest point of the artefact. The deepest point of the artefact is likely to be somewhat centrally located

in the artefact, though this may vary based on characteristics of the method of impaction. The widest point of the artefact is likely to be located somewhat near the opening of the artefact, though this may also vary based on characteristics of the method of impaction.

[0049] The artefacts 402 may not be of a uniform shape or size, however broadly the artefacts 402 can be considered to have a depth (i.e. distance into the surface 404) and a width (i.e. a distance across the surface 404). In the same way, the artefacts can be considered to have a maximum depth and a maximum width. In the specific example shown, the maximum depth D of impact artefact 402A is of a similar length to the maximum width 402A. Taken as a whole, the series of artefacts 402 can therefore be understood as having, as a collective, an average maximum width and an average maximum depth.

[0050] In an advantageous example of the present invention, the average maximum depth of the series of artefacts 402 is greater than the average maximum width of the series of artefacts 402. This provides an improved likelihood of low energy electron re-absorption after re-emission.

[0051] Referring now to Figure 5, there is shown a schematic view of a device 500 with a surface 504 with a series of impact artefacts 502 on it. In the example of Figure 5, the device 500 has a first impact artefact 502A and a second impact artefact 502B. The widths of the two impact artefacts 502A, 502B are similar, however the depth of the second impact artefact 502B is greater than the depth of impact artefact 502A. In the example shown, the device 500 has absorbed a high energy electron in each of the artefacts 502A, 502B. The device 500 is in the process of re-emitting 4 lower energy electrons 530A, 530B, 532A, 532B, 534A, 534B, 536A, 536B from each of the impact artefacts 502A, 502B.

[0052] As can be seen from the example of Figure 5, two 532A, 534A of the four 530A, 532A, 534A, 536A lower energy electrons will be released from the device 500. As such, the impact artefact 502A in and of itself provides an "effective" SEY of 2, as one higher energy electron has been absorbed and, of the four electrons 530A, 532A, 534A, 536A re-emitted, only two electrons 532A, 534A are actually released from the impact artefact 502A. The other two re-emitted electrons 530A, 536A are re-emitted in directions so as to collide again with the surface 504 of the device 500 and be absorbed. The lower energy electrons result in a lower SEY. As such, for a few iterations of electrons impacting the surface, being absorbed and re-emitted, and having a reduced likelihood of escaping the surface, the total number that escape from the surface is reduced in a very significant manner. As such, the system results in a very few electrons being successfully emitted from the surface and these are likely lower energy electrons than those electrons originally incident on the surface.

[0053] Referring now to impact artefact 502B, none of the four 530B, 532B, 534B, 536B lower energy electrons that have been re-emitted are released from the impact

artefact 502A. Each direction arrow (which indicate the same directions as for the electrons 530A, 532A, 534A, 536A in impact artefact 502A) points into another wall portion of the surface artefact 502B. As such, each lower energy electron 530B, 532B, 534B, 536B will collide with the surface 504 of the device 500 and be absorbed.

[0054] As such, in the example of Figure 5, the device 500 has an SEY of 4. The artefact 502A provides an "effective" SEY of 2, which is clearly a reduction when compared to the non-treated device. The artefact 502B proves an "effective" SEY of 0, which is further reduced again. If such an SEY could be provided in practice (noting Figure 5 is schematic), this would provide for multipactor-free operation, as it would be impossible to create an electron avalanche via electron multiplication. The same could be said for an effective SEY of less than 1.

[0055] Each artefact 502 is formed by impaction and so the shape of each artefact 502 will not necessarily be the same, though the broad shape is likely to be common for artefacts 502 that are formed via the same impaction method. However, in the broadest sense each artefact 502 will have an opening in the top of the surface 504 of the device 500 through which re-emitted electrons must pass to be released from the device 500. Each artefact 502 will have side walls and a floor though these may somewhat blend into one another. These are formed in the surface 504 similar to the manner of a crater.

[0056] As can be seen in the example of the two artefacts 502A, 502B in Figure 5, there may be advantages in having a greater depth of artefact 502 for the same width. In a particular example, as illustrated in Figure 5, advantages to reduction in the SEY can be gained wherein the average depth is greater in magnitude than the average width. Indeed, aspect ratios (width to depth) of artefacts 502 of above around 1:2 have been found to be particularly effective at reduction of SEY. Furthermore, an average maximum depth of around 200 nm has been found to be particularly advantageous. An average maximum width of around 100 nm has been found to be particularly advantageous.

[0057] The balance to strike relates to size of the opening of the artefact so that the high energy electron can penetrate into the artefact, and depth of artefact so that the high energy electron contacts the side wall of the artefact deep into the artefact. The deeper the contact point, and the narrower the opening, the more likely the re-emitted low energy electrons are to hit the side walls and be re-absorbed. However, if the artefact is too narrow as a whole, the incident high energy electron is more likely to be absorbed higher on the walls of the artefact such that the re-emitted low energy electrons are more likely to be released. As such, there is a balance to strike in the use of this technique.

[0058] Referring now to Figure 6, there is shown a schematic view of a device 600 with a surface 604 with a series of impact artefacts 602 on it. In the example of Figure 6, the device 600 is shown in a top down schematic view. The device 600 has a portion of the surface 604

which has impact artefacts 602 formed on it. This portion is labelled by the arrow T. This is the portion T of the device 600 that has been treated with impaction to form the impact artefacts 602. The surface 604 has another portion U which does not have impact artefacts 602 on it, this is the untreated portion U of the device 600.

[0059] Consideration of the relative sizes of the treated portion T to the untreated portion U is relevant for particularly effective reduction of the SEY of the device 600. For particularly effective reduction, a "minimum area" of the surface 604 should have impact artefacts arranged on it. In accordance with this, the minimum area should be the treated portion T of the surface 604.

[0060] This stems from the occurrence of multipactor from a resonant electron cloud being "amplified" by the SEY and due to an alternating electric field which may occur between the two surfaces. As such the arrangement of the surfaces in question and the power of the RF used in/near the surfaces are considerations for determining the minimum area for any particular device set up. In an example, the device 600 may have two surfaces which face one another. The two surfaces should be treated such that the treated portions T of both surfaces cover a minimum area. In this illustrative example, each surface is 10 cm² in area. If the surfaces both have an untreated portion U, for example even as small as 0.1 cm², and these two untreated portions U are facing one another, there may be electron emission from these two surfaces which combine to produce a multipactor effect as strong as if the two surfaces were entirely untreated. As such, the specific arrangement of the device, on which the treatment is provided, is a consideration in regards to the minimum area. The minimum area being covered reduces the likelihood of the multipactor performance from a small untreated portion U of the device undermining the improved multipactor performance of the device from the remaining treated portion T.

[0061] In the above example therefore, the minimum area could be considered as around 99% of the surface as, in the worst scenario (that of matching, untreated 1 cm² portions), the multipactor performance may be undermined if less than 99% is treated. In other scenarios, such as when one surface is not facing another surface, the minimum area may be much lower than 99% of the surface.

[0062] In such an example, the device 600 may have two surfaces that face one another. At a certain power level, as an example 1000 W, there will be a multipactor discharge between the surfaces. However, in this arrangement there is also a screw which projects from the first surface towards the second surface. At a lower power level, as an example 10 W, there will be a multipactor discharge between the surface of the screw and the second surface. As such, the consideration that the device is to be operated at 20 W informs the user that the second surface and the surface of the screw should be treated to provide effective multipactor suppression. In this way, the "minimum area" is the area of the second surface

and the area of the screw. Whereas, if the device is to be operated at 1200 W, the "minimum area" would be the full surfaces of both the first and second surfaces and also the screw.

[0063] In this respect, the minimum area takes into account both the areas and surfaces that are involved in the device to be treated, as well as the multipactor discharge at the power ranges of interest. In some examples, the surface of the device may be entirely treated.

[0064] For completeness of terminology, the surfaces of a device that will be the first to sustain multipactor when increasing the RF power gradually, are known as the "critical area". In the example above, the second surface and the screw surface are the relevant surfaces to consider as the "critical area".

[0065] Referring now to Figure 7, there is shown a schematic view of a device 700 with a surface 704 and a body 706. In the example of Figure 7, the device 700 is shown in a longitudinal cross-sectional view. Also shown in Figure 7 is a group of particles 710 incident on the device 400 along a direction of travel indicated by shade arrows A. The group of particles 710, in the schematic illustration of Figure 7, have the same direction of travel A, though in a real example the directions of travel would not be identical but rather mostly the same. The group of particles 710 are incident on the surface 704 of device 700 with an incident angle 740, shown in a dot-dash line measured against a 90 degree perpendicular line from the surface 704.

[0066] Factors which may impact the surface artefacts formed on the device include the particles chosen for impaction 710, the angle of incidence 740 for those particles, the speed of the particles and the material, or materials, from which the device 700 is formed. As mentioned above, preferentially the surface artefacts are deeper than they are wider. The surface artefacts may preferentially be directly into the surface (i.e. perpendicular to the surface) for certain usages or device arrangements and may preferentially be at an angle to the surface for other usages or device arrangements.

[0067] Therefore, it can be understood that the impaction required for the formation of the surface artefacts is advantageously a controlled impaction. By exacting control over the impaction, in particular over the impaction method, the shape of the surface artefacts can be controlled. By controlling the shape of the surface artefacts, the efficacy of the proposed method can be controlled and therefore optimised to any of the particular arrangement, shape or intended usage of the device being treated. In this sense, therefore, "controlled" in this instance may be taken to mean "generated in a controlled way" and this may related to any of the above factors including type of particle used for impaction, defined energy range, angle of incidence, fluence and time of exposure in particle beam.

[0068] Referring now to Figure 8, there is shown a schematic view of an example arrangement 800 for treating a device. The arrangement 800 involves a pulsed

CO₂ laser 802 which pulses through a ZnSe window 804 of a main chamber 806. The laser beam 808 is incident on a focussing gold mirror 810 located inside the main chamber 806. The laser beam 808 is focussed into a copper expansion nozzle 812. The copper expansion nozzle 812 is connected to a pulsed valve 814 which itself is connected to an oxygen (O₂) gas supply 816. The gas supply 816 provides oxygen to the valve 814 which exits through the copper expansion nozzle 812 into an atomic oxygen beam 818. The sample holder 820 for holding a sample in the main chamber 806 is shown and the atomic oxygen beam 818 is incident on the sample holder 820.

[0069] Shown connected to the main chamber 806 is a differential pumping chamber 822. The differential pumping chamber 822 is connected to an RGA chamber 824. The RGA chamber 824 is connected to a quadrupole RGA 826 for atomic oxygen beam timing and composition observation.

[0070] In the particular arrangement shown, experimental operating conditions may be used as follows. Molecular oxygen is introduced into an evacuated conical expansion nozzle 812 at several atmospheres pressure through a pulsed molecular beam valve 814. A laser induced breakdown is generated in the nozzle 812 throat by a pulsed CO₂ TEA laser 802 focused to intensities greater than or around 109 W/cm². The resulting plasma is heated in excess of around 20,000 K by the ensuing laser supported detonation wave, and then rapidly expands and cools. The nozzle 812 geometry confines the expansion to promote rapid electron-ion recombination into atomic oxygen. The source generates an atomic oxygen beam 818 with fluxes greater than or around 10¹⁸ atoms per pulse at 8 ± 1.6 km/s with an ion content below 1% for LEO testing. For other applications the beam velocity can be varied over a range from 5 to 13 km/s by changing the discharge conditions.

[0071] Use of atomic oxygen in this technique results in artefacts of around 100 to 150 nm width and 200 nm depth. As mentioned above, such an aspect ratio is advantageous for use in improving multipactor performance. Use of other particles may provide different aspect ratios but these may also be advantageous in different circumstances as disclosed above.

[0072] The proposed technique may be used to significantly benefit the performance of any RF component. In particular, high power RF devices or components may benefit from the proposed invention. In particular, this may include any of an antenna, a RF filter or multiplexer, a RF switch, an isolator, a circulator, a RF ferrite device, RF loads and/or attenuators, RF transmission lines, RF power combiners and/or dividers, and Travelling Wave Tubes. In particular, this technique is advantageous for re-emitted electrons below around 1000 eV energy level for SEY characterisation.

[0073] The proposed technique has significant advantages over present methods for improving multipactor. The device for use can be designed and materials

sourced, then treated and the improvement requires no further adjustment from a design level. The present technique may be used in a "post processing step" rather than during previous steps in manufacture. In contrast, present methods which use additional layering of materials are necessarily used during process of manufacture of the device and render further adjustments and optimisations of the device necessary. Furthermore, the present technique may well be used in future building techniques which may have significantly increased sensitivities which may be negatively impacted by additional layering of materials, a method not employed by the proposed technique. There is also no requirement for calculations regarding chemical compatibility as there is in present techniques which utilise layering of additional materials. Therefore, the present invention provides a less preparation intensive, less process intensive technique which has an improved result over present methods.

[0074] Other examples of the invention may include modelling the performance of a device and determining the desired multipactor performance of the device and the required surface geometry, then modifying the surface of the device according to a method described herein in response to the predetermined surface geometry. In an example, the relevant surfaces may be considered alongside the RF power usage of those surfaces alongside the likely direction of incoming electrons when in use. These criteria may be used by the user to inform the properties of the impaction used to create the surface artefacts. In this way, a series of tailored surface artefacts can be provided to the surface of the device to enable a particularly effective multipactor response for the device. Properties available for varying by the user include, the specific technique of forming impaction (via particle or via impacting element), if particle-based impaction used, the type or types of particles used, the angle or angles of the particle beam and the energy or energies of the particle beam.

[0075] In an example of a tailored design, the surface artefacts may be tapered by moving the particle beam relative to the surface during impaction. In an example, the beam may be directed initially perpendicular to the surface so that a drilling effect is provided. Subsequently the beam may be rotated or moved in an arc or circle or both so as to machine a surface artefact, using the particle beam as an abrasion tool (as a sort of nano machining). In other examples, the surface artefacts may be tapered or vertical or one sided, asymmetrical or whatever shape might be desirable by moving the source relative to the surface during the impact operation. While high levels of control over the particle beam would be necessary to achieve such tailored surface artefacts, it is relevant to consider that such control, used in this manner, would provide a particularly effective artefact for providing an improved multipactor performance of a device. Other particularly effective shapes include, for example, a truncated cone formed in the surface. As electrons en-

ter the narrow opening, they are likely to be released from the bottom wider portion of such a cone. Of course, high levels of control would be required to form such a shape from an impact artefact.

[0076] In an example, the SEY of a device ready for use can be modelled (based on the arrangement of the device's surfaces, other nearby surfaces and likely RF power usage). The critical area i.e. those areas most likely to suffer from multipactor events may be determined. The critical area will be affected by the RF power level and the surfaces arrangements of and around the device. Furthermore, a consideration of the incoming direction of electrons for the device when in use can be made to inform the surface treatment required. Surface treatments may then be determined to appropriately improve the resistance to multipactor events for the relevant surfaces. A treatment, which is then expected to be particularly effective, may then be applied to the relevant surfaces in a post-processing step for the device (and other relevant surfaces). In this way, the method can be used, if desirable, on only the relevant surfaces and therefore be a more efficient process in terms of resources required to provide the surface treatment. Material layering processes typically apply material across full surfaces, whereas the present technique can be used sparingly to cover only relevant areas.

[0077] In an alternate arrangement, the material of the device, the RF power level of the device and the typical SEY of the material of the device but in a flat, idealised arrangement is considered. A model may be produced to find the number of electrons produced as a result of a certain energy of incident electron. This informs the SEY improvement required. This is then used to inform the surface treatment that is to be provided.

[0078] The improvements in multipactor, or multipactor performance, discussed herein relate to the improvement in the E1, Emax and SEYmax criteria of surfaces. The E1 (of a surface) relates to the minimum energy of an electron at which a surface has an SEY of 1. Therefore, to reduce the likelihood of multipactor occurring, a high E1 is desirable. This ensures that only higher energy incident electrons can result in a multipactor event. As such, "improvement in multipactor performance" may mean an increase in the E1 of a surface or material.

[0079] Relevant other factors include Emax and SEYmax. The Emax is the energy of the incident electrons at which the SEY of the surface/material is at its maximum (SEYmax). By reducing the SEYmax of a surface, the overall magnitude of any multipactor event from that surface is also reduced, though not necessarily by the same factor. As such, an "improvement in multipactor performance" could instead or also be seen as a reduction in the SEYmax of a surface.

[0080] Because multipactor is the repeated absorption and re-emission of electrons from a surface, small gains in E1 or SEYmax have a compounded effect on overall multipactor performance. For example, an improvement by as little as 3 or 4% over a few iterations of the above-

described absorption and re-emission process leads to vast gains in overall performance for the device.

[0081] In non-optimised uses of this technique on a variety of samples including alumina, Teflon, rexolite, and ultem significant improvements in both E1 and SEYmax have been found. Indeed, in presently available techniques improvements of 5 to 10 eV for E1 is a major achievement while the present technique has provided, in non-optimised uses, 20 to 60 eV improvements for E1. Furthermore, improvements in SEYmax have ranged from reductions of 1.5 to 3.5 (up to around 50%). As such, this new technique is particularly efficient at improving the multipactor performance of surfaces/materials.

[0082] As such, there is disclosed a device, comprising a surface, wherein the surface comprises a series of impact artefacts formed on the surface, the device arranged to provide an improved multipactor performance.

[0083] The foregoing discussion discloses and describes merely exemplary embodiments of the present disclosure. As will be understood by those skilled in the art, the present disclosure may be embodied in other specific forms without departing from the essential characteristics thereof. Accordingly, the content of the present disclosure is intended to be illustrative, but not limiting of the scope of the disclosure, as well as of the claims. The disclosure, including any readily discernible variants of the teachings herein, defines, in part, the scope of the foregoing claim terminology.

Claims

1. A method of modifying a dielectric, ferrite or metallic surface, the method comprising the steps of causing a flow of particles to collide with the surface at a predetermined angle and energy so as to cause microscopic discontinuities or modifications extending into the surface by virtue of inelastic collisions of the particles and the surface.
2. The method of claim 1 wherein the particles are individual atoms or molecules.
3. The method of claim 1 or 2, wherein the particles are atomic oxygen particles.
4. The method of any of claims 1 to 3, wherein the flow of particles is movable relative to the surface during the method.
5. The method of claims 1 to 4, wherein the predetermined angle and the energy is continuous across the surface or changes in response to desired collisions.
6. A high power RF device comprising a surface against which in use electrons may collide, the surface comprising one or more regions having been exposed to

a flow of particles so as to collide therewith and to create microscopic discontinuities or modifications extending into the surface by virtue of inelastic collisions of the particles and the surface.

7. A device, comprising:

a surface, wherein the surface comprises a series of impact artefacts formed on the surface, the device arranged to provide an improved multipactor performance.

8. A device according to claim 7, wherein the series of impact artefacts are formed by impactation of particles on the surface.
9. A device according to claims 7 or 8, wherein the impactation of particles on the surface is a controlled impactation of particles on the surface.
10. A device according to any of claims 7 to 9, wherein the impact artefacts are arranged on at least a minimum area of the surface.
11. A device according to any of claims 7 to 10, wherein the secondary electron yield of the surface is improved by around a factor of from around 1.1 to around 10.
12. A device according to any of claims 7 to 11, wherein the series of impact artefacts have an average depth and an average width, the average depth being greater in magnitude than the average width.
13. A device according to any of claims 7 to 12, wherein the series of impact artefacts have an aspect ratio of above around 1:2.
14. A method of treatment of a surface for improving multipactor performance of the surface, comprising: forming a series of impact artefacts extending into the surface.
15. A method according to claim 14, wherein forming a series of impact artefacts comprises impacting the surface with particles.

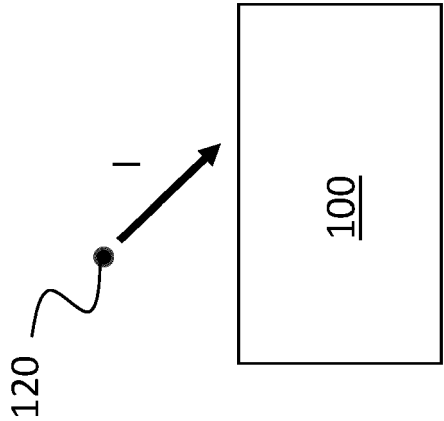


Figure 1A

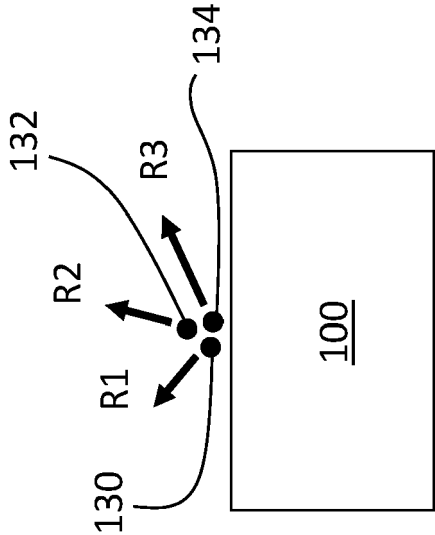


Figure 1B

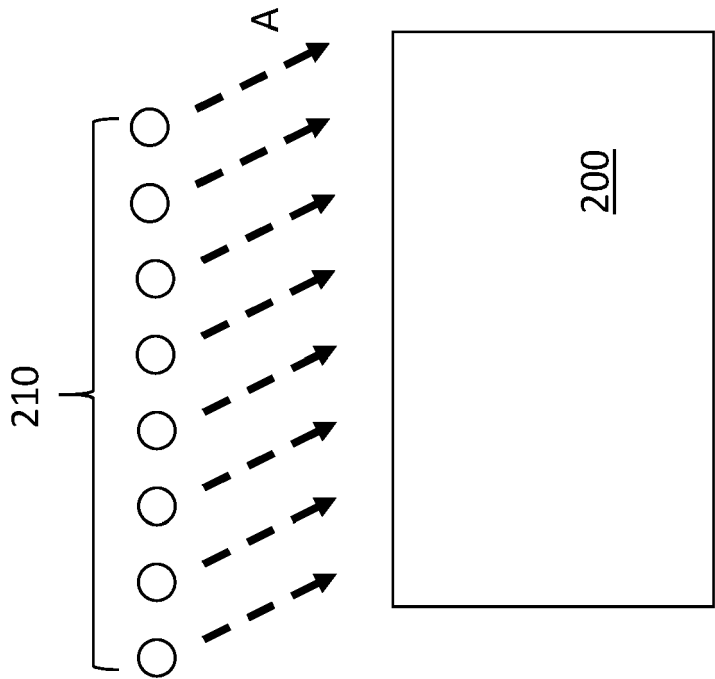


Figure 2A

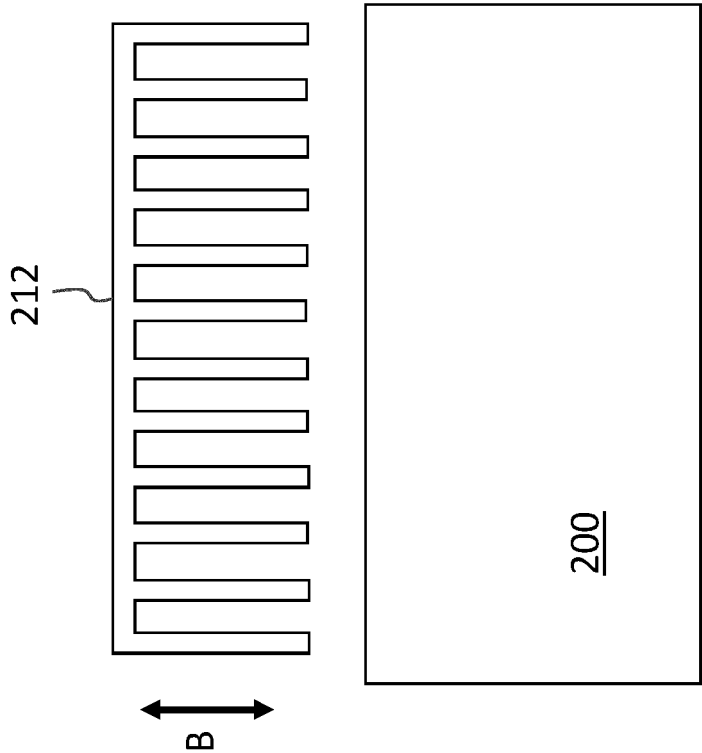


Figure 2B

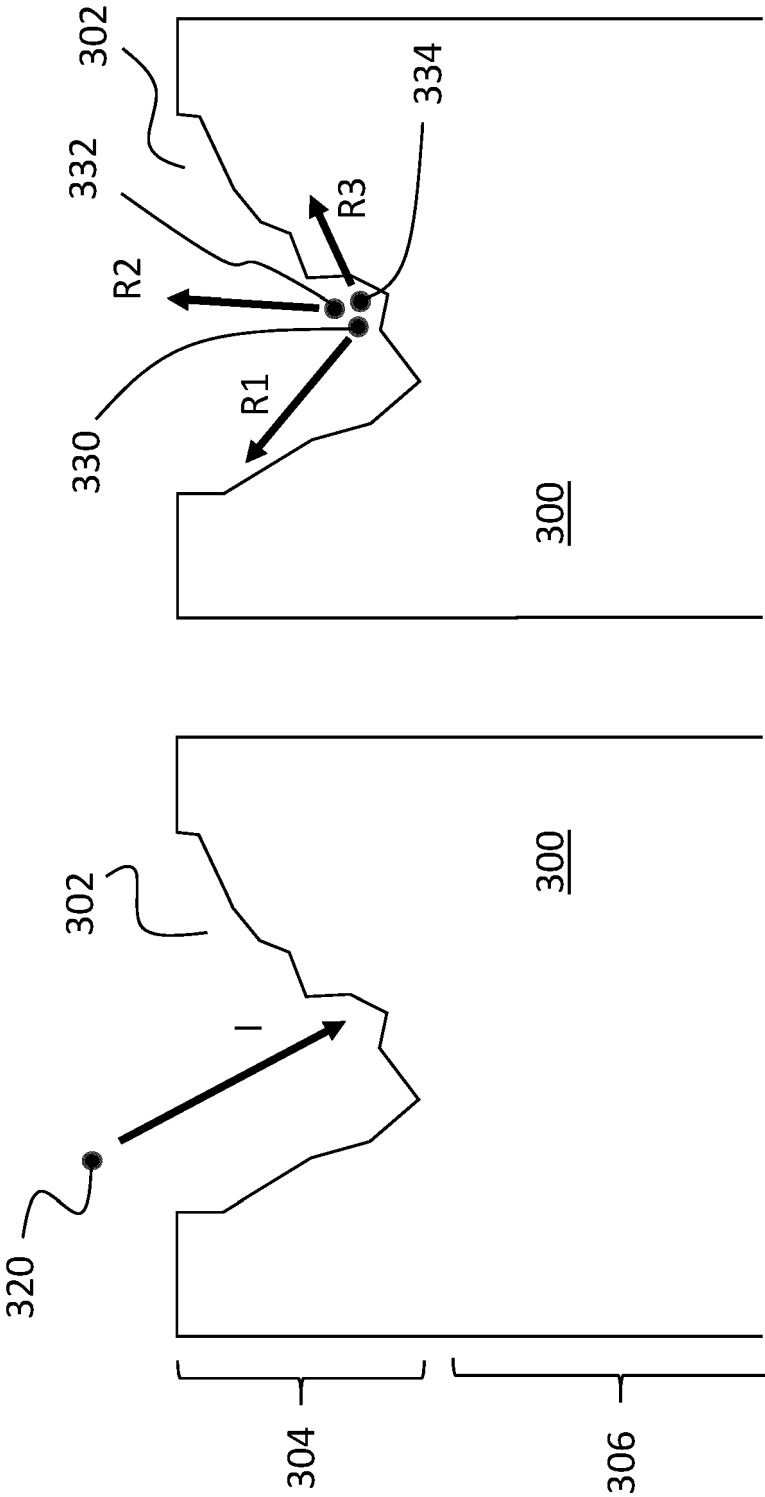


Figure 3B

Figure 3A

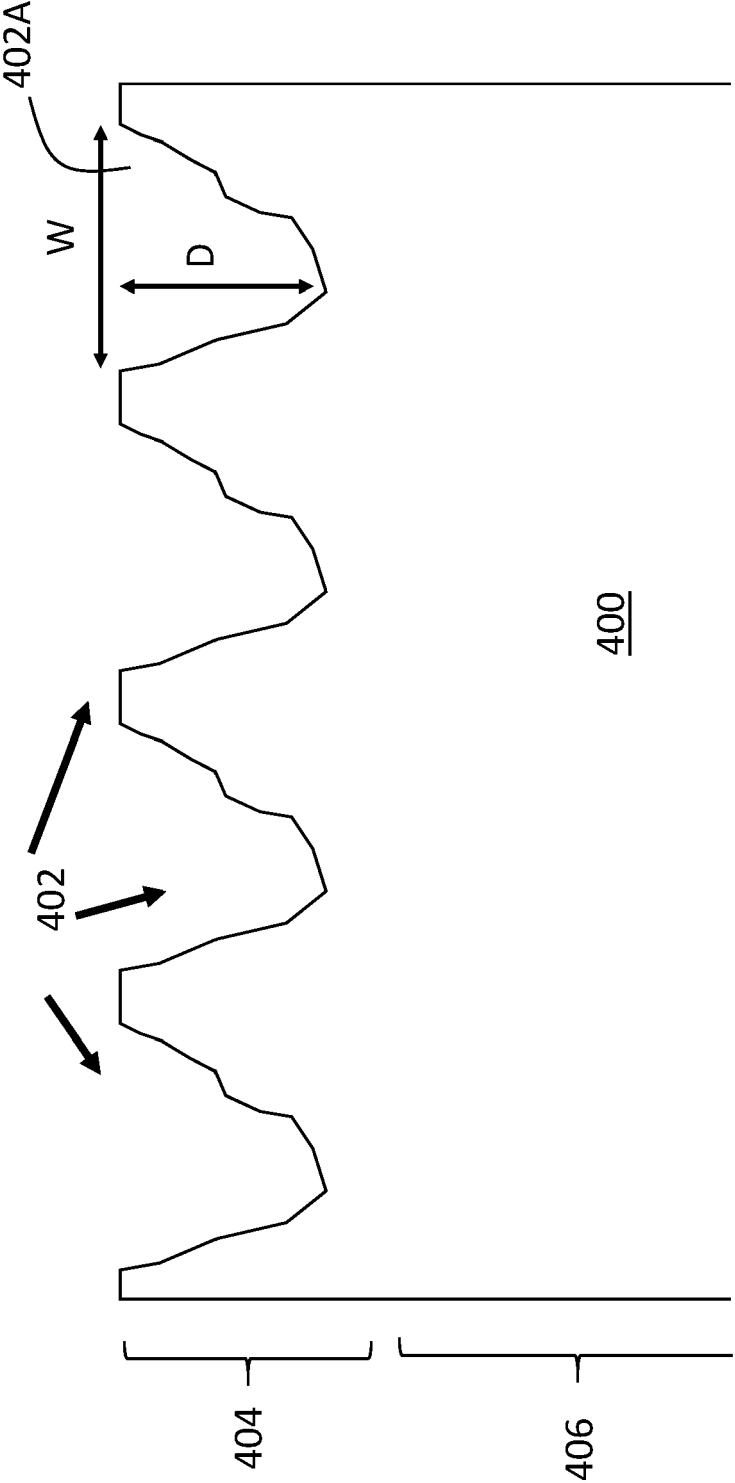


Figure 4

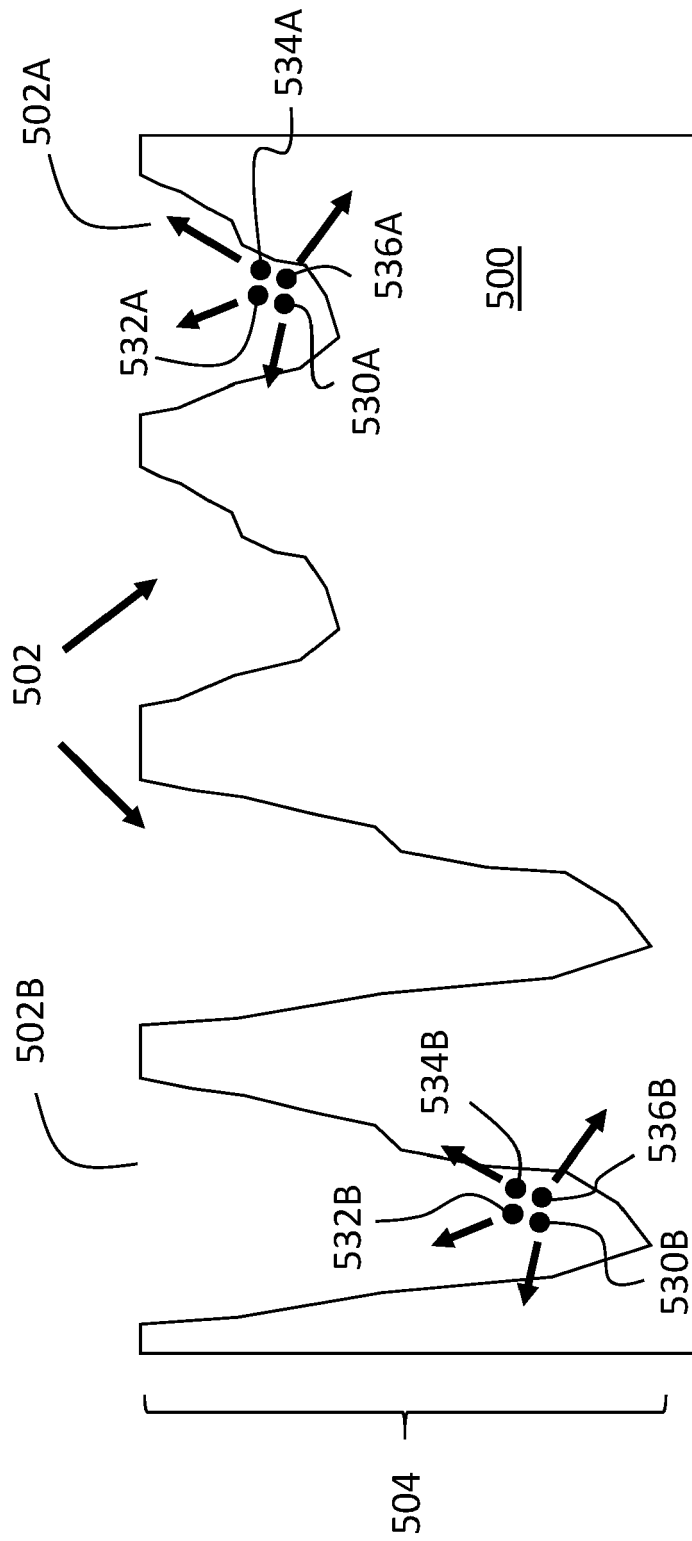


Figure 5

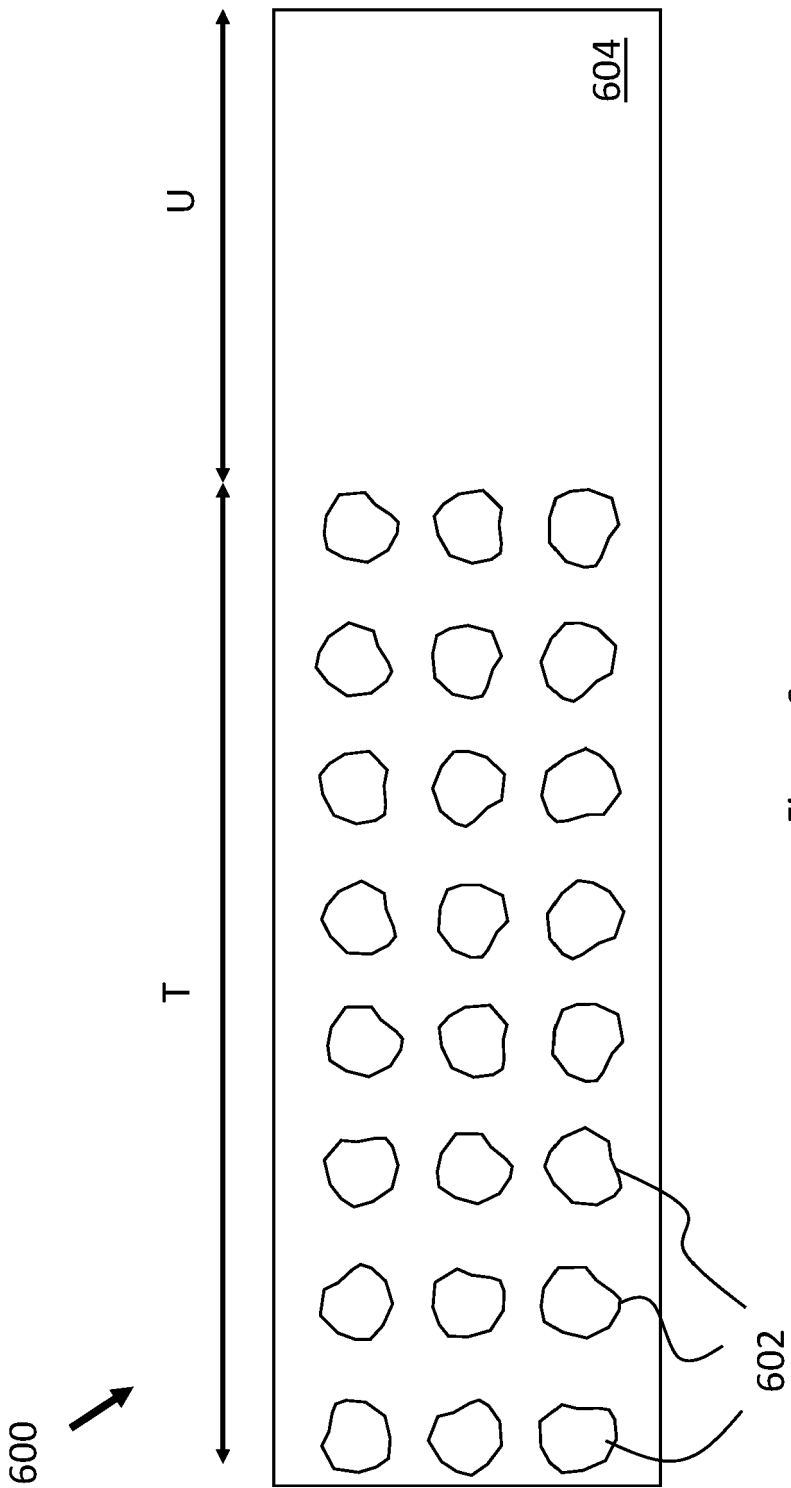


Figure 6

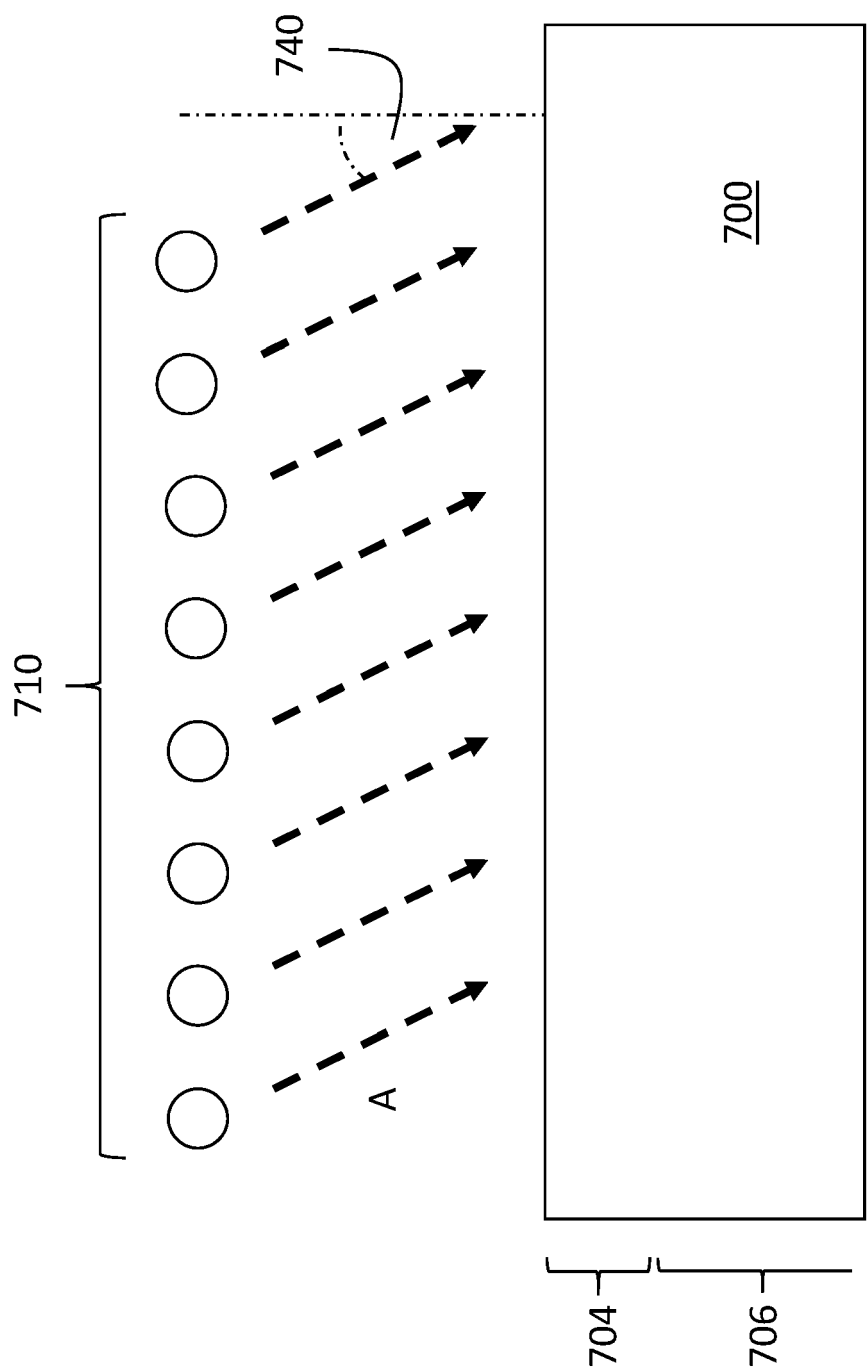


Figure 7

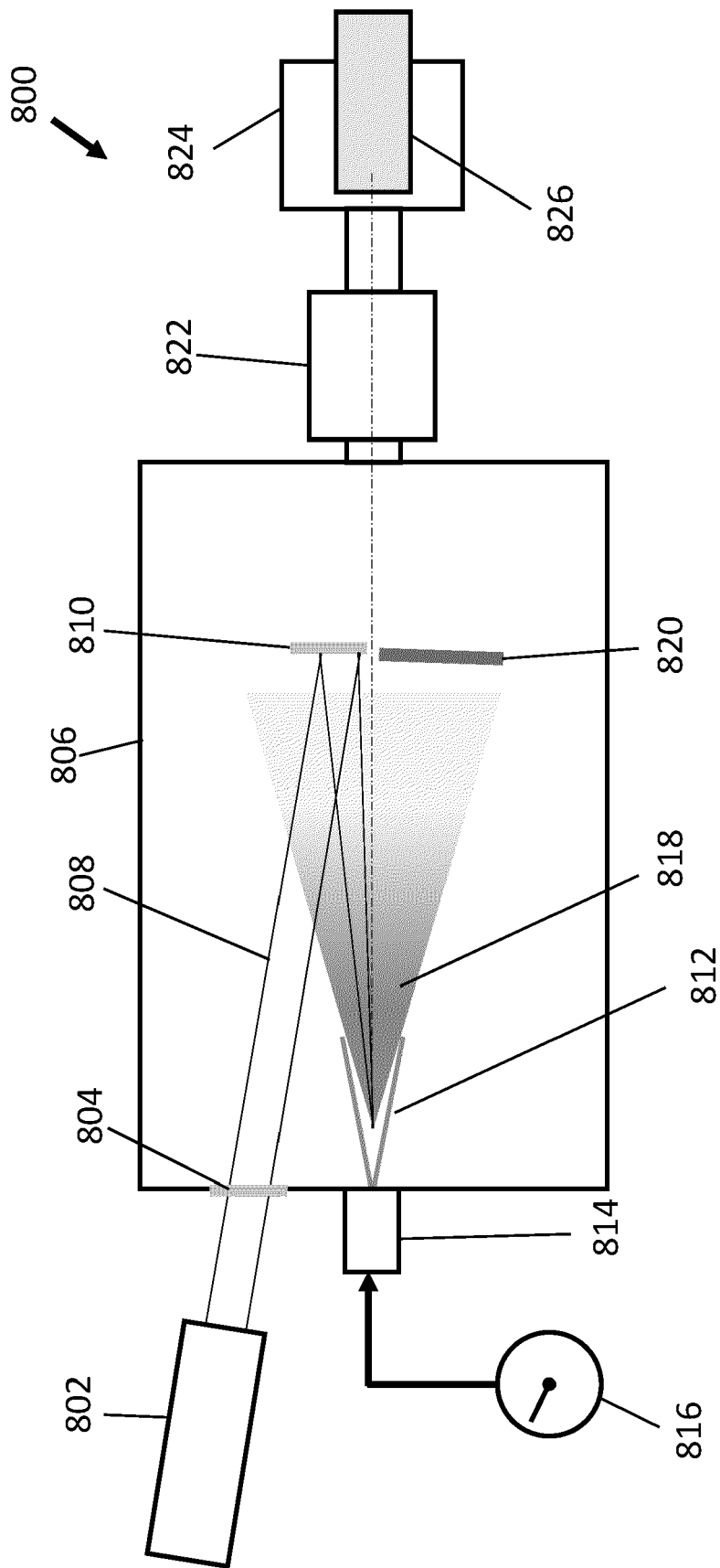


Figure 8



EUROPEAN SEARCH REPORT

Application Number
EP 20 19 9656

5

10

15

20

25

30

35

40

45

50

55

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	YANG JING ET AL: "Nanofabrication Techniques Used for Suppressing Multipactor in Space Applications", 2018 IEEE INTERNATIONAL CONFERENCE ON MANIPULATION, MANUFACTURING AND MEASUREMENT ON THE NANOSCALE (3M-NANO), IEEE, 13 August 2018 (2018-08-13), pages 241-244, XP033458315, DOI: 10.1109/3M-NANO.2018.8552197 [retrieved on 2018-11-28] * figure 1A * * figure 5 * * figure 6 * * Section I; paragraph [first] * * Section II.A * * Section III.B; paragraph [first] - paragraph [second] * -----	1-15	INV. H01Q1/00 H01P1/08 ADD. H01P1/14
X	CHANG C ET AL: "The effect of grooved surface on dielectric multipactor", JOURNAL OF APPLIED PHYSICS, AMERICAN INSTITUTE OF PHYSICS, US, vol. 105, no. 12, 24 June 2009 (2009-06-24), pages 123305-123305, XP012125664, ISSN: 0021-8979, DOI: 10.1063/1.3153947 * figure 1 * * figure 6 * * Section I, 1st paragraph * ----- -/--	6,7	TECHNICAL FIELDS SEARCHED (IPC) H01P H01Q
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 4 March 2021	Examiner Kalialakis, Christos
CATEGORY OF CITED DOCUMENTS		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			

EPO FORM 1503 03.82 (P04C01)



EUROPEAN SEARCH REPORT

Application Number
EP 20 19 9656

5

10

15

20

25

30

35

40

45

50

55

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	PIVI M ET AL: "Sharp reduction of the secondary electron emission yield from grooved surfaces", JOURNAL OF APPLIED PHYSICS, AMERICAN INSTITUTE OF PHYSICS, US, vol. 104, no. 10, 18 November 2008 (2008-11-18), pages 104904-104904, XP012116567, ISSN: 0021-8979, DOI: 10.1063/1.3021149 * figure 1a * * figure 1b * * figure 3 * * Section I * * Section II *	6,7	
X	SONG BAI-PENG ET AL: "Investigation of grooved surface suppressing multipactor across HPM dielectric window", 2014 INTERNATIONAL SYMPOSIUM ON DISCHARGES AND ELECTRICAL INSULATION IN VACUUM (ISDEIV), IEEE, 28 September 2014 (2014-09-28), pages 97-100, XP032687911, DOI: 10.1109/DEIV.2014.6961628 ISBN: 978-1-4799-6750-6 [retrieved on 2014-11-18] * figure 2 * * Section I *	6,7	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC)
Place of search The Hague		Date of completion of the search 4 March 2021	Examiner Kalialakis, Christos
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 03.82 (P04C01)



EUROPEAN SEARCH REPORT

Application Number
EP 20 19 9656

5

10

15

20

25

30

35

40

45

50

55

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	GENG R L ET AL: "Suppression of multipacting in rectangular coupler waveguides", NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH. SECTION A, ELSEVIER BV * NORTH-HOLLAND, NL, vol. 508, no. 3, 11 August 2003 (2003-08-11), pages 227-238, XP004442404, ISSN: 0168-9002, DOI: 10.1016/S0168-9002(03)01660-7 * figure 4 * * figure 12 * * Section 4 *	6,7	
X	VALIZADEH R ET AL: "Reduction of secondary electron yield for E-cloud mitigation by laser ablation surface engineering", APPLIED SURFACE SCIENCE, ELSEVIER, AMSTERDAM, NL, vol. 404, 4 February 2017 (2017-02-04), pages 370-379, XP029934053, ISSN: 0169-4332, DOI: 10.1016/J.APSUSC.2017.02.013 * figure 3 * * Section III * * Table III *	6,7	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC)
Place of search		Date of completion of the search	Examiner
The Hague		4 March 2021	Kalialakis, Christos
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 03.82 (P04C01)



EUROPEAN SEARCH REPORT

Application Number
EP 20 19 9656

5

10

15

20

25

30

35

40

45

50

55

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	TEL: "UltraTrimmer Plus(TM) Products and Service Tokyo Electron Ltd. Gas Cluster Ion Beam system UltraTrimmer Series", 29 November 2018 (2018-11-29), XP055781735, Retrieved from the Internet: URL:https://web.archive.org/web/20181129101117/https://www.tel.com/product/ultratrimmer.html [retrieved on 2021-03-03] * Table: Product Comparison; page 2 *	3	
A	SONG QIANG ET AL: "Recent Advances in the Theory and Experiment of Multipactor Suppression", 2019 INTERNATIONAL SYMPOSIUM ON ANTENNAS AND PROPAGATION (ISAP), ANTENNA BRANCH OF CHINESE INSTITUTE OF ELECTRONICS, 27 October 2019 (2019-10-27), pages 1-3, XP033692261, [retrieved on 2020-01-17] * figure 2 * * figure 3 * * Section I * * Section II.B *	1-15	TECHNICAL FIELDS SEARCHED (IPC)
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 4 March 2021	Examiner Kalialakis, Christos
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

EPO FORM 1503 03.82 (P04C01)