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(54) **MILLIMETER-WAVE AREA-PROTECTION SYSTEM AND METHOD**

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(51) **Int. Cl.**
G08B 13/18 (2006.01)

(52) **U.S. Cl.** **340/567**; 340/541; 340/545.3

(58) **Field of Classification Search** .... 340/541, 340/552, 553, 554, 555, 556, 565, 567, 545.3; 342/27, 28, 175; 343/700 MS, 866
See application file for complete search history.

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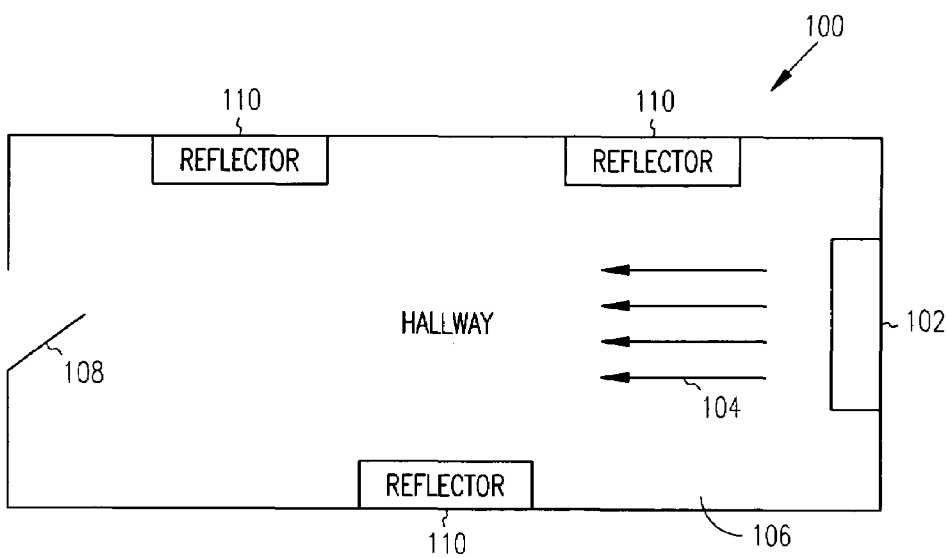
(57) **ABSTRACT**

An area-protection system uses an active-array antenna to generate a high-power millimeter-wave wavefront to deter an intruder within a protected area. One or more reflectors may be positioned within the protected area to help retain energy of the wavefront within the area. The area-protection system may include an intrusion-detection subsystem to detect presence of the intruder within the protected area and to generate a detection signal. The active-array antenna may generate the high-power millimeter-wave wavefront in response to the detection signal. In some embodiments, the intrusion-detection subsystem may detect the presence of a tag worn by the intruder, and may instruct the array antenna to refrain from generating the wavefront when tag is authenticated. In some embodiments, an illuminator may be used detect intruder movement based on return signals. In some embodiments, the array antenna includes semiconductor wafers arranged together on a substantially flat surface.

29 Claims, 7 Drawing Sheets



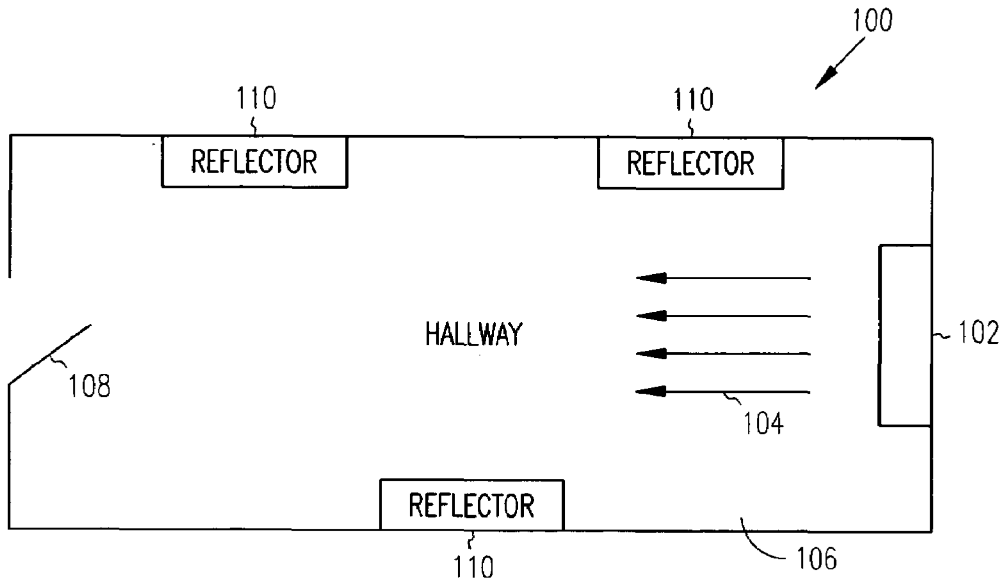

100
110
REFLECTOR
110
REFLECTOR
HALLWAY
102
108
104
REFLECTOR
110
106

FIG. 1A

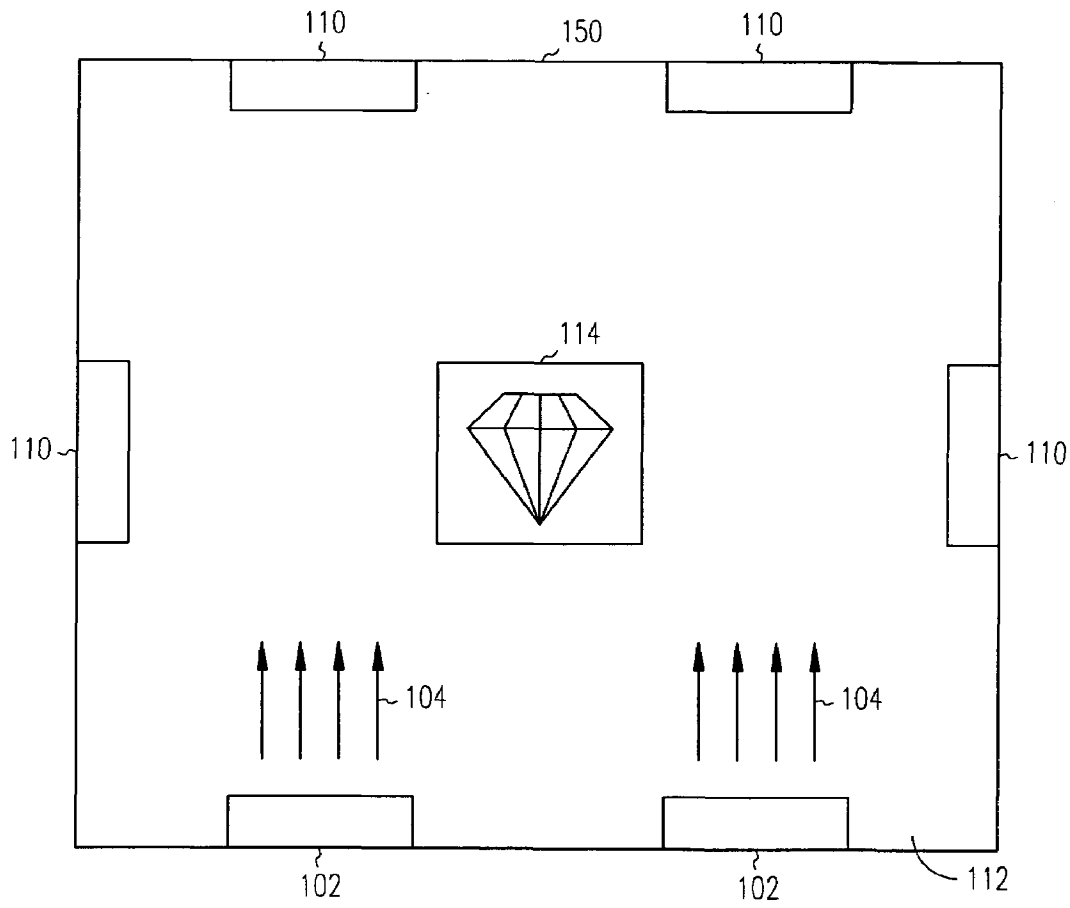

110
150
110
114
110
110
104
104
102
102
112

FIG. 1B

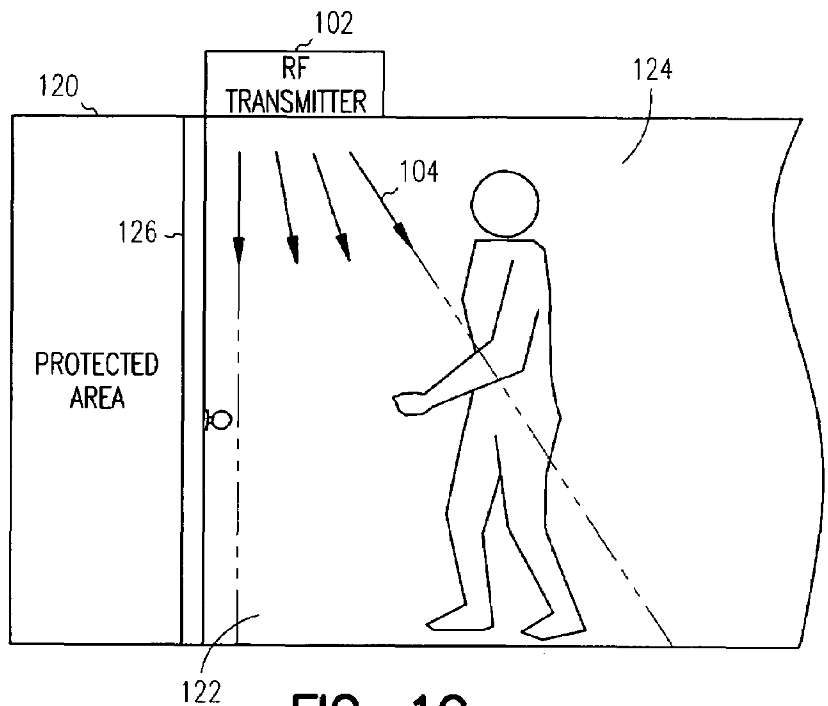

102
RF
TRANSMITTER
120
124
104
126
PROTECTED
AREA
122

FIG. 1C

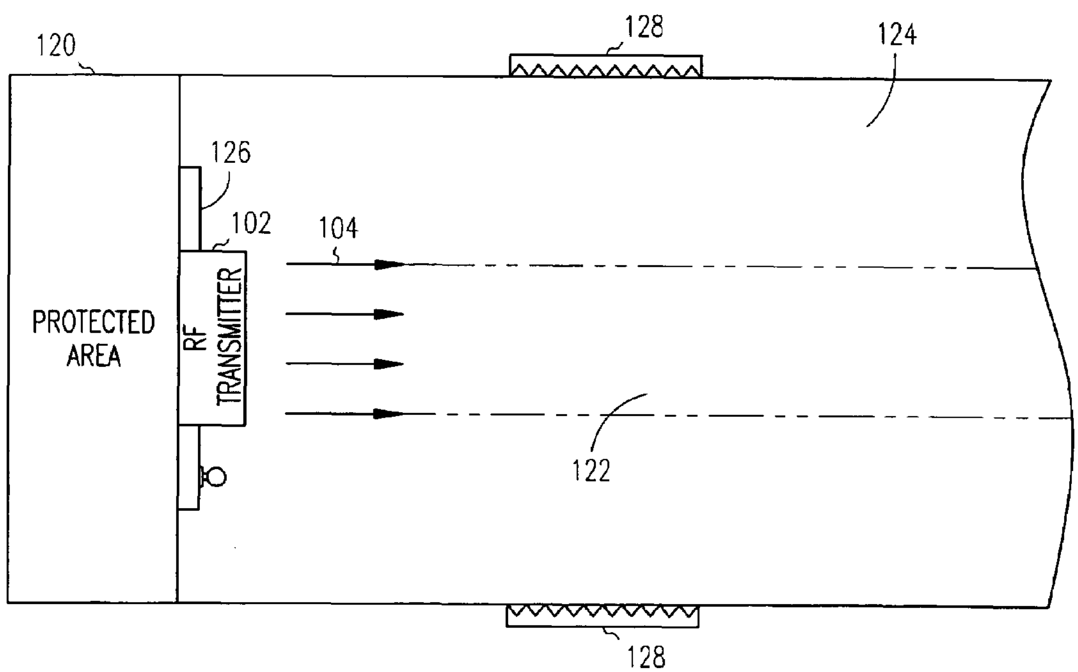

128
120
124
126
102
104
PROTECTED
AREA
RF
TRANSMITTER
122
128

FIG. 1D

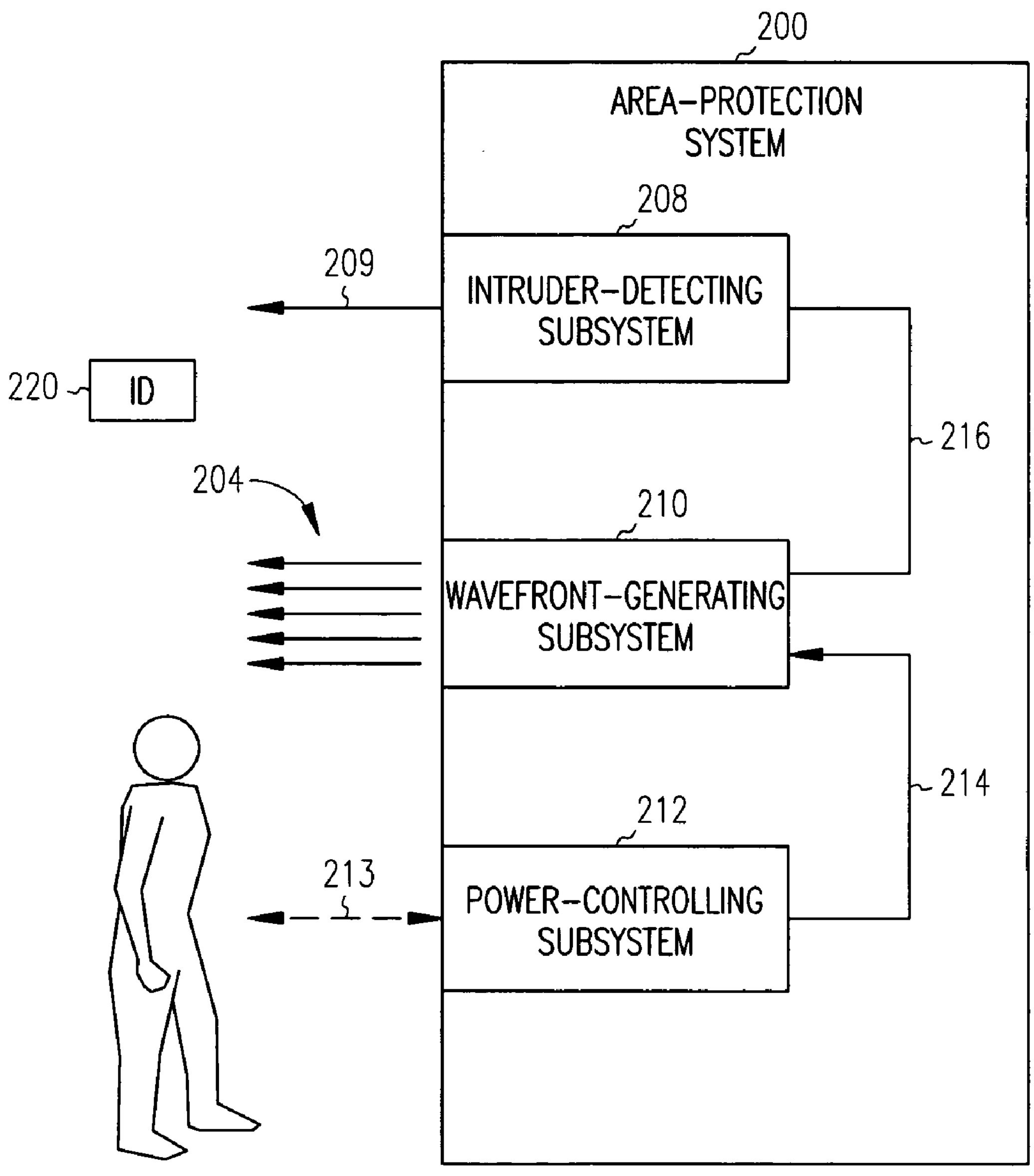

200
AREA-PROTECTION SYSTEM
208
INTRUDER-DETECTING SUBSYSTEM
209
220
ID
216
204
210
WAVEFRONT-GENERATING SUBSYSTEM
214
212
213
POWER-CONTROLLING SUBSYSTEM

FIG. 2

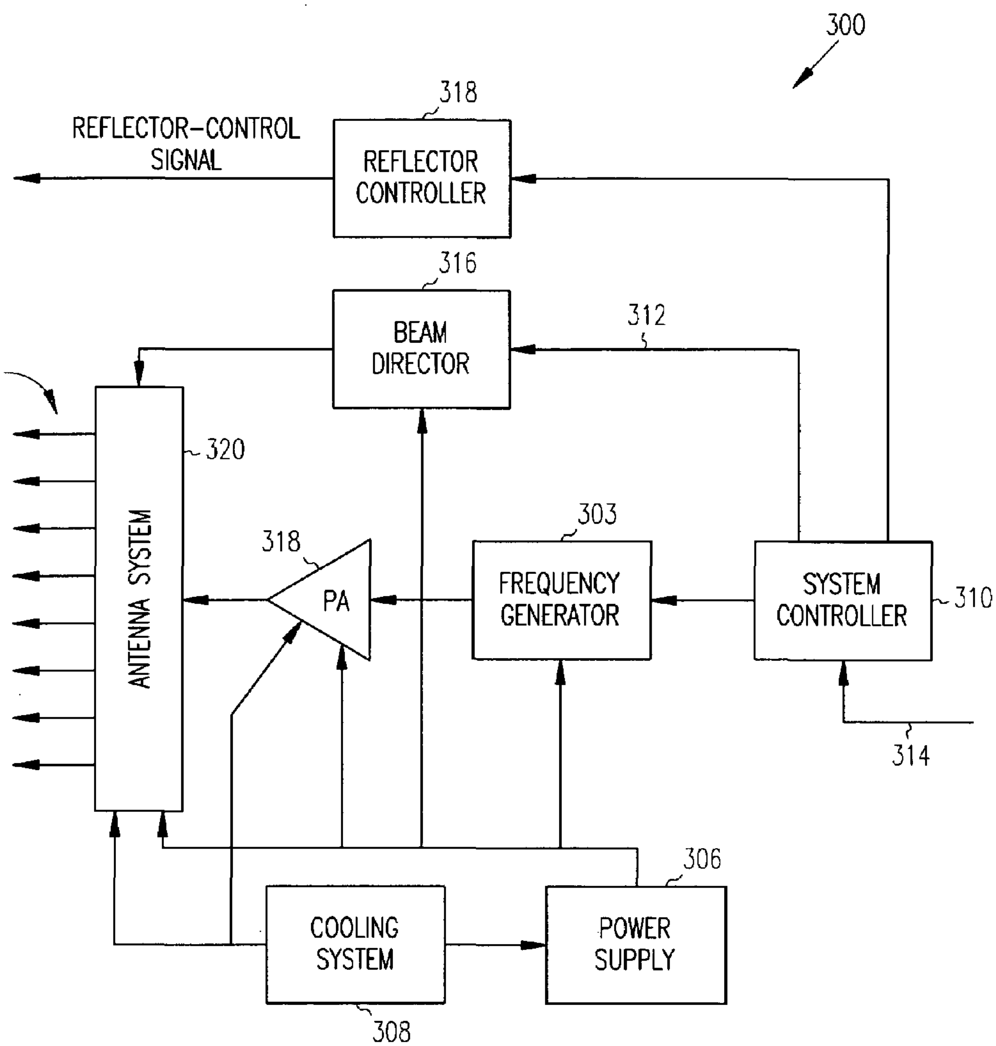

300
318
REFLECTOR-CONTROL SIGNAL
REFLECTOR CONTROLLER
316
BEAM DIRECTOR
312
304
320
ANTENNA SYSTEM
318
PA
303
FREQUENCY GENERATOR
SYSTEM CONTROLLER
310
314
306
COOLING SYSTEM
POWER SUPPLY
308

FIG. 3

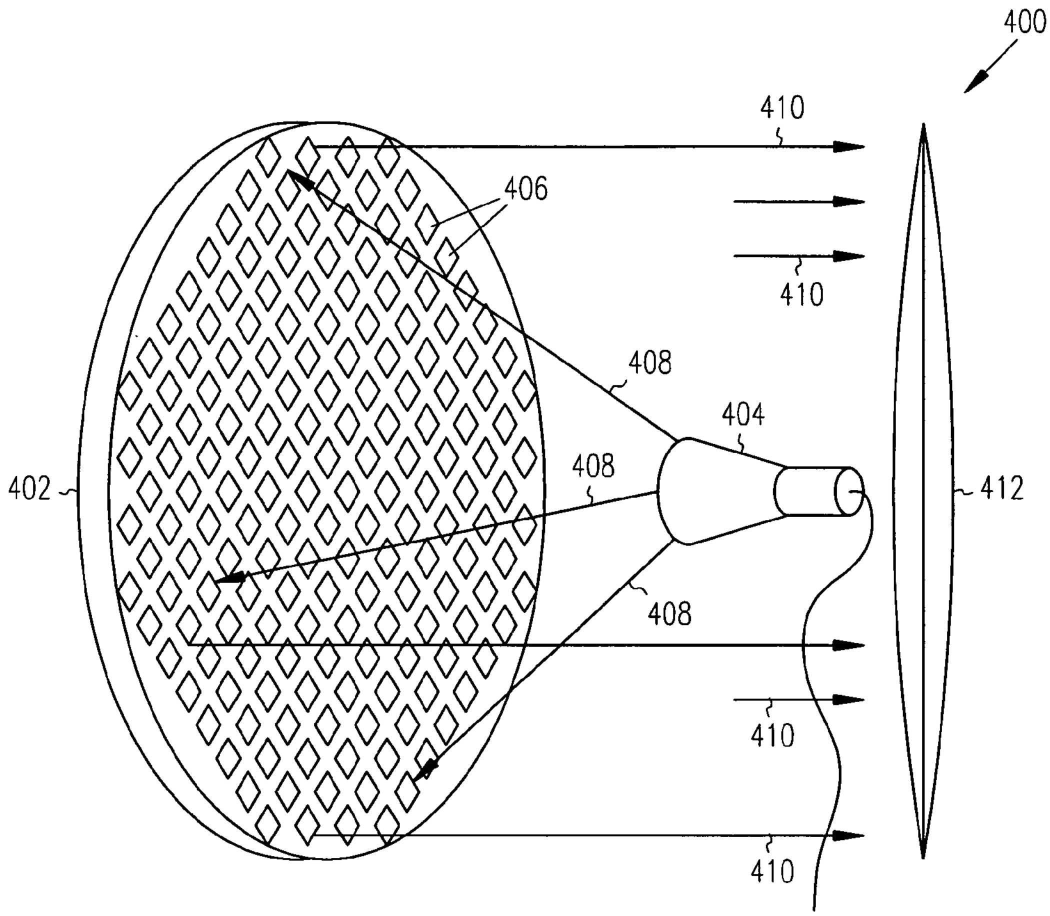


FIG. 4

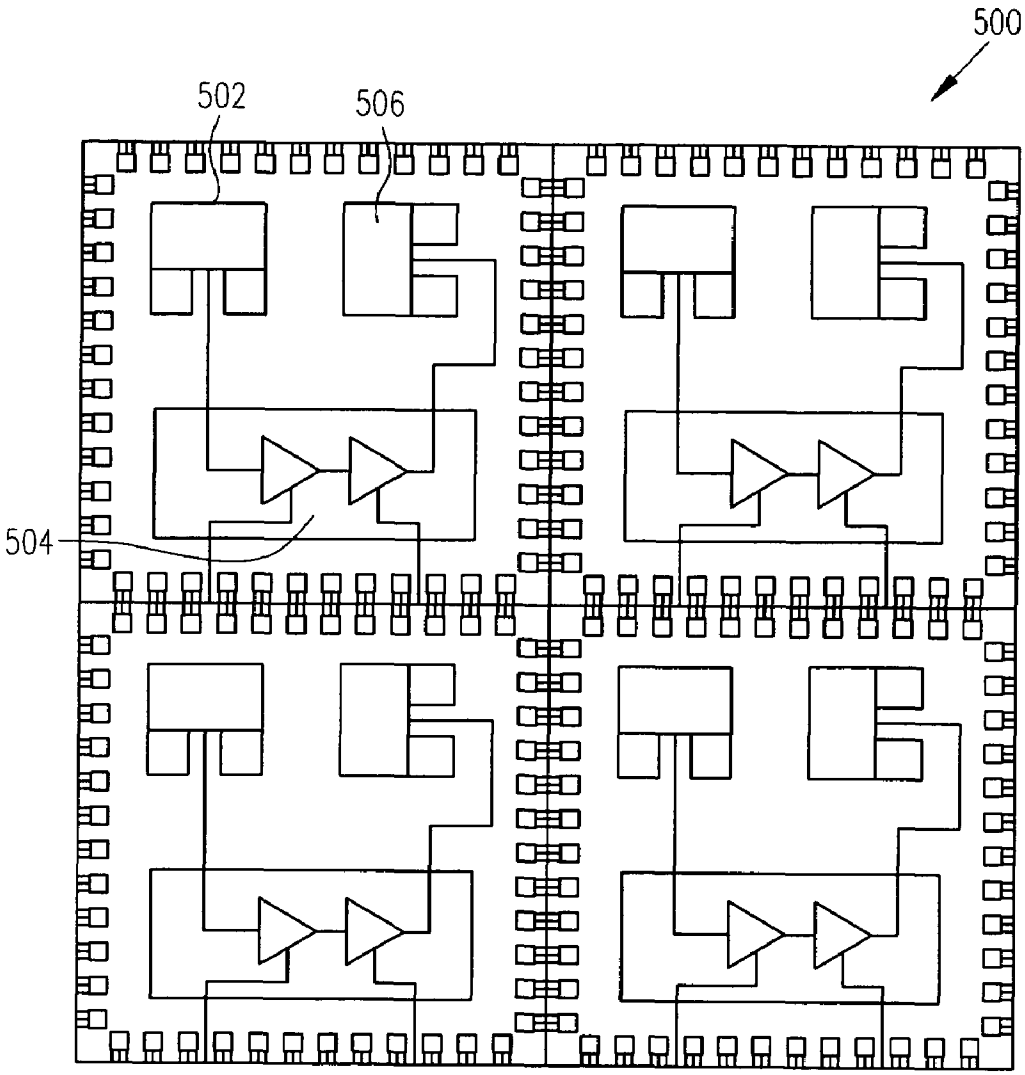


FIG. 5

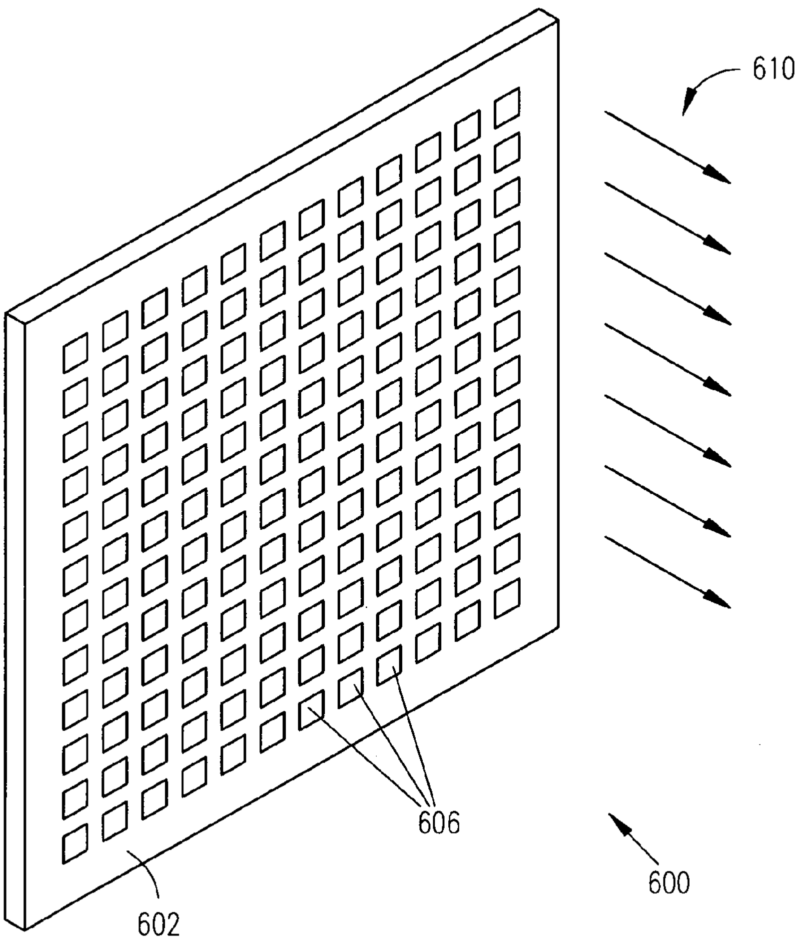


FIG. 6

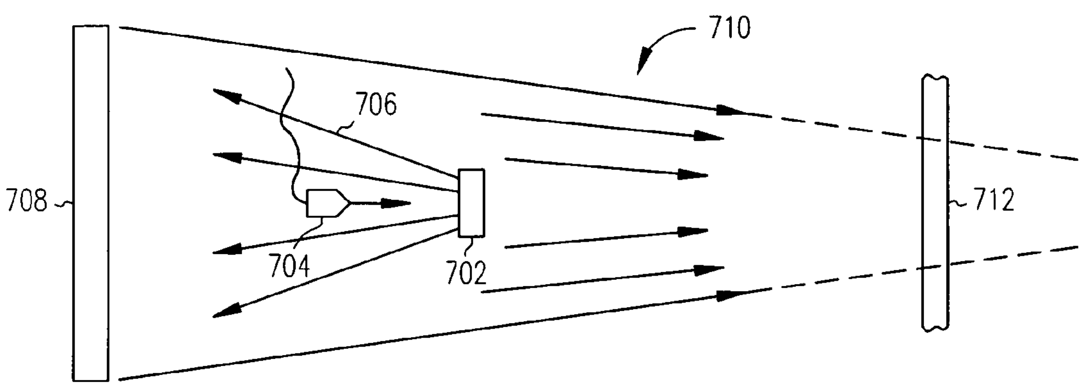


FIG. 7

MILLIMETER-WAVE AREA-PROTECTION SYSTEM AND METHOD

TECHNICAL FIELD

Embodiments of the present invention pertain to security systems, and in particular, to systems that inhibit intruders using RF energy.

BACKGROUND

Some conventional intrusion-deterring techniques rely on lethal force to deter an intruder. For example, armed guards including police officers carrying lethal weapons are typically used to protect a building or store, armored car, a location within a building or other location. Guards armed with non-lethal weapons are generally less effective in deterring intruders. One problem with the use of lethal weapons is that discipline and restraint must be exercised before their use to preserve valuable human life. This is sometimes difficult for even the most trained and experienced persons to exercise. The use of automated lethal force (e.g., without human control) is generally prohibited.

Conventional security systems, on the other hand, use locks, vaults or other mechanical devices to protect an item or an area and deter an intruder. Some conventional security systems may also employ electronic means to detect an intruder and notify authorities. Many of these conventional systems can be easily circumvented by intruders, and many times the intruder may make off with the goods before authorities can respond. Another problem with these conventional security systems is that they may generate false alarms causing an unnecessary waste of resources.

Thus, there are general needs for improved security systems and methods of deterring intruders from a protected area. There are also general needs for systems and methods that provide improved security. There are also needs for non-lethal systems and methods that provide security. There are also needs for area-protection systems and methods that can deter intruders with non-lethal force.

SUMMARY

An area-protection system uses an active-array antenna to generate a high-power millimeter-wave wavefront to deter an intruder within a protected area. One or more reflectors may be positioned within the protected area to help retain and/or concentrate energy of the wavefront within the area. In some embodiments, the one or more reflectors are positioned to increase an energy density of the wavefront at a predetermined location of the area. In some embodiments, the area-protection system may include an intrusion-detection subsystem to detect presence of the intruder within the protected area and to generate a detection signal. The active-array antenna may generate the high-power millimeter-wave wavefront in response to the detection signal. In some embodiments, the intrusion-detection subsystem may detect the presence of a tag worn by the intruder, and may instruct the array antenna to refrain from generating the wavefront when tag is authenticated. In some embodiments, an optical illuminator, a LASER illuminator, a sonic illuminator, an ultrasonic illuminator, or an RF/RADAR illuminator may be used detect intruder movement based on return signals. In some embodiments, the array antenna includes semiconductor wafers arranged together on a substantially flat surface. In some embodiments, each semiconductor wafer may include power amplifiers and a transmit antenna to reflect an incident lower-power wavefront and to generate the high-power wavefront, although the scope of the invention is not limited in this respect.

BRIEF DESCRIPTION OF THE DRAWINGS

The appended claims are directed to some of the various embodiments of the present invention. However, the detailed description presents a more complete understanding of embodiments of the present invention when considered in connection with the figures, wherein like reference numbers refer to similar items throughout the figures and:

FIGS. **1**A and **1**B illustrate operational environments of area-protection systems in accordance with some embodiments of the present invention;

FIGS. **1**C and **1**D illustrate side and top views of an operational environment of an area-protection system in accordance with some embodiments of the present invention;

FIG. **2** illustrates a functional block diagram of an area-protection system in accordance with some embodiments of the present invention;

FIG. **3** is a functional block diagram of a wavefront-generating subsystem in accordance with some embodiments of the present invention;

FIG. **4** illustrates an active-array antenna system in accordance with some embodiments of the present invention;

FIG. **5** illustrates a portion of a semiconductor wafer suitable for use as part of an active reflect-array in accordance with some embodiments of the present invention;

FIG. **6** illustrates a planar active-array antenna system in accordance with some embodiments of the present invention; and

FIG. **7** illustrates a side view of a passive reflect-array antenna system in accordance with some other embodiments of the present invention.

DETAILED DESCRIPTION

The following description and the drawings illustrate specific embodiments of the invention sufficiently to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Examples merely typify possible variations. Individual components and functions are optional unless explicitly required, and the sequence of operations may vary. Portions and features of some embodiments may be included in or substituted for those of others. The scope of embodiments of the invention encompasses the full ambit of the claims and all available equivalents of those claims.

FIGS. **1**A through **1**D illustrate operational environments of area-protection systems in accordance with some embodiments of the present invention. FIG. **1**A illustrates hallway-protection system **100** in which area-protection system **102** may direct high-power RF wavefront **104** within hallway **106** to deter or inhibit intruders. In these embodiments of the present invention, area-protection system **102** may detect an intruder and may responsively generate wavefront **104**, or alternatively, area-protection system **102** may continually generate wavefront **104** within hallway **106**. In some embodiments, the opening or jarring of a window or a door, such as door **108**, may trigger or cause area-protection system **102** to generate wavefront **104**. In some embodiments, system **104** may employ an intruder-detection subsystem to detect the presence of an intruder. This is described in more detail below. Wavefront **104** may increase the skin temperature of an intruder and may cause pain or even intense pain depending on the characteristics of wavefront **104**.

In some embodiments, hallway protection system **100** may include one or more reflectors **110** which may be positioned to help direct and/or reflect wavefront **104** toward a particular location, such as door **108**. Reflectors **110** may include almost any element that reflects RF energy, including metallic surfaces and mirrors. The particular type of reflectors selected for use in system **100** may depend on the specific frequency and characteristics of wavefront **104**.

In embodiments, reflectors **110** may be used to control the volume of the emitted beam which may increase the power density of wavefront **104** in the area or location being protected. Furthermore, reflectors **110** may help reduce the amount of energy escaping the protected area helping to reduce effects of the energy on persons and equipment external to the protected area.

Although hallway protection system **100** is illustrated with area-protection system **102** located opposite door **108** in hallway **106**, the scope of the present invention is not limited in this respect. In embodiments, area-protection system **102** may be located at almost any location depending on the characteristics of wavefront **104** and reflectors **110**. For example, in some embodiments area-protection system **102** may be located on the ceiling, at an angle, behind wall panels, etc. Although hallway protection system **100** is illustrated with a single area-protection system **102**, it should be understood that more than one area-protection system **102** may be included within system **100**.

FIG. **1**B illustrates environment **150** in which one or more area-protection system **102** may direct one or more high-power RF wavefronts **104** within area **112** to deter or inhibit intruders. In these embodiments, one or more reflectors **110** may be positioned at various locations within area **112** to direct energy from wavefronts **104** from one or more area-protection systems **102**. In these embodiments, the energy may be directed at or toward specific locations within area **112** to inhibit intruders at those specific locations (e.g., doors, windows). Alternatively, the energy of wavefronts **104** may be directed to cover substantially the entire room or area. In some embodiments, the energy of wavefronts **104** may be directed to protect an item at one or more particular locations, such as location **114**. In these embodiments, systems **102** may be used to guard a valuable item such as jewelry, weapons, or works or art, although the scope of the present invention is not limited in this respect. In some embodiments, an area, such a hallway **106** or area **112** may have a plurality of emitters (e.g., antennas for area-protection system **102** to provide a sufficient power density within the hallway or area.

Referring to both FIGS. **1**A and **1**B, in some embodiments, high-power wavefronts **104** may be a high-power collimated wavefronts in which the energy may be substantially provided in a cylindrical-type shape. In these embodiments, the energy may be substantially uniform for being directed down hallway **106**. In other embodiments, high-power wavefront **104** may be a focused-controlled high-power wavefront, such as a high-power converging wavefront, in which the energy may substantially be provided in a converging shape. In these embodiments, the energy density may increase toward a location which may be at or near door **108** or location **114**. The wavefront characteristics may depend on the particular antenna system selected for use by area-protection system **102**. These embodiments are described in more detail below.

Wavefront **104** generated by area-protection system **102** may comprise an RF frequency selected specifically to deter an intruder. For example, a millimeter-wave frequency may be selected to increase the skin temperature of an intruder and inhibit the intruder from proceeding down hallway **106** or entering area **112**. In embodiments, the frequency may be selected to increase a bond-resonance between the atoms of water molecules (e.g., the hydrogen-to-oxygen bonds), although the scope of the invention is not limited in this respect. Millimeter-wave frequencies (e.g., 30 to 300 GHz) may be suitable, and in some embodiments, W-band frequencies (e.g., 77 to 110 GHz) may be particularly suitable, although the scope of the invention is not limited in this respect. A millimeter-wave frequency may also be chosen so that heating occurs primarily within a predetermined surface depth of an intruder's skin. In embodiments, the skin-depth may, for example, be much less than a millimeter, although the scope of the invention is not limited in this respect.

Those of ordinary skill in the art may choose appropriate power levels and associated system components for providing high-power wavefront **104** depending on distance, temperature, and operational environment for which area-protection system **102** is used. In some embodiments, area-protection system **102** may be configured to generate a predetermined power density at a distance of up to several meters and greater.

In some embodiments, wavefront **104** may be a wavefront comprised of coherent RF energy to help reduce spreading, although the scope of the invention is not limited in this respect. In some embodiments, area-protection system **102** generates a pulsed high-power wavefront. In these embodiments, area-protection system **102** may change either a pulse-repetition-rate or a pulse-duration time of wavefront **104** to control the amount of energy directed at an intruder. In other embodiments, area-protection system **102** may generate a continuous-wave wavefront and the power level of the wavefront may be varied to control the amount of energy directed at an intruder. In some embodiments, area-protection system **102** may include a power-controlling subsystem to change the amount of energy in wavefront **104** based on the location of the intruder, the temperature of the intruder's skin, and/or the movement of the intruder. For example, area-protection system **102** may increase the energy level in wavefront **104** when the intruder is approaching, and decrease the energy level when the intruder is leaving. These embodiments are described in more detail below.

In some embodiments, area-protection system **102** may be disabled by an authorized party wearing a tag. In these embodiments, the presence of the tag may be sensed by area-protection system **102**, and the party may be authorized by information on the tag. Accordingly, area-protection system **102** may refrain from generating wavefront **104** in response to the presence of an authorized party in hallway **106** or area **112** to permit the authorized party access.

In some embodiments, reflectors **110** may be controlled by area-protection system **102** to help focus or direct wavefront **104** at a particular location. In some embodiments, area-protection system **102** may have a beam director to direct to change the direction of wavefront **104** and may direct wavefront **104** at one or more reflectors **110** as well as one or more locations in hallway **106** or area **112**.

In some embodiments, area-protection system **102** may be used to protect passages areas against unauthorized entry or intrusion. The use of area-protection system **102** may be safe for nearby people in case of accidental use, which is unlike lethal systems. In some embodiments, area-protection system **102** may be used to protect a cockpit of an aircraft.

FIGS. **1**C and **1**D illustrate side and top views of an operational environment of an area-protection system in accordance with some embodiments of the present invention. In these embodiments, area-protection system **102** may inhibit an intruder from entering protected area **120** by generating wavefront **104** within region **122** of hallway **124**. In these embodiments, a transmitter or antenna for generating the energy may be positioned above door **126** as illustrated, although this is not a requirement. In some embodiments, batters **128** may be used to reflect, shape and/or control the energy within region **122** to help maximize energy density. Batters **128** may include reflectors, mirrors and/or other passive elements.

Although the operational environments illustrated in FIGS. **1**A through **1**D show one or more area-protection systems **102** at various locations, it should be understood that it may be necessary to only locate the antenna or transmitting element of an area-protection system at the location indicated, as other system components may be located remotely.

FIG. **2** illustrates a functional block diagram of an area-protection system in accordance with some embodiments of the present invention. Area-protection system **200** may be suitable for use as area-protection system **102** (FIGS. **1**) although other systems may be suitable. Area-protection system **200** includes wavefront-generating subsystem **210** to generate high-power wavefront **204**. In some embodiments, area-protection system **200** may also include intruder-detecting subsystem **208** to detect a presence of an intruder, and/or power-controlling subsystem **212** to control the amount of energy directed by wavefront **204**.

In some embodiments, power-controlling subsystem **212** may measure a skin temperature of an intruder with thermal-sensing signal **213**. Power-controlling subsystem **212** may generate temperature control signal **214** for wavefront-generating subsystem **210** as part of a feedback-loop to help maintain the temperature within or below a predetermined temperature or within a predetermined temperature range. For example, power-controlling subsystem **212** may help maintain temperature below a predetermined temperature, or within a predetermined temperature range. In some embodiments, subsystem **212** may be used to configure subsystem **210** to generate a lowest-power wavefront required to achieve the desired effect on an intruder. The power level of wavefront **204** may be selected to cause the intruder pain, and may be selected to cause mild pain or severe pain.

In some embodiments, wavefront-generating subsystem **210** may act as a warning device to indicate that an area should not be entered. In these embodiments, power levels of wavefront **204** may be reduced to less-than-painful levels, such as by changing duty-cycles to allow egress. A sidelobe power level that is graded in intensity may also be provided. The graded power levels may provide some discomfort and may cause an aversion effect before the intruder is in a more painful part of wavefront **204**.

In some embodiments, intruder-detecting subsystem **208** may include an intruder tracker to track movement and/or location of an intruder and generate tracking-control signal **216**. In some embodiments, wavefront-generating subsystem **210** may direct high-power wavefront **204** at or toward the tracked intruder in response to tracking-control signal **216**. In some embodiments, intruder-detecting subsystem **208** may include a biometric identifier to determine whether the intruder is actually a biological entity (e.g., a human, animal, or other a living creature) or a non-biological entity (e.g., a non living thing like a rock, vehicle, or tank). In these embodiments, intruder-detecting subsystem **208** may generate tracking-control signal **216** when a biological entity is detected, and may refrain from generating tracking-control signal **216** and wavefront **204** when a biological entity is not detected.

In at least one embodiment, intruder-detecting subsystem **208** may track the movement or location of a detected intruder and generate control signal **216** for wavefront-generating subsystem **210**. In these embodiments, wavefront-generating subsystem **210** may direct high-power wavefront **204** at the intruder in response to directional information provided in control signal **216**.

In embodiments, intruder-detecting subsystem **208** may include an illuminator to detect a biological entity based on movement using motion-detection signal **209**. The illuminator may be an active illuminator and may comprise an infrared (IR) sensor, a LASER sensor, an ultrasonic sensor, or a RF/RADAR system which transmits signals and detects movement based on returns or received signals. In other embodiments, intruder-detecting subsystem **208** may include a passive subsystem for detecting intruders and may include an optical or video sensor, an infrared (IR) sensor and/or a noise sensor to detect an intruder based on light, heat or sound. When signal **209** is a laser signal, subsystem **208** may direct and place a laser spot on an intruder and determine the distance to the intruder and/or to determine whether the intruder is moving toward or away from a protected area. The laser signal placed on the intruder may also be used to warn the intruder.

In some embodiments, area-protection system **200** may be disabled by an authorized party wearing tag **220**. In these embodiments, the presence of tag **220** may be sensed by intruder-detecting subsystem **208**, and the party may be authorized by identity (ID) information on the tag. Accordingly, wavefront-generating subsystem **210** may refrain from generating wavefront **204** in response to the presence of an authorized party. In some embodiments, tag **220** may comprise a transponder to identify the person to system **200**. In some embodiments, tag **220** may be a passive RF tag, and intruder-detecting system **208** may be configured to read such tags. In other embodiments, tag **220** may be an active RF tag which may transmit an RF identification signal in response to an inquiry from subsystem **208**.

In some embodiments, wavefront-generating subsystem **210** may perform at least some functions of intruder-detecting subsystem **208** and a separate intruder detecting system may not be required. In these embodiments, wavefront-generating subsystem **210** may include a receiver, and may detect intruders by transmitting a lower-power millimeter-wave signal. A detector within the receiver may look for indications of intrusions, such as a Doppler-shift or variation of intensity over time of returned signals. When an intruder is detected, subsystem **210** may responsively generate high-power wavefront **204**. The Doppler-shift may also be used by subsystem **210** to determine whether the intruder is approaching or receding from a protected area and subsystem **210** may responsively change power and/or direction of wavefront **204**.

In some embodiments, wavefront **204** may be multiplexed and sent in more than one direction at different times to provide coverage over a larger area. In some embodiments, area-protection system **200** may, in addition to serving as an area protection system, serve as an animal control system. In some embodiments, system **200** may be incorporated into a building's walls, hallways, ceilings and/or floors.

Although area-protection system **200** is illustrated with intruder-detecting subsystem **208** and power-controlling subsystem **212**, either or both of these subsystems can be optional. For example, wavefront-generating subsystem **210** may be turned on and off manually, such as when a security guard spots an intruder. In some embodiments, wavefront **204** may be pulsed and the duration of the pulses may be changed depending on whether the intruder is approaching or receding from a protected location or area. In these embodiments, the power may be turned off for a short time to see if the intruder leaves. This may allow time for the intruder to leave.

FIG. **3** is a functional block diagram of a wavefront-generating subsystem in accordance with some embodiments of the present invention. Wavefront-generating subsystem **300** may be suitable for use as wavefront-generating subsystem **210** (FIG. **2**), although other systems and subsystems may also be suitable. Wavefront-generating subsystem **300** includes antenna system **320** which generates high-power wavefront **304** at a millimeter-wave frequency. Wavefront-generating subsystem **300** may also comprise frequency generator **303** to generate the millimeter-wave frequency and power supply **306** to provide power for the various elements of subsystem **300**. High-power wavefront **304** may be, for example, either in a collimated wavefront, a converging wavefront or a diverging wavefront.

In some embodiments, antenna system **320** may be a passive system which receives a high-power millimeter-wave frequency signal provided by frequency generator **303** and/or power amplifier **318**. In these embodiments, frequency generator **303** and power amplifier **318** may comprise single or separate elements and may include a gyrotron, a traveling wave tube (TWT), and/or a klystron to generate a high-power millimeter-wave frequency signal for antenna system **320**. In some embodiments, frequency generator **303** may generate a low-power millimeter-wave frequency signal, which may be amplified by power amplifier **318**. In these embodiments, power amplifier **318** may comprise a high-power amplifier such as a traveling wave tube (TWT), or a klystron to generate the high-power millimeter-wave frequency signal for antenna system **320**.

In other embodiments, antenna system **320** may be an active antenna system which receives a lower-power millimeter-wave frequency signal provided by frequency generator **303** and/or power amplifier **318**. In these embodiments, frequency generator **303** and/or power amplifier **318** may comprise a crystal oscillator and/or semiconductor-based amplifier elements (e.g., transistor amplifiers) to generate the lower-power millimeter-wave frequency signal for antenna system **320**. In these embodiments, antenna system **320** may amplify the lower-power millimeter-wave frequency signal to provide high-power wavefront **304**.

Frequency generator **303** may utilize Gunn or Impatt diodes (e.g., on InP HEMP) to generate the millimeter-wave frequency signal, although other ways of generating and/or amplifying frequencies are also suitable. In some embodiments, power amplifier **318** is optional depending on the power level required by antenna system **320** and the power level provided by frequency generator **303**.

Power supply **306** may include a low-voltage, high-current power supply capable of generating a high-surge current for antenna system **320**. In these embodiments, power supply **306** may utilize large capacitors which can provide high-surge current as required by power amplifier **318**, frequency generator **303** and/or antenna system **320**.

Subsystem **300** may also include cooling subsystem **308** to reduce and/or control the temperature of elements of the subsystem, such as antenna system **320**, frequency generator **303**, power amplifier **318** and/or power supply **306**. In some embodiments, cooling subsystem **308** may be a distributed system and may comprise one or more thermo-electric-cooling (TEC) elements, while in other embodiments cooling system **308** may incorporate a phase-change fluid, refrigerant, or coolant.

Subsystem **300** may also include system controller **310** which, among other things, may be responsive to signals **314** from other subsystems. For example, system controller **310** may receive temperature-control signal **214** (FIG. **2**) from other subsystems, such as subsystem **212** (FIG. **2**), and may respond accordingly.

In some embodiments, subsystem **300** may include beam director **316**. System controller **310** may generate beam-forming control signals **312** to control beam director **316** to direct wavefront **304** in a particular direction, although the scope of the invention is not limited in this respect. In these embodiments, antenna system **320** may be capable of directing wavefront **304**, and may comprise a phased-array type of antenna although the scope of the invention is not limited in this respect. The inclusion of beam director **316** in subsystem **300** may depend on the particular application for which subsystem **300** is intended, as well as the particular type of antenna system used for antenna system **320**.

In some embodiments antenna system **320** may emit wavefront **304** comprised of either single frequencies, different frequencies or broadband frequencies. In these embodiments, the use of multiple frequencies emitted together or at different times may be used to achieve a desired temperature profile as a function of time on an intruder.

Those of ordinary skill in the art may choose appropriate power levels and associated system components for providing high-power wavefront **304** depending on distance and/or temperature requirements of subsystem **300**. In some embodiments, subsystem **300** may generate a predetermined power density at a distance of up to several meters and greater. In some embodiments, wavefront **304** may be a wavefront comprised of coherent RF energy to help reduce spreading, although the scope of the invention is not limited in this respect.

In some embodiments, subsystem **300** may include reflector controller **318** which may actively control one or more reflectors, such as reflectors **110** (FIG. **1**). In these embodiments, system controller **310** may control the reflectors based on intruder location information provided by intruder-detecting subsystem **208** (FIG. **2**) to direct energy toward an intruder.

Although system **200** (FIG. **2**) and subsystem **300** are illustrated as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, application specific integrated circuits (ASICs), and combinations of various hardware and logic circuitry for performing at least the functions described herein.

FIG. **4** illustrates an active-array antenna system in accordance with some embodiments of the present invention. Active-array antenna system **400** generates a high-power wavefront at a millimeter-wave frequency and may be suitable for use as antenna system **320** (FIG. **3**) although other antennas and antenna systems may also be suitable. Active-array antenna system **400** may be concealed in walls, ceilings, floors, above doorways, etc. as part of an area protection system. Active-array antenna system **400** may receive a lower-power millimeter-wave frequency signal from frequency generator **303** (FIG. **3**) and/or power amplifier **318** (FIG. **3**) for use in generating high-power wavefront **304** (FIG. **3**).

In these embodiments, active-antenna system **400** includes active reflect-array **402** which may be spatially fed by low-power feed **404**. Active reflect-array **402** may comprise a plurality of semiconductor wafers **406** (e.g., monolithic substrates) arranged or tiled together. In the illustrated embodiments, wafers **406** may be tiled together in a substantially parabolic shape, although the scope of the invention is not limited in this respect. Low-power feed **404** may provide lower-power wavefront **408** at a millimeter-wave frequency for incident on active reflect-array **402**. Wavefront **408** may be a substantially vertically-polarized wavefront, although this is not a requirement. In response to wavefront **408**, active reflect-array **402** may generate high-power wavefront **410**.

In embodiments, active reflect-array **402** may include a plurality of receive antennas to receive wavefront **408** from low-power feed **404**, and may include a plurality of power amplifiers to amplify signals of the wavefront received by an associated one of the receive antennas. Active reflect-array **402** may also include a plurality of transmit antennas to transmit the amplified signals to provide high-power wavefront **410**.

In embodiments, low-power feed **404** be a passive feed, such as a directional antenna, to provide wavefront **408** for incidence on active reflect-array **402**. In other embodiments, feed **404** may comprise a passive reflector to reflect a millimeter-wave frequency and provide wavefront **408** for incidence on active reflect-array **402**. In these embodiments, feed **404** may reflect a millimeter-wave signal transmitted by a feed which may be near the center of array **402**, although the scope of the invention is not limited in this respect.

In some other embodiments, low-power feed **404** may be an active feed to coherently amplify and reflect a millimeter-wave frequency received from a source within (e.g., at or near the center) active reflect-array **402**, although the scope of the invention is not limited in this respect. In these embodiments, low-power feed **404** may comprise one or more receive antennas to receive the millimeter-wave frequency from the feed source, one or more amplifiers to amplify the received millimeter-wave frequency, and one or more transmit antennas to transmit the amplified signals and provide lower-power wavefront **408** for incidence on active reflect-array **402**.

In yet other embodiments, low-power feed **404** may receive a signal from a signal source for transmission such frequency generator **303** (FIG. **3**) and/or power amplifier **318** (FIG. **3**). Alternatively, low-power feed **404** may include a frequency generator and a power amplifier, such frequency generator **303** (FIG. **3**) and/or power amplifier **318** (FIG. **3**), to generate the millimeter-wave frequency and generate wavefront **408**.

Depending on the shape of active reflect-array **402**, and the phasing, polarization and/or coherency of wavefront **408**, (among other things), active reflect-array **402** may be configured to generate either a high-power collimated wavefront, or a high-power converging or diverging wavefront. In some embodiments, beamforming element **412** may be used to collimate, converge or diverge wavefront **410** depending on the desired outcome and the type of wavefront generated by array **402**. In some embodiments, beamforming element **412** may be an RF lens or a Fresnel type lens, although the scope of the invention is not limited in this respect.

In other embodiments, low-power feed **404** may be a passive source. In these embodiments, feed **404** may be implemented as a passive partly-reflecting plate element to provide a wavefront emission (e.g., wavefront **408**) to reflect array **402**. In these embodiments, the wavefront emission may actually be part of the wavefront emission (e.g., wavefront **410**) that is reflected back. In these embodiments, millimeter-wave frequencies may be generated with the natural and/or induced oscillations of individual semiconductor wafers **406** of a passive reflect array in place of active reflect-array **402**. In one embodiment, a passive low power feed (e.g., feed **404**) may be used together with a beamforming element in the path of wavefront **408** to reflect into a partly reflecting single plate element. In these embodiments, the spacing between monolithic array **402** and the partly reflecting element resulting from the combination of passive source **404** and beam forming element **412** may control the final output frequency radiated as wavefront **410**. In these embodiments, active-array system **400** may have its output radiative emission generated without the necessity of other low-level sources, such as frequency generator **303** (FIG. **3**). In these embodiments, the shape of the combined partly reflecting elements (e.g., **404** and **412**) may control the phase of the individual semiconductor wafers **406** to allow the final beam (e.g., wavefront **410**) to have a desired phase front. Control of phase constants between elements of the active reflect-array **402** or by physically or electrically shifting the low-power feed element may provide for more optimal distributions or direction-steering capabilities of wavefront **410**.

FIG. **5** illustrates a portion of a semiconductor wafer suitable for use as part of an active reflect-array, such as active reflect-array **402** (FIG. **4**) in accordance with some embodiments of the present invention. Portion **500** may be suitable for wafers **406** (FIG. **4**) although other semiconductor wafers may also be suitable. Semiconductor wafer portion **500** may include one or more receive antennas **502** to receive a wavefront, such as wavefront **408** (FIG. **4**) which may be a substantially vertically-polarized wavefront. Portion **500** may also include one or more sets of power amplifiers **504** to amplify signals of the wavefront received by an associated one of receive antennas **502**. Portion **500** may also include one or more transmit antennas **506** to transmit the amplified signals to generate a high-power wavefront, such as wavefront **410** (FIG. **4**) at a millimeter-wave frequency. In embodiments, each set of power amplifiers **504** may be associated with one of the transmit and one of the receive antennas. In some embodiments, portion **500** may include separate receive and transmit antennas, while in other embodiments, amplification elements may utilize a single antenna for receiving and transmitting.

In embodiments, antennas **502** and **506** may be patch antennas; however other antennas such as a dipole antenna, a monopole antenna, a loop antenna, a microstrip antenna or other type of antenna suitable for reception and/or transmission of millimeter-wave signals may also be suitable. In one embodiment, a dual-polarized patch antenna may be used for both transmit and receive functions.

Examples of active-reflect array antennas which may be suitable for use as active-array antenna system **400** (FIG. **4**) and semiconductor wafer portion **500** are described in U.S. patent application Ser. No. 10/153,140, entitled "MONOLITHIC MILLIMETER-WAVE REFLECT ARRAY SYSTEM", having a file date of May 30, 3002, and assigned to same assignee as the present invention. The U.S. Patent Application is hereby incorporated by reference.

FIG. **6** illustrates a planar active-array antenna system in accordance with some embodiments of the present invention. Active-array antenna system **600** generates high-power wavefront **610** at a millimeter-wave frequency and may be suitable for use as antenna system **320** (FIG. **3**) although other antennas may also be suitable. Active-array antenna system **600** may be concealed in walls, ceilings, floors, above doorways, etc. as part of an area protection system. Active-array antenna system **600** may receive a lower-power millimeter-wave frequency signal from frequency generator **303** (FIG. **3**) and/or power amplifier **318** (FIG. **3**) for use in generating high-power wavefront **610**.

In some embodiments, antenna system **600** may include substantially flat structural element **602** having a plurality of semiconductor wafers **606** (e.g., monolithic substrates) arranged therein or tiled together in a substantially flat shape. Each of semiconductor wafers **606** may comprise one or more sets of power amplifiers to amplify the millimeter-wave frequency, and one or more transmit antennas to generate high-power wavefront **610** at the millimeter-wave frequency. Each set of power amplifiers may be associated with one of the transmit antennas. In these embodiments, wafers **606** of planar active-array antenna system **600** may be fed with one or more millimeter-wave signals from a signal source (not shown) for amplification and transmission. In some embodiments, array antenna system **600** may comprise a single monolithic semiconductor substrate, rather than many wafers **606** tiled together.

Active-array antenna system **600** may be configured to generate either a high-power collimated wavefront, or a high-power converging or diverging wavefront depending on factors such as coherency, phasing and/or polarization. In some embodiments, a separate beamforming element may be used to collimate, converge or diverge wavefront **610** depending on the desired outcome and the type of wavefront desired to be generated by antenna system **600**. In some embodiments, the additional beamforming element may be an RF lens, although the scope of the invention is not limited in this respect. In some embodiments, the direction of wavefront **610** may be controlled by a beam director, such as beam director **316** (FIG. **3**).

FIG. **7** illustrates a side view of a passive reflect-array antenna system in accordance with some other embodiments of the present invention. Passive reflect-array antenna system **700** generates high-power wavefront **710** at a millimeter-wave frequency and may be suitable for use as antenna system **320** (FIG. **3**) although other antennas may also be suitable. Passive reflect-array antenna system **700** may be concealed in or behind walls, ceilings, floors, above doorways, etc. as part of an area protection system. Passive reflect-array antenna system **700** may receive a high-power millimeter-wave frequency signal from frequency generator **303** (FIG. **3**) and/or power amplifier **318** (FIG. **3**) for use in generating high-power wavefront **710**.

Antenna system **700** includes passive reflector **702** which may reflect a millimeter-wave frequency signal received from signal source **704**. Reflector **702** may provide wavefront **706** for incidence on passive reflect antenna **708**. Wavefront **706** may be a high-power vertically-polarized wavefront and reflector **702** may be a substantially flat circular metallic element. Passive reflect antenna **708** may be spatially fed and may include a plurality of antennas to receive wavefront **706** and provide high-power wavefront **710**. In some embodiments, high-power wavefront **710** may be a converging (or diverging) wavefront which may converge (or diverge) at or near surface **712**. In some other embodiments, high-power wavefront **710** may be a collimated wavefront. In embodiments in which a high-power converging-conical wavefront is generated, the spacing between reflector **702** and reflect antenna **708** may be changed to change the convergence point of the wavefront **710**.

Passive reflect antenna **708** may have a flat or parabolic shape and may comprise a plurality of individual antenna elements, such as dual-polarized dipoles of differing sizes, arranged circumferentially around a center point. In these embodiments, each antenna element may receive and transmit and may provide approximately a 180 degree phase shift, although the scope of the invention is not limited in this respect. The antenna elements may have varying sizes and shapes to receive wavefront **706** and generate wavefront **710**. An example of one type of antenna suitable for use as passive reflect antenna **708** is the flat parabolic surface reflector antenna by Malibu Research of Calabasas, Calif., although other passive reflect antennas may also be suitable. Although reflector **702** and feed **704** are illustrated as being located or positioned within wavefront **710**, reflector **702** and feed **704** may actually be positioned below or to the side so as to at least partially avoid wavefront **710**.

In some embodiments, reflector **702**, feed **704**, reflect antenna **708** and other system components may be mounted or located on a tripod or other transportable device. These embodiments, along with the changing of the focus distance, may allow wavefront **710** to be directed and focused at almost any surface or any thing to protect an area.

In some embodiments, reflector **702** and source **704** of the low-power feed network may be removed, and surface **712** may be reflective or may include a reflective plate. In these embodiments, a cavity may be formed between a plate of antenna **708** and the plate in surface **712** to reflect energy therebetween. As a result of these reflections, the radiative emissions of antenna **708** may become coherent due to the reflected energy causing the monolithic amplifiers to phase lock. The relative phase of the amplifiers of antenna **708** may be controlled to allow for beam steering, among other things.

It is emphasized that the Abstract is provided to comply with 37 C.F.R. Section 1.72(b) requiring an abstract that will allow the reader to ascertain the nature and gist of the technical disclosure. It is submitted with the understanding that it will not be used to limit or interpret the scope or meaning of the claims.

In the foregoing detailed description, various features are occasionally grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments of the subject matter require more features that are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate preferred embodiment.

What is claimed is:

1. An area-protection system comprising:

sensors to detect an intruder within a protected area;

an active-array antenna to generate a high-power millimeter-wave wavefront to deter the intruder when detected within the protected area; and

one or more reflectors positioned within the protected area to help retain energy of the wavefront within the area, wherein the active-array antenna comprises a plurality of semiconductor wafers arrnged together on a substantially flat surface, each semiconductor wafer including a power amplifier and a transmit antenna which together generate the high-power millimeter-wave wavefront.

2. The system of claim **1** wherein the one or more reflectors are positioned to increase an energy density of the wavefront in a predetermined location of the protected area.

3. The system of claim **1** wherein the high-power millimeter-wave wavefront generated by the plurality of semiconductor wafers is a coherent wavefront.

4. An area-protection system comprising:

an active-array antenna to generate a high-power millimeter-wave wavefront to deter an intruder within a protected area;

one or more reflectors positioned within the protected area to help retain energy of the wavefront within the area; and

an intrusion-detection subsystem to detect a presence of the intruder within the protected area and generate a detection signal for the active-array antenna,

wherein the active-array antenna is to generate the high-power millimeter-wave wavefront in response to the detection signal, and

wherein the high-power wavefront is to increase a skin temperature of the intruder to deter the intruder.

5. The system of claim **4** wherein the intrusion-detection subsystem is to detect the presence of a tag worn by the intruder and is to instruct the active-array antenna to refrain from generating the wavefront when the tag is authenticated.

6. The system of claim **4** wherein the intrusion-detection subsystem includes an illuminator comprising one of an optical illuminator, a LASER illuminator, a sonic illuminator, an ultrasonic illuminator, or an RF/RADAR illuminator to transmit signals and detect intruder movement based on return signals.

7. An area-protection system comprising:

an intrusion-detection subsystem to detect presence of an intruder; and

an intrusion-inhibiting subsystem comprising an active-array antenna to provide a high-power millimeter-wave wavefront in response to the detection of the intruder, the high-power millimeter-wave wavefront to deter the intruder,

wherein the active-array antenna comprises a plurality of semiconductor wafers arranged together on a surface, each semiconductor wafer including a power amplifier and a transmit antenna which together generate the high-power millimeter-wave wavefront.

8. The system of claim **7** wherein the intrusion-detection subsystem includes an intruder tracker to track movement of the intruder and to generate a tracking-control signal for the array antenna, and

wherein the intrusion-inhibiting subsystem further comprises a beam director to configure the array antenna to direct the high-power millimeter-wave wavefront toward the intruder to deter the intruder in response to the tracking-control signal.

9. The system of claim **7** wherein the intrusion-detection subsystem includes an illuminator to detect the intruder based on movement, and

wherein the illuminator is an active illuminator comprising one of an optical illuminator, a LASER illuminator, a sonic illuminator, an ultrasonic illuminator, or an RADAR illuminator which transmits signals and detects intruder movement based on return signals.

10. The system of claim **7** wherein the intrusion-detection subsystem comprises a passive detection subsystem comprising one of an infrared (IR) sensor, an optical sensor, a sonic sensor or an ultrasonic sensor to detect the presence of the intruder.

11. The system of claim **7** wherein the high-power millimeter-wave wavefront generated by the plurality of semiconductor wafers is a coherent wavefront.

12. The system of claim **7** wherein the active-array antenna is to receive a spatially-fed millimeter-wave lower-power wavefront and is to amplify the lower-power wavefront to generate the high-power wavefront,

wherein each semiconductor wafer further includes a receive antenna to receive millimeter-wave signals of the spatially-fed millimeter-wave lower-power wavefront for subsequent amplification by the power amplifier and transmission by the transmit antenna of an associated semiconductor wafer.

13. The system of claim **12** wherein the active-array antenna further comprises a passive reflector to reflect a millimeter-wave frequency signal from a feed and provide the lower-power wavefront for incident on an active reflect-array comprising the plurality of semiconductor wafers,

wherein the plurality of semiconductor wafers is arranged on an at least partially parabolic surface, and

wherein the receive and transmit antennas have orthogonal polarizations.

14. The system of claim **7** wherein the plurality of semiconductor wafers is arranged on a substantially flat surface.

15. An area-protection system comprising:

an intrusion-detection subsystem to detect presence of an intruder; and

an intrusion-inhibiting subsystem comprising one of either an active-array antenna or a passive reflect-array antenna to provide a high-power millimeter-wave wavefront in response to the detection of the intruder to deter the intruder,

wherein the high-power wavefront increases a skin temperature of the intruder, and

wherein the system further comprises a thermal-sensing subsystem to measure the skin temperature and to generate a control signal for the intrusion-inhibiting subsystem to maintain the skin temperature either within a predetermined temperature range or below a predetermined temperature.

16. The system of claim **15** wherein when the system includes the active-array antenna, the active-array antenna to generates a continuous-wave wavefront, and

wherein the intrusion-inhibiting subsystem further comprises a system controller to reduce a transmit power level of the wavefront in response to the control signal from the thermal- sensing subsystem to maintain the skin temperature either within the predetermined temperature range or below the predetermined temperature.

17. The system of claim **16** wherein the system controller reduces one of either a pulse-repetition-rate or a pulse-duration time of the wavefront in response to the control signal to maintain the skin temperature either within the predetermined temperature range or below the predetermined temperature.

18. An area-protection system comprising:

an intrusion-detection subsystem to detect presence of an intruder; and

an intrusion-inhibiting subsystem comprising one of either an active-array antenna or a passive reflect-array antenna to provide a high-power millimeter-wave wavefront in response to the detection of the intruder to deter the intruder,

wherein the intrusion-detection subsystem includes a biometric lock to determine whether the intruder is one or either a biological entity or a non-biological entity, the intrusion-detection subsystem to generate a biological-identification signal when a biological entity is detected,

wherein the intrusion-inhibiting subsystem generates the high-power wavefront in response to the biological-identification signal, and

wherein the intrusion-inhibiting subsystem refrains from generating the high-power wavefront when a non-biological entity is detected.

19. The system of claim **18** wherein the intrusion-detection subsystem further comprises a biometric tracker to further track movement of a detected biological entity and to generate a biological-entity tracking-control signal for the intrusion-inhibiting subsystem, the intrusion-inhibiting subsystem to direct the wavefront toward the biological entity in response to the biological-entity tracking-control signal.

20. An area-protection system comprising:

an intrusion-detection subsystem to detect presence of an intruder; and

an intrusion-inhibiting subsystem comprising a passive reflect-array antenna to provide a high-power millimeter-wave wavefront in response to the detection of the intruder to deter the intruder,

wherein the passive reflect-array antenna comprises a plurality of semiconductor wafers arranged on an at least partially parabolic surface to reflect a spatially-fed incident millimeter-wave signal to generate the high-power millimeter-wave wavefront,

wherein each semiconductor wave comprises a receive antenna coupled to a transmit antenna to respectively receive and retransmit the spatially-fed incident millimeter-wave signals, and

wherein the receive and transmit antennas have orthogonal polarizations.

21. An area-protection system comprising:

an intrusion-detection subsystem to detect presence of an intruder; and

an intrusion-inhibiting subsystem comprising one of either an active-array antenna or a passive reflect-array antenna to provide a high-power millimeter-wave wavefront in response to the detection of the intruder to deter the intruder,

wherein the intrusion-detection subsystem is to detect the presence of a tag worn by the intruder,

wherein the intrusion-detection subsystem instructs the intrusion-inhibiting subsystem to refrain from generating the wavefront when the tag is authenticated by the intrusion-detection subsystem.

22. A method of protecting an area comprising:

detecting a presence of an intruder; and

generating a high-power millimeter-wave wavefront with one of either an active-array antenna or a passive reflect-array antenna in response to the detection of the intruder to deter the intruder,

wherein when the generating is performed with an active-array antenna, the method comprises generating the wavefront with a plurality of semiconductor wafers arranged together on a surface, each semiconductor wafer including a power amplifier and a transmit antenna which together generate the high-power millimeter-wave wavefront, and

wherein when the generating is performed with a passive reflect-array antenna, the method comprises generating the wavefront with a plurality of passive antenna elements by receiving and retransmitting an incident millimeter-wave signal.

23. The method of claim **22** further comprising:

tracking movement of the intruder and to generate a tracking-control signal for the array antenna; and

configuring the array antenna to direct the wavefront toward the intruder in response to the tracking-control signal.

24. The method of claim **22** wherein detecting comprises illuminating an area with an active illuminator comprising one of an optical illuminator, a LASER illuminator, a sonic illuminator, an ultrasonic illuminator, or an RF/RADAR illuminator which transmits signals to detect the intruder based on return signals.

25. The method of claim **22** wherein the passive reflect-array antenna comprises a plurality of passive semiconductor wafers arranged together, each passive semiconductor wafer comprising a receive antenna coupled with a transmit antenna, the receive antennas to receive a spatially fed incident millimeter-wave signal for retransmission by the transmit antennas to provide the high-power millimeter-wave wavefront.

26. A method of protecting an area comprising:

detecting a presence of an intruder;

generating a high-power millimeter-wave wavefront with one of either an active-aray antenna or a passive reflect-aray antenna in response to the detection of the intruder to deter the intruder;

increasing a skin temperature of the intruder with the high-power millimeter-wave wavefront;

measuring the skin temperature; and

generating a control signal to maintain the skin temperature either within a predetermined temperature range or below a predetermined temperature.

27. The method of claim **26** further comprising reducing a transmit power level of the wavefront in response to the control signal to maintain the skin temperature either within the predetermined temperature range or below the predetermined temperature.

28. The method of claim **26** further comprising reducing one of either a pulse-repetition-rate or a pulse-duration time of the wavefront in response to the control signal to maintain the skin temperature either within the predetermined temperature range or below the predetermined temperature.

29. A method of protecting an area comprising:

detecting a presence of an intruder;

generating a high-power millimeter-wave wavefront with one of either an active-array antenna or a passive reflect-array antenna in response to the detection of the intruder to deter the intruder;

detecting a presence of a tag worn by the intruder;

authenticating the tag; and

refraining from generating the wave front when tag is authenticated.

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