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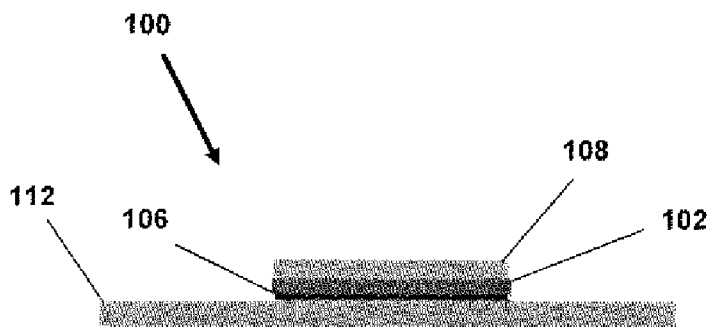


FIG. 1

(57) Abstract: Thin-film infrared emitter includes one or more thin-film layers of low thermal mass material suspended in thermal isolation. A current source can be configured to apply a current with a predetermined pattern. The current source can be electrically coupled to the one or more thin-film layers of low thermal mass material, and the predetermined pattern can correspond to a modulation of infrared emission from the emitter. A method of fabricating a thin-film infrared emitter and a method of using a thin-film infrared emitter are also provided.

SYSTEMS AND METHODS FOR THIN-FILM LOW THERMAL MASS INFRARED EMITTERS

CROSS-REFERENCE TO RELATED APPLICATIONS

5 This application claims priority to U.S. Provisional Patent Application Serial No. 61/576,733, filed on December 16, 2011, which is incorporated by reference herein in its entirety.

BACKGROUND

10 The disclosed subject matter relates to infrared emitters and techniques for fabricating and using such emitters, including thermal emitters.

 Infrared (IR) light can be considered as electromagnetic radiation with longer wavelengths than those of visible light, extending from the nominal red edge of the visible spectrum at 0.74 micrometers (μm) to 300 μm . This range of wavelengths
15 can correspond to a frequency range of approximately 1 to 400 THz, and include most of the thermal radiation emitted by objects near room temperature.

 An infrared emitter can be configured as an electrically-powered device to emit light wavelengths in the infrared spectrum, which are generally invisible to the naked eye. Such emitters can be used in a variety of consumer
20 electronics, such as remote controls in television sets, for sensors in security systems, and in other applications such as for industrial heating processes. The range of applications for an infrared emitter can be due at least in part to the range of the infrared spectrum, from about 1,000,000 nanometers in wavelength down to about 750 nanometers.

25 Certain infrared emitters, called thermal emitters, can be configured using materials that emit photons in the infrared spectrum in response to thermal motion of charges in the material. Furthermore, the thermal emitters can utilize a modulator, such as a mechanical chopper, configured to periodically interrupt the infrared emission, for example to allow for synchronous detection. Modulation can
30 also be performed by operating the thermal emitter at a high frequency. However, there is an opportunity for thermal emitters that can be operated at increased speed, while having a reduced size and improved thermal characteristics.

SUMMARY

Systems and methods for infrared emitters, including thermal emitters, are disclosed herein.

5 The disclosed subject matter provides systems and methods for a thin-film, low thermal mass infrared emitter. In an exemplary embodiment, a thin-film infrared emitter includes one or more thin-film layers of low thermal mass material suspended in thermal isolation. A current source can be configured to apply a current with a predetermined pattern. The current source can be electrically coupled to the
10 one or more thin-film layers of low thermal mass material. Furthermore, the predetermined pattern can correspond to a modulation of infrared emission from the emitter.

 The one or more thin-film layers can be suspended over a substrate. The substrate can include a plastic, such as polyethylene naphthalate. The one or
15 more thin-film layers can be suspended in an optically resonant cavity. The substrate can be configured as a frame substantially surrounding the one or more thin-film layers. The substrate can have a window, and the one or more thin-film layers can be disposed on the substrate proximate the window to form the optically resonant cavity

 In some embodiments, the low thermal mass material can include one
20 or more of graphene, carbon nanotubes, boron nitride nanotubes, SnF₆, MoSe, MoS, MoS₂, WSe, and WS. The emitter can include a polymer layer disposed on the one or thin-film layers. The polymer layer can include a poly-p-xylylene polymer.

 Furthermore, the current source can be coupled to the one or more thin-film layers at opposing sides of the one or more thin-film layers. Additionally or
25 alternatively, the current source can be coupled to the one or more thin-film layers using a conductive paste.

 According to another aspect of the disclosed subject matter, methods for fabricating a thin-film infrared emitter are provided. In one example, a method includes depositing thin-film layers of low thermal mass material onto an intermediate
30 material, attaching an adhesive sheet to a first surface of the thin-film layers, removing at least a portion of the intermediate material such that the thin-film layers are attached to the adhesive sheet, transferring the one or more thin-film layers onto a

substrate, the edges of the frame being in contact with the adhesive sheet, and removing at least a portion of the adhesive sheet.

In some embodiments, the depositing can include using chemical vapor deposition. The transferring can include suspending the thin-film layers in an optically resonant cavity. The substrate can be configured as a frame having a window, and the transferring can include placing the thin-film layers proximate to the window to form the optically resonant cavity.

The method can further include removing one or more of the thin-film layers from a second surface opposite the first surface, and in some embodiments, removing the one or more of the thin-film layers can include exposing the second surface to ozone.

The method can further include coating the substrate and the thin-film layers with a polymer. The method can further include applying conductive paste to opposing edges of the thin-film layers.

According to another aspect of the disclosed subject matter, a method for using a thin-film infrared emitter is provided. The infrared emitter used can have one or more thin-film layers of low thermal mass material suspended in thermal isolation over a substrate and a resonant emitting cavity disposed between the one or more thin-film layers and the substrate. The method can include electrically coupling a current source to the one or more thin-film layers of low thermal mass material, and applying a current with the current source. The current can have a pattern corresponding to a modulation of infrared emission from the emitter.

In some embodiments, the emitter can include an optically resonant cavity disposed between the one or more thin-film layers and the substrate, and the pattern can correspond to a modulation of infrared emission from the optically resonant cavity.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is diagram illustrating a cross-sectional side view of an exemplary emitter according to the disclosed subject matter.

FIG. 2 is a diagram illustrating a plan view of the emitter of FIG. 1.

FIG. 3 is diagram illustrating a cross-sectional side view of an exemplary frame for the emitter of FIG. 1.

FIG. 4 is a diagram illustrating a plan view of the frame of FIG. 3.

FIG. 5 is a diagram illustrating an exemplary current source coupled to the emitter of FIG. 1.

5

DETAILED DESCRIPTION

One aspect of the disclosed subject matter relates to systems and methods for a thin-film low thermal mass infrared emitter. An exemplary thin-film low thermal mass infrared emitter can exhibit improved IR emission turn-on and turn-off time. The thin film infrared emitters disclosed herein can have application in
10 sensing, imaging, acoustic, and a wide range of other applications.

FIGS. 1-2 are diagrams showing a cross-sectional side view and a plan view, respectively, illustrating an exemplary infrared emitter according to the disclosed subject matter. As shown in FIG. 1, the exemplary infrared emitter 100 includes one or more thin-film layers of low thermal mass material 102 suspended in
15 thermal isolation over a substrate 112. As such, a resonant emitting cavity 106 can be formed between the one or more thin-film layers 102 and the substrate 112. The resonant emitting cavity 106 can be an optically resonant cavity.

The low thermal mass material 102 can include one or more of graphene, carbon nanotubes, boron nitride nanotubes, tin hexafluoride (SnF_6),
20 molybdenum selenide (MoSe), molybdenum sulfide (MoS), molybdenum disulfide (MoS_2), tungsten selenide (WSe), and tungsten sulfide (WS).

Emitter 100 can be formed, for example and without limitation, by synthesizing the one or more thin-film layers 102 on an intermediate material using chemical vapor deposition (CVD). The intermediate material can include a metal.
25 For example and without limitation, the intermediate material can be copper. As such, the one or more thin-film layers 102 can be deposited onto both sides of a strip of the intermediate material. A section of the combined thin-film layers and intermediate material can then be cut and placed onto an adhesive sheet. For example and without limitation, the combined material can be cut into a square, approximately
30 $6 \times 6 \text{ mm}^2$ and placed onto a $1 \times 1 \text{ cm}^2$ of adhesive tape.

The one or more thin-film layers 102 on the surface of the intermediate material opposite the adhesive sheet can then be removed. For example, the one or more thin-film layers 102 opposite the adhesive sheet can be removed from the

intermediate material by exposing the surface of the intermediate material and the thin-film layers 102 to ozone.

Additionally or alternatively, the one or more thin-film layers 102 can be coated with a layer of a fluorinated material, for example a fluorinated polymer and/or photoresist, which can be cured or dried. For purpose of illustration and not limitation, the fluorinated material can include 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-Heptadecafluorodecyl methacrylate. The fluorinated polymer layer can adhere to the one or more thin-film layers 102 and be used to transport the one or more thin-film layers 102 to the intermediate material or to a substrate. The fluorinated material can be removed by a fluorinated solvent. Further details of transferring one or more thin-film layers 102 using a fluorinated material can be found, for example, in U.S. Provisional Patent Application Serial No. 61/579,347, which is incorporated by reference in its entirety.

The thin-film layers 102 can then be placed into an etchant bath. For example, and as embodied herein, the thin-film layers 102 can be placed into the bath with the intermediate material facing the bath. The etchant bath can include an etchant, which can be, for example and as embodied herein, APS-100 copper etchant, along with a stir rod. The bath with the thin-film layers 102 can be placed onto a heating surface, and the thin-film layers 102 can be spun with the stir rod. For example and without limitation, and as embodied herein, the thin-film layers 102 can be spun in the bath at about 110 rpm for approximately 45 minutes. In this manner, the intermediate material can be at least partially dissolved. In some embodiments, the intermediate material can be completely dissolved in the bath. The thin-film layers 102 can then be removed from the bath, rinsed with deionized water, and dried.

The emitter 100 can include a substrate 112, as shown for example in FIGS. 3-4. The substrate 112 can be configured as a plastic frame, including, for example and as embodied herein, polyethylene naphthalate (PEN). The substrate 112 can include a window 110 formed proximate the center of the substrate 112. For example and as embodied herein, the window 110 can be a 5x5 mm² window. The thin-film layers 102 can be placed into the window 110 of the substrate 112, and as such, the resonant emitting cavity 106 can be formed between the thin-film layers 102 and the substrate 112. The thin-film layers 102 can be secured by remaining portions of the adhesive sheet to hold the emitting structure 110 in the window. In this manner, a polymer coating 108 can then be deposited over the substrate 112. For

example and without limitation, and has embodied herein, the polymer coating 108 can include a poly-p-xylylene polymer, such as Parylene C, or any other suitable polymer. The polymer coating 108 can be deposited over the portion of the substrate 112 in which the thin-film layers 102 are held. Additionally or alternatively, the
5 polymer coating 108 can be deposited over the entire substrate 112, including the thin-film layers 102 proximate the window 110. As such, the thin-film layers 102 can adhere to the polymer coating 108. The adhesive tape can then be removed. For example, the adhesive sheet can have a reduced adhesiveness when heated to a predetermined temperature, e.g., 90°C, and thin-film layers 102 can be placed on a
10 heating surface at 90°C or greater until the adhesive sheet reaches the desired temperature to be removed.

With the adhesive sheet removed, thin-film layers 102 can remain within the window of the substrate 112, secured by the polymer coating 108. A conductive, adhesive paste, such as a silver paste, can then be applied to opposite
15 edges of the thin-film layers 102. The conductive, adhesive paste can further secure the emitting structure 110 to the substrate 112 and can serve as leads for the emitter 100.

As shown in FIG. 5, a current source 114 can be coupled to the emitter 100. For example, the current source 114 can be coupled by placing leads on opposite
20 edges of the thin-film layers 102, which can be the edges of the emitting structure to which the adhesive paste was applied to the thin-film layers 102. Emitter 100 can be operated by applying a current from the current source 114 to excite emission of the emitter at a predetermined pattern. For example, the current source 114 can be an alternating current source configured to provide current at a predetermined frequency,
25 which can correspond to a modulation of infrared emission from the resonant emitting cavity 106. For purpose of illustration and not limitation, the predetermined frequency can be in a range of about 1 to 400 THz. Alternatively, the emitter can be pulsed, for example with a direct current source or any other non-synchronous current source, to provide a corresponding modulation of infrared emission from the emitter
30 100. Induced temperature fluctuation can occur in the surrounding air when the alternating current is applied across the thin-film layers 102 of the emitter. As such, this temperature oscillation can create a thermoacoustic effect in the thin-film layers 102 to emit infrared light from the emitter.

Example

In one example, emitter 100 was tested using a polyvinylidene fluoride (PVDF) piezoelectric sensor with a black carbon paint layer. The sensor was placed about 2 cm from the emitter 100. Upon application of an alternating current, an audible indication from the sensor indicated that emission from the emitter 100 was detected. Both single- and double-layer emitters 100 were tested, which had resistances of 1.7 k Ω and 1.3 k Ω , respectively. The single-layer emitter 100 emitted a higher response, due at least in part to its lower heat capacity per unit area (HCPUA). The output of both emitters 100 increased proportionally to the amplitude of the alternating current input. Furthermore, as the frequency of the alternative current increased, the output of the devices become increasingly stable and constant.

While the disclosed subject matter is described herein in terms of certain exemplary embodiments, those skilled in the art will recognize that various modifications and improvements can be made to the disclosed subject matter without departing from the scope thereof.

The foregoing merely illustrates the principles of the disclosed subject matter. Various modifications and alterations to the described embodiments will be apparent to those skilled in the art in view of the teachings herein. It will be appreciated that those skilled in the art will be able to devise numerous modifications which, although not explicitly described herein, embody its principles and are thus within its spirit and scope.

CLAIMS

1. A thin-film infrared emitter, comprising:
one or more thin-film layers of low thermal mass material suspended in thermal isolation;
5 a current source configured to activate emission with a predetermined pattern, the current source electrically coupled to the one or more thin-film layers of low thermal mass material; and
wherein a current modulation of the current source corresponds to a modulation of infrared emission from the emitter.
- 10 2. The emitter of claim 1, wherein the one or more thin-film layers are suspended over a substrate.
3. The emitter of claim 2, wherein the substrate comprises a plastic.
4. The emitter of claim 2, wherein the substrate comprises polyethylene naphthalate.
- 15 5. The emitter of claim 2, wherein the one or more thin-film layers are suspended in an optically resonant cavity.
6. The emitter of claim 5, wherein the substrate is configured as a frame substantially surrounding the one or more thin-film layers.
7. The emitter of claim 6, the substrate having a window, the one or more
20 thin-film layers being disposed on the substrate proximate the window to form the optically resonant cavity.
8. The emitter of claim 1, wherein the low thermal mass material is selected from the group consisting of graphene, carbon nanotubes, boron nitride nanotubes, SnF6, MoSe, MoS, MoS2, WSe, and WS.
- 25 9. The emitter of claim 1, further comprising a polymer layer disposed on the one or thin-film layers.
10. The emitter of claim 9, wherein the polymer layer comprises a poly-p-xylylene polymer.
11. The emitter of claim 1, wherein the current source is coupled to the one or
30 more thin-film layers at opposing sides of the one or more thin-film layers.
12. The emitter of claim 1, wherein the current source is coupled to the one or more thin-film layers using a conductive paste.
13. A method for fabricating a thin-film infrared emitter, comprising:

depositing one or more thin-film layers of low thermal mass material onto an intermediate material;

attaching an adhesive sheet to a first surface of the one or more thin-film layers;

5 removing at least a portion of the intermediate material whereby the one or more thin-film layers are attached to the adhesive sheet;

transferring the one or more thin-film layers onto a substrate, whereby edges of the substrate are contacted by the adhesive sheet; and

removing at least a portion of the adhesive sheet.

10 14. The method of claim 13, wherein the depositing comprises using chemical vapor deposition.

15. The method of claim 13, wherein the substrate comprises a plastic.

16. The method of claim 13, wherein the transferring includes suspending the one or more thin-film layers in an optically resonant cavity.

15 17. The method of claim 16, wherein the substrate is configured as a frame having a window, the transferring comprising placing the one or more thin-film layers proximate to the window to form the optically resonant cavity.

18. The method of claim 13, further comprising removing one or more of the thin-film layers from a second surface opposite the first surface.

20 19. The method of claim 18, wherein removing the one or more of the thin-film layers comprises exposing the second surface to ozone.

20. The method of claim 13, further comprising coating the substrate and the one or more thin-film layers with a polymer.

21. The method of claim 13, further comprising applying conductive paste to
25 at least a portion of opposing edges of the one or more thin-film layers.

22. A method for using a thin-film infrared emitter having one or more thin-film layers of low thermal mass material suspended in thermal isolation over a substrate, the method comprising:

30 electrically coupling a current source to the one or more thin-film layers of low thermal mass material; and

applying a current with the current source, the current having a pattern corresponding to a modulation of infrared emission from the emitter.

23. The method of claim 22, wherein the emitter includes an optically resonant cavity disposed between the one or more thin-film layers and the substrate,

and the pattern corresponds to a modulation of infrared emission from the optically resonant cavity.

24. The method of claim 22, wherein the low thermal mass material is selected from the group consisting of graphene, carbon nanotubes, boron nitride
5 nanotubes, SnF₆, MoSe, MoS, MoS₂, WSe, and WS.

25. The method of claim 22, wherein electrically coupling the current source comprises coupling the current source to the one or more thin-film layers at opposing sides of the one or more thin-film layers.

26. The method of claim 22, wherein electrically coupling the current source
10 comprises coupling the current source to the one or more thin-film layers using a conductive paste.

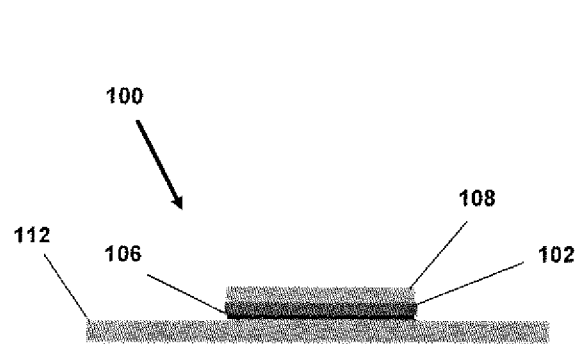


FIG. 1

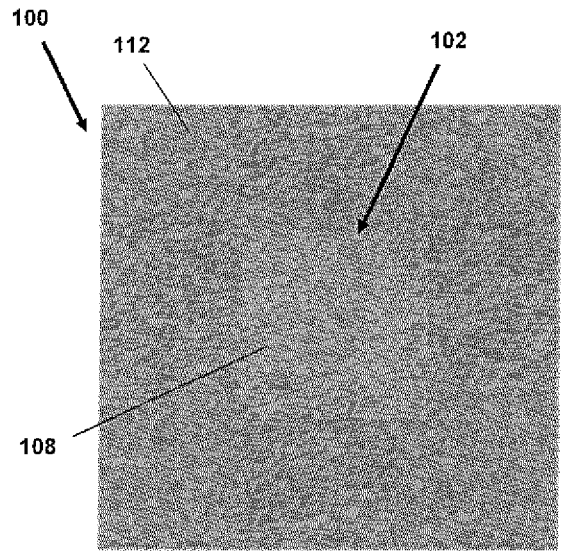


FIG. 2



FIG. 3

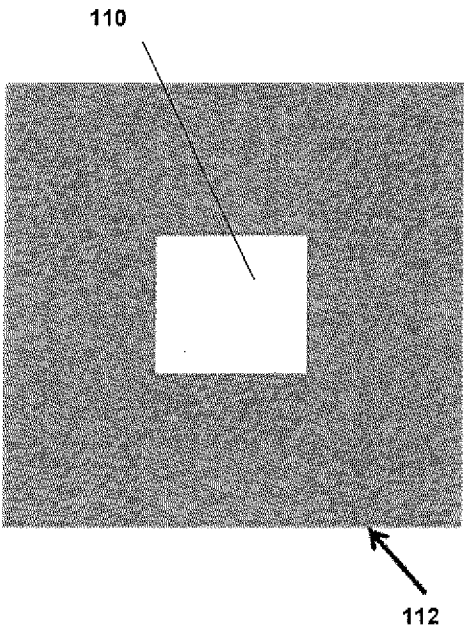
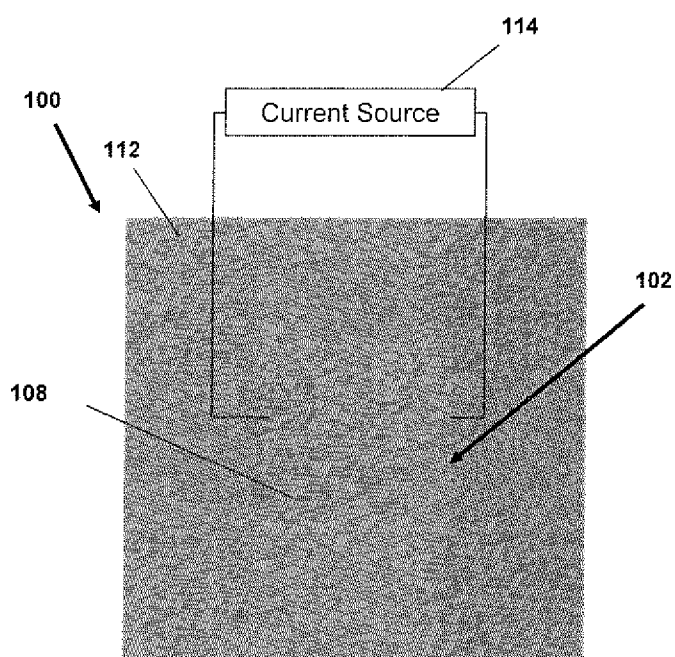


FIG. 4

**FIG. 5**