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(54) **HEATING AND DEPOSITION FOR BENEFICIATION OF LUNAR REGOLITH**

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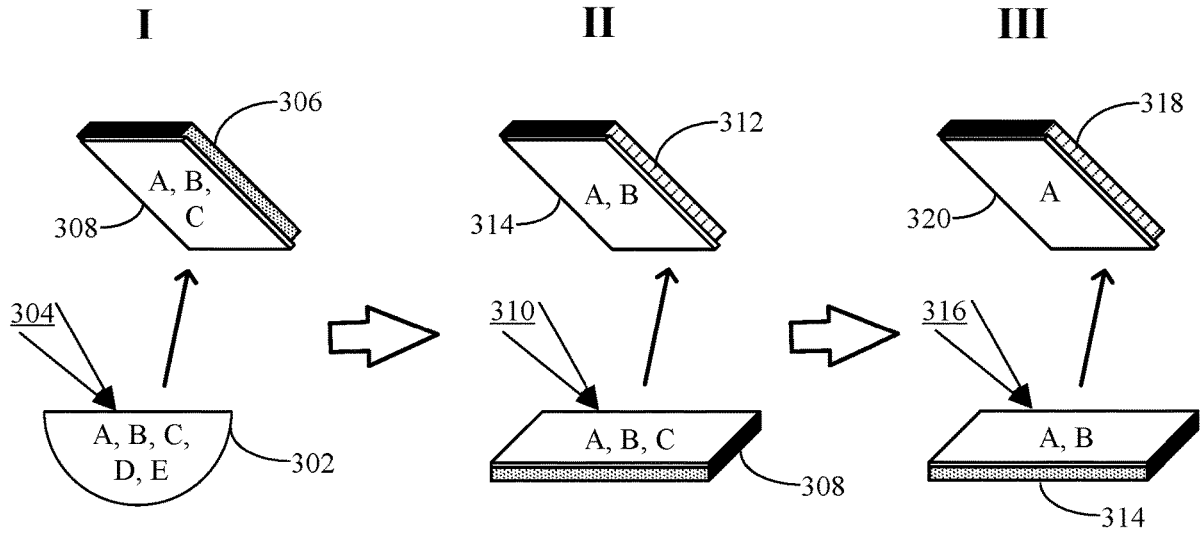
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(57) **ABSTRACT**

Methods and configurations for solar heating and beneficiation of a material, such as raw mine-extracted material like lunar rocks or regolith, are presented. Beneficiation may have an end-goal of purifying the material and/or removing particular impurities or undesired substances from the material. For example, purification or elimination of particular substances from a bulk material may be achieved by vaporizing, via solar or electron beam heating, a portion of the bulk material that does not include the particular substances. The bulk material, sans the particular substances, may be subsequently condensed onto a cold substrate as a thin film, which itself may be placed in a subsequent beneficiation iteration for further elimination of selected substances.



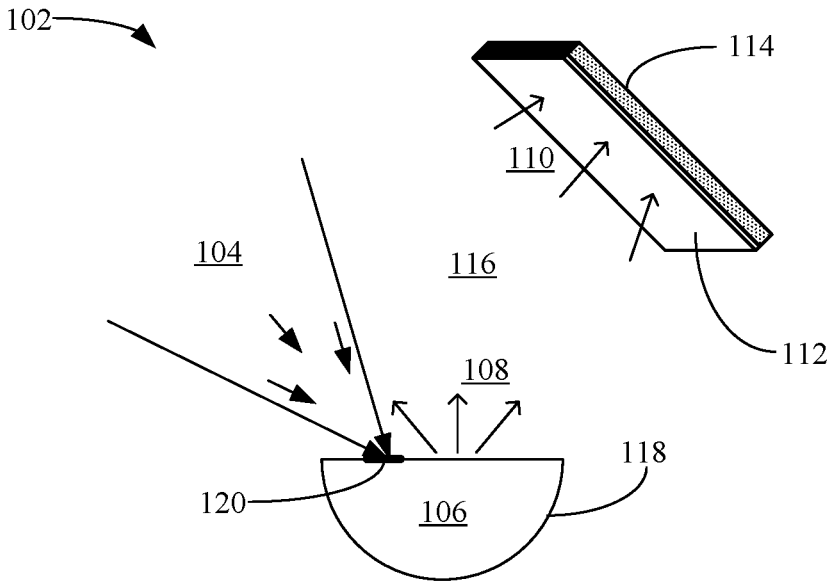

102
114
110
104
116
112
108
118
120
106

FIG. 1

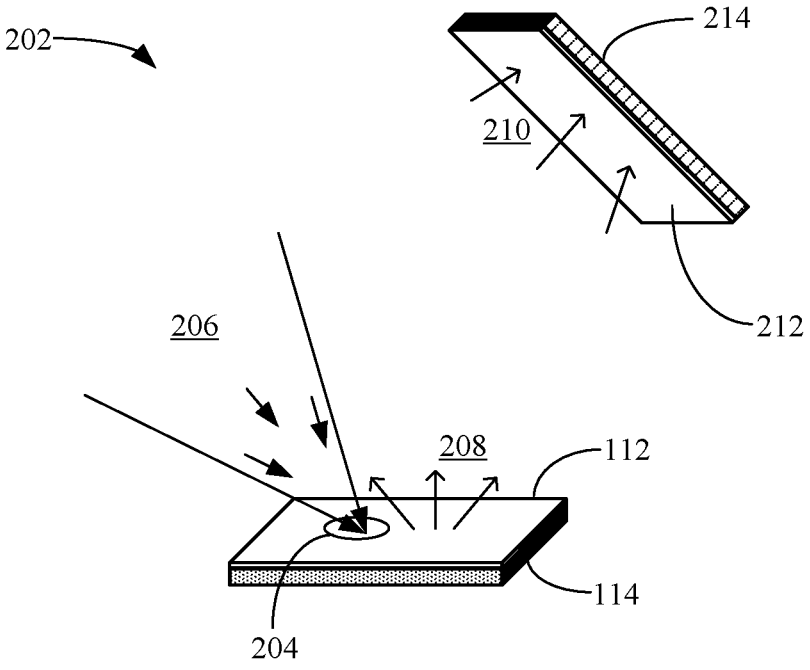

202
214
210
206
212
208
112
114
204

FIG. 2

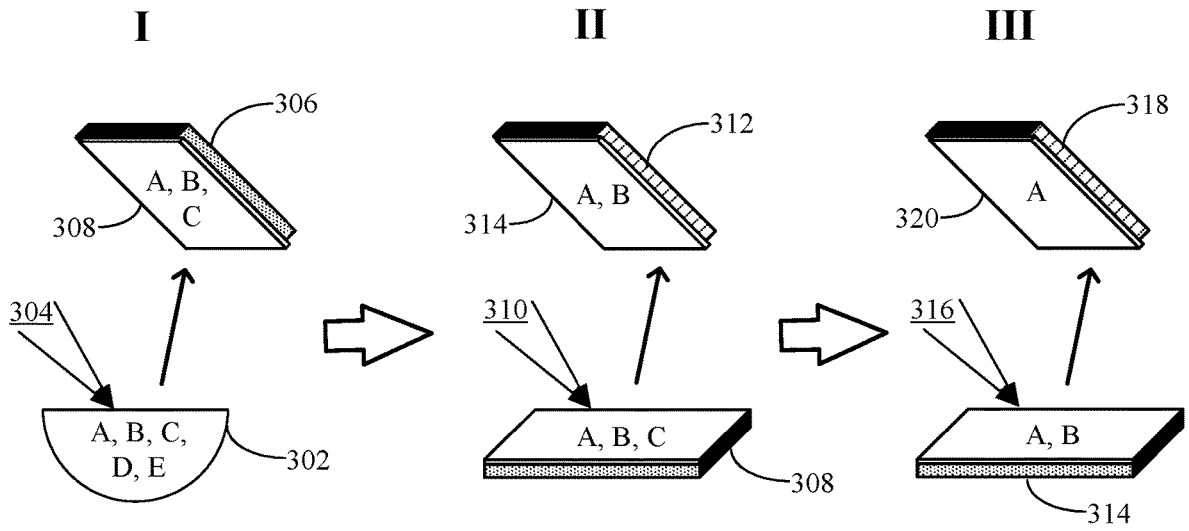


FIG. 3

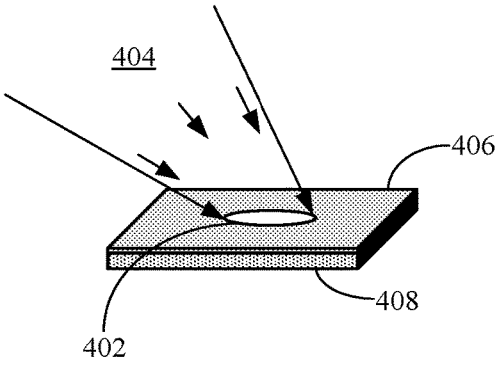


FIG. 4

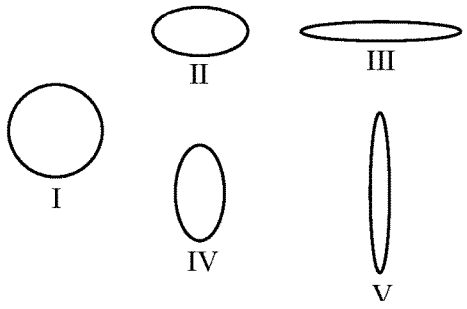


FIG. 5

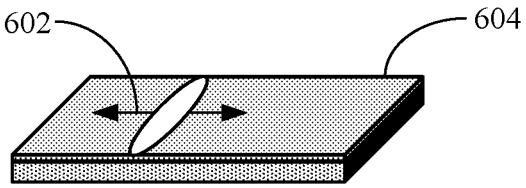


FIG. 6

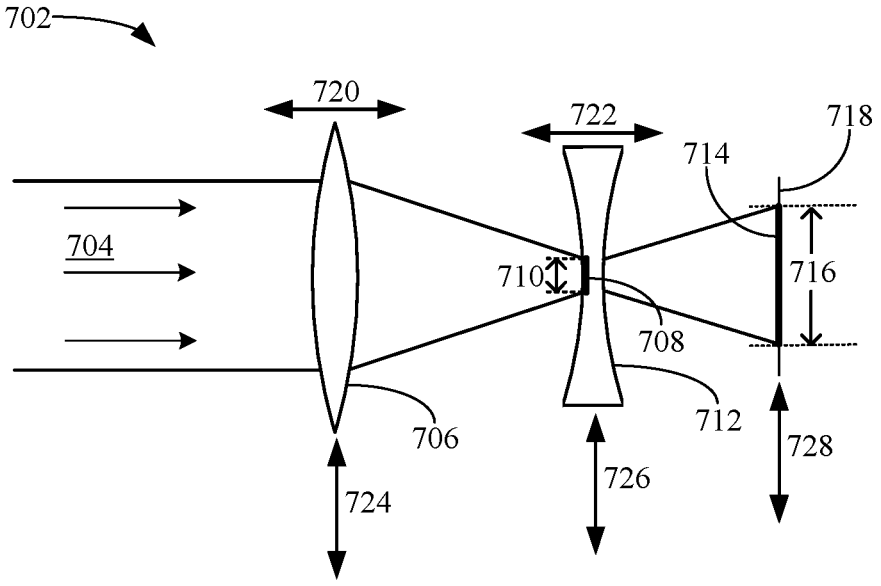


FIG. 7

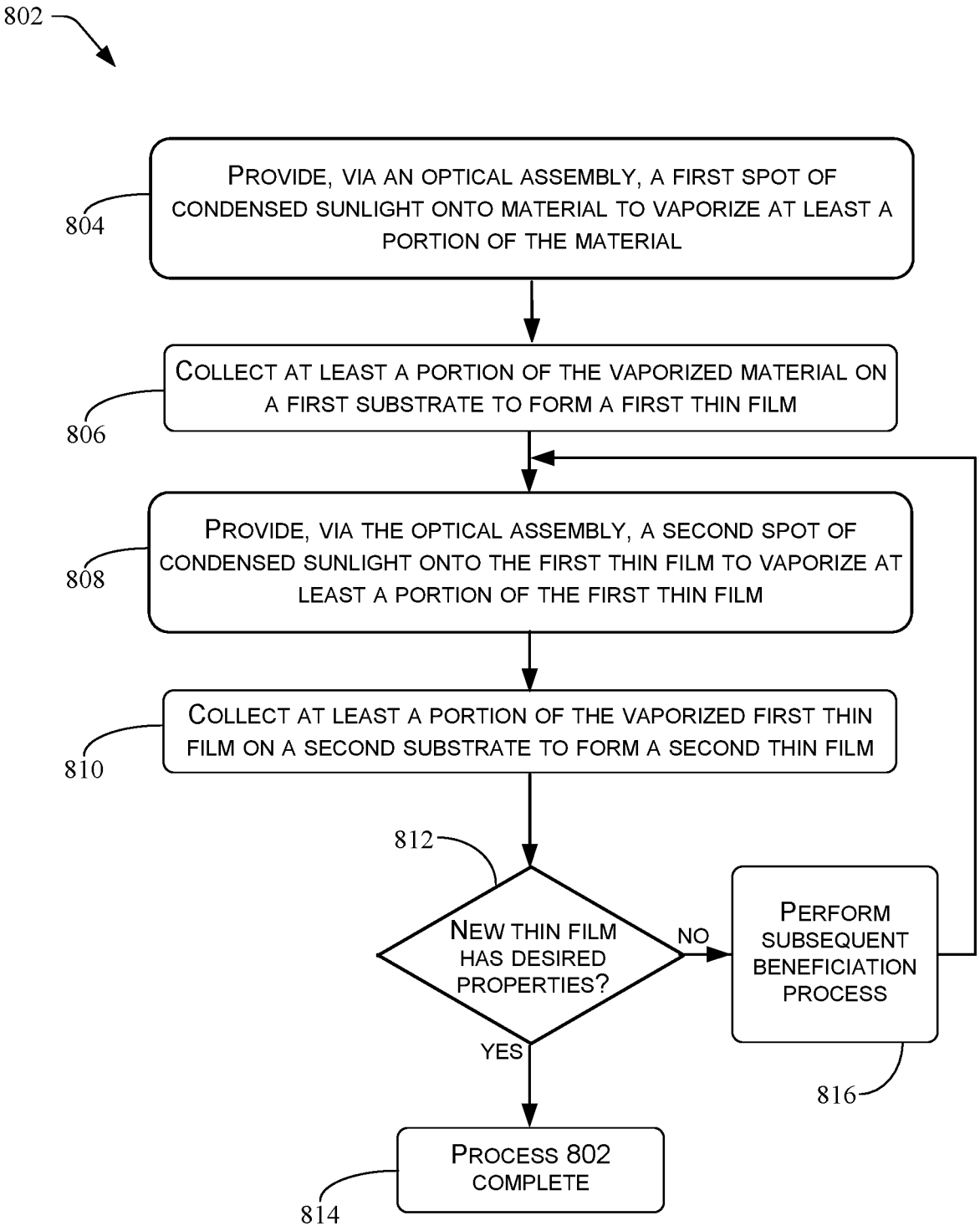

802
PROVIDE, VIA AN OPTICAL ASSEMBLY, A FIRST SPOT OF CONDENSED SUNLIGHT ONTO MATERIAL TO VAPORIZE AT LEAST A PORTION OF THE MATERIAL
804
COLLECT AT LEAST A PORTION OF THE VAPORIZED MATERIAL ON A FIRST SUBSTRATE TO FORM A FIRST THIN FILM
806
PROVIDE, VIA THE OPTICAL ASSEMBLY, A SECOND SPOT OF CONDENSED SUNLIGHT ONTO THE FIRST THIN FILM TO VAPORIZE AT LEAST A PORTION OF THE FIRST THIN FILM
808
COLLECT AT LEAST A PORTION OF THE VAPORIZED FIRST THIN FILM ON A SECOND SUBSTRATE TO FORM A SECOND THIN FILM
810
812
NEW THIN FILM HAS DESIRED PROPERTIES?
NO
YES
PERFORM SUBSEQUENT BENEFICIATION PROCESS
816
PROCESS 802 COMPLETE
814

FIG. 8

HEATING AND DEPOSITION FOR BENEFICIATION OF LUNAR REGOLITH

BACKGROUND

[0001] Fabrication of devices and processing of materials are generally energy-intensive operations. Most often, this energy takes the form of electricity. On Earth, there is an ever-increasing recognition that energy is a valuable resource to be conserved or used wisely. On the Moon, availability of energy, such as electricity for use in fabrication or material processing, is presently limited to Earth-derived resources (e.g., fuel cells, batteries, etc.). Thus, providing electricity for fabrication or material processing on the Moon may be challenging.

[0002] Lunar regolith is composed of a mixture of rocks and minerals, the fundamental chemical components of which are elements typically expressed as oxides, including silica, titania, alumina, magnesia, iron oxide, and calcium oxide. For most applications it is beneficial to have some oxides and less of others. Some elements and their oxides may be detrimental if included in material to make clear glass, which may be used in the fabrication of solar cells for providing electricity on the Moon. For example, the presence of iron oxide in materials used for glass fabrication may result in relatively dark, low-transmittance glass. In addition to possible problems created by the presence of undesired components in a bulk material, impurities in the bulk material not only can modify the development of grain structure formation but can also interact with structural defects to create regions of deleterious minority carrier lifetime recombination in solar cells, for example.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] The disclosure will be understood more fully from the detailed description given below and from the accompanying figures of embodiments of the disclosure. The figures are used to provide knowledge and understanding of embodiments of the disclosure and do not limit the scope of the disclosure to these specific embodiments. Furthermore, the figures are not necessarily drawn to scale.

[0004] FIG. **1** is a schematic view of concentrated sunlight incident on a mass of material leading to evaporation and condensation into a thin film, according to some embodiments.

[0005] FIG. **2** is a schematic view of a spot of concentrated sunlight incident on a thin film leading to evaporation and condensation into a second thin film, according to some embodiments.

[0006] FIG. **3** is a schematic representation of an iterative beneficiation process, according to some embodiments.

[0007] FIG. **4** is a schematic view of a spot of concentrated sunlight incident on a thin film, according to some embodiments.

[0008] FIG. **5** illustrates various example embodiments of spots of concentrated sunlight.

[0009] FIG. **6** is a schematic view of a spot of concentrated sunlight varying in location on a surface of material, according to some embodiments.

[0010] FIG. **7** is a schematic cross-section view of an optical assembly that includes moveable optical elements, according to some embodiments.

[0011] FIG. **8** is a flow diagram of a process for solar heated beneficiation of a material, according to some embodiments.

DETAILED DESCRIPTION

[0012] This disclosure describes methods and configurations for solar heating and beneficiation of a material, such as raw geologic material like lunar rocks or regolith. Other methods for heating, instead of, or in addition to, solar heating may include electron-beam (e-beam) heating, for example. Beneficiation may have an end-goal of purifying or increasing the concentration of a material and/or removing particular impurities or undesired substances from the material. For example, in some implementations, beneficiation may be used to yield an iron-free material (e.g., purified quartz) from a material that previously included iron oxide. The iron oxide-free material may be glass that can be deposited as a thin film on a substrate, for example. The use of solar heating allows these processes to occur without electricity, which may be a scarce resource on the Moon.

[0013] Lunar regolith, rocks, or other impure feedstocks may generally lead to materials with impurities that are undesired in subsequent steps of production or fabrication. For example, silicon needs to be purified (e.g., greater than 99.999% pure) before being utilized for solar panels.

[0014] Techniques for solar heating, described herein, may be applied to beneficiation processes of various materials. For example, elimination of particular substances from a bulk material may be achieved by vaporizing, via solar heating, a portion of the bulk material that does not include the particular substances. This may be accomplished by heating the bulk material to temperatures beyond the boiling points of desired substances in the bulk material while maintaining the temperature below the boiling points of the undesired particular substances. The bulk material, sans the particular substances, may be subsequently condensed onto a cold substrate as a thin film, as described below. For example, silicon may be deposited, via condensation, as thin film layers (e.g., with thicknesses of hundreds of nanometers) using concentrated sunlight to evaporate or sublimate the silicon in a bulk, raw material that includes impurities or undesired substances such as iron oxide. In a particular embodiment, silicon may be in a quartz crucible while concentrated sunlight is focused on the silicon. The concentrated sunlight heats the silicon to its boiling temperature. Above its boiling temperature, the silicon evaporates and subsequently deposits onto a relatively cold substrate. Such a deposition process may allow for glass-covered solar cell fabrication using concentrated sunlight. The use of sunlight for heating can replace the use of electricity, which would otherwise power a deposition process using an electron beam or thermal evaporation resulting from consuming tens to hundreds of kilowatts (e.g., 208 VAC, 3-Ph). In other implementations, however, electron beam heating may be used for performing the beneficiation processes described herein, and claimed subject matter is not limited to any particular method of heating.

[0015] In some embodiments, a method for solar heated beneficiation of a material may include providing, via an optical assembly, a spot of concentrated sunlight onto the material to vaporize at least a portion of the material. The optical assembly may be configured to collect sunlight and condense the sunlight to a focused, concentrated spot that may impinge on the material. The material may be crushed

regolith or other raw material, for example. The optical assembly may include optical elements, such as lenses and/or mirrors, that are moveable to vary the location of the focused spot of sunlight on the material. In some implementations, an optical assembly may be a parabolic solar reflector that is configured to track the movement of the sun across the sky (e.g., via stepper motors, etc.). A parabolic solar reflector may produce a focused beam of light that may be aimed onto a material for heating the material. The spot of concentrated sunlight may heat and vaporize the material, which may be collected via condensation on a relatively cold substrate. Thus, the condensed material may form a thin film. The vaporized material may be exposed to the vacuum of the Moon while transiting to the substrate. This exposure, of the substrate and the vaporized material, may help prevent impurities from adding into the condensing thin film by facilitating a degree of purification based on vapor pressure differences.

[0016] The method for solar heated beneficiation may further include, as mentioned above, collecting at least a portion of the vaporized material on a first substrate to form a first thin film. Subsequently, a second spot of concentrated sunlight may be aimed onto the first thin film to vaporize at least a portion of the first thin film. At least a portion of the vaporized first thin film may be collected on a second substrate to form a second thin film. At this stage, solar heated beneficiation may be complete, depending on whether the second thin film is the desired material or has desired physical properties. In other words, the method for solar heated beneficiation may be complete at this stage or may continue with another iteration of vaporizing the second thin film to form a third thin film, and so on until the resulting thin film is the desired material or has desired physical properties.

[0017] FIG. **1** is a schematic view of a configuration **102** that includes concentrated sunlight **104** incident on a mass of material **106** leading to evaporation, indicated by arrows **108**, and condensation, indicated by arrows **110**, into a thin film **112**, according to some embodiments. Thin film **112** may form on a substrate **114** that is relatively cold to allow for condensation of the ambient vapor from material **106**. In some implementations, the environment **116** of the Moon may be used to maintain the cold substrate temperatures. Herein, a substrate being relatively cold means that the substrate is substantially colder than an ambient vaporized material. One substrate is illustrated for clarity, but multiple substrates may be included in configuration **102** to capture vaporized material. The direction and orientation of concentrated sunlight **104** and material **106**, as well as the container **118** holding the material, are merely examples and claimed subject matter is not so limited. Though examples of processes of beneficiation described herein are performed on the Moon with lunar regolith, such processes may also be performed on Earth with earth-sourced materials, and claimed subject matter is not limited in this respect.

[0018] Concentrated sunlight **104** impinges as a spot **120** on material **106**. As explained below, the shape and size of the spot, and its location on material **106**, may be varied to allow for uniform heating of the material surface.

[0019] In a process of beneficiation, as described above, concentrated sunlight **104** heats material **106** leading to evaporation and condensation into formation of thin film **112** on substrate **114**. The portion of material **106** that is evaporated may be controlled by controlling the temperature of the material. For example, an impurity in material **106** that has a boiling temperature above the boiling temperature of material **106** may be excluded (e.g., left behind) from vaporization of material **106** by maintaining the temperature of material **106** between the two boiling temperatures. Thus, a condensed thin film (e.g., **112**) will not include the impurity. The temperature of material **106** may be controlled by controlling (e.g., via a shutter or other control of concentrated sunlight) the amount of time that material **106** is exposed to concentrated sunlight **104**, the flux and/or the intensity of the concentrated sunlight.

[0020] FIG. **2** is a schematic view of a configuration **202** that includes substrate **114** with thin film **112** exposed to a spot **204** of concentrated sunlight **206**, which may lead to evaporation, represented by arrows **208**, of a portion of thin film **112** and condensation, represented by arrows **210**, into a second thin film **212** on a substrate **214**, according to some embodiments. The direction and orientation of concentrated sunlight **206** and thin film **112**, as well as its size and shape, are merely examples, and claimed subject matter is not so limited.

[0021] Configuration **202** is an arrangement of substrates allowing for evaporating a portion of a thin film, which was previously formed by evaporation/condensation in a previous step, illustrated in FIG. **1**, into a second thin film. A process of beneficiation may generally involve iterative steps of evaporation/condensation that each produce a thin film that is closer than that of the previous iterative step to a material having the desired properties and/or composition. For example, though thin film **112** may have less impurities than that of material **106**, there may remain a need for another evaporation/condensation step, provided by configuration **202**, that can remove additional impurities from thin film **112**. Resultantly, there may be fewer impurities in thin film **212** than in thin film **112**. In some implementations, thin film **212** may be subjected to another evaporation/condensation iteration to further remove impurities. Such an iterative process of beneficiation is described below.

[0022] FIG. **3** is a schematic representation of an iterative beneficiation process, according to some embodiments. Generally, a single beneficiation process may not yield a desired material, but merely provide an intermediate material for one or more subsequent beneficiation processes that ultimately end with the desired material. For example, a bulk material comprising substances A, B, C, D, and E in a container **302** may be heated by concentrated sunlight **304**. Generally, different substances will evaporate at different temperatures, which may be respective boiling temperatures. Concentrated sunlight **304** heats the bulk material of beneficiation process I to a temperature above boiling points of substances A, B, and C, but below boiling points of substances D and E. Thus, substances A, B, and C evaporate and condense onto a cold substrate **306** to form a thin film **308** comprising only these substances as a result of substances D and E being left behind in container **302**. In some implementations, thin film **308** comprising substances A, B, and C may be the desired material and there need not be any additional beneficiation iterations. In other implementations, thin film **308** is only an intermediate material because, for example, substance C is an undesired substance in thin film **308**. Accordingly, beneficiation process II may be performed with concentrated sunlight **310** heating thin film **308** to a temperature above boiling points of substances A and B but below the boiling point of substance C. Thus, substances A

and B evaporate and condense onto a cold substrate **312** to form a thin film **314** comprising only these substances as a result of substance C being left behind in thin film **308**. In some implementations, thin film **314** comprising substances A and B may be the desired material and there need not be any additional beneficiation iterations. In other implementations, thin film **314** is only yet another intermediate material because, for example, substance B is an undesired substance in thin film **314**. In these implementations, the desired material may be only substance A sans any impurities.

[0023] Accordingly, beneficiation process III may be performed with concentrated sunlight **316** heating thin film **314** to a temperature above the boiling point of substance A but below the boiling point of substance B. Thus, substance A evaporates and condenses onto a cold substrate **318** to form a thin film **320** comprising only substantially purified substance A as a result of substance B being left behind in thin film **314**.

[0024] FIG. **4** is a schematic view of a spot **402** of concentrated sunlight **404** incident on a mass of material **406**, which may be a thin film on a substrate **408** or bulk material in a container (e.g., **118**), according to some embodiments. This situation may be similar to or the same as those illustrated in FIGS. **1-3**, for example. Heat from spot **402** principally heats the material in the spot. Diffusion of heat from the material in the spot may also heat surrounding material. The rate and extent to which diffusion heats the surrounding material may depend on the material, spot size, and the intensity of concentrated sunlight **404**, among other things. As described below, in some implementations, processes of melting, boiling, or evaporating material may involve varying the location, size, and or shape of spot **402** on the mass of material. For example, such variations may allow for increasing uniformity of heating of the mass of material. Such variations in spot size may also allow for changing the intensity of the concentrated sunlight. For the same quantity of incoming sunlight, a smaller spot size will provide heat that is more intense than that of a larger spot. Accordingly, varying the spot size may allow for controlling the rate of melting or vaporizing a material.

[0025] FIG. **5** illustrates various example embodiments of spots of concentrated sunlight, which may represent the example spots illustrated in FIGS. **1-4**. The various sizes and shapes of spots I-V may be formed by a series of lenses and/or mirrors placed between a material surface and the incoming sun rays. Shapes of the spots may be formed by spheric or aspheric lenses or mirrors or gradient-index lenses, for example.

[0026] In addition to the circular and elliptical shapes, a concentrated sunlight spot may be substantially square or rectangular. Also, in addition to varying shapes, a process of heating a material may involve moving, from time to time or cyclically, the spot across the surface of the material. This is illustrated in FIG. **6**. For example, the elongated spot III or V may be cyclically moved, represented by arrows **602**, across a surface area of material **604** so that substantially all portions of the area are equally and uniformly heated.

[0027] FIG. **7** is a schematic cross-section view of an optical assembly **702** that includes moveable optical elements, according to some embodiments. Such optical elements may be mirrors and or lenses. Though lenses are illustrated in the figure, some or all of the lenses may be replaced by mirrors. For example, spherical or aspherical mirrors may provide focus and collimation similar to or the same as corresponding lenses. Thus, claimed subject matter is not limited to lenses or mirrors in an optical assembly.

[0028] In the example illustrated in the figure, sunlight **704** is incident on a first optical element **706**, which may be a convex lens. Sunlight **704** may be naturally collimated due to the large distance to the sun or may be a priori focused by one or more beam steering elements not illustrated. For example, such beam steering may arise from tracking the sun's movement across the sky. In some implementations, however, optical assembly **702**, or a portion thereof, may be rotated to track the movement of the sun's position. First optical element **706** may focus and concentrate sunlight **704** to a spot **708** having a spot size **710**. Spot **708** may be incident on a material for heating the material. In this case, optical assembly **702**, as described thus far, is relatively simple, comprising a "single" lens (e.g., not to exclude the possible use of a compound lens) or mirror. Spot size **710** may be varied by changing the distance between the surface of the material and first optical element **706**.

[0029] The addition of another lens (or mirror), however, may allow for techniques for varying the size and location of the concentrated sunlight spot without moving the material to be heated. For example, the addition of second optical element **712**, which may be a concave lens, may produce a spot **714** having a size **716** larger than that of spot **708** (depending on the distance between the surface of the material and first optical element **706**) on a material surface **718**. Generally, the size of the spot depends on the relative distances between first and second optical elements and material surface **718**. Accordingly, the relative locations of the optical elements may be moved, represented in the figure by arrows **720** and **722**, respectively, to vary the size of the spot (e.g., **708** or **714**).

[0030] In addition to changing their relative distances apart, the optical elements may be moved transversely off axis, as represented in the figure by arrows **724** and **726**, to vary the location of the concentrated sunlight spot on the surface of the material. For example, movement of second optical element in a direction **726** may lead to spot **714** changing location, indicated by arrow **728**, on material surface **718**.

[0031] In some embodiments, though not illustrated, optical assembly **702** may include an optical shutter that may be used to regulate the amount of concentrated sunlight (e.g., heat) incident on a material to be heated. For example, such an optical shutter may open and close cyclically or from time-to-time, wherein a closed shutter blocks incident sunlight and an opened shutter allows incident sunlight to impinge on the material. The shutter may be opened and closed via one or more motion transducers, similar to or the same as what may be used to move any of the optical elements in optical assembly **702**.

[0032] Generally, electromagnetic energy in the ultraviolet (UV) through the infrared (IR) spectrum is transmitted, reflected, and/or absorbed by optical elements. Energy that is absorbed by an optical element contributes to heating the optical element. Because optical elements included in optical assembly **702** are receiving sunlight, and because some of the elements are receiving at least partially concentrated, high-intensity sunlight, even a relatively small percentage of absorption may detrimentally affect these optical elements due to relatively high heat input. Accordingly, in some embodiments, the relatively cold environment in shadowed

areas of the Moon may be used to maintain relatively cool temperatures of the optical elements. For example, while portions of the optical elements in the optical path of the sunlight may heat due to absorption, cold portions of the optical elements outside the optical path (e.g., edge portions of the optical elements) where sunlight is blocked (e.g., shadowed areas) may draw the heat away from the optical path portions of the elements. In some implementations, radiative heat sinks may be attached to optical elements outside the optical path.

[0033] FIG. **8** is a flow diagram of a process **802** for solar heated beneficiation of a material, according to some embodiments. Process **802** may be performed by an operator that is human, a computer processor performing executable electronic instructions, or a combination of both. For sake of example, process **802** is described below as being applied to configurations **102** and **202**.

[0034] At **804**, an operator may provide, via an optical assembly (e.g., **702**), a first spot **120** of concentrated sunlight **104** onto material **106** to vaporize (e.g., **108**) at least a portion of the material. At **806**, the operator may collect at least a portion of the vaporized material on a first substrate **114** by allowing a first thin film **112** to form (e.g., via condensation) on the substrate. At **808**, the operator may provide, via the optical assembly, a second spot **204** of concentrated sunlight **206** onto first thin film **112** to vaporize (e.g., **208**) at least a portion of the first thin film. At **810**, the operator may collect at least a portion of the vaporized first thin film on a second substrate **214** by allowing a second thin film **212** to form on the substrate.

[0035] In some embodiments, process **802** may allow for glass-covered solar cell fabrication using concentrated sunlight. For example, second substrate **214** may be a photovoltaic cell and second thin film **212** may be transparent glass that covers, as a thin film layer, the photovoltaic cell. In this example, material **106** may be lunar regolith containing iron oxide, the presence in silica of which is generally responsible for relatively dark glass. The boiling point of iron oxide may be substantially above that of most of the other substances in lunar regolith. If so, then first thin film **112**, which is material evaporated from **106**, may have substantially less iron oxide than material **106**. The additional process of vaporizing at least a portion of the first thin film and forming a second thin film **212** may be to remove other substances from the first thin film and/or to form substantially purified transparent silicate glass on substrate **214**.

[0036] At **812**, the operator may determine whether to vaporize the second thin film to form a third thin film, the determining based on physical properties of the second thin film. If second thin film **212** has desired physical properties, such as desired chemical composition, or desired purity, for example, then process **802** may proceed to **814** where the process is complete as a result of the second thin film being the desired final material. On the other hand, if second thin film **212** is not the desired final material, or does not have the desired physical properties, then process **802** may proceed to **816** to perform a subsequent beneficiation process by returning to **808** for another iteration of the beneficiation process.

[0037] In some implementations, the operator may use the environment of the Moon to maintain first substrate and second substrate temperatures that are substantially colder than the vaporized material and the vaporized first thin film. The operator may also expose the vaporized material and the vaporized first thin film to the vacuum of the Moon. The operator may vary relative positions of optical elements of the optical assembly to vary the location of the spot of concentrated sunlight on the material.

[0038] The foregoing description, for purposes of explanation, used specific nomenclature to provide a thorough understanding of the disclosure. However, it will be apparent to one skilled in the art that the specific details are not required in order to practice the systems and methods described herein. The foregoing descriptions of specific embodiments or examples are presented by way of examples for purposes of illustration and description. They are not intended to be exhaustive of or to limit this disclosure to the precise forms described. Many modifications and variations are possible in view of the above teachings. The embodiments or examples are shown and described in order to best explain the principles of this disclosure and practical applications, to thereby enable others skilled in the art to best utilize this disclosure and various embodiments or examples with various modifications as are suited to the particular use contemplated. It is intended that the scope of this disclosure be defined by the following claims and their equivalents.

We claim as follows:

1. A method for solar heated beneficiation of a material, the method comprising:

providing, via an optical assembly, a first spot of concentrated sunlight onto the material to vaporize at least a portion of the material;

collecting at least a portion of the vaporized material on a first substrate to form a first thin film;

providing, via the optical assembly, a second spot of concentrated sunlight onto the first thin film to vaporize at least a portion of the first thin film;

collecting at least a portion of the vaporized first thin film on a second substrate to form a second thin film; and

determining whether to vaporize the second thin film to form a third thin film, the determining based on physical properties of the second thin film.

2. The method of claim **1**, wherein the second substrate comprises a photovoltaic cell and the second thin film comprises transparent glass.

3. The method of claim **1**, wherein the concentration of iron oxide in the first thin film is less than the concentration of iron oxide in the material.

4. The method of claim **1**, wherein the concentration of impurities in the first thin film is less than the concentration of the impurities in the material.

5. The method of claim **4**, wherein the concentration of impurities in the second thin film is less than the concentration of the impurities in the first thin film.

6. The method of claim **4**, wherein the impurities originate from lunar regolith.

7. The method of claim **1**, wherein the material comprises lunar regolith.

8. The method of claim **1**, wherein the physical properties of the second thin film include chemical composition of the second thin film.

9. The method of claim **1**, wherein the physical properties of the second thin film include concentration of impurities in the second thin film.

10. The method of claim **1**, further comprising using the environment of the Moon to maintain first substrate and

second substrate temperatures that are substantially colder than the vaporized material and the vaporized first thin film, respectively.

11. The method of claim **1**, further comprising varying relative positions of optical elements of the optical assembly to vary the location of the spot of concentrated sunlight on the material.

12. The method of claim **1**, further comprising exposing the vaporized material and the vaporized first thin film to the vacuum of the Moon.

13. The method of claim **1**, wherein the second thin film comprises glass.

14. A method for solar heated beneficiation of a material, the method comprising:

providing concentrated sunlight onto the material to vaporize at least a portion of the material;

condensing at least a portion of the vaporized material on an intermediary surface to form a first thin film on the intermediary surface;

providing concentrated sunlight onto the first thin film to vaporize at least a portion of the first thin film;

condensing at least a portion of the vaporized first thin film on a substrate to form a second thin film; and

determining whether to vaporize the second thin film to form a third thin film, the determining based on chemical composition of the second thin film.

15. The method of claim **14**, wherein the substrate comprises a photovoltaic cell and the second thin film comprises transparent glass.

16. The method of claim **14**, wherein the concentration of iron oxide in the first thin film is less than the concentration of iron oxide in the material.

17. The method of claim **14**, wherein the concentration of impurities in the first thin film is less than the concentration of the impurities in the material.

18. The method of claim **17**, wherein the impurities originate from lunar regolith.

19. The method of claim **14**, wherein the material comprises lunar regolith.

20. The method of claim **14**, further comprising exposing the vaporized material and the vaporized first thin film to the vacuum of the Moon.

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