

Radiation Shielding

Technical Field

[0001] The present application relates to an application of radiation shielding in the field of aerospace.

Background

- 5 [0002] In space, the ionizing radiation environment is significantly different from on Earth, and entities in space, such as satellites and spacecraft, are exposed to a harsh radiation environment consisting of primary and secondary protons, alpha particles, high charge and energy (HZE) particles, neutrons, electrons, X-rays and gamma rays. Electronical components must therefore be protected from ionizing radiation.
- 10 [0003] To protect the electronics, two conventional solutions exist: 1) the use of intrinsically radiation hardened components, and the use of 2) passive shielding. In terms of performance, radiation hardened components consume more power, they are expensive, and they are at least one generation behind comparable Commercial Off-The-Shelf (COTS) components. However, the use of COTS components in satellites and other space platforms requires shielding from ionizing radiation, since they are more
- 15 susceptible to the deleterious effects of the space radiation environment than radiation hardened components customized for high reliability in space.

- [0004] Based on the above, there is an unmet need for shielding configuration and/or arrangement that would address the shortcomings of conventional solutions such as described above in attempting to minimize both the mass and volume impacts required to shield, for example, COTS components and
- 20 other parts on spacecraft platforms.

[0005] It is understood that the aspects and embodiments described below are not limited to solving any or all of the disadvantages of the known approaches described above.

Summary

- 25 [0006] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to determine the scope of the claimed subject matter; variants and alternative features which facilitate the working of the invention and/or serve to achieve a substantially similar technical effect should be considered as falling into the scope of the invention disclosed herein.
- 30 [0007] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to determine

the scope of the claimed subject matter; variants and alternative features which facilitate the working of the invention and/or serve to achieve a substantially similar technical effect should be considered as falling into the scope of the invention disclosed herein.

5 [0008] The present disclosure provides a conformal thin (1-20 mm) shielding of electronic components from a mixed ionizing radiation field. The conformal shielding is placed directly in contact with the electronic components of an entity (i.e. spacecraft) in space, or in close contact/proximity of the electronic components such that synergistically with its composition is able to 1) stop protons and heavier charged particles, 2) achieve a reduction in electron radiation, 3) absorb the produced slow and thermal neutrons, and 4) reduce the produced Bremsstrahlung, a metal or additional compound as
10 described herein can be included in the composite material.

[0009] In addition to the radiation shielding properties, conformal shielding has optimal directional heat transfer properties to enable heat transfer from the electronic components to the ambient space, with reduced heat transfer from the ambient space to the electronic components.

15 [0010] In a first aspect, the present disclosure provides an apparatus, comprising: an electronic component comprising at least one circuit; a shielding material, coupled to the electronic component, forming a protective shield over or a protective shield that partially surrounds said at least one circuit, wherein the protective shield comprises at least one layer formed of a composite material, wherein at least one layer is disposed on the electronic component to form the protective shield protecting the electronic component from radiation; wherein the composite material comprises a polymer composite
20 comprising an arrangement of carbon material to increase the emissivity of the composite material, and/or wherein the composite material comprises a thermal conductive coating disposed over said at least one layer facing towards the electronic component, and/or the composite material comprises a thermal reflective coating disposed over said at least one layer facing away from the electronic component.

25 [0011] In a second aspect, the present disclosure provides an apparatus for radiation shielding, comprising: a shielding material configured to form a protective shield over or partially surrounding at least one circuit of an entity in space, wherein the protective shield comprises at least one layer formed of a composite material, wherein said at least one layer is configured to be disposed on at least one circuit to form the protective shield protecting the at least part of one circuit from radiation; wherein the
30 composite material comprises a polymer composite of an arrangement of carbon material to increase the emissivity of the composite material; and/or wherein the composite material comprises a thermal conductive coating configured to be disposed over said at least one layer facing towards the at least one circuit, and/or the composite material comprises a thermal reflective coating configured to be disposed over said at least one layer facing away from the electronic component.

[0012] In a third aspect, the present disclosure provides a method for providing an apparatus of another aspect as described herein, the method comprising: forming a shielding material using one or more of: additive manufacturing, compression molding, injection molding, compression molding, 3D-compression molding, and thermoforming; and applying the shielding material directly disposed onto a surface of an electronic component; or applying the shielding material proximal to an electronic component.

[0013] In a fourth aspect, the present disclosure provides an apparatus, comprising: an electronic component comprising at least one circuit; a shielding material coupled to the electronic component forming a protective shield over said at least one circuit or a protective shield that partially surrounds said at least one circuit, wherein the protective shield comprises at least one layer formed of a composite material, wherein said at least one layer is disposed on the electronic component to form the protective shield protecting the electronic component from radiation; wherein the composite material comprises a polymer composite comprising an arrangement of carbon fibers and/or pure elemental carbon in the form of colloidal particles, e.g. Carbon Black, to increase the emissivity and thermal conductivity; and wherein the composite material comprising a thermal conductive coating disposed over said at least one layer facing towards the electronic component, and/or a thermal reflective coating disposed over said at least one layer facing away from the electronic component.

[0014] In a fifth aspect, the present disclosure provides a system comprising one or more circuitry, wherein the system is configured to apply said apparatus of another aspect as described herein onto said one or more circuitry using a vacuum coating, a high emissivity foil, painting, or a physical vapor deposition coating.

[0015] The methods described herein for producing the shielding material may be performed by software in machine-readable form on a tangible storage medium e.g., in the form of a computer program comprising computer program code means adapted to perform all the steps of any of the methods described herein when the program is run on a computer or apparatus for manufacturing the composite material and where the computer program may be embodied on a computer-readable medium. Examples of tangible (or non-transitory) storage media include disks, thumb drives, memory cards etc. and do not include propagated signals. The software can be suitable for execution on a parallel processor or a serial processor such that the method steps may be carried out in any suitable order, or simultaneously.

[0016] The optional features or options described herein may be combined as appropriate, as would be apparent to a skilled person, and may be combined with any of the aspects of the present invention.

Brief Description of the Drawings

[0017] Embodiments of the invention will be described, by way of example, with reference to the following drawings, in which:

5 [0018] Figure 1 is an example of shielding material disposed on an electronic component shielding the electronic component from a mixed ionizing radiation field according to an aspect of the present invention;

[0019] Figure 2 is an example of shielding material that comprises a composite material with at least one layer of polymer composite according to an aspect of the present invention;

[0020] Figure 3 is another example of shielding material that comprises multiple functional layers of polymer composite according to an aspect of the present invention;

10 [0021] Figure 4 is an example chart of the temperature profile in respect of the doped shielding material (labelled as radiator layer) according to an aspect of the present invention; and

[0022] Figure 5 are example charts of the thermal conductivity and reflectivity of the shielding material according to an aspect of the present invention.

[0023] Common reference numerals are used throughout the figures to indicate similar features.

15 Detailed Description

[0024] Embodiments of the present invention are described below by way of example only. These examples represent the suitable modes of putting the invention into practice that are currently known to the applicant although they are not the only ways in which this could be achieved. The description sets forth the functions of the example and the sequence of steps for constructing and operating the example. However, the same or equivalent functions and sequences may be accomplished by different examples.

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[0025] It is widely known that pure aluminum, aluminum alloys, and any other metals and metal alloys are typically not suitable to shield Commercial Off-The-Shelf (COTS) electronics components against the space radiation environment, at least not to a level suitable for a long-duration space mission because these metals due to their limiting stopping power are unable to fully block charged particles from reaching the electronics components.

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[0026] It is also known that metals also produce a large amount of ionizing secondary particles, both from the impinging space radiation (projectile fragments) and from the metal itself (target fragments) and produce charged particles (protons and heavier ions), neutrons, electrons, X-rays and gamma rays. That means behind the shielding, assuming the metal e.g. Al, is used as part of the shielding, there will be a new mixed radiation field of protons, alpha particles, high charge and energy (HZE) particles,

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neutrons, electrons, X-rays and gamma rays, which is even more damaging to the electronic components than the primary radiation field. Especially the target fragments have short ranges but high ionization density and can no doubt cause severe damage to the electric components, where the electronic components would be situated on or within an entity in space, such as satellites and spacecraft.

[0027] Electronic components herein refer to any electronic device or system with several terminals or a physical entity that is part of such a device or system used to affect electrons or their associated fields, e.g., a Central Processing Unit (CPU), a Graphics Processing Unit (GPU), a Random Access Memory (RAM), a Solid-State Drives (SSD), metal-oxide semiconductor field-effect transistor (MOSFET), a Non-Volatile Memory Express (NVMe) interface, a High-Density Non-Volatile Memories (HDNVM). The terminals may connect to other electrical components to create an electronic circuitry comprising one or more circuitry with a particular function. In one example, the electronic component that may be shielded by the apparatus described herein may be a radio wave receiver, otherwise known as a radio tracker. In an alternative example, the electronic component may form part of a complex avionics system.

[0028] In order to optimize both the mass and volume impacts required to shield the electronic components and/or other parts of a space-faring entity, i.e., a small spacecraft platform, there is a need for a suitable shielding arrangement and its material composition. The shielding should be arranged in a way to minimize both mass and volume impacts by minimizing the distance between the shielding material and the electronic components, as shown in the data that follows.

[0029] In an aspect of the present invention, the shielding material could be coupled to the electronic component, either directly or in proximity, to form a protective shield over the electronic circuitry of the electronic component. This type of shielding is thus known herein as conformal/spot shielding and described by way of examples to shield the circuitry synergistically from homogenous ionizing radiation and/or a mixed ionizing radiation field created by charged particles, such as protons, alpha particles, and heavy ions; photons, such as X-rays and gamma rays; fast, slow, and thermal secondary neutrons.

[0030] Accordingly, conformal shielding herein refers to a shielding layer covering the whole or a larger part of an electronic circuit or a combination of circuitry. Spot shielding refers to a shielding layer covering a single electronic component, or a combination of electrical components. The main difference between the two is that while conformal shielding comprises a homogenous layer over a large part of the whole electronic circuit, on the other hand, spot shielding can cover a single radiation sensitive component. The two are however not mutually exclusive, meaning a certain type of conformal shielding is spot shielding.

[0031] It can be understood from the aspect of the present invention that the shielding material functions to stop electrons, protons and heavier charged particles, and thus the electromagnetic and

nuclear energy deposition would be relatively high or as high as possible, meeting certain criteria of the physical property of the material. Thus, hydrogen rich material offers superior electronic stopping power and superior nuclear energy deposition.

[0032] In general, the reduction of electron radiation can be achieved through three primary processes:

- 5 1) inelastic scattering by atomic electrons, which is highest for hydrogen targets, 2) elastic scattering from atomic nuclei, which is higher for high-Z materials, 3) the production of bremsstrahlung radiation, which consists of photons emitted during velocity changes of the electrons. Inclusion of metal particles in a hydrogen rich composite will reduce the X-ray production while attenuating the initial electrons.

[0033] To absorb the produced slow and thermal neutrons, a component with a high neutron absorption cross section described herein can be included in the composite material. To reduce the amount of primary and secondary electrons a low-Z metal, e.g. Al, can be included in the composite material. To reduce the produced Bremsstrahlung, a high-Z metal can be included in the composite material. In addition to the radiation shielding properties, the shielding material would have good directional heat transfer properties to enable heat transfer from the electronic components to the ambient space, with reduced heat transfer from the ambient space to the electronic components themselves.

[0034] Shielding material may be a composite material. The composite material may be produced or manufactured in various ways, including but not limited to additive manufacturing, compression molding, injection molding, compression molding, 3D-compression molding, or thermoforming. Further details on the production or methodology are described herein and the produced composite material would be adapted to provide shielding, namely against charged particles, such as electrons, protons, alpha particles, and heavy ions; photons, such as X-rays and gamma rays; fast, slow, and thermal secondary neutrons, while also serving structural purposes, ballistic protection (micrometeoroids, debris, etc.), including heat protection and protection against atomic oxygen when used at or above low Earth orbits

[0035] The composite material may comprise a polymer composite comprising an arrangement of different variations of polyethylene or polypropylene, carbon material, i.e., fibers that are short, long or chopped polymers and/or long or chopped carbon fibers, and/or pure elemental carbon in the form of colloidal particles, and/or Carbon Black, which would increase the emissivity and thermal conductivity of the material. The long or chopped polymers may be in a matrix structure or comprise a multifunctional-layered structure that provides shielding as described herein. For example, the shielding may be adapted to minimize the effects of galactic cosmic radiation, particles trapped in radiation belts, as well as against solar energetic particles and electromagnetic radiation, including X-rays and gamma rays.

[0036] For example, the composite material comprising a type of polypropylene, instead of polyethylene, that is doped with Boron, Aluminum, and Carbon Black for the purpose of conformal/spot shielding. Polypropylene is better since doped polypropylene has a melting temperature of 164-170 C, compared to doped polyethylene which has a melting temp around 125-135 C. This makes composite material comprising polypropylene better when being displaced to cover an electronic component. Carbon Black gives a very high emissivity and improved conductivity so that the heat will be absorbed very well and transferred to the outer surface of the conformal shielding and then to the ambient space.

[0037] The multifunctional-layered structure refers to a single merged layer or a plurality of separate layers, where the layers in one example of the single merged layer may gradually merge into each other, forming a single structure. In another example, layers of shielding refer to two or more (plurality of) layers of the composite material with radiation shielding characteristics. The layers in combination have multiple functions but serve a single purpose to protect, in this case, electronic components, in space or travelling in space from or by minimizing physical, thermal, chemical, and radiation damages. For example, the layers may be used to mitigate chemical damage from corrosive atomic oxygen.

[0038] Composite material may also comprise a polymer matrix or as one or more layers, where the layers may gradually merge into each other, forming a single structure. There may be two or more layers of the composite material with radiation shielding characteristics. The layers are multifunctional serving a single purpose, that is to protect electronic component(s) in space or travelling in space from or by minimizing physical, thermal, chemical, and radiation damages. For example, the layers may be used to mitigate chemical damage from corrosive atomic oxygen.

[0039] Layers may also be in the form of gradients, coatings, or sublayers of a single or plurality of layers. The layers may gradually merge into each other, forming a single layered structure. The layers may be stacked or disposed on top of one another, forming the composite material. Each layer may comprise structural material with the same or different optimized mechanical and/or thermal properties.

[0040] An example of the composite material in the layered structure may comprise the shielding layer, metal containing layer, as well any other layer(s) as described below.

[0041] Exemplary shielding layer may be a part of the composite material, layer, gradient, or coating with radiation shielding characteristics or affords protection from radiation exposure to by the objects or entities in space. The shielding layer comprises thermoplastic polymers such as ultra-high molecular weight polyethylene (UHMWPE), high-density polyethylene (HDPE), medium-density polyethylene (MDPE), atactic polypropylene (aPP), syndiotactic polypropylene (sPP) and isotactic polypropylene (iPP), doped with one or more types of chemical compounds. The chemical compounds may be Boron-based or Lithium-based. The chemical compounds may include but are not limited to B, BN, BC₄, B₂O₃, LiH, ⁶LiH, LiBH₄, Li¹⁰BH₄, Li₂B₁₂H₁₂, Li₄BH₄(NH₂)₃, NH₃BH₃, NH₃, Mg(BH₄)₂. Lithium may be Li with natural abundance or enriched ⁶Li, and boron may be B with natural abundance or enriched ¹⁰B.

For the purpose of providing radiation protection, it is understood that various alternative B-based or Li-based compositions and derivatives thereof may be integrated or able to be integrated with the thermoplastic polymers as part of the shielding layer. The thermoplastic polymers, i.e., UHMWPE, HDPE, MDPE, or PP are produced to certify mechanical strength, and thermoplastic polymers' high
 5 hydrogen content certifies good radiation shielding characteristics or properties with respect to high or highly energetic charged particles present in space. The thermoplastic polymers also slow down secondary produced neutrons. The boron and/or lithium, specifically by 1 to 20%, doping is to absorb slow and thermal neutrons, further improving the quality of the shielding.

[0042] Shielding layer for example may be a mechanical strong radiation shielding, which also acts to protect from Micrometeoroids and Orbital Debris (MMOD). The layer comprises UHMWPE, HDPE, MDPE, LDEP, or a mixture of the mentioned PE fibers, and/or PP doped with 1 to 20% (i.e. 5%) boron and/or lithium compounds. The boron and or lithium compounds can be B, BN, BC₄, B₂O₃, LiH, ⁶LiH LiBH₄, Li¹⁰BH₄, Li₂B₁₂H₁₂, Li₄BH₄(NH₂)₃, NH₃BH₃, NH₃, Mg(BH₄)₂. For the boron and lithium compounds, Lithium can be either Li with natural abundance or enriched ⁶Li, and boron can either be B
 10 with natural abundance or enriched ¹⁰B. Compounds include but are not limited to aluminium, aluminium hydroxide, phosphorus, nitrogen, antimony, chlorine, bromine, magnesium, magnesium hydroxide, antimony, tin zinc, and carbon may be included as fire/flame retardant.
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[0043] Shielding layer for example may also be a mechanical strong radiation shielding. The shielding layer comprises UHMWPE, HDPE, MDPE, LDPE, or a mixture of the mentioned PE fibers, or PP doped
 20 with 1-20% (i.e. 5%), boron and/or lithium compounds. The boron and or lithium compounds can be: B, BN, BC₄, B₂O₃, LiH, ⁶LiH LiBH₄, Li¹⁰BH₄, Li₂B₁₂H₁₂, Li₄BH₄(NH₂)₃, NH₃BH₃, NH₃, Mg(BH₄)₂. For the boron and lithium compounds, Lithium can be either Li with natural abundance or enriched ⁶Li, and boron can either be B with natural abundance or enriched ¹⁰B. Aluminium, aluminium hydroxide, phosphorus, nitrogen, antimony, chlorine, bromine, magnesium, magnesium hydroxide, antimony, tin
 25 zinc and carbon as fire-retardant compounds may also be added.

[0044] Structural layers for example may comprise layers for protection against atomic oxygen present at LEO, where the strong UV radiation breaks down the O₂ to atomic oxygen. The layer may be made of SiO₂ without and filled with 8 to 15% (by volume) fluoropolymer, thin gold or platinum layer or silicon-based paint. The structural layer may further comprise a strong micro-meteoroid (MMOD), debris and
 30 heat protection layer. For space vehicle and/or space habitat applications, the ceramic material is made of aluminium oxide Al₂O₃, boron carbide (B₄C), or silicon carbide (SiC), aluminium carbide (Al₄C₃).

[0045] Metal containing layer for example may be a part of the composite material, layer, gradient, or coating. The metal containing layer may be, for example, a metal layer, metal oxide layer, metal/metal oxide powder dispersed in a polymer matrix, metal/metal oxide enriched layer, or a coating of the
 35 composite metal/metal oxide. The metal containing layer may comprise, for example, metal(s) / metal oxide(s) and derivatives thereof.

[0046] Metal containing layer is adapted to minimize the effects of electrons, X-ray(s), gamma rays, or radiation from the X-ray. The composite material, layer, gradient, or coating may comprise one or more metal containing layers. The metal containing layer or layers are situated between or adjacent to the shielding layer of the composite material. The metal containing layer may have any thickness between
5 1mm and 30mm, inclusive of 1mm and 30mm, and are stacked on top of one another to form multiple metal containing layers as part of the composite material, gradients, coating, or powdered form of metal/metal oxide(s) in the thermoplastic.

[0047] Metal containing layers may comprise a metal/metal oxide or a metal/metal oxide, metal/metal oxide powder dispersed in the polymer matrix, with an atomic number (Z) equal to 13, or any value from
10 22 to 30, is to minimize the X-ray production while attenuating the initial electrons.

[0048] Metal containing layer, a metal/metal oxide layer, or oxide powder dispersed in the polymer matrix may comprise a metal/metal oxide with an atomic number (Z) equal to any value from 72 to 79 is to maximize the attenuation of the X-rays, which was created.

[0049] Metal containing layer, a metal/metal oxide, or oxide powder dispersed in the polymer matrix
15 may comprise a metal/metal oxide with an atomic number (Z) ranging from 13, or any value from 22 to 30, is to stop the secondary electrons without creating significant more X-rays.

[0050] More than one metal containing layer may be used to generate the composite material. An example of multiple metal containing layers may be a first layer consisting of a metal/metal oxide with an atomic number (Z) equal to 13 or any value from 22 to 30. The first layer is disposed on a second
20 layer consisting of a metal/metal oxide with an atomic number (Z) equal to any value from 72 to 79. The second layer is disposed on a third layer consisting of a metal/metal oxide with an atomic number (Z) ranging from 13 or any value from 22 to 30. The first, second, and third layers each may have a thickness of at least 1 mm, preferably from 1mm to 30 mm. The layers may be part of the thermoplastic material in the form of a gradient.

[0051] Metal containing layers (or specifically, metal/metal oxide layers) or any of the herein described layer(s) may be embedded or part of the thermoplastic polymers of the composite material as gradients to induce the effect of radiation shielding, as described above. This effect is inherent in the nature of metal/metal oxides with low atomic weight, ranging from 13 or any value between 22 and 30, inclusive
25 of 22 and 30. The metal containing layer(s) serve as shielding for electrons and the heavier metal with an atomic number between 72 and 79, inclusive of 72 and 79, for photons (emitted by X-rays and gamma rays).
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[0052] Layers may be gradually merged into each other to form a single structure or a polymer matrix. The composite material also comprises one or more structural layers. A structural layer refers to a part of the composite material, layer, gradient, or coating that provides structural support against

Micrometeoroids and Orbital Debris (MMOD) or coating that is adapted to protect against physical, thermal, corrosion and radiation damages, where structural support against Micrometeoroids and Orbital Debris (MMOD) or protection against physical damage is needed when the shielding material is applied onto electronic components on the surface of a spacecraft.

- 5 **[0053]** It is understood that the composite material may be required to have physical properties meeting a certain standard or threshold to be suitable for use in space or above the Earth's atmosphere, for example, above the orbits, i.e., Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Geostationary Erath Orbit (GEO), and including cis-lunar and beyond, the deep space. These properties exhibited by the layers of the composite material are the result of a composition or part composition of radiation-resistant materials combined to form a radiation-resistant composite material.
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- [0054]** For example, these properties include but are not limited to structural properties, strength or hardness properties; shielding properties for high energetic charged particle(s); shielding properties for electromagnetic radiation including X-rays and gamma rays; shielding properties for fast neutrons; shielding properties for slow and thermal neutrons; micrometeoroid protection on outer layer; atomic oxygen resistant coating on outer surface; low density; do not release toxic gases; do not have a relatively low melting point; low flammability (which is dependent on materials specific heat, thermal conductivity, decomposition and ignition temperatures, and the heat produced (heat of combustion) as the material burns); withstand vibrations; keep functionality and geometry even when exposed to large temperature changes; and thermal conductivity and heat insulation properties. These properties may be used or for choosing the composition when providing or manufacturing the composite material.
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- 20 Accordingly, a multi-functional structure for radiation shielding, as an option, can also be used as a structural material with optimized properties in terms of protecting against physical, thermal, radiation damage when the object or entity is situated or traveling in space, or used for habitat construction on a Moon, on an asteroid or on a planet.

- 25 **[0055]** The composite material herein described is also purposed to provide shielding against galactic cosmic radiation, particles trapped in radiation belts, as well as against solar energetic particles and electromagnetic radiation. The radiation, for example, may include X-rays and gamma rays. The radiation protection or shielding may include against fast, slow, and thermal secondary neutrons. The shielding may extend to protection again atomic oxygen when used at or above low Earth orbits (LEO).

- 30 **[0056]** The composite material may provide structural protection or ballistic protection (e.g., against micrometeoroids, debris, and other objects in space). That is, the composite material is used to shield radiation exposure received by an entity in space or suitable for a space environment, such as a spacecraft and/or as part of construction material for a spacecraft, a spacesuit, or a space habitat. In addition, the composite material may be used as construction materials for shielding a spacecraft, construction materials of a habitat, a spacesuit, or used in addition to construction materials for radiation shielding of a habitat, shielding of a satellite or any high-altitude space vehicle.
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[0057] When in close contact with the and the electronic components, the synergistic effects (heat is transferred through conduction, together with high emissivity, decent conductivity, and high reflectivity) of shielding material may amplified. To absorb thermal heat from the electronics, high emissivity of composite material or the surface facing the electronics can be made by either, or a combination of: 1. Mixing in 1-10% Carbon Black, 2. Paint high emissivity black paint, 3. Vacuum coating, 4. Physical vapor deposition (PVD), 5. Chemical vapor deposition (CVD), 6. High emissivity foil as described herein.

[0058] It is understood that when using carbon material, which includes Carbon Black and/or carbon fibers, which is a form of paracrystalline carbon that has a high surface-area-to-volume ratio, albeit lower than that of activated carbon, the thermal conductivity is increasing, and the mechanical properties are also improving.

[0059] It is further understood that to reflect heat from the surface facing away from the electronics, high reflectivity can be achieved with a very thin layer of metal, e.g., aluminum in the form of deposited (PVD, e.g., sputter deposition, CVD, electrodeposition, etc.) nano- or microparticles, or deposition of a thin sheet of a metal on the surface, or paint, or multi surface paint (MSP).

[0060] The combination of contact, high emissivity and high reflectivity gives good heat transfer from the hot electronics to the colder vacuum where the electronics are located, but bad heat transfer from the ambient space in which the electronics are located to the electronics, as shown according to data in Figure 5. Accordingly, carbon material, i.e., Carbon Black and/or polymer and/or an arrangement of carbon fibers effectively increase(s) the conductivity and the mechanical properties of the composition.

[0061] The shielding material can be produced through various manners. For example, the production of the shielding material may begin with providing the composition of materials to the device. The device may be a 3D printer or a molding apparatus suitable for receiving and processing the composition of materials. The composite material is generated based on a model using the materials. The composite material uses the materials to generate the composite material. Specifically, the materials are combined to form layers of the composite material. The method for combining the material to form the layer may be done using various techniques such that the layers are merged into each other gradually. As an option, the imperfections or defects on the composite material is removed in accordance with the model based on one or more inputs.

[0062] Further, the composite material may be generated, for example, by merging the composition in 0° warp and 45° to 90° fill direction to produce at least one layer of the composite material, wherein the composition comprises carbon fibres and thermoplastic polymers. As another option, the composition comprises thermoplastic polymers that are cross-linked prior or after to generating the composite material.

[0063] More specifically, the layers of the doped multifunctional composite material may be 3D printed or molded together, where one or more models of the composite material may be generated prior to printing or molding using appropriate computing or system tools such as using computer-aided design software. During the 3D printing or molding process, in one example, an epoxy resin matrix can be used to fill the space between the thermoplastic polymers, more specifically the UHMWPE or HDPE or MDPE or LDPE or a mixture of different PE fibers, or any form of PP, and the material can have interwoven carbon and PE fibers laid or 3D printed in the 0° warp and 45° to 90° fill direction. The composite material is 50 to 100 percent by volume UHMWPE or HDPE or MDPE or LDPE or a mixture of PE fibers, or any form of PP, and the remaining percent by volume an epoxy resin matrix and dopants, with graphite fibers. The same can be done without epoxy resin and graphite fibers.

[0064] The fiber/pore size and orientations may be optimized to get maximum material strength and thermoregulation over the material to minimize structural and morphological changes during mechanical stress and temperature variations.

[0065] The production of the composite material may also be performed by using an extrusion process, in which all components (dopants and raw plastic) is melted and formed into a continuous profile. The extrusion process starts by feeding plastic material (pellets, granules, flakes or powders) from a hopper into the barrel of the extruder. The material is gradually melted by the mechanical energy generated by turning screws and by heaters arranged along the barrel. The molten polymer is then forced into a die, which shapes the polymer into a filament that hardens during cooling. If needed to achieve the required uniformity of the composite materials with its components, the filament can be pelletized and the process repeated. After achieved a satisfactory dispersion of all components in the composite material, the filament is transferred to a 3D printer, which prints the required form factor. Molding or thermoforming techniques can be used as an alternative or in addition to 3D printing.

[0066] The mechanical strength and melting temperature of the composite material during production may be increased by cross-linking the thermoplastic polymers or polyethylene with ionizing or UV radiation. Additional catalysts (i.e. acidic catalysts) for accelerating the reaction may be applied in the process.

[0067] The production of the composite material is not limited to only the method and techniques described herein. Further techniques for doping the plastic may be applicable in order to produce the composite material under various conditions for providing various benefits and advantages associated with the composite material.

[0068] The composite material produced from the above exemplary methods would be part of the shielding material and integrated with the electronic components, as shown according to Figure 1.

[0069] Figure 1 is an example of conformal and spot shielding in black color disposed on a circuit board, i.e. Xilinx 7 evaluation kit to shield its components comprising one or more circuitry from radiation or a mixed ionizing radiation field. Shown in the figure is a conformal shielding of the whole board, with thicker spot shielding of the more radiosensitive components. The shielding material is in direct contact with the electronic components in certain areas, while remaining in close proximity to the electronic components its other areas.

[0070] Conformal and spot shielding may be displaced onto the electronic component (and its one or more circuitry) directly or proximally, and onto the MSP, which may comprise a thin layer of metal, e.g., aluminum or any other high reflective metal/compound deposited or sprayed onto the conformal and spot shielding, (sputtered, chemical or physical vapor deposition, electrodeposition, etc.) in the form of nano- or microparticles, or deposition of a thin sheet of metal on the surface of the MSP. It is understood that the thin layer of metal may comprise any one or more types of the metal/compounds described herein.

[0071] Conformal and spot shielding can be produced through conventional manufacturing methods, including but not limited to additive manufacturing, compression molding, injection molding, compression molding, 3D-compression molding, and thermoforming. It is understood that these methods can be further tailored to provide conformal and spot shielding according to any of the aspects described herein.

[0072] The conform and spot shielding produced as shown in the figure and applied to the Xilinx 7, as an example, may be part of a system comprising one or more circuitry, wherein the system may be configured to apply the conform and spot shielding on one or more circuitry using, for example, a manufacturing method as described herein that may be used to produce various types of coating such as a paint coating, a vacuum coating, a high emissivity foil, and a physical vapor deposition coating. Specifically, the system may be configured to apply the shielding material directly displaced or disposed onto a surface of an electronic component or any of the underlying circuitry in some areas, and/or apply the shielding material proximal to the electronic component or circuit, where the shielding material is applied using the paint coating, vacuum coating, the high emissivity foil, or the physical vapor deposition coating to the Xilinx 7, or any other circuit or electronic component, by way of operating the system.

[0073] Figure 2 is another example of the different layers 200 of the composite materials for shielding means. The figure shows composite multifunctional material or composite material including at least one shielding layer 206 for minimizing effects damage from traveling or residing in space, above the Earth's orbits. When disposed on each other, the layers of the composite material may gradually merge into each other layer forming a single structure or block of composite material.

[0074] Based on Figure 2, the comprise material may comprise a first shielding layer 210, at least one metal containing layer 208 over the first shielding layer 210, and a second shielding layer 206 over said

at least one metal containing layer 208 opposite of the first shielding layer 210. The metal containing layer or layers 208 are sandwiched between the two shielding layers 206, 210. The two shielding layers 206, 210 each and/or in combination with other layers of the composite material provide the composite material with radiation shielding characteristics.

- 5 **[0075]** The layers may include radiation-resistant composite materials meeting a set of mechanical and thermal requirements. These characteristics include shielding against not only HZE particles but also fast neutrons and slow thermal neutrons by incorporating Boron-based and/or lithium-based compounds with thermoplastic polymers. The shielding layers 206, 210 thereby effectively retard secondary produced neutrons and absorb slow and thermal neutrons. Examples of the shielding layers
10 206, 210 comprising thermoplastic polymers doped with one or more metals or compounds for shielding are provided herein.

- [0076]** As an option, the composite material may conclude one or more structural layers 202, 204 over the second shielding layer opposite of said at least one metal containing layer. Each of the structural layers comprises multifunctional composite materials that are prone to or comprising oxidation-resistant
15 material, heating resistant material, and polymer-based material—the multifunctional composite materials for shielding purposes in addition to radiation shielding.

- [0077]** As another option, the structural layer(s) 202, 204 may further include at least one atomic oxygen resistance layer 202 over at least one micrometeoroid layer 204, wherein at least one micrometeoroid layer 204 is disposed on the second shielding layer 206 opposite of said at least one
20 metal containing layer 208. As another option, at least one thermal protection layer 212 disposed under the first shielding layer 210 opposite of said at least one metal containing layer 208.

- [0078]** In addition, the structural layers(s) 202, 204 may comprise a heat protection layer. As an option, the heat protection layer may be disposed on the atomic oxygen resistance layer. As another option, the heat protection layer may be integrated onto the atomic oxygen resistance layer 202 over at least
25 one micrometeoroid layer 204.

- [0079]** The chemical compounds used for shielding in the shielding layers 206, 210 comprise at least boron and/or lithium. For example, the composition may comprise a boron-based or lithium-based compound that includes but is not limited to the categories of boron and lithium compounds described herein. The boron-based and lithium-based compounds may be either naturally occurring elements or
30 other, for example, boron-10 enriched B₄C. The natural abundance of boron-10 is 19.9 atom percent such that the shielding layers 206, 210 with boron-10 act as an absorber of backscattered thermal neutrons. Such absorption is significantly increased when natural boron is replaced with boron-10 enriched B₄C.

- [0080] The metal containing layer(s) 208 is sandwiched between the two shielding layers 206, 210 as shown in the figure. Each metal containing layer 208 may comprise elemental metal/metal oxide with an atomic number (Z), as an option, from 22 to 30 and/or 72 to 79. As another option, atomic number (Z) is 13 for at least two metal/metal oxide layers. As another option, atomic number (Z) is from 72 to 79, wherein said at least one metal containing layer 208 is positioned between at least two other metal containing layers 208 of lower atomic number (Z). Each layer may be the thickness, for example, of 1 to 30 mm such that when one or more metal containing layers 208 are introduced, the thickness is at least 1 mm. The thickness is adapted to or suitable for performing the function the composite material is being used, whether it is on a spacecraft or in a spacesuit, as described herein.
- 10 [0081] The described above and illustrated in Figure 2, composite material forms a protective shield surrounding the electronic component, i.e., Xilinx 7 evaluation kit as shown in Figure 1. The electronic component may comprise at least one circuit to which the protective shield forms over said at least one circuit or partially surrounds said at least one circuit.
- 15 [0082] The composite material may comprise at least one layer, that is merged from a plurality of layers, where at least one layer is disposed on the electronic component to form the protective shield protecting the electronic component from radiation. Said at least one layer of the composite material may comprise a thermal conductive coating. The coating may be disposed over said at least one layer facing towards the electronic component, and/or a thermal reflective coating disposed over said at least one layer facing away from the electronic component. For example, said at least one layer functionally
- 20 may be related to a single merged layer in respect of a multifunctional-layered structure as described herein.
- [0083] The composite material may also comprise at least two (or plurality of) layers, separately or merged together, where at least one layer of the two is disposed on the electronic component to form the protective shield protecting the electronic component from radiation. Said at least two layers of the composite material comprise a thermal conductive coating. The coating may be disposed over a first layer of said at least two layers facing towards the electronic component and a thermal reflective coating disposed over a second layer of said at least two layers facing away from the electronic component as shown in Figure 2.
- 25 [0084] The composite material may comprise a polymer composite of an arrangement of long or chopped polymers and/or long or chopped carbon fibers, and/or pure elemental carbon in the form of colloidal particles, or referred herein as carbon material, which is made from thermoplastics such as polypropylene compositions. The polymer composite may further comprise or be doped with at least one compound or metal as described herein, for example, boron, boron-based compound, lithium, lithium-based compound, Carbon Black, aluminum, aluminum-based compound, and one or more paint
- 30 types, and each is of 0.1-20 % w/w, preferably 0.1-10% w/w, more preferably 0.1-5% w/w.
- 35

[0085] Each of the compound or metal in the polymer composite may be one of: 0.1-1 % w/w, 0.1-2 % w/w, 0.1-3 % w/w, 0.1-4 % w/w, 0.1-5 % w/w, 0.1-6 % w/w, 0.1-7 % w/w, 0.1-8 % w/w, 0.1-9 % w/w, 0.1-10 % w/w, 0.1-11 % w/w, 0.1-12 % w/w, 0.1-13 % w/w, 0.1-14 % w/w, 0.1-15 % w/w, 0.1-16 % w/w, 0.1-17 % w/w, 0.1-18 % w/w, 0.1-19 % w/w, 0.1-20 % w/w, 1-2 % w/w, 1-5 % w/w, 1-10 % w/w, 1-20 % w/w, 2-5 % w/w, 2-10 % w/w, 2-15 % w/w, 2-20 % w/w, 5-10 % w/w, 5-15 % w/w, 5-20 % w/w, 0.1 % w/w, 1 % w/w, 5 % w/w, 10 % w/w, and 20 % w/w. It is understood that the each of the compound or metal cannot exceed 20-25 % w/w.

[0086] Figure 3 is another example of the different layers 300 of the composite multifunctional materials for shielding means. The figure shows the composite shielding material as a plurality of layers. The material includes one or more of the multifunctional layers, with each layer stacked on top of one another, forming the composite shielding material with optimized thermal properties. Alternatively, the multifunctional layers be gradients merging into each other, forming a single merged layer. The plurality of multifunctional layers includes one or more shielding layers 304, with each shielding layer 304 disposed between one or more other multifunctional layers selected from a structural layer 302, metal containing layer 306, micrometeoroid layer, and thermal protection layer as well as a different structural layer 302. The multifunctional layers correspond to the layers shown in Figure 1 and Figure 2.

[0087] The multifunctional layer may further encompass structural and shielding layer in addition to the structural layer 302 or in place of the structural layer 302, for example, a fire barrier, a layer for structural and radiation shielding against HZE particles and fast, slow and thermal neutrons, a layer of radiation shielding against HZE particles and fast neutrons, layers of radiation shielding against X-rays and photons, a layer for micrometeoroid and thermal protection, where the layer may comprise radiation shielding properties with doped radiation absorbing compounds, and atomic oxygen resistant coating/layer.

[0088] An example of a fire barrier or thermal protection layer may comprise a flexible graphite sheet/layer weighing about 20 to 300 g/m². The elastic graphite sheet/layer provides excellent chemical, thermal, and mechanical resistance and therefore act as a protective barrier against the interior of a spacecraft.

[0089] An example of a shielding layer may be a 3D printed natural boron or boron-10 (¹⁰B) doped carbon material, carbon fiber of short, long or chopped polymers and/or long or chopped, that could be made from reinforced ultra-high molecular weight (UHMW) polyethylene, or high-density polyethylene (HDPE), medium density polyethylene (MDPE), low density polyethylene (LDPE) or a combination of different PE, or any form of polypropylene (PP), the composite comprising 30 to 95 percent by volume of fibers, 5 to 20 percent by volume of natural boron or ¹⁰B. A remaining percent by volume can be filled with an epoxy resin matrix to fill the space between the fibers. The PE or PP comprises layers of interwoven carbon and PE fibers laid in the 0° warp and 45° to 90° fill direction. The fiber/pore size can be optimized to get maximum material strength and thermoregulation over the material to minimize

structural and morphological changes during significant temperature variations. The shielding layer may comprise characteristics and material for physical shielding against objects in space.

[0090] Another example of a shielding layer may be an ultra-high molecular weight (UHMW) polyethylene, or high-density polyethylene (HDPE), medium density polyethlen (MDPE), low density polyethylene (LDPE) or a combination of different PE, or any form of PP, the composite comprising 65 to 95 percent by volume of ultra-high molecular weight (UHMW) polyethylene fibers. The PE or PP comprises layers of fibers laid in the 0° warp and 45° to 90° fill direction. The fiber/pore size can be optimized to get maximum material strength and thermoregulation over the material to minimize structural and morphological changes during significant temperature variations. Between layers 2 and 3 in relation to figure 1, one or more metal containing layers 306 may be added to protect against electrons, X-rays and gamma radiation.

[0091] An example of a structure layer (also serving as radiation shielding, specifically for neurons) may comprise, for example, boron carbide, silicon carbide, aluminium carbide, or a combination thereof. Shown in Table 2 are boron carbide coating (B₄C), best choice considering hardness, young's modulus, compressive strength, density, as well as it acts as shielding against thermal neutrons, silicon carbide coating (as another choice), or aluminium carbide coating (as yet another choice). Boron carbide can be made of natural boron or boron-10 enriched boron carbide, which is better for shielding against thermal neutrons than natural boron.

[0092] In the case of using B₄C as a coating on the composite material layers, the thermal testing has shown that on exposing the B₄C layer to temperatures 1,200°C and above, the maximum temperature recorded at the bottom of the 12.7 cm thick carbon foam sample does not exceed 40°C. This thermal capability is comparable to that of the high-temperature ceramic tiles used on the space shuttle.

[0093] An example may be using a combination of open-cell carbon foam and plasma deposited B₄C coating on the exterior surface of the carbon foam. Coal-based carbon foam has low density (0.268 g/cm³), low thermal conductivity (0.25 to 5 W/mK depending on the cell structure), and the ability to withstand temperatures up to 3,000°C in a nonoxidizing atmosphere or with suitable surface protection. The thermal conductivity of the carbon foam is comparable to that of the HRSI tiles used on the space shuttle. B₄C can be deposited on the surface of the carbon foam via vacuum plasma spraying (VPS).

[0094] An example of yet another structural layer 302 may be an atomic oxygen resistant coating for protecting the other layers of space structure at or above low Earth orbit (LEO) from atomic oxygen. The composite materials may further comprise this atomic oxygen resistant coating. For the coating, the layer of B₄C (alt. Silicon carbide (SiC) or aluminium carbide (Al₄C₃)) will be coated with a very thin layer of Silicon dioxide glass, which has already been oxidized, so it cannot be damaged by atomic oxygen. When making the layer very thin, it is flexible and does not sacrifice any thermal properties. Alternative coatings are graphite coating using e.g., or dipping the material into a graphite oxide

solution. As part of or in addition to layer 5, further coating or gradient may be imposed to protect against particles trapped in radiation belts, debris, micrometeoroids.

[0095] The shielding material described above with respect to figures 2 to 3 may further comprise at least one layer that is configured to protect the electronic component from electromagnetic interference (EMI). That is, the shielding material may comprise at least one layer configured to provide electromagnetic shielding. Electromagnetic interference may otherwise be referred to as radio-frequency interference, and so the layers providing electromagnetic shielding may also be described as providing shielding from waves in the radio frequency spectrum. The layer(s) providing electromagnetic interference shielding may otherwise be referred to as EMI layer(s). The at least one EMI layer is provided to prevent electromagnetic signals from entering sensitive areas of the electronic component. In an example, the shielding material comprises a single EMI layer (i.e., only one EMI layer). In another example, the shielding material comprises two or more EMI layers. The at least one EMI layer may be comprised of one or more types of materials. The at least one EMI layer may have a high electrical conductivity and/or a high magnetic permeability. The at least one EMI layer may be configured to reflect electromagnetic signals. Alternatively, or additionally, the at least one EMI layer may be configured to absorb electromagnetic signals.

[0096] The at least one EMI layer may comprise at least one of the following material types: metal, carbon and graphene. Where the at least one EMI layer comprises a metal, the layer may be a metal coating, a metal sheet or a metal tape. In specific examples, the metal of the at least one EMI layer may be copper, silver, aluminium, carbon steel, nickel, zinc, tin, beryllium and/or an alloy combining different amounts of the aforementioned metals. Alternatively, the at least one EMI layer may comprise one or more oxides of one of the aforementioned metals. In an example, the at least one EMI layer is an additional layer of the shielding material 200 to the layers 202-212 illustrated in figure 2. That is, the at least one EMI layer may be a further layer of the protective shield that is separate to the layer formed of the composite material. The at least one EMI layer may be located on the surface of the shielding material (i.e., may form an outer layer of the shielding material), or alternatively may form a seal that surrounds the periphery of the shielding material. In a specific example, the at least one EMI layer may be a gasket. Alternatively, the at least one EMI layer may be one or more of the layers 206, 210 illustrated in figure 2. That is, the alternative example, the at least one EMI layer is a layer of the shielding material that is formed of a composite material.

[0097] In the example where at least one EMI layer is one or more of the shielding layers 206, 210 illustrated in figure 2, the electromagnetic shielding function of the at least one EMI layer is achieved by loading the shielding layer(s) with a filler. The filler of the at least one shielding layer may be any of the metals mentioned above with respect to the EMI layer. The filler may be an alloy comprising one or more of the aforementioned metals. The filler may be an oxide of one or more of the aforementioned metals.

[0098] Figure 4 shows a profile 400 of temperature distributions inside the doped shielding material (with i.e., MSP) according to any aspects described herein. The chart in the figure plots temperature (K) vs distance (cm) from the top surface of the shielding material. The top surface of the shielding material receives solar irradiation that would effectively decrease (in intensity) with respect to the depth of the shielding material from the surface. The heat Q_s from solar irradiation may be calculated by the equation $\dot{Q}_s = \alpha_{eff} A J_0$. The heat Q_{rad} is also released from the top surface of the shielding material. The heat Q_{rad} is calculated by the equation $\dot{Q}_{rad} = \epsilon_{eff} A (T(x=0))^4 - T_{\infty}^4$. The heat Q_m from the electronic component is generated and can be measured at the bottom layer of the shielding material with respect to the distance, as shown in the figure.

10 [0099] Different reflectivity ρ_{eff} is shown and plotted in the figure 4. An exemplary curve plotted may have the following parameters and values.

- Solar irradiance at LEO: 1376.5 W/m^2
- Layer thickness: 5 cm .
- Cross section area: $10 \times 10 \text{ cm}^2$.
- Heat generation from electronics: 5 W .
- Thermal conductivity: 0.5 W/mK
- Ambient temperature: 3 K .
- Transmissivity $\tau_{eff} = 0$.
- Reflectivity $\rho_{eff} = 0.4$.
- Emissivity: $\epsilon_{eff} = 0.96$.

[00100] It is understood that the conformal shielding and the composite material herein described provide a high emissivity and improved conductivity (see Figure 5) so that the heat will be absorbed very well and transferred to the outer surface of the shielding and then to the ambient space. Here, the profile of temperature distributions illustrates the heat transfer through a conformal shielding with a variation of different composite materials and to the ambient space.

[00101] In relation to the temperature distribution, an example of the composite material may comprise PP doped with Al, BN or B_4C , and Carbon Black. The composite material has increased emissivity and thermal conductivity, as shown according to the profile of temperature distributions. The reflective layer may also be applied to the outer surface of the composite material, which is done with vacuum coating, a high emissivity foil, painting, or a physical vapor deposition coating.

[00102] Figure 5 is an example of charts 500 showing both thermal conductivity and reflectivity of the shielding material. On the left chart 502 is the temperature at the lower boundary of a conformed shielding vs. the thermal conductivity for different effective reflectivities and for a shielding material exposed to 1376.5 W/m^2 heat source (simulating the heat from the Sun) on the top layer/outer surface and a heat source of 5 W on the bottom layer/inner surface (simulating the heat from an electronic component). As can be seen, the shape of the curves is similar, but the absolute values depend on the

reflectivity. It can also be seen that when the thermal conductivity increases from 0 W/mK to 2-3 W/mK, the heat transfer increases quite much and therefore decrease the temperature at the lower boundary of the conformed shielding, but for higher conductivities, the heat transfer is not increasing so much with increasing conductivity.

- 5 **[00103]** On the right chart 504 is the temperature at the lower boundary vs. the reflectivity, for different thermal conductivities, for a shielding material exposed to an arbitrary heat source on the outer surface. As can be seen, the shape of the curves is similar, but the absolute values depend on the reflectivity.

- 10 **[00104]** In one aspect is an apparatus, comprising: an electronic component comprising at least one circuit; a shielding material coupled to the electronic component forming a protective shield over said at least one circuit or a protective shield that partially surrounds said at least one circuit, wherein the protective shield comprises at least one layer offforming a composite material, wherein said at least one layer is disposed on the electronic component to form the protective shield protecting the electronic component from radiation; wherein the composite material comprises a polymer composite comprising an arrangement of carbon material; and wherein the composite material comprising a thermal
15 conductive coating disposed over said at least one layer facing towards the electronic component, and/or a thermal reflective coating disposed over said at least one layer facing away from the electronic component.

- 20 **[00105]** In another aspect is an apparatus for radiation shielding, comprising: a shielding material coupled to the electronic component forming a protective shield over at least one circuit of an entity in space or a protective shield that partially surrounds at least one circuit of an entity in space, wherein the protective shield comprises at least one layer offforming a composite material, wherein said at least one layer is disposed on the electronic component to form the protective shield protecting the electronic component from radiation; wherein the composite material comprises a polymer composite of short, long or chopped polymers and/or long or chopped carbon fibers or material such as Carbon Black; and
25 wherein the composite material comprising a thermal conductive coating disposed over said at least one layer facing towards the electronic component, and/or a thermal reflective coating disposed over said at least one layer facing away from the electronic component.

- 30 **[00106]** In another aspect is a method for providing an apparatus of another aspect as described herein, the method comprising: forming a shielding material using one or more of: additive manufacturing, compression molding, injection molding, compression molding, 3D-compression molding, and thermoforming; and applying the shielding material directly disposed onto a surface of an electronic component; or applying the shielding material proximal to an electronic component.

- 35 **[00107]** In another aspect is a system comprising one or more circuitry, wherein the system is configured to apply said apparatus of another aspect as described herein onto said one or more circuitry using a vacuum coating, a high emissivity foil, or a physical vapor deposition coating.

- [00108] The following optional features may be combined at least with the above aspects as understood by the skilled person.
- [00109] As an option, the shielding material is directly disposed onto a surface of the electronic component forming direct contact with the electronic component, and/or wherein the shielding material is situated in a proximity of the electronic component forming proximal contact.
- [00110] As another option, the direct contact is formed via the thermal conductive coating of a first layer facing towards the electronic component.
- [00111] As another option, the proximal contact is formed via the thermal conductive coating of a first layer facing towards the electronic component.
- [00112] As another option, the polymer composite is made from at least one of: a hydrogen rich thermoplastic polymer, high density polyethylene, medium-density polyethylene, atactic polypropylene, syndiotactic polypropylene, or isotactic polypropylene, or a mixture of two or more of these components
- [00113] As another option, the polymer composite is doped with at least one compound or metal.
- [00114] As another option, said at least one compound is boron or lithium.
- [00115] As another option, said at least one metal is a metal or a metal oxide.
- [00116] As another option, the metal or the metal oxide is dispersed in a matrix composition or in a layered structure, wherein the matrix composition or the layered structure is part of the hydrogen rich thermoplastic polymer, high density polyethylene, medium-density polyethylene, or any form of polypropylene.
- [00117] As another option, the metal or metal oxide has an atomic number (Z), wherein (Z) is 13 or is from 22 to 30.
- [00118] As another option, the metal or metal oxide has an atomic number (Z), wherein (Z) is from 72 to 79.
- [00119] As another option, the shielding material has a thickness less than or equal to 30 mm.
- [00120] As another option, the thickness is between 1 mm to 30 mm.
- [00121] As another option, the thermal conductive coating comprises a carbon black mixture, a black color paint, a type of vacuum coating, a type of high emissivity foil, or a type of physical vapor deposition coating, wherein the thermal conductive coating is applied using a method for applying a type of paint or mixture, the vacuum coating, the high emissivity foil, or the physical vapor deposition coating.

- [00122] As another option, the carbon black mixture is applied to the polymer composite to form a mixture with high emissivity.
- [00123] As another option, the carbon black mixture is applied to the arrangement of carbon material of the composite material to form a mixture with high emissivity.
- 5 [00124] As another option, the carbon black mixture is 0.1 - 5 % w/w forming a mixture with high emissivity and reflectivity.
- [00125] As another option, the thermal reflective coating is a type of paint coating or a layer of metal that is deposited to the composite material as nano or micro particles.
- [00126] As another option, the type of paint coating is color white to minimize the emissivity and
10 increase the reflectivity.
- [00127] As another option, the layer of metal comprises aluminum or another high reflective metal.
- [00128] As another option, the shielding material is produced using one or more of: additive manufacturing, compression molding, injection molding, compression molding, 3D-compression molding, or thermoforming.
- 15 [00129] As another option, the shielding material is a type of conformal shielding or spot shielding.
- [00130] As another option, the composite material further comprises one or more of: boron, boron-based compound, lithium, lithium-based compound, Carbon Black, aluminum, aluminum-based compound, and one or more paint types.
- [00131] As another option, the one or more of: boron, boron-based compound, lithium, lithium-based
20 compound, Carbon Black, aluminum, aluminum-based compound, and one or more paint types, each is of 0.1-20 % w/w, preferably 0.1-10% w/w, more preferably 0.1-5% w/w.
- [00132] As an option, method comprising: applying the shielding material directly disposed onto a surface of an electronic component; or applying the shielding material proximal to an electronic component; and wherein said applying shielding material comprises a method for applying a paint
25 coating, vacuum coating, a high emissivity foil, or a physical vapor deposition coating on the inner boundary of the shielding material facing the electronic component.
- [00133] . As an option, method comprising: applying the shielding material directly disposed onto a surface of an electronic component; or applying the shielding material proximal to an electronic component; and wherein said applying shielding material comprises a method for applying a paint
30 coating, vacuum coating, a high reflectivity foil, or a physical vapor deposition coating on the on the outer boundary of the shielding material facing away from the electronic component.

5 [00134] In a different aspect is a composite material comprising: a first shielding layer; at least one metal containing layer over the first shielding layer; and a second shielding layer over said at least one metal containing layer opposite of the first shielding layer; wherein the first shielding layer and the second shielding layer each and/or in combination with other layers of the composite material provide the composite material with radiation shielding characteristics.

10 [00135] In a different is a composite material comprising: a first shielding layer; at least one metal/metal oxide layer over the first shielding layer; and a second shielding layer over said at least one metal/metal oxide layer opposite of the first shielding layer; wherein the first shielding layer and the second shielding layer each and/or in combination with other layers of the composite material provide the composite material with radiation shielding characteristics.

15 [00136] In a different aspect is a plurality of multifunctional layers with each layer stacked on top of one another or as gradients merging into each other layer forming the composite shielding material with optimized thermal properties; wherein the plurality of multifunctional layers comprise at least two shielding layers with each shielding layer disposed between at least two other multifunctional layers selected from a structural layer, metal/metal oxide layer, micrometeoroid layer, and thermal protection layer.

20 [00137] In a different aspect is a method for providing the composite material, comprising: generating a model of the composite material in a virtual environment, wherein the model comprises a digital representation of a composite material comprising: a first shielding layer, at least one metal/metal oxide layer over the first shielding layer, and a second shielding layer over said at least one metal/metal oxide layer; providing a composition of the composite material to a device; generating the composite material based on the model using the composition, wherein the composition is combined to form layers of the composite material; and removing imperfections or defects on the composite material in accordance with the model based on one or more inputs.

25 [00138] In a different aspect is composite material comprising: a first layer, a second layer disposed on the first layer; and a third layer disposed on the second layer opposite the first layer, such that the second layer is disposed between the first layer and the third layer; wherein the first layer comprises a structural and radiation shielding layer; wherein the second layer comprises a radiation shielding layer; and wherein optionally the third layer comprises a micrometeoroid and thermal protection layer. It is understood that the three layers may be merged into a single layer according to another aspect.

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[00139] It will be understood that the benefits and advantages described above may relate to one embodiment/aspect or may relate to several embodiments/aspects. The embodiments/ aspects are not limited to those that solve any or all of the stated problems or those that have any or all of the stated benefits and advantages. Variants should be considered to be included in the scope of the invention.

[00140] Any reference to 'an' item refers to one or more of those items. The term 'comprising' is used herein to mean including the method steps or elements identified, but that such steps or elements do not comprise an exclusive list and a method or apparatus may contain additional steps or elements.

5 [00141] As used herein, the term "exemplary", "example" or "embodiment" is intended to mean "serving as an illustration or example of something". Further, to the extent that the term "includes" is used in either the detailed description or the claims, such term is intended to be inclusive in a manner similar to the term "comprising" as "comprising" is interpreted when employed as a transitional word in a claim.

10 [00142] The figures illustrate exemplary methods. While the methods are shown and described as being a series of acts that are performed in a particular sequence, it is to be understood and appreciated that the methods are not limited by the order of the sequence. For example, some acts can occur in a different order than what is described herein. In addition, an act can occur concurrently with another act. Further, in some instances, not all acts may be required to implement a method described herein.

15 [00143] The order of the steps of the methods described herein is exemplary, but the steps may be carried out in any suitable order, or simultaneously where appropriate. Additionally, steps may be added or substituted in, or individual steps may be deleted from any of the methods without departing from the scope of the subject matter described herein. Aspects of any of the examples described above may be combined with aspects of any of the other examples described to form further examples without losing the effect sought.

20 [00144] It will be understood that the above description of a preferred embodiment is given by way of example only and that various modifications may be made by those skilled in the art.

25 [00145] What has been described above includes examples of one or more embodiments. It is, of course, not possible to describe every conceivable modification and alteration of the above devices or methods for purposes of describing the aforementioned aspects, but one of ordinary skill in the art can recognize that many further modifications and permutations of various aspects are possible. Accordingly, the described aspects are intended to embrace all such alterations, modifications, and variations that fall within the scope of the appended claims.

CLAIMS

1. An apparatus, comprising:
an electronic component comprising at least one circuit;
a shielding material, coupled to the electronic component, forming a protective shield
5 over or partially surrounding said at least one circuit;
wherein the protective shield comprises at least one layer formed of a composite material, wherein said at least one layer is disposed on the electronic component to form the protective shield protecting the electronic component from radiation; and
wherein the composite material comprises a polymer composite comprising an
10 arrangement of carbon material to increase the emissivity of the composite material; and/or
wherein the composite material comprises a thermal conductive coating disposed over said at least one layer facing towards the electronic component, and/or the composite material comprises a thermal reflective coating disposed over said at least one layer facing away from the electronic component.
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2. The apparatus of claim 1, wherein the shielding material is directly disposed onto a surface of the electronic component forming direct contact with the electronic component, and/or wherein the shielding material is situated in a proximity of the electronic component forming proximal contact.
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3. The apparatus of claim 2, wherein the direct contact is formed via the thermal conductive coating of said at least one layer facing towards the electronic component.
4. The apparatus of claim 2, wherein the proximal contact is formed via the thermal conductive
25 coating of said at least one layer facing towards the electronic component.
5. The apparatus of any preceding claim, wherein the polymer composite is made from at least one of: a hydrogen rich thermoplastic polymer, high density polyethylene, medium-density polyethylene, atactic polypropylene, syndiotactic polypropylene, or isotactic polypropylene.
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6. The apparatus of claim 5, wherein the polymer composite is doped with at least one compound or metal.
7. The apparatus of claim 6, wherein said at least one compound is boron or lithium.
- 35
8. The apparatus of claim 6, wherein said at least one metal is a metal or a metal oxide.

9. The apparatus of claim 8, wherein the metal or the metal oxide is dispersed in a matrix composition or in a layered structure, wherein the matrix composition or the layered structure is part of the hydrogen rich thermoplastic polymer, high density polyethylene, medium-density polyethylene, or any form of polypropylene.
- 5
10. The apparatus of claim 8 or 9, wherein the metal or metal oxide has an atomic number (Z), wherein (Z) is 13 or is from 22 to 30.
11. The apparatus of claim 8 or 9, wherein the metal or metal oxide has an atomic number (Z), wherein (Z) is from 72 to 79.
- 10
12. The apparatus of any preceding claim, wherein the shielding material has a thickness less than or equal to 20 mm.
13. The apparatus of claim 12, wherein the thickness is between 1 mm to 20 mm.
- 15
14. The apparatus of any preceding claim, wherein the thermal conductive coating comprises a carbon black mixture, a black color paint, a type of vacuum coating, a type of high emissivity foil, or a type of physical vapor deposition coating, wherein the thermal conductive coating is applied using a method for applying a type of paint or mixture, the vacuum coating, the high emissivity foil, or the physical vapor deposition coating.
- 20
15. The apparatus of claim 14, wherein the carbon black is mixed with the composite material to form the carbon black mixture with high emissivity.
- 25
16. The apparatus of claim 14, wherein the carbon black mixture is applied to the arrangement of carbon material of the composite material to form a mixture with high emissivity.
17. The apparatus of claims 13 to 16, wherein the carbon black mixture is 0.1 - 5 % w/w forming a mixture with high emissivity and reflectivity.
- 30
18. The apparatus of any preceding claim, wherein the thermal reflective coating is a type of paint coating or a layer of metal that is deposited to the composite material as nano or micro particles.
- 35
19. The apparatus of claim 18, wherein the type of paint coating is color white in order to minimize the emissivity and increase reflectivity.

20. The apparatus of claim 18, wherein the layer of metal comprises aluminum or another high reflective metal.
- 5 21. The apparatus of any preceding claim, wherein the shielding material is produced using one or more of: additive manufacturing, compression molding, injection molding, compression molding, 3D-compression molding, or thermoforming.
22. The apparatus of any preceding claim, wherein the shielding material is a type of conformal shielding or spot shielding.
- 10 23. The apparatus of any preceding claim, wherein the composite material further comprises one or more of: boron, boron-based compound, lithium, lithium-based compound, Carbon Black, aluminum, aluminum-based compound, and one or more paint types.
- 15 24. The apparatus of claim 23, wherein the one or more of: boron, boron-based compound, lithium, lithium-based compound, Carbon Black, aluminum, aluminum-based compound, and one or more paint types, each is of 0.1-20 % w/w, preferably 0.1-10% w/w, more preferably 0.1-5% w/w.
- 20 25. The apparatus of any preceding claim, wherein the protective shield further comprises at least one layer that is configured to protect the electronic component from electromagnetic interference.
- 25 26. The apparatus of claim 25, wherein the at least one layer that is configured to protect the electronic component from electromagnetic interference is the layer formed of a composite material.
27. The apparatus of claim 25, wherein the at least one layer that is configured to protect the electronic component from electromagnetic interference is a further layer of the protective shield that is separate to the layer formed of a composite material.
- 30 28. The apparatus of any of claims 25 to 27, wherein the at least one layer that is configured to protect the electronic component from electromagnetic interference comprises at least one of a metal, carbon and graphene.
- 35 29. An apparatus for radiation shielding, comprising:

a shielding material configured to form a protective shield over or partially surround at least one circuit of an entity in space;

wherein the protective shield comprises at least one layer formed of a composite material, wherein said at least one layer is configured to be disposed on the at least one circuit
5 to form the protective shield protecting the at least one circuit from radiation; and

wherein the composite material comprises a polymer composite of an arrangement of carbon material to increase the emissivity of the composite material; and/or

wherein the composite material comprises a thermal conductive coating configured to be disposed over said at least one layer facing towards the at least one circuit, and/or the
10 composite material comprises a thermal reflective coating configured to be disposed over said at least one layer facing away from the at least one circuit.

30. A system comprising one or more circuitry, wherein the system is configured to apply said apparatus based on claim 26 onto said one or more circuitry using a vacuum coating, a high
15 emissivity foil, or a physical vapor deposition coating.

31. A method for providing an apparatus according to any of claims 1 to 28, the method comprising:

forming a shielding material using one or more of: additive manufacturing, compression
20 molding, injection molding, compression molding, 3D-compression molding, and thermoforming; and

applying the shielding material directly disposed onto a surface of an electronic component; or

applying the shielding material proximal to an electronic component.
25

32. The method of applying an apparatus according to claim 29, the method comprising:

applying the shielding material directly disposed onto a surface of an electronic component; or

applying the shielding material proximal to an electronic component; and
30

wherein said applying shielding material comprises a method for applying a paint coating, vacuum coating, a high emissivity foil, or a physical vapor deposition coating to the electronic component.