(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 462 810 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
03.04.2019 Bulletin 2019/14

(51) Int Cl.:
H05B 3/44 *(2006.01)*

(21) Application number: **17194235.2**

(22) Date of filing: **29.09.2017**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA MD

(71) Applicant: **Heraeus Noblelight GmbH**
63450 Hanau (DE)

(72) Inventors:
- **Gaab, Lotta**
64289 Darmstadt (DE)
- **Sternkiker, Christoph**
63457 Hanau (DE)
- **Wewer, Nico**
63579 Freigericht (DE)
- **Piela, Thomas**
63450 Hanau (DE)

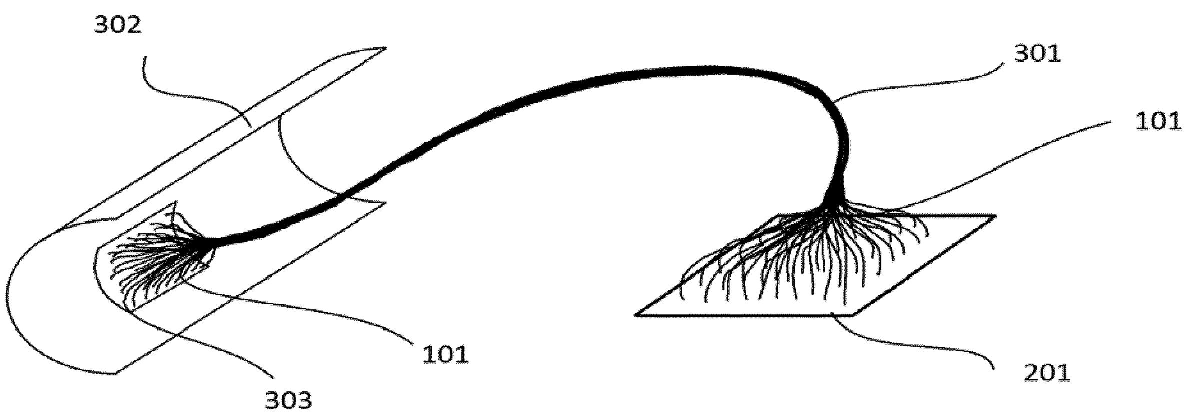
(74) Representative: **Herzog, Fiesser & Partner Patentanwälte PartG mbB**
Immermannstrasse 40
40210 Düsseldorf (DE)

(54) A DEVICE FOR HEATING A TARGET WITH IR RADIATION

(57) The invention relates to a device for heating a target, the device comprising the following:
a. an IR source;
b. a set of elongate bodies consisting of three or more elongate bodies, each having an inlet and an outlet, collectively the inlets and the outlets respectively; and
c. a support;
wherein the IR source and the elongate bodies are arranged such that IR radiation emitted from the IR source is coupled into the set of elongate bodies via the inlets and decouples from the set of elongate bodies via the outlets,
wherein the support is arranged and configured to hold the outlets in a relative spatial configuration.

In general, the invention relates to a device for heating a target with IR radiation. More specifically, the invention relates to a device, a process for heat treating a target, a process for making a composite, a use of an IR source, a use of an array of IR sources and a use of the device.

Figure 3



EP 3 462 810 A1

Description

FIELD OF THE INVENTION

[0001] In general, the invention relates to a device for heating a target with IR radiation. More specifically, the invention relates to a device, a process for heat treating a target, a process for making a composite, a use of an IR source, a use of an array of IR sources and a use of the device.

BACKGROUND OF THE INVENTION

[0002] Devices and processes for heating a target have numerous industrially important applications including moulding and forming of thermoplastics; curing of substrates and substrate surfaces, especially of plastic substrates; curing of coatings; chemical activation; welding; burr removal; sterilisation; cleaning and oxidation. A number of approaches to heating a target presented in the state of the art employ a simple thermal emitter, which can be approximated by a black body. Such approaches can suffer from the disadvantage that the wavelength of the radiation cannot be easily controlled and selective and controlled heating is not possible. A number of approaches presented in the art employ direct heating from an emitter and can suffer from the disadvantage of uneven heating of a target surface. There exists a need in the state of the art for improved approaches to heating a target, in particular for heating a non-flat target surface or for selective heating of a composite target.

SUMMARY OF THE INVENTION

[0003] The invention is generally based on the object of overcoming at least one of the problems encountered in the state of the art in relation to heating a target.
[0004] More specifically, the invention is further based on the object of providing a device for applying IR radiation to a target, in particular to a non-flat target surface.
[0005] An object of the invention is to provide a device for applying IR radiation with a reduced wavelength bandwidth to a target.
[0006] An object of the invention is to provide a device for applying IR radiation with a well defined wavelength to a target.
[0007] An object of the invention is to provide a device for applying IR radiation with a controllable wavelength to a target.
[0008] An object of the invention is to provide a device for heating a target.
[0009] An object of the invention is to provide a device for melting a target.
[0010] An object of the invention is to provide a device for selectively heating a constituent of a composite.
[0011] An object of the invention is to provide a device for selectively melting a constituent of a composite.
[0012] An object of the invention is to provide a device for creating a composite.
[0013] An object of the invention is to provide a device for applying IR radiation selectively to part of a target surface.
[0014] An object of the invention is to provide a device for applying IR radiation to a target whilst reducing heating of the target by conduction.
[0015] An object of the invention is to provide a device for applying IR radiation to a target whilst reducing heating of the target by convection.
[0016] An object of the invention is to provide a device for applying IR radiation with a well defined wavelength to a target whilst reducing the application of radiation with other wavelengths to the target.
[0017] An object of the invention is to provide a device for removing irregularities from a target.
[0018] An object of the invention is to provide a device for removing moulding burrs from a target. An object of the invention is to provide a device for treating a moulded item.
[0019] An object of the invention is to provide a device for heating a plastic.
[0020] An object of the invention is to provide a device for melting a plastic.
[0021] An object of the invention is to provide a process for applying IR radiation with a reduced wavelength bandwidth to a target.
[0022] An object of the invention is to provide a process for applying IR radiation with a well defined wavelength to a target.
[0023] An object of the invention is to provide a process for applying IR radiation with a controllable wavelength to a target.
[0024] An object of the invention is to provide a process for heating a target.
[0025] An object of the invention is to provide a process for melting a target.
[0026] An object of the invention is to provide a process for selectively heating a constituent of a composite.
[0027] An object of the invention is to provide a process for selectively melting a constituent of a composite.
[0028] An object of the invention is to provide a process for creating a composite.

[0029] An object of the invention is to provide a process for applying IR radiation selectively to part of a target surface.
[0030] An object of the invention is to provide a process for applying IR radiation to a target whilst reducing heating of the target by conduction.
[0031] An object of the invention is to provide a process for applying IR radiation to a target whilst reducing heating of the target by convection.
[0032] An object of the invention is to provide a process for applying IR radiation with a well defined wavelength to a target whilst reducing the application of radiation with other wavelengths to the target.
[0033] An object of the invention is to provide a process for removing irregularities from a target.
[0034] An object of the invention is to provide a process for removing moulding burrs from a target. An object of the invention is to provide a process for removing irregularities from a non-flat target surface.
[0035] An object of the invention is to provide a process for removing moulding burrs from a non-flat target surface.
[0036] An object of the invention is to provide a process for treating a moulded item.
[0037] An object of the invention is to provide a process for heating a plastic.
[0038] An object of the invention is to provide a process for melting a plastic.
[0039] A particular object of the invention is to provide a device for applying IR radiation to a non-flat target surface.
[0040] A particular object of the invention is to provide a device for heating a non-flat target surface.
[0041] A particular object of the invention is to provide a device for melting a non-flat target surface.
[0042] A particular object of the invention is to provide a device for removing irregularities from a non-flat target surface.
[0043] An particular object of the invention is to provide a device for removing moulding burrs from a non-flat target surface.
[0044] A particular object of the invention is to provide a device for treating a moulded item having a non-flat target surface.
[0045] A particular object of the invention is to provide a process for applying IR radiation to a non-flat target surface.
[0046] A particular object of the invention is to provide a process for heating a non-flat target surface.
[0047] A particular object of the invention is to provide a process for melting a non-flat target surface.
[0048] A particular object of the invention is to provide a process for removing irregularities from a non-flat target surface.
[0049] A particular object of the invention is to provide a process for removing moulding burrs from a non-flat target surface.
[0050] A particular object of the invention is to provide a process for treating a moulded item having a non-flat target surface.
[0051] A contribution to achieving at least one of the above described objects is made by the subject matter of the category forming claims of the invention. A further contribution is made by the subject matter of the dependent claims of the invention which represent specific embodiments of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0052] A contribution to achieving at least one of the above objects is made by the following embodiments.

|1| A device for heating a target, the device comprising the following:

a. an IR source;
b. a set of elongate bodies consisting of three or more elongate bodies, each having an inlet and an outlet, collectively the inlets and the outlets respectively; and
c. a support;

wherein the IR source and the elongate bodies are arranged such that IR radiation emitted from the IR source is coupled into the set of elongate bodies via the inlets and decouples from the set of elongate bodies via the outlets, wherein the support is arranged and configured to hold the outlets in a relative spatial configuration. The set of elongate bodies may consist of 5 or more elongate bodies, or 10 or more, or 20 or more, or 50 or more, or 100 or more, or 200 or more, or 500 or more, or 1000 or more. The set of elongate bodies can sometimes consist of as many as 10,000 elongate bodies.

|2| The device according to embodiment |1|, wherein the IR source comprises a semiconductor.

|3| The device according to any of the preceding embodiments, wherein the IR source comprises a laser.

|4| The device according to any of the preceding embodiments, wherein the IR source comprises an IR-LED.

|5| The device according to any of the preceding embodiments, wherein the IR source comprises an IR semiconductor laser.
In one embodiment, the IR source comprises a thermal emitter.

|6| The device according to any of the preceding embodiments, wherein the IR source has one or more of the following properties:

a. an emitter surface with an optical power flux in the range from 1 to 250 W/cm^2, preferably in the range from 5 to 200 W/cm^2, more preferably in the range from 10 to 150 W/cm^2;
b. a peak emission wavelength in the range from 800 to 1600 nm, preferably in the range from 800 to 1300 nm, more preferably in the range from 800 to 1000 nm;
c. a bandwidth of emission wavelength in the range from 1 to 50 nm, preferably in the range from 2 to 40 nm, more preferably in the range from 3 to 35 nm;
d. total power output in the range from 10 W to 100 kW, preferably in the range from 100 W to 10 kW, more preferably in the range from 300 W to 5 kW.

In one aspect of this embodiment, the IR source comprises a semiconductor IR source element.

|7| The device according to any of the preceding embodiments, wherein the IR source has one or more of the following properties:

a. an emitter surface with an optical power flux in the range from 1 to 50 W/cm^2, preferably in the range from 2 to 45 cm^2, more preferably in the range from 5 to 40 cm^2;
b. a peak emission wavelength in the range from 800 to 1600 nm, preferably in the range from 800 to 1300 nm, more preferably in the range from 800 to 1000 nm;
c. a bandwidth of emission wavelength in the range from 5 to 50 nm, preferably in the range from 10 to 45 nm, more preferably in the range from 15 to 40 nm;
d. total power output in the range from 10 W to 100 kW, preferably in the range from 100 W to 10 kW, more preferably in the range from 300 W to 5 kW.

In one aspect of this embodiment, the IR source comprises an IR LED.

|8| The device according to any of the preceding embodiments, wherein the IR source has one or more of the following properties:

a. an emitter surface with an optical power flux in the range from 20 to 250 W/cm^2; preferably in the range from 30 to 200 W/cm^2, more preferably in the range from 50 to 150 W/cm^2;
b. a peak emission wavelength in the range from 800 to 1600 nm, preferably in the range from 800 to 1300 nm, more preferably in the range from 800 to 1000 nm;
c. a bandwidth of emission wavelength in the range from 1 to 50 nm, preferably in the range from 2 to 30 nm, more preferably in the range from 3 to 20 nm;
d. total power output in the range from 10 W to 100 kW, preferably in the range from 100 W to 10 kW, more preferably in the range from 300 W to 5 kW.

In one aspect of this embodiment, the IR source comprises an IR VCSEL.

|9| The device according to any of the preceding embodiments, wherein the IR source has one or more of the following properties

a. an emitter surface with an optical power flux in the range from 1 to 60 W/cm^2, preferably in the range from 5 to 50 W/cm^2, more preferably in the range from 10 to 50 W/cm^2;
b. a peak emission wavelength in the range from 800 to 3000 nm, preferably in the range from 800 to 2500 nm, more preferably in the range from 800 to 2000 nm;
c. a bandwidth of emission wavelength in the range from 100 to 4800 nm, preferably in the range from 500 to 4000 nm, more preferably in the range from 1000 to 3500 nm
d. total power output in the range from 10 W to 100 kW, preferably in the range from 25 W to 50 kW, more preferably in the range from 50 W to 10 kW.
e. Comprises an electrical insulator at a temperature in the range from 200°C to 1100°C during normal operation,

preferably in the range from 150°C to 850°C, more preferably in the range from 100°C to 650°C.

In one aspect of this embodiment, the IR source comprises a thermal IR emitter.

|10| The device according to any of the preceding embodiments, wherein the IR source has one or more of the following properties:

a. an emitter surface with an optical power flux in the range from 1 to 250 W/cm^2, preferably in the range from 5 to 200 W/cm^2, more preferably in the range from 10 to 150 W/cm^2;
b. a peak emission wavelength in the range 200 to 5000 nm, preferably in the range from 600 to 3000 nm, more preferably in the range from 800 to 2500 nm;
c. a bandwidth of emission wavelength in the range from 1 to 4800 nm, preferably in the range from 2 to 4000 nm, more preferably in the range from 3 to 3500 nm;
d. total power output in the range from 10 W to 100 kW, preferably in the range from 100 W to 10 kW, more preferably in the range from 300 W to 5 kW.

|11| The device according to any of the preceding embodiments, wherein the IR source comprises an IR source element having one or more of the following properties:

a. an emitter surface with an optical power flux in the range from 0.1 to 1000 W/cm^2, preferably in the range from 1 to 800 W/cm^2, more preferably in the range from 2 to 700 W/cm^2;
b. a peak emission wavelength in the range from 800 to 1600 nm, preferably in the range from 800 to 1300 nm, more preferably in the range from 800 to 1000 nm;
c. a bandwidth of emission wavelength in the range from 1 to 50 nm, preferably in the range from 2 to 40 nm, more preferably in the range from 3 to 35 nm;
d. total power output in the range from 0.001 to 15 W, preferably in the range from 0.005 to 8 W, more preferably from 0.01 to 5 W.

In one aspect of this embodiment, the IR source comprises a semiconductor IR source element.

|12| The device according to any of the preceding embodiments, wherein the IR source comprises an IR source element having one or more of the following properties:

a. an emitter surface with an optical power flux in the range from 20 to 1000 W/cm^2, preferably in the range from 30 to 800 W/cm^2, more preferably in the range from 50 to 700 W/cm^2;
b. a peak emission wavelength in the range from 800 to 1600 nm, preferably in the range from 800 to 1300 nm, more preferably in the range from 800 to 1000 nm;
c. a bandwidth of emission wavelength in the range from 5 to 100 nm, preferably in the range from 10 to 50 nm, more preferably in the range from 15 to 40 nm;
d. total power output in the range from 0.05 to 15 W, preferably in the range from 0.5 to 8 W, more preferably in the range from 1 to 5 W.

In one aspect of this embodiment, the IR source comprises an IR LED.

|13| The device according to any of the preceding embodiments, wherein the IR source comprises an IR source element having one or more of the following properties:

a. an emitter surface with an optical power flux in the range from 0.1 to 20 W/cm^2, preferably in the range from 1 to 18 W/cm^2, more preferably in the range from 2 to 15 W/cm^2;
b. a peak emission wavelength in the range from 800 to 1600 nm, preferably in the range from 800 to 1300 nm, more preferably in the range from 800 to 1000 nm;
c. a bandwidth of emission wavelength in the range from 1 to 50 nm, preferably in the range from 2 to 30 nm, more preferably in the range from 3 to 20 nm;
d. total power output in the range from 1 to 100 mW, preferably in the range from 5 to 70 mW, more preferably in the range from 10 to 50 mW.

In one aspect of this embodiment, the IR source comprises an IR VCSEL.

|14| The device according to any of the preceding embodiments, wherein the outlets are arranged and configured to adopt a first relative spatial configuration and a second relative spatial configuration, wherein the first and second relative spatial configurations are different.

|15| The device according to any of the preceding embodiments, wherein the outlets are arranged and configured to adopt a relative spatial configuration complementary to a target surface of a target to be heated.

|16| The device according to any of the preceding embodiments, wherein the outlets are outlet faces.

|17| The device according to any of the preceding embodiments, wherein the outlets are arranged and configured to adopt a relative spatial configuration in which a first outlet face and a second outlet face are not parallel.

|18| The device according to any of the preceding embodiments, wherein the outlets are arranged and configured to adopt a first and a second relative spatial configuration, wherein the normal to a first outlet face and the normal to a second face subtend a first angle in the first relative spatial configuration and the normal to the first outlet face and the normal to the second face subtend a second angle in the second relative spatial configuration; wherein the first angle and the second angle are different.

|19| The device according to any of the preceding embodiments, wherein the set of elongate bodies consists of four or more elongate bodies and wherein the outlets are arranged and configured to adopt a relative spatial configuration in which the outlets do not all lie in a common plane.

|20| The device according to any of the preceding embodiments, wherein the outlets are arranged and configured to adopt a relative spatial configuration comprising a repeating spatial unit.

|21| The device according to any of the preceding embodiments, wherein the support comprises one or more support elements, wherein each support element is arranged and configured to hold the relative spatial configuration of two or more of the outlets.

|22| The device according to any of the preceding embodiments, wherein the set of elongate bodies are made of a glass.

|23| The device according to any of the preceding embodiments, wherein the IR radiation source comprises IR source elements corresponding one-to-one to the set of elongate bodies and wherein the light from each IR source element couples into the corresponding elongate body. In one aspect of this embodiment, an optical element is positioned between each IR source element and the corresponding elongate body.

|24| The device according to any of the preceding embodiments, comprising a cooling means for the IR source.

|25| The device according to any of the preceding embodiments, wherein the device is arranged and configured to providing a maximum total power output from the outlets in the range from 10 W to 10 kW, preferably in the range from 100 W to 5 kW, more preferably in the range from 500 W to 3 kW.

|26| The device according to any of the preceding embodiments, wherein the device is arranged and configured to providing a maximum power output at a single outlet in the range from 0.01 to 5 W, preferably in the range from 0.1 to 4 W, more preferably in the range from 1 to 3.5 W.

|27| The device according to any of the preceding embodiments, wherein the device is arranged and configured to providing heat to a target surface with an average power density in the range from 20 to 1000 W/cm^2, preferably in the range from 40 to 800 W/cm^2, more preferably in the range from 60 to 700 W/cm^2;

|28| The device according to any of the preceding embodiments, comprising an optical element. The optical element is preferably positioned between the IR source and the inlets. The optical element is preferably a lens.

|29| A process for making a heat treated target surface, comprising the following process steps:

a. providing a device according to any of the preceding embodiments and a target surface;
b. adapting the relative spatial configuration of the outlets to the target surface;

c. applying IR radiation to the target surface.

|30| A process for making a heat treated target surface, comprising the following process steps:

a. providing a flexible IR emitting surface and a target surface;
b. adapting the flexible IR emitting surface to the target surface;
c. applying IR radiation to the target surface.

|31| The process according to embodiment 1301, wherein the IR radiation is emitted from a semiconductor based IR emitter.

|32| The process according to embodiment 1301 or 1311, wherein in step b. the flexible IR emitting surface and the target surface are arranged to satisfy one or more of the following features:

a. The maximum separation between the flexible IR emitting surface and the target surface is in the range from 1 to 30 mm, preferably in the range from 2 to 28 mm, more preferably in the range from 3 to 25 mm;
b. The root mean square separation between the flexible IR emitting surface and the target surface is in the range from 1 to 20 mm, preferably in the range from 2 to 18 mm, more preferably in the range from 3 to 15 mm;

|33| The process according to any of the embodiments 1301 to 1321, wherein at least a part of the target surface is heated to a temperature in the range from 30 to 500 °C, preferably in the range from 40 to 500 °C, more preferably in the range from 50 to 500 °C.

|34| The process according to any of the embodiments 1301 to 1331, wherein the flexible IR emitting surface has a peak emission wavelength λ_E and the target surface has a peak absorption wavelength λ_A, wherein λ_E & λ_A differ by at most 50 nm, preferably at most 30 nm, more preferably at most 20 nm.

|35| The process according to any of the embodiments 1301 to 1341, wherein the flexible IR emitting surface is arranged and configured to emit IR radiation from a proportion of its surface area in the range from 0.1 to 0.9, preferably in the range from 0.2 to 0.8, more preferably in the range from 0.3 to 0.7.

|36| The process according to any of the embodiments 1301 to 1351, wherein the flexible IR emitting surface comprises 9 or more IR sources elements, wherein the 9 or more IR source elements are arranged in a lattice.

|37| The process according to any of the embodiments 1301 to 1361, wherein the target surface comprises one or more selected from the group consisting of the following: a plastic, a metal or a metal oxide.

|38| The process according to any of the embodiments 1301 to 1371, wherein the target surface comprises a thermoplastic. Preferred thermoplastics are thermoplastic elastomers.

|39| The process according to any of the embodiments 1301 to 1381, wherein the target surface is a composite comprising two or more plastics.

|40| A process for making a composite comprising the following process steps:

a. Providing a heat treated target surface obtainable, preferably obtained, by a process according to any of the embodiments 1291 to 1391;
b. Contacting the heat treated target surface with a further part to obtain the composite.

|41| A use of an IR source in a device, wherein the device is arranged and configured to emit IR radiation from an emitter surface, wherein the emitter surface is arranged and configured to adopt a first relative spatial configuration and a second relative spatial configuration, wherein the first and second relative spatial configurations are different.

|42| A use of an array of IR source elements in a device, wherein the device is arranged and configured to emit IR radiation from an emitter surface, wherein the emitter surface is arranged and configured to adopt a first relative spatial configuration and a second relative spatial configuration, wherein the first and second relative spatial configurations are different.

|43| A use of a device according to any of the embodiments |1| to |28| for improving homogeneity of heating of a non-flat target surface.

Device

[0053] A contribution to achieving at least one of the above mentioned objects is made by a device for heating a target. The device comprises an IR source for providing IR radiation. IR radiation provided by the IR source is employed for heating the target. The device comprises a set of elongate bodies each having an inlet and an outlet. IR radiation from the IR source is coupled into the inlets of the elongate bodies and decoupled at the outlets of the elongate bodies. In this way, the elongate bodies provide a path for IR radiation from the IR source to be delivered at the outlets, preferably to the surface of the target. The device comprises a support for holding the outlets in a relative spatial configuration.

Elongate Bodies

[0054] The device comprises a set of elongate bodies. Preferred elongate bodies serve to convey IR radiation from the radiation source to the target. Each elongate body comprised in the set of elongate bodies has an inlet and an outlet. The inlet allows coupling of IR radiation emitted from the IR source into the elongate body. The outlet allows decoupling of IR radiation from the elongate body. An inlet is preferably a face, more preferably a substantially flat face, most preferably a flat face. An outlet is preferably a face, more preferably a substantially flat face, most preferably a flat face. The elongate body has two ends. Preferably the inlet of an elongate body is at one end of the elongate body and the outlet of the elongate body is at the other end of the elongate body. Preferred elongate bodies are light guides.

[0055] In one embodiment, the set of elongate bodies consists of 3 or more elongate bodies, preferably 10 or more, more preferably 20 or more, more preferably 50 or more, more preferably 100 or more, more preferably 200 or more. The set of elongate bodies may consist of up to 10,000 elongate bodies. In one embodiment, the number of elongate bodies is in the range from 3 to 500, preferably in the range from 10 to 400, more preferably in the range from 20 to 300.

[0056] The elongate bodies preferably have a low attenuation measured at an IR emission wavelength of the IR source. The attenuation is preferably less than 1000 dB/km, more preferably less than 100 dB/km, most preferably less than 20 dB/km. Attenuation might be as low as about 1 dB/km.

[0057] Preferred elongate bodies are one or more selected from the group consisting of the following: a glass fibre, a plastic optical fibre, a hollow silica tube, a liquid light guide, preferably a glass fibre.

[0058] In one embodiment, one or more elongate bodies are glass fibres, preferably quartz glass fibres. Preferred glass fibres have a core diameter in the range from 5 to 1500 μm, preferably in the range from 6 to 1000 μm, more preferably in the range from 8 to 500 μm. A glass fibre may have a cladding, preferably making a diameter contribution in the range from 20 to 200 μm, more preferably in the range from 20 to 180 μm, most preferably in the range from 20 to 150 μm. Preferred glass fibres which comprise a core and a cladding have a numerical aperture in the range from 0.05 to 0.9, preferably from 0.1 to 0.9, more preferably from 0.2 to 0.9. The numerical aperture is given by the following fomula:

$$\mathrm{NA} = \sqrt{n_{\mathrm{core}}^2 - n_{\mathrm{clad}}^2}$$

[0059] In which n_{core} is the refractive index of the core material and n_{clad} is the refractive index of the cladding material.

[0060] Preferred materials for a cladding are one or more selected from the group consisting of: glass or hard polymer, preferably glass. The preferred glass is quartz glass.

[0061] In one embodiment, one or more elongate bodies are plastic optical fibres. Preferred materials for plastic optical fibres are one or more selected from the group consisting of the following: Polymethacrylate or polymethylmethacrylate. Preferred plastic optical fibres have a core diameter in the range from 200 to 3000 μm, preferably in the range from 250 to 2900 μm, more preferably in the range from 300 to 2500 μm. A plastic optical fibre may have a cladding, preferably making a diameter contribution in the range from 250 to 3050 μm, preferably in the range from 300 to 2900 μm, more preferably in the range from 350 to 2500 μm.

[0062] Preferred glass fibres which comprise a core and a cladding have a numerical aperture in the range from 0.05 to 0.9, preferably from 0.1 to 0.9, more preferably from 0.2 to 0.9.

[0063] In one embodiment, one or more elongate bodies are hollow silicate tubes. Preferred hollow silicate tubes have a core diameter in the range from 300 to 1000 μm, preferably in the range from 350 to 950 μm, more preferably in the range from 400 to 900 μm. Preferred hollow silicate tubes have a cladding. The cladding may make a diameter contribution in the range from 400 to 1300 μm, preferably in the range from 450 to 1200 μm, more preferably in the range from 500 to 1000 μm. The cladding is preferably an aluminium halide or silver halide. Preferred glass fibres which comprise a core and a cladding have a numerical aperture in the range from 0.05 to 0.9, preferably from 0.1 to 0.9, more preferably from 0.2 to 0.9.

[0064] In one embodiment, one or more elongate bodies are liquid light guides. Preferred liquid light guides have a core diameter in the range from 3000 to 5000 μm, preferably in the range from 3300 to 4700 μm, more preferably in the range from 3500 to 4500 μm. A glass fibre may have a cladding, preferably making a diameter contribution in the range from 6000 to 1000 μm, more preferably in the range from 6500 to 9500 μm, most preferably in the range from 7000 to 9000 μm.

[0065] Preferred glass fibres have a numerical aperture in the range from 0.05 to 0.9, preferably from 0.1 to 0.9, more preferably from 0.2 to 0.9.

[0066] The set of elongate bodies may be gathered together into a bundle over at least part of the length of the elongate bodies.

Support

[0067] The device comprises a support. Preferred supports serve to hold the outlets of the elongate bodies in a relative spatial configuration. In the preferred embodiments of the invention, the support has a degree of flexibility, allowing the outlets to adopt more than one relative spatial configuration. This flexibility preferably allows an outlet surface to be adapted to a target surface.

[0068] A relative spatial configuration of the outlets of the set of elongate bodies is defined by the relative spatial position of the set of outlets in three dimensional space. A relative spatial configuration of the outlets is unchanged by a rotation or translation of the entire set of outlets.

[0069] In preferred embodiments of the invention, the support is arranged and configured to hold the outlets in more than one relative spatial configurations. To this end, the support allows movement between the various relative spatial configurations. The greater the number of different relative spatial configurations the outlets can adopt, the greater then degree of flexibility of the support.

[0070] In one embodiment, the support comprises one or more support elements each of which hold two or more outlets in a relative spatial configuration. Where more than one support element are present in the support, the support elements can together hold a network of outlets in a relative spatial configuration.

Outlet surface and Emitter Surface

[0071] The relative configuration of the outlets defines an outlet surface, wherein the outlets lie within the outlet surface. The outlet surface is a continuous smooth surface on distance scales which are large compared to the distance between individual outlets. The outlet surface is a single connected area having a perimeter defined by the outermost outlets, which lie on the perimeter. The emitter surface of the IR source is the surface over which the IR source emits IR radiation. Where the IR source consists of a single IR source element, the emitter surface of the IR source is simply the area over which the IR source element emits IR radiation. Where the IR source consists of a plurality of IR source elements, the emitter surface of the IR source is surface defined by the IR source elements, wherein the IR source elements lie within the emitter surface of the IR source. The emitter surface of the IR source is a single connected area having a perimeter defined by the outermost IR source elements, which lie on the perimeter.

[0072] The outlets lie within the outlet surface and there may be gaps in the outlet surface between the area occupied by the outlets. IR radiation provided is provided from the proportion of the outlet surface which is occupied by outlets. In one embodiment, the outlets are densely packed. It is preferred in this embodiment for the IR radiation to be provided from a proportion of the outlet surface in the range from 0.1 to 0.9, preferably in the range from 0.2 to 0.8 more preferably in the range from 0.3 to 0.8.

[0073] In one embodiment of the invention, it is preferred for the support to be arranged and configured to hold the outlets in relative spatial configuration, such that the outlet surface has a greater area than the emitter surface of the IR source.

[0074] In one embodiment, the outlets are arranged and configured to adopt a relative spatial configuration which is a regular pattern. Preferred regular patterns comprise a repeating spatial unit. Preferred regular patterns comprise at least a portion which is made up of repeating spatial units. A preferred regular pattern is an array. In one aspect of this embodiment, the outlets and the support are constructed such that the outlets are in a regular pattern and other relative spatial configurations are achieved by deformation away from the regular pattern.

Arrangement of IR source and Elongate Bodies

[0075] A number of arrangements of the IR source and the set of elongate bodies are possible within the scope of the invention. Such arrangements are determined by the relationship between the individual elongate bodies which make up the set of elongate bodies and the individual IR source elements which make up the IR source.

[0076] The relationship between individual IR source elements and individual elongate bodies can be one-to-one, many-to-one, one-to-many, many-to-many, or a mixed. In a one-to-one relationship, a single IR source element is arranged in correspondence with a single elongate body. The IR radiation emitted from the IR source element couples predominantly, preferably substantially exclusively, more preferably exclusively into the elongate body. The light coupled into the elongate body is coupled predominantly, preferably substantially exclusively, more preferably exclusively from the IR source element. In a many-to-one relationship a grouping of two or more IR source elements is arranged in correspondence with a single elongate body. The IR radiation emitted from the grouping of IR source elements couples predominantly, preferably substantially exclusively, more preferably exclusively into the elongate body. The light coupled into the elongate body is coupled predominantly, preferably substantially exclusively, more preferably exclusively from the group of IR source elements. In a one-to-many relationship, a single IR source element is arranged in correspondence with a grouping of two or more elongate bodies. The IR radiation emitted from the IR source element couples predominantly, preferably substantially exclusively, more preferably exclusively into the grouping of elongate bodies. The light coupled into the grouping of elongate bodies is coupled predominantly, preferably substantially exclusively, more preferably exclusively from the IR source element. In a many-to-many relationship, a grouping of two or more IR source elements is arranged in correspondence with a grouping of two or more elongate bodies. The IR radiation emitted from the grouping of IR source elements couples predominantly, preferably substantially exclusively, more preferably exclusively into the grouping of elongate bodies. The light coupled into the grouping of elongate bodies is coupled predominantly, preferably substantially exclusively, more preferably exclusively from the grouping of IR source elements. Mixed relationships between IR source elements and elongate bodies which are not fully described by a one-to-one, one-to-many, many-to-one or many-to-many relationship are also possible.

[0077] In one embodiment of the invention, the IR source elements of the IR source and the elongate bodies of the set of elongate bodies are arranged in one-to-one relationships. Each IR source elements corresponds one-to-one with a corresponding elongate body.

[0078] In one embodiment of the invention, the IR source elements of the IR source and the elongate bodies of the set of elongate bodies are arranged in one-to-many relationships. Each IR source element corresponds one-to-many with a corresponding grouping of elongate bodies.

[0079] In one embodiment of the invention, the IR source elements of the IR source and the elongate bodies of the set of elongate bodies are arranged in one-to-many relationships. Each IR source elements belongs to a grouping of two or more IR source elements which corresponds many-to-one with a corresponding elongate body.

[0080] In one embodiment of the invention, the IR source elements of the IR source and the elongate bodies of the set of elongate bodies are arranged in many-to-many relationships. Each IR source elements belongs to a grouping of two or more IR source elements which corresponds many-to-many with a corresponding grouping of elongate bodies.

[0081] In one embodiment of the invention, IR source elements of the IR source and the elongate bodies of the set of elongate bodies are arranged to include two different types of relationship selected from the group consisting of the following: one-to-one, one-to-many, many-to-one, many-to-many and mixed.

IR Source

[0082] The device comprises an IR source. Preferred IR sources serve to provide IR radiation for heating the target surface. IR radiation from the IR source is conveyed to the target by the set of elongate bodies.

[0083] The IR source may be a single IR source element or may consist of a collection of IR source elements. An IR source element emits radiation from a single connected area. An IR source which emits radiation from more than one connected areas consists of more than one IR source element.

[0084] An IR source element may be selected by the skilled person depending on its suitability in the context of the present invention.

[0085] In one embodiment, the IR source comprises a semiconductor IR emitter. Semiconductor IR emitters are also referred to IR diode emitters. A semiconductor IR emitter is arranged and configured to emit IR radiation from a semiconductor part. Preferred semiconductor IR emitters harness a semiconductor bandgap to emit radiation at a wavelength which depends on the width of the semiconductor bandgap. Preferred types of semiconductor IR emitters are IR LEDs and IR semiconductor lasers.

[0086] In one embodiment, the device comprises an IR source element having a peak emission wavelength in the range from 790 to 830 nm, preferably in the range from 800 to 820 nm, more preferably in the range from 805 to 815 nm, the IR source element preferably being an IR LED.

[0087] In one embodiment, the device comprises an IR source element having a peak emission wavelength in the range from 830 to 870 nm, preferably in the range from 840 to 860 nm, more preferably in the range from 845 to 855 nm, the IR source element preferably being an IR LED.

[0088] In one embodiment, the device comprises an IR source element having a peak emission wavelength in the range from 920 to 960 nm, preferably in the range from 930 to 950 nm, more preferably in the range from 935 to 945 nm, the IR source element preferably being an IR LED.

[0089] In one embodiment, the device comprises an IR source element having a peak emission wavelength in the range from 950 to 990 nm, preferably in the range from 960 to 980 nm, more preferably in the range from 965 to 975 nm, the IR source element preferably being an IR VCSEL.

[0090] In one embodiment, the device comprises an IR source element having a peak emission wavelength in the range from 960 to 1000 nm, preferably in the range from 970 to 990 nm, more preferably in the range from 975 to 985 nm, the IR source element preferably being an IR VCSEL.

[0091] In one embodiment, the IR source comprises a thermal IR emitter, preferably is a thermal IR emitter.

[0092] In one embodiment, the device comprises an IR source element having a peak emission wavelength in the range from 0.8 to 3 μm, preferably in the range from 1 to 2.5 μm, more preferably in the range from 1.25 to2 μm, the IR source element preferably being a thermal IR emitter.

Selective Provision of IR Radiation

[0093] A preferred device according to the invention is arranged and configured to allow a selective provision of IR radiation. Selective provision of IR radiation allows the provision of IR radiation at one or more of the outlets to be varied. Preferred selective provisions of IR radiation serve to allow the provision of IR radiation to a target surface to be controlled either by switching the provision of IR radiation a portion on or by varying the intensity of IR radiation provided to a portion of the target surface.

[0094] In one embodiment, the selective provision of radiation of IR radiation allows the provision of IR radiation at one or more outlets to be varied individually, independently of the provision of IR radiation at the remaining outlets. This embodiment allows the provision of IR radiation to be controlled down to the level of individual outlets. In one aspect of this embodiment, individual outlets can be switched on and off. In another aspect of this embodiment, the intensity of IR radiation provided at individual outlets can be increased and decreased.

[0095] In another embodiment, selective provision of radiation of IR radiation allows the provision of IR radiation at one or more groupings of outlets to be varied individually, independently from the provision of IR radiation at the remaining outlets. This embodiment allows the provision of IR radiation to be controlled at the level of portions of the outlet surface each portion comprising two or more outlets. In one aspect of this embodiment, groupings of outlets can be switched on and off. In another aspect of this embodiment, the intensity of IR radiation provided at portions of the outlet surfaced can be increased and decreased.

[0096] Selective provision of IR radiation is preferably effected by one or more of the following: varying the output of IR radiation from an IR source element, varying the coupling between an IR source element and an elongate body or varying the decoupling of IR radiation from an elongate body. It is preferred to vary the output of IR radiation from an IR source element. In a preferred embodiment of the invention, the device allows one or more IR source elements to be turned on and off. In one aspect of this embodiment, one or more IR source elements can be turned on and off individually. In another aspect of this embodiment, IR source elements can be turned on and off in groupings of two or more IR source elements.

Optical Elements

[0097] The device may comprise one or more optical elements. Preferred optical elements serve to alter the path of IR radiation emitted from the IR source. In particular an optical element can be employed for one or more of the following: adjusting coupling, preferably coupling into an elongate body; adjusting decoupling, preferably decoupling from an elongate body; focusing; divergence and collimation. The skilled person may employ an optical element which he considers suitable in the context of the invention. Preferred optical elements selected from the group consisting of the following: a lens; a collimator; a diffractor, preferably a diffraction grating.

[0098] In one embodiment, the device of the invention comprises an optical element for increasing the proportion of IR radiation emitted from an IR source element which is coupled into the elongate bodies.

Coupling

[0099] IR radiation couples into the elongate bodies at the inlets and decouples from the elongate bodies at the outlets. The inlet may be in contact with either an IR source element or an optical element or neither.

Process

[0100] The device of the invention may comprise a moving means. One preferred moving means is arranged and configured for changing the relative spatial configuration of the outlets. Another preferred moving means is for performing a relative motion between the outlets and a target surface.

[0101] The process of the invention may comprise a motion. One preferred motion is a change in the relative spatial configuration of the outlets. Another preferred motion is a relative motion between the outlets and a target surface. In one embodiment, a relative motion between the outlets and the target surface is performed whilst IR radiation is being provided from the device to the target surface. The process of the invention may be a continuous. The process of the invention may comprise the provision of IR radiation to more than one target.

Technological Applications

[0102] The device and the process of the invention are useful for heating a target, especially a target surface which is not flat. One application of the invention is for treating moulded parts, preferably moulded plastic parts. A preferred treatment of moulded parts is the removal of moulding burrs. The invention may be employed for heating one or more selected from the group consisting of the following: a plastic, silicon, a metal, an inorganic compound. and a composite. Preferred thermoplastics are one or more selected from the group consisting of the following: acrylonitrile butadiene styrene co-polymer, polyacrylate, a polylactide, polymethyl methacrylate, polycarbonate, polyethylene terephthalate, poly ethylene, poly propylene, poly styrene, poly ether ketone and poly vinyl chloride. Preferred inorganic compounds are ZnO or SiC.

[0103] Another application of the invention is for making a composite item from two or more parts. The device or the process of the invention or both can be employed for heating a target surface to soften or melt it. A further part is then welded to the softened or melted target surface.

DESCRIPTION OF THE FIGURES

[0104] The invention is now further elucidated with the aid of figures. These figures are for illustrative purposes only and do not restrict the scope of the invention. The specific embodiment presented in the figures might be generalised in the following way: IR LEDs are employed as IR source elements, but other IR source elements are possible, such as IR VCSELs; Glass fibres are employed as elongate bodies, but other elongate bodies are possible, such as plastic fibres; lenses are employed as optical elements, but other optical elements are possible, such as diffraction gratings.

Figure 1a is a schematic diagram showing a one-to-one relationship between an IR LED and a glass fibre.
Figure 1b is a schematic diagram showing a many-to-one relationship between a grouping of IR LEDs and a glass fibre.
Figure 1c is a schematic diagram showing a one-to-many relationship between an IR LED and a grouping of glass fibres.
Figure 1d is a schematic diagram showing a many-to-many relationship between a grouping of IR LED and a grouping of glass fibres.
Figure 1e is a schematic diagram showing a mixed relationship between IR LEDs and glass fibres.
Figure 2 is a schematic diagram showing an array of IR LEDs corresponding one-to-one with a set of glass fibres.
Figure 3 is a schematic diagram showing the device of the invention used to apply IR radiation to a non-flat target surface.
Figure 4 is a schematic diagram showing the device of the invention having an array of IR LEDs and a flexible outlet surface.
Figure 5 is a schematic diagram showing the construction of a support element for connecting two glass fibres.
Figure 6 is a schematic diagram showing a connected network formed by support elements.
Figure 7 is a schematic diagram showing glass fibres connected by support elements.
Figure 8 is a process flow diagram showing the inventive process for heating a target.
Figure 9 is a process flow diagram showing the inventive process for making a composite.
Figure 10 is a schematic diagram showing a target having a saw tooth target surface.
Figure 11 is a schematic diagram showing a target having an undulating target surface.
Figure 12 is four schematic diagrams showing application of radiation to the target of figure 10.
Figure 13 is four schematic diagrams showing application of radiation to the target of figure 11.
Figure 14 shows glass fibres held in a lattice by a flexible rubber layer.

[0105] Figure 1a is a schematic diagram showing a one-to-one relationship in which a single IR LED 103 corresponds with a single glass fibre 101. IR radiation 104 emitted from the IR LED 101 is coupled into the inlet of the glass fibre 101 via a lens 102. The IR radiation 104 emitted from the IR LED 103 couples only into the glass fibre 101, not into any other glass fibres 101. Only IR radiation from the IR LED 103 is coupled into the glass fibre 101, not IR radiation from any other IR LEDs.

[0106] Figure 1b is a schematic diagram showing a one-to-many relationship in which a single IR LED 103 corresponds with a grouping of two glass fibres 101. IR radiation 104 emitted from the IR LED 101 is coupled into the inlets of the grouping of glass fibres 101 via a lens 102. The IR radiation 104 emitted from the IR LED 103 couples only into the grouping of glass fibres 101, not into any other glass fibres 101. Only IR radiation from the IR LED 103 is coupled into the grouping of glass fibre 101, not IR radiation from any other IR LEDs.

[0107] Figure 1c is a schematic diagram showing a many-to-one relationship in which a grouping of 4 IR LEDs 103 corresponds with a single glass fibre 101. IR radiation 104 emitted from the grouping of IR LED 101 is coupled into the inlet of the glass fibre 101 via a lens 102. The IR radiation 104 emitted from the grouping of IR LEDs 103 couples only into the glass fibre 101, not into any other glass fibres 101. Only IR radiation from the grouping of IR LEDs 103 is coupled into the glass fibre 101, not IR radiation from any other IR LEDs.

[0108] Figure 1d is a schematic diagram showing a many-to-many relationship in which a grouping of 4 IR LEDs 103 corresponds with a grouping of 2 glass fibres 101. IR radiation 104 emitted from the grouping of IR LED 101 is coupled into the inlets of the grouping of glass fibres 101 via a lens 102. The IR radiation 104 emitted from the grouping of IR LEDs 103 couples only into the grouping of glass fibres 101, not into any other glass fibres 101. Only IR radiation from the grouping of IR LEDs 103 is coupled into the grouping of glass fibres 101, not IR radiation from any other IR LEDs.

[0109] Figure le is a schematic diagram showing a mixed relationship between 6 IR LEDs 103 and 2 glass fibres 101. IR radiation 104 emitted from the 4 IR LEDs on the left 103c is coupled into the left glass fibre 101b via the lens 102b. IR radiation 104 emitted from the 4 IR LEDs on the right 103a is coupled into the right glass fibre 101a via the lens 102a. IR radiation 104 emitted from the 2 IR LEDs in the centre 103b is coupled into both the right glass fibre 101a via the lens 102a and the left glass fibre 101b via the lens 102b. The left glass fibre 101b receives IR radiation from both the 4 IR LEDs on the left 103c and the 2 IR LEDs in the centre 103b. The right glass fibre 101a receives IR radiation from both the 4 IR LEDs on the right 103a and the 2 IR LEDs in the centre 103b. The relationship between the IR LEDs 103 and the glass fibres 101 here cannot be described as any of the following: one-to-one, one-to-many, many-to-one or many-to-many.

[0110] Figure 2 is a schematic diagram showing an array 201 of IR LEDs 103 corresponding one-to-one with a set of glass fibres 101. The IR LEDs 103 are together considered to be the IR source 201. Each IR LED 103 is in one-to-one correspondence with a corresponding glass fibre 101. IR radiation source from and IR LED 103 is coupled to the corresponding glass fibre 101 via a lens 102.

[0111] Figure 3 is a schematic diagram showing the device of the invention used to apply IR radiation to a non-flat target surface. IR radiation is emitted from the IR source 201. The IR source 201 may be an array of individual IR LEDs 103, although this is not shown in the figure. The IR radiation emitted from the IR source 201 is coupled into the inlets of a set of glass fibres 101. This may be via one or more optical elements 102 (not shown), optionally a lens. The outlets of the glass fibres 101 are held in place by a support 303, which allows the outlets of the glass fibres 101 to lie in a flexible outlet surface 303. The glass fibres are collected into a fibre bundle 301 between the IR source 201 and the outlet surface 303. The flexible outlet surface 303 is adapted to and located next to the surface of a target 302. This allows IR radiation from the IR source 201 to be applied to the surface of the target 302 to heat it.

[0112] Figure 4 is a schematic diagram showing the device of the invention having an array 201 of IR LEDs 103 and a flexible outlet surface 303. IR radiation is emitted from the IR source 201. The IR source 201 is shown in the figure as an array 201 of individual IR LEDs 103. The IR radiation emitted from the IR source 201 is coupled into the inlets of a set of glass fibres 101. This may be via one or more optical elements 102 (not shown), optionally a lens. The IR LEDs 103 of the array 201 are in one-to-one correspondence with the glass fibres 101. The outlets 401 of the glass fibres 101 are held in place by a support 303, which allows the outlets 401 of the glass fibres 101 to lie in a flexible outlet surface 303. The glass fibres are collected into a fibre bundle 301 between the IR source 201 and the outlet surface 303.

[0113] Figure 5 is a schematic diagram showing a support element connecting two glass fibres 101. The support element comprises arms 502 which are pinioned together at a nexus 503. Clamps 501 are pinioned to the ends of the arms 502. The claims 501 clamp around the glass fibres 101. The support elements hold the glass fibres in a relative spatial configuration, but allow movement to other relative spatial configurations.

[0114] Figure 6 is a schematic diagram showing a connected network formed by support elements 601. Each support element is attached to two glass fibres 101. The glass fibres 101 are arranged in a square matrix with each glass 101 fibre being connected to the 4 adjacent and 4 diagonal neighbouring glass fibres 101 by a support element 601. The support elements 601 hold the glass fibres 101 in a relative spatial configuration, but allow movement to other relative spatial configurations. The support elements 601 can be according to figure 5.

[0115] Figure 7 is a schematic diagram showing glass fibres connected by support elements. Each support element makes connections 702 between 4 glass fibres 101 and a nexus 701. The glass fibres 101 are arranged in a square matrix with each glass 101 fibre being connected to the 4 diagonal neighbouring glass fibres 101 by support elements. The support elements hold the glass fibres 101 in a relative spatial configuration, but allow movement to other relative spatial configurations.

[0116] Figure 8 is a process flow diagram showing the inventive process for heating a target. In a first step 801, a device according to the invention is provided along with a target surface. In a second step 802 the outlet surface of the device is adapted to the target surface. The adapted outlet surface and the target surface are complementary, thereby allowing the outlet surface to be positioned at a uniform distance from the target surface. In a third step 803, IR radiation is applied to the target surface from the outlet surface, thereby heating the target surface.

[0117] Figure 9 is a process flow diagram showing the inventive process for making a composite. The first 801 second 802 and third 803 steps proceed as in figure 8. The heat treated target surface obtained following step 803 is in a softened or melted state. In a fourth step 901 a further part is provided and brought into contact with the heat treated target surface. The softened or melted target surface allows a weld joint to be made with the further part. In a process variant, the process of the present invention can be used to heat a further target surface on the further part also. The weld joint between the target surface and the further part is made by contacting the heat treated target surface with the further heat treated target surface.

[0118] Figure 10 is a schematic diagram showing a target having a saw tooth target surface. The target surface has peaks at a height of 5 cm 1104 from the base and troughs at a height of 1 cm 1101 from the base. The base is 25cm 1102 by 30cm 1103. Measuring positions are indicated as follows: A is at the top of a peak, B is at the bottom of a trough, C is half way up a gradient between a peak and a trough and D is half way up a sheer vertical section between a peak and a trough.

[0119] Figure 11 is a schematic diagram showing a target having an undulating target surface. The target surface has peaks at a height of 5 cm 1104 from the base and troughs at a height of 1 cm 1101 from the base. The base is 25cm 1102 by 30cm 1103. Measuring positions are indicated as follows: A is at the top of a peak, B is at the bottom of a trough and C is half way up a gradient between a peak and a trough.

[0120] Figure 12a shows application of IR radiation to the saw tooth target surface of a target 1001 according to figure 10 using a device having a flexible outlet surface 1003. The flexible support 1003 is adapted to the shape of the target surface of the target 1001. The outlets of glass fibres which are held by the flexible support 1003 are aligned with the support 1003. IR radiation 1002 is therefore emitted perpendicular to the outlet surface and is applied to the target surface in a direction perpendicular to the target surface. This allows a uniform application of IR radiation 1002 to the target surface.

[0121] Figure 12b shows application of IR radiation to the saw tooth target surface of a target 1001 according to figure 10 using a device having a rigid planar outlet surface 1003. The planar support 1003 is positioned in a plane parallel to the base of the target 1001. The outlets of glass fibres which are held by the planar support 1003 are aligned with the support 1003. IR radiation 1002 is therefore emitted perpendicular to the plane of the support and is applied to the target surface in a direction perpendicular to the target basal plane. This configuration does not produce a uniform application of IR radiation to the target surface. In particular, the surface of the peaks receives more radiation than the surface of the troughs and the vertical sections joining adjacent peak and trough receive very little IR radiation because the radiation is emitted in a direction which is oblique to the target surface there.

[0122] Figure 12c shows application of IR radiation to the saw tooth target surface of a target 1001 according to figure 10 using a device having no support. Individual glass fibres are adapted to the shape of the target surface and are arranged to have their outlet face perpendicular to the basal plane of the target. IR radiation is thereby applied to the target surface in a direction perpendicular to the basal plane. This configuration does not produce a uniform application of IR radiation to the target surface. In particular, the vertical sections joining adjacent peak and trough receive very little IR radiation because the radiation is emitted in a direction which is oblique to the target surface there.

[0123] Figure 12d shows application of IR radiation to the saw tooth target surface of a target 1001 according to figure 10 using an array of IR LED emitters arranged on a rigid planar support 1003. The individual IR LEDs emit radiation 1002 with a higher divergence than IR radiation emitted from a glass fibre. This configuration does not produce a uniform application of IR radiation to the target surface. In particular, the surface of the peaks receives more radiation than the surface of the troughs and the vertical sections joining adjacent peak and trough receive very little IR radiation because the radiation is emitted substantially in a direction which is oblique to the target surface there.

[0124] Figures 13a-13d show application of radiation to the undulating target surface of target of figure 11. Similar principles are observed as for the saw tooth target of figures 12a-12d.

[0125] Figure 14 shows a set of glass fibres 903 which is held in a square lattice by a layer of rubber 902. The layer of rubber has been formed around the glass fibres 901.

TEST METHODS

Optical Power Flux

[0126] Optical power flux is measured according to CIE 84-1989.

Peak emission wavelength and Bandwidth

[0127] Peak emission wavelength and bandwidth are measured according to CIE 63-1984.

[0128] Peak emission wavelength is at a maximum in the spectral emission density. Bandwidth is the width of the distribution about the peak emission wavelength for which spectral emission density is greater than or equal to half the peak value.

Temperature at Target Surface

[0129] Temperature is measured according to DIN IEC 60584.

Adhesion

[0130] Adhesion is measured using the tape test of ASTM D3359-17 using a ranking from 1 to 5, where 1 is the poorest performing and 5 is the best performing.

EXAMPLES

[0131] The following examples describe how the invention may be put into practice. The examples are not exhaustive and do not represent a limit on the scope of the claimed invention.

Example 1a

[0132] A device was provided according to figures 2 and 4. As IR source a 12 by 12 square array of IR LEDs commercially available from the company Osram having the following properties was employed: emitter wavelength = 940 nm, emission wavelength bandwidth = 100 nm, optical flux = 10 W/cm^2, emitting area 1 mm^2. The square array had a spacing between adjacent IR LEDs of 2.5 mm. The array therefore had an overall size of 39.5 mm by 39.5 mm. Over each IR LED was positioned a circular collimating lens commercially available from the company Heraeus Noblelight GmbH, Germany having a cross sectional diameter of 1.25 mm. Each lens was at a distance of 1 mm from the corresponding IR LED with the flat side directed towards the IR LED. A quartz glass fibre with a numerical aperture of 0.37 commercially available from the company Laser Components GmbH, Germany having the following properties was positioned with one end 1 mm from the curved surface of each lens: Length = 5 m, core diameter = 0.8 mm, cladding material = hard polymer, coating diameter contribution = 0.1 mm. The other end of each glass fibre was incorporated into a flexible support as shown in figure 14 by setting a 5 mm thick layer of UV hardening silicone rubber available from Dowcorning around the fibres to hold their outlet surfaces in a 12 by 12 square array of size 39.5 mm by 39.5 mm. The outlet surface was adapted to a non-flat target surface at a distance of 5 mm as shown in figure 10 made of acrylonitrile butadiene styrene such that the outlet surface was at a distance of 5 mm from the target surface. IR radiation was applied to the target surface for 5 s by activating the IR LED array.

Example 1b

[0133] Example 1a was repeated but with the IR LED array replaced with an IR VCSEL array. The array was a hexagonally packed array of wafer-level integrated VCSEL emitters commercially available from the company Princeton Optronics Inc., USA. The emitter surface had a lattice parameter of approximately 0.022 mm and the array had an overall size of 39.5 mm by 39.5 mm. Lenses of the same type as in example 1 were positioned over the emitter array with the flat side directed towards the emitter array. The lenses were position in a 12 by 12 square array with lattice parameter 3.5 mm and at a distance of 1 mm from the emitter array. A quartz glass fibre commercially available from the company Laser Components GmbH, Germany having the following properties was positioned with one end 1 mm from the curved surface of each lens: Length = 5 m, core diameter = 0.8 mm, coating material = hard polymer clad, coating diameter contribution=0.1 mm. The other end of each glass fibre was incorporated into a flexible support as shown in figure 14 by setting a 5 mm thick layer of UV hardening silicone rubber available from Dowcorning around the fibres to hold their outlet surfaces in a 12 by 12 square array of size 39.5 mm by 39.5 mm. The outlet surface was adapted to a non-flat target surface as shown in figure 10 made of acrylonitrile butadiene styrene such that the outlet surface was at a distance of 5 mm from the target surface. IR radiation was applied to the target surface for 1 s by activating the IR VCSEL array.

Example 2a

[0134] The array of IR LEDs of example 1a was employed without the corresponding lenses, glass fibres or support for the outlet surface. IR radiation was applied to the same surface as in example 1a by positioning the array at a distance of 5 mm from the peaks on the target surface. IR radiation was likewise applied to the target surface for 5 s by activating the IR LED array.

Example 2b

[0135] The array of IR VCSELs of example 1b was employed without the corresponding lenses, glass fibres or support for the outlet surface. IR radiation was applied to the same surface as in example 1b by positioning the array at a distance of 5 mm from the peaks on the target surface. IR radiation was likewise applied to the target surface for 1 s by activating the IR VCSEL array.

Example 3a

[0136] The array of example 1a was employed except that the support was replaced with a rigid planar support. The outlet surface had a 12 by 12 square array having lattice parameter 3.5 mm. The outlet surface was positioned 5 mm from the peaks on the emitter surface. IR radiation was applied to the target surface for 5 s by activating the IR LED array.

Example 3b

[0137] The array of example 1b was employed except that the support was replaced with a rigid planar support. The outlet surface had a 12 by 12 square array having lattice parameter 3.5 mm. The outlet surface was positioned 5 mm from the peaks on the emitter surface. IR radiation was applied to the target surface for 1 s by activating the IR VCSEL array.

Example 4a

[0138] The array of example 1a was employed except that the glass fibres were not held by a support. The outlet ends of the glass fibres were arranged in a 12 by 12 array over the target surface having a lattice parameter 3.5 mm with their outlet face being parallel to the base of the target and the outlets each lying at a distance of 0 mm from the target surface. IR radiation was applied to the target surface for 5 s by activating the IR LED array.

Example 4b

[0139] The array of example 1a was employed except that the glass fibres were not held by a support. The outlet ends of the glass fibres were arranged in a 12 by 12 array over the target surface having a lattice parameter 3.5mm with their outlet face being parallel to the base of the target and the outlets each lying at a distance of 0 mm from the target surface. IR radiation was applied to the target surface for 1 s by activating the IR VCSEL array.

<u>Temperature Testing for examples 1a to 4b</u>

[0140] For each of the examples 1a, 1b, 2a, 2b, 3a, 3b, 4a and 4b the temperature at points A, B, C and D as shown in figure 10 was measured directly at the end of the heating. The results are shown in table 1.

Table 1

Example	Temperature at A [°C]	Temperature at B [°C]	Temperature at C [°C]	Temperature at D [°C]
1a	150	150	150	150
1b	150	150	150	150
2a	150	75	100	40
2b	150	75	100	40
3a	150	75	100	40
3b	150	75	100	40
4a	150	150	150	50
4b	150	150	150	50

[0141] As is evident from table 1, the inventive examples 1a and 1b provided a higher uniformity of heating to the target surface than the corresponding comparative examples 2a and 2b respectively.

Examples 5a-8b

[0142] Examples 1a, 1b, 2a, 2b, 3a, 3b, 4a and 4b were repeated, but with a target having the shape shown in figure 11 rather than the shape shown in figure 10. The results of the softness testing are presented in table 2.

Table 2

Example	Temperature at A [°C]	Temperature at B [°C]	Temperature at C [°C]
5a	150	150	150
5b	150	150	150
6a	150	75	100
6b	150	75	100
7a	150	75	100
7b	150	75	100
8a	150	150	150
8b	150	150	150

Examples 1a'-8b'

[0143] Examples 1a-8b were repeated except that the target was made of silicon (wafer) and was provided with a coating of polyimide resist precursor. Following irradiation for 5 s, the coating was tested for adhesion onto the silicon wafer surface by a tape test. The results are shown in tables 3 and 4.

Table 3

Example	adhesion rank	adhesion rank	adhesion rank	adhesion rank
1a'	5	5	5	5
1b'	5	5	5	5
2a'	5	2	3	1
2b'	5	2	3	1
3a'	5	2	3	1
3b'	5	2	3	1
4a'	5	5	5	1
4b'	5	5	5	1

Table 4

Example	adhesion rank	adhesion rank	adhesion rank
5a'	5	5	5
5b'	5	5	5
6a'	5	2	3
6b'	5	2	3
7a'	5	2	3
7b'	5	2	3

(continued)

Example	adhesion rank	adhesion rank	adhesion rank
8a'	5	5	5
8b'	5	5	5

REFERENCE LIST

[0144]

101 Elongate body
102 Optical element
103 IR source element
104 IR radiation
201 IR source (array)
301 Fibre bundle
302 Target
303 Support/flexible outlet surface
401 Outlet
501 Clamp
502 Support strut
503 Pinion
601 Support element
701 Support node
702 Flexible support strut
801 First step
802 Second step
803 Third step
901 Fourth step
1101 Trough
1102 Width
1103 Length
1104 Peak
902 Rubber layer
903 Glass fibre

Claims

1. A device for heating a target, the device comprising the following:

a. an IR source;
b. a set of elongate bodies consisting of three or more elongate bodies, each having an inlet and an outlet, collectively the inlets and the outlets respectively; and
c. a support;

wherein the IR source and the elongate bodies are arranged such that IR radiation emitted from the IR source is coupled into the set of elongate bodies via the inlets and decouples from the set of elongate bodies via the outlets, wherein the support is arranged and configured to hold the outlets in a relative spatial configuration.

2. The device according to any of the preceding claims, wherein the IR source comprises an IR-LED.

3. The device according to any of the preceding claims, wherein the IR source comprises an IR semiconductor laser.

4. The device according to any of the preceding claims, wherein the IR source has one or more of the following properties:

a. an emitter surface with an optical power flux in the range from 1 to 250 W/cm^2;
b. a peak emission wavelength in the range from 800 to 1600 nm;
c. a bandwidth of emission wavelength in the range from 1 to 50 nm;
d. total power output in the range from 10 W to 100 kW.

5. The device according to any of the preceding embodiments, wherein the IR source has one or more of the following properties:

a. an emitter surface with an optical power flux in the range from 1 to 60 W/cm^2;
b. a peak emission wavelength in the range from 200 to 5000 nm;
c. a bandwidth of emission wavelength in the range from 100 to 4800 nm;
d. total power output in the range from 10 W to 100 kW;
e. Comprises an electrical insulator at a temperature in the range from 200°C to 1100°C during normal operation.

6. The device according to any of the preceding claims, wherein the outlets are arranged and configured to adopt a first relative spatial configuration and a second relative spatial configuration, wherein the first and second relative spatial configurations are different.

7. The device according to any of the preceding claims, wherein the outlets are arranged and configured to adopt a relative spatial configuration complementary to a target surface of a target to be heated.

8. The device according to any of the preceding claims, wherein the set of elongate bodies consists of four or more elongate bodies and wherein the outlets are arranged and configured to adopt a relative spatial configuration in which the outlets do not all lie in a common plane.

9. The device according to any of the preceding claims, wherein the set of elongate bodies are made of a glass.

10. The device according to any of the preceding claims, wherein the IR radiation source comprises IR source elements corresponding one-to-one to the set of elongate bodies and wherein the light from each IR source element couples into the corresponding elongate body.

11. The device according to any of the preceding claims, wherein the device is arranged and configured to providing a maximum total power output from the outlets in the range from 10 W to 10 kW.

12. A process for making a heat treated target surface, comprising the following process steps:

a. providing a device according to any of the preceding claims and a target surface;
b. adapting the relative spatial configuration of the outlets to the target surface;
c. applying IR radiation to the target surface.

13. A process for making a heat treated target surface, comprising the following process steps:

a. providing a flexible IR emitting surface and a target surface;
b. adapting the flexible IR emitting surface to the target surface;
c. applying IR radiation to the target surface.

14. The process according to claim 13, wherein the flexible IR emitting surface comprises 9 or more IR sources elements, wherein the 9 or more IR source elements are arranged in a lattice.

15. A use of an IR source in a device, wherein the device is arranged and configured to emit IR radiation from an emitter surface, wherein the emitter surface is arranged and configured to adopt a first relative spatial configuration and a second relative spatial configuration, wherein the first and second relative spatial configurations are different.

16. A use of an array of IR source elements in a device, wherein the device is arranged and configured to emit IR radiation from an emitter surface, wherein the emitter surface is arranged and configured to adopt a first relative spatial configuration and a second relative spatial configuration, wherein the first and second relative spatial configurations are different.

17. A use of a device according to any of the claims 1 to 11 for improving homogeneity of heating of a non-flat target surface.

Figure 1a

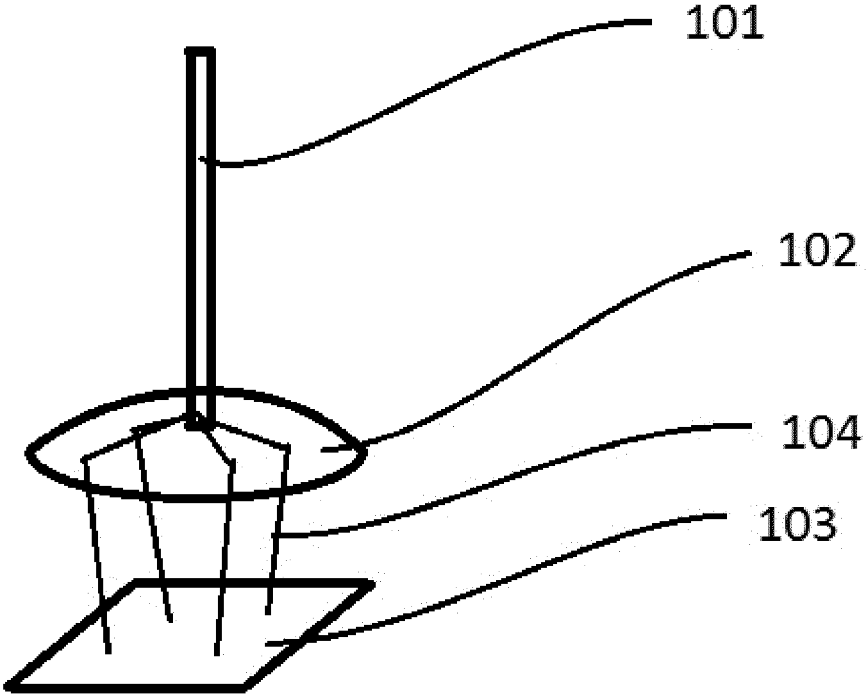


Figure 1b

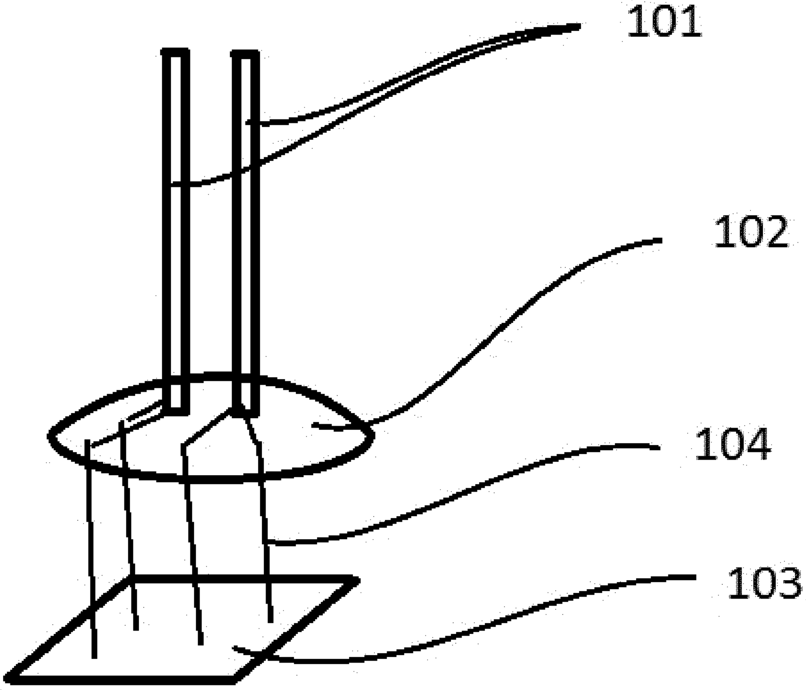


Figure 1c

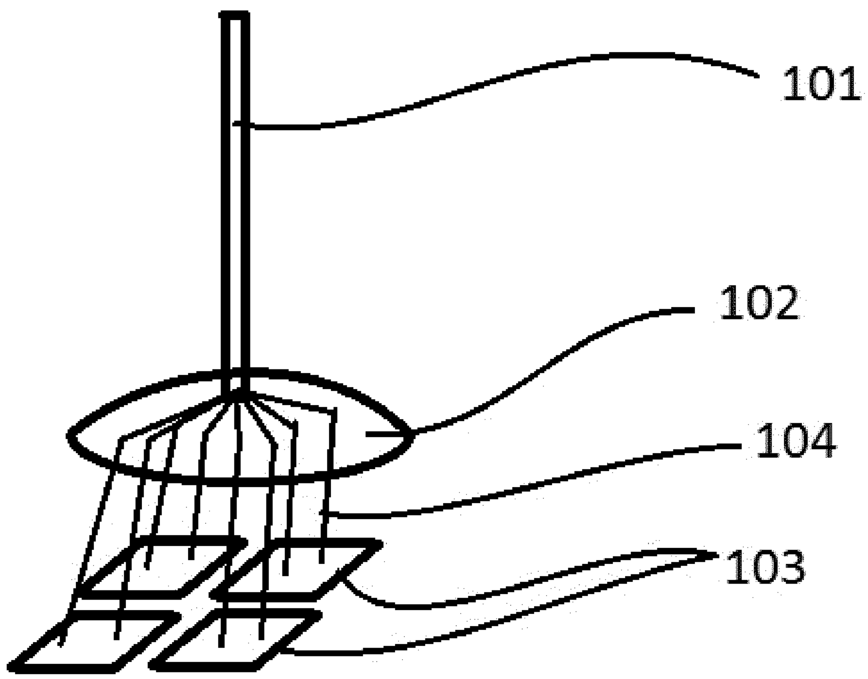


Figure 1d

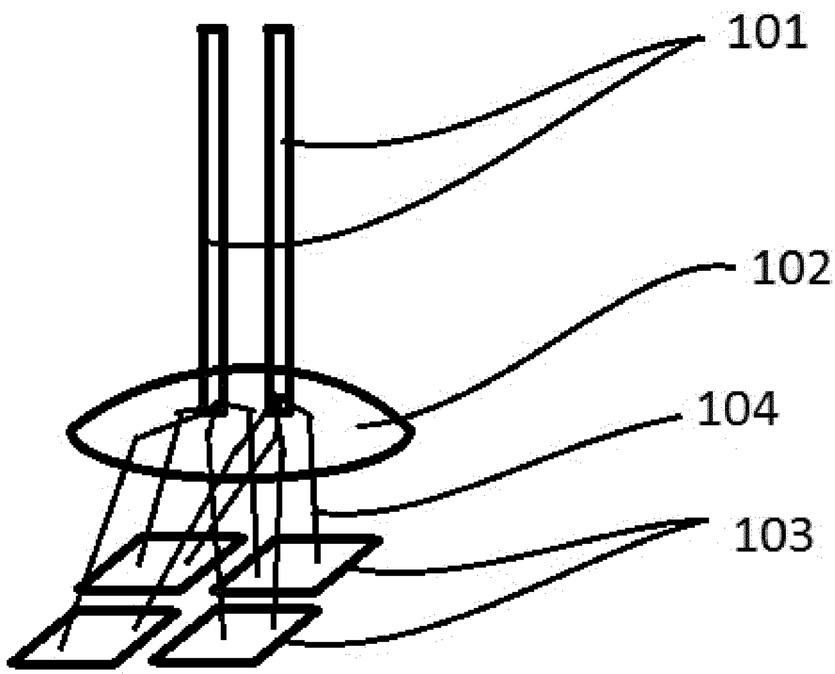


Figure 1e

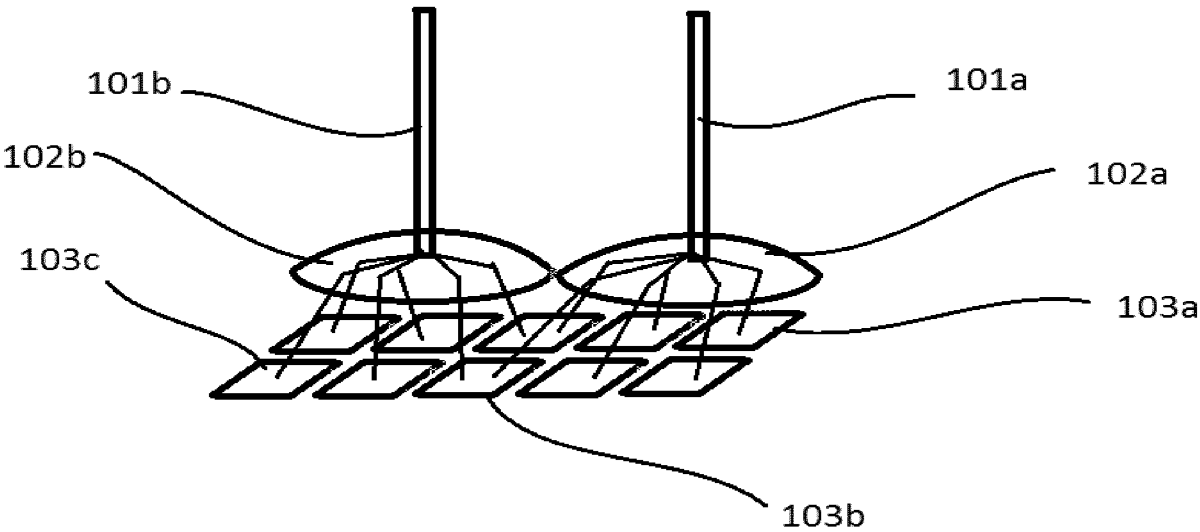


Figure 2

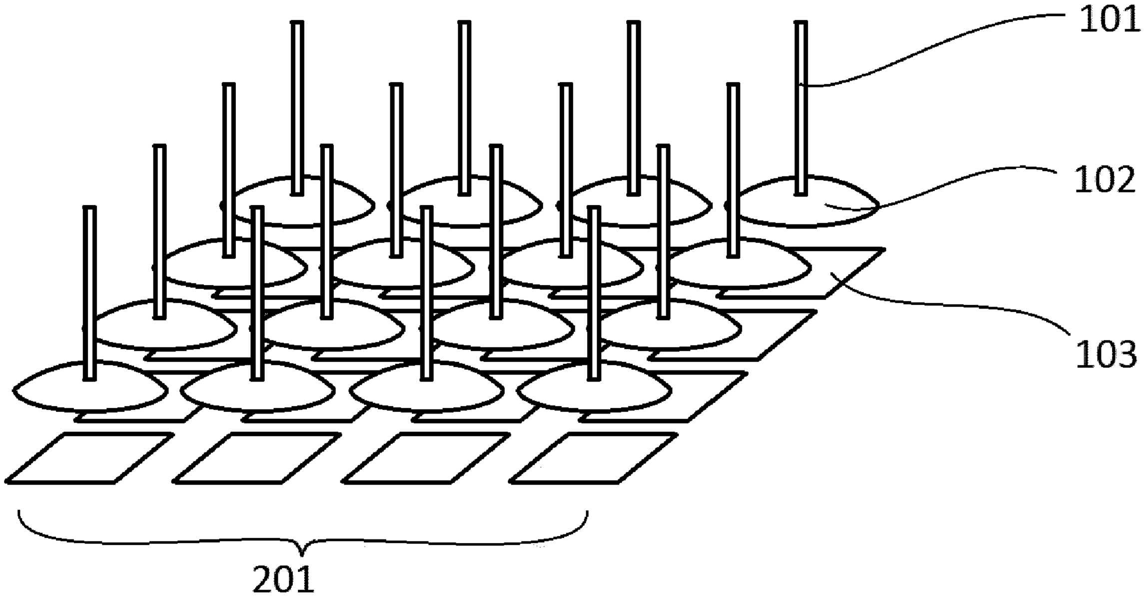


Figure 3

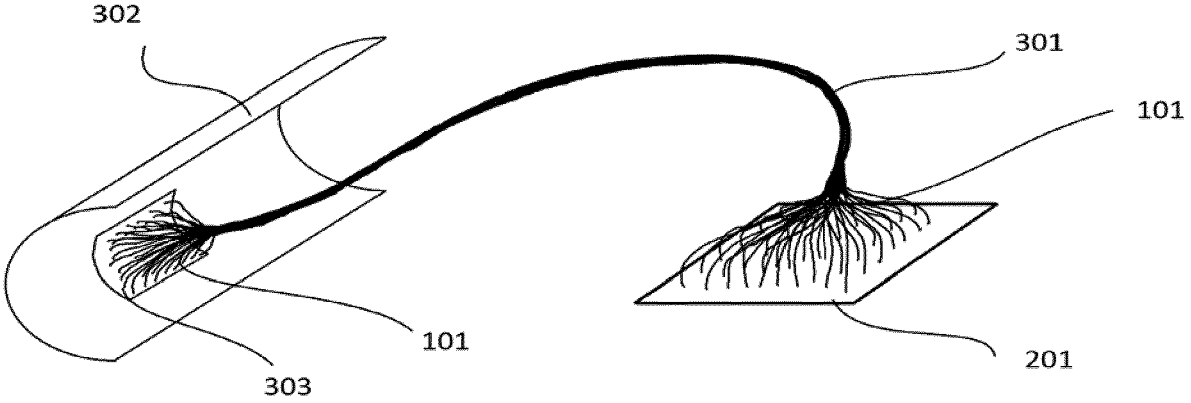


Figure 4

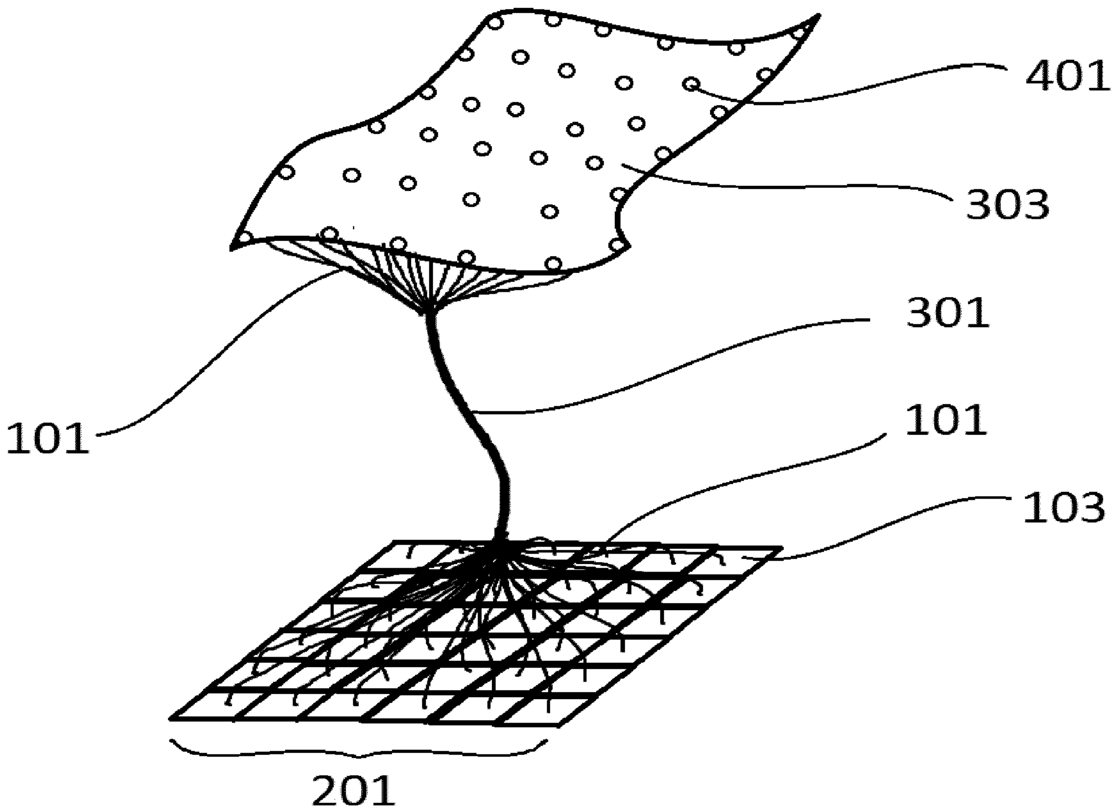


Figure 5

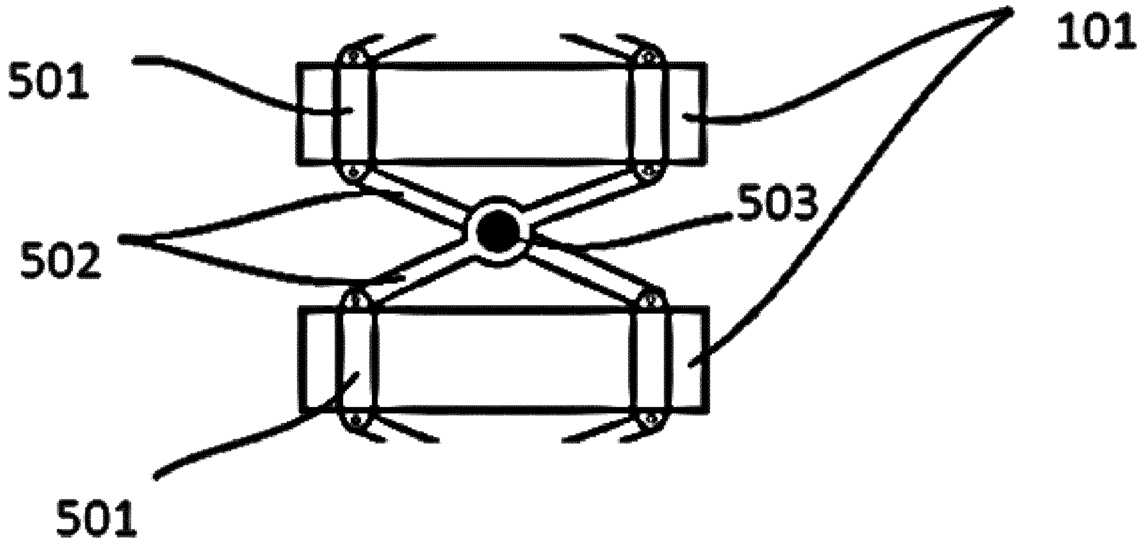


Figure 6

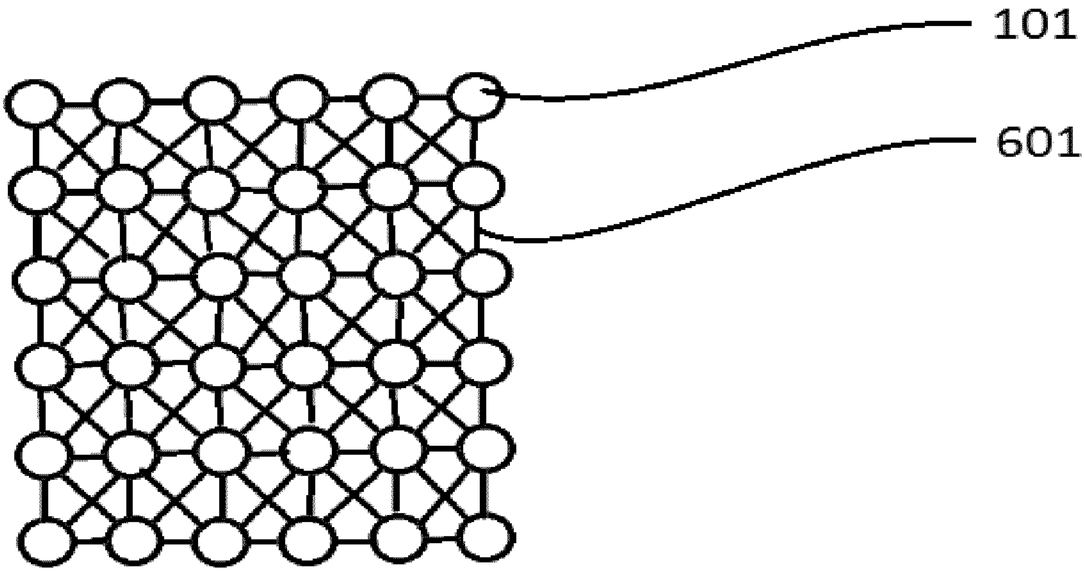


Figure 7

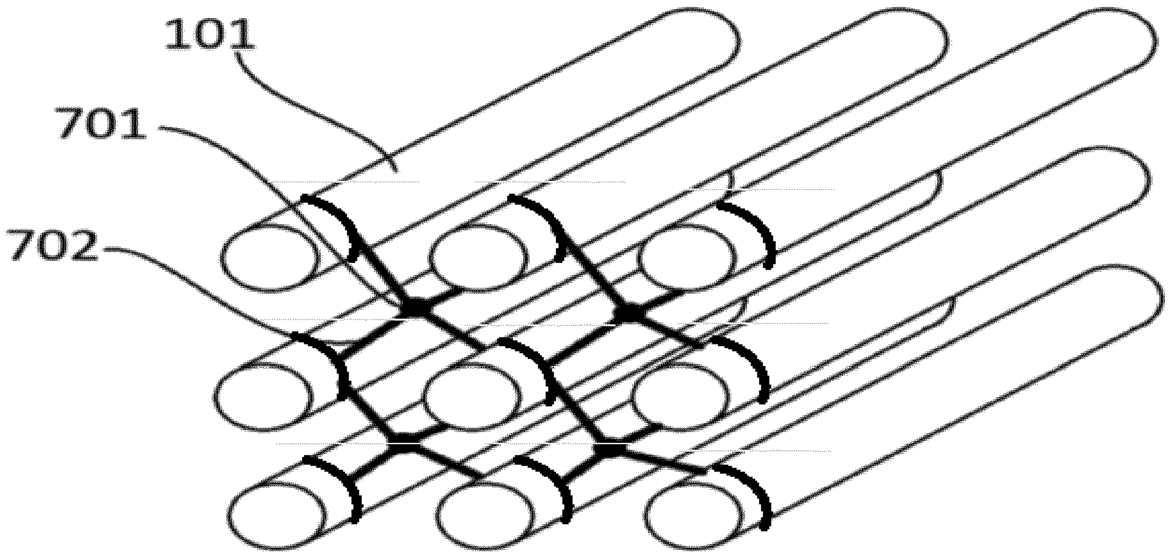


Figure 8

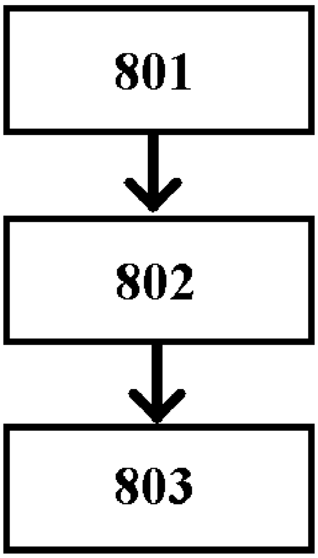


Figure 9

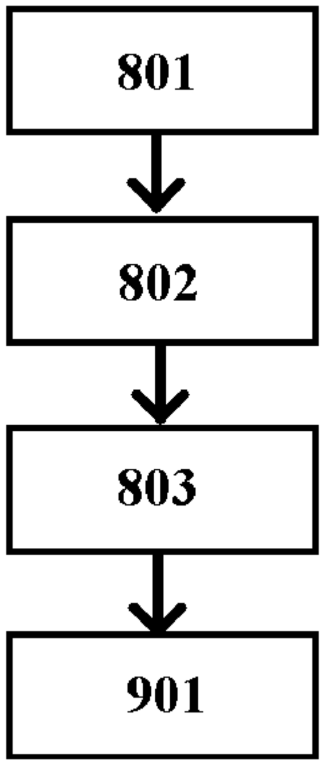


Figure 10

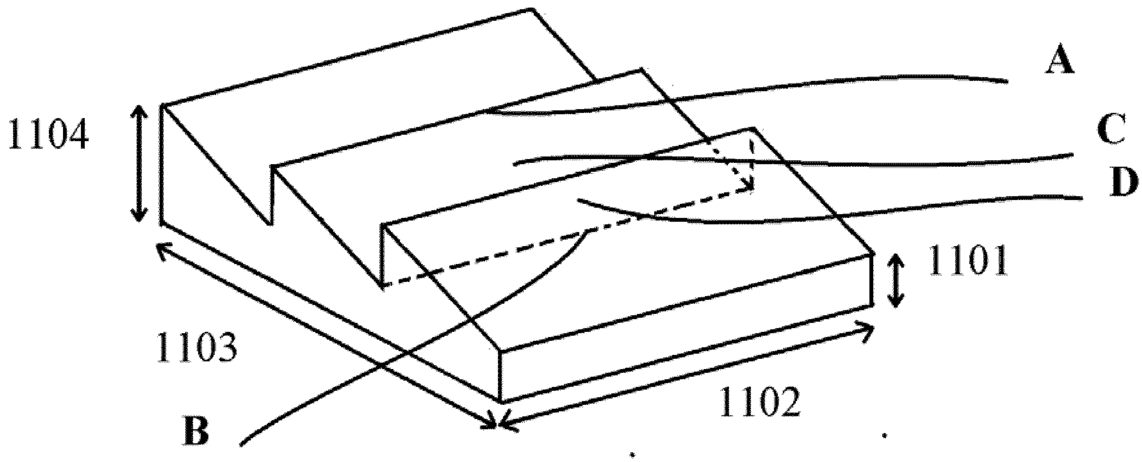


Figure 11

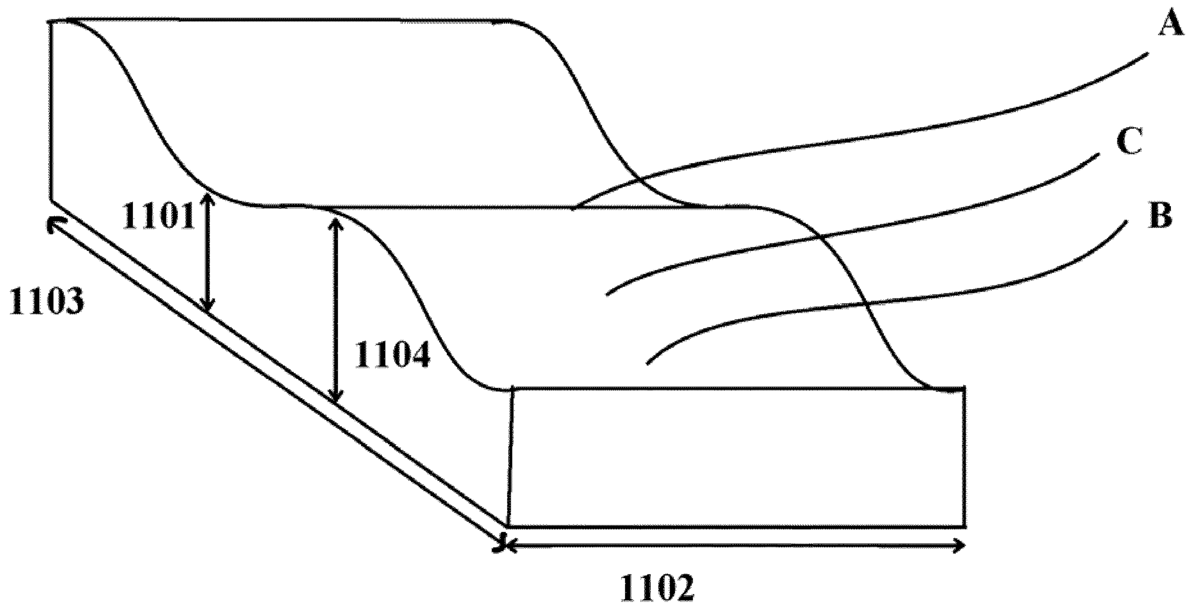


Figure 12a

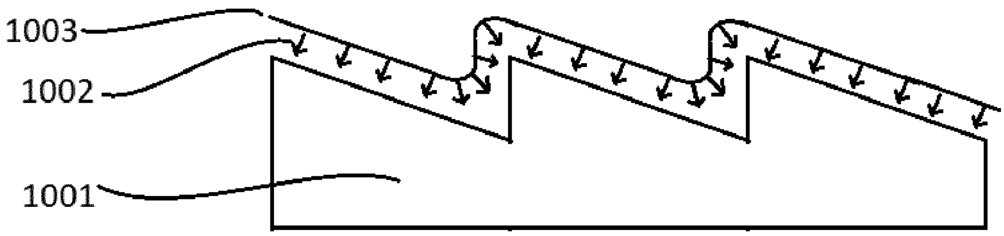


Figure 12b

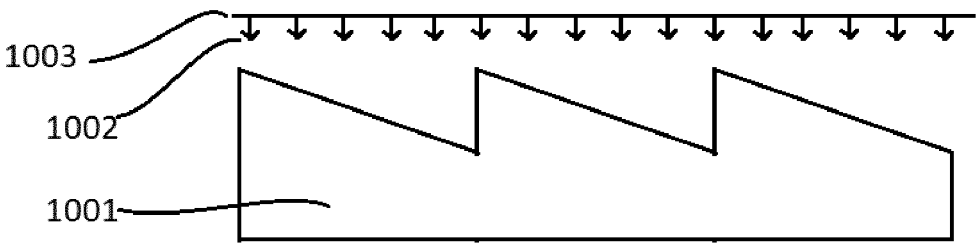


Figure 12c

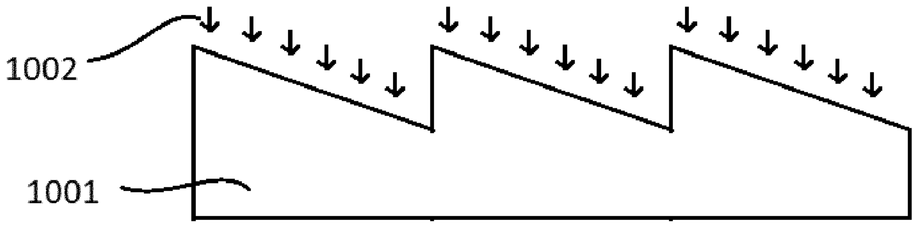


Figure 12d

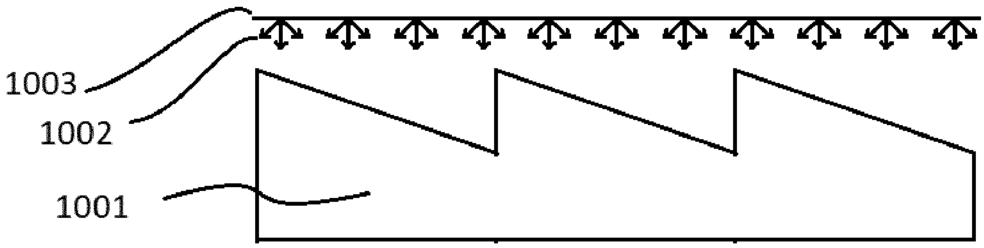


Figure 13a

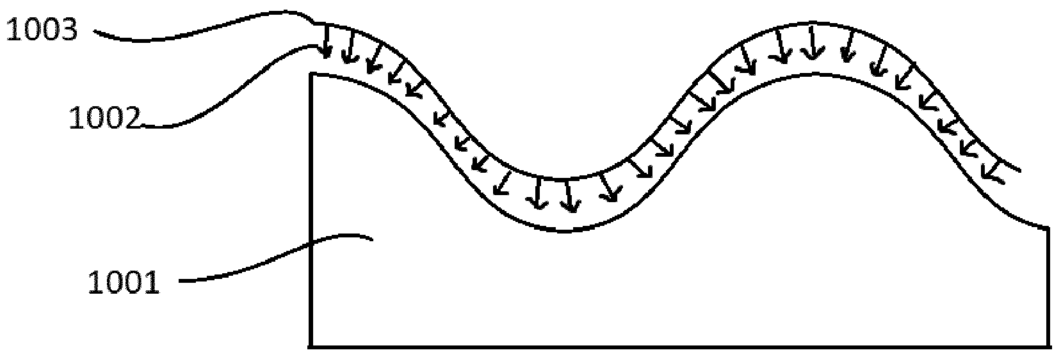


Figure 13b

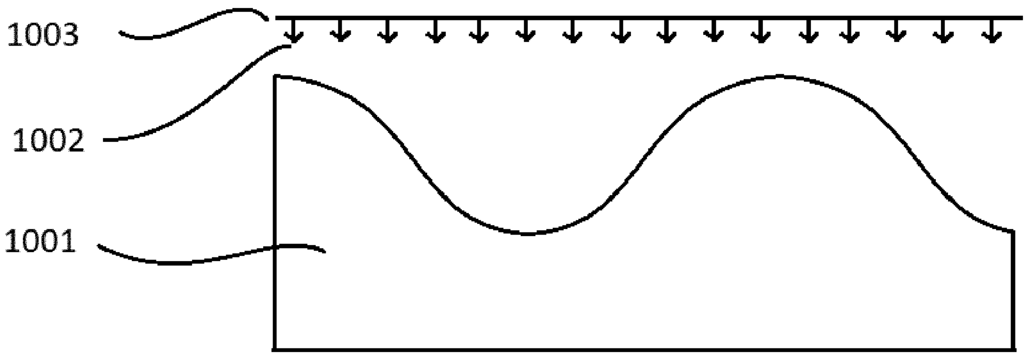


Figure 13c

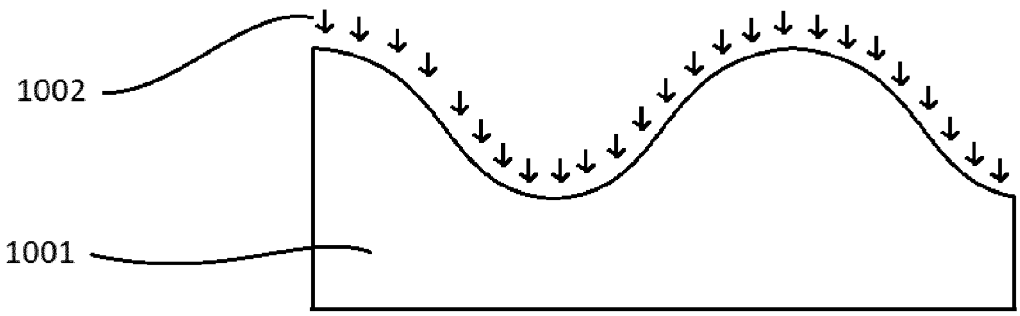


Figure 13d

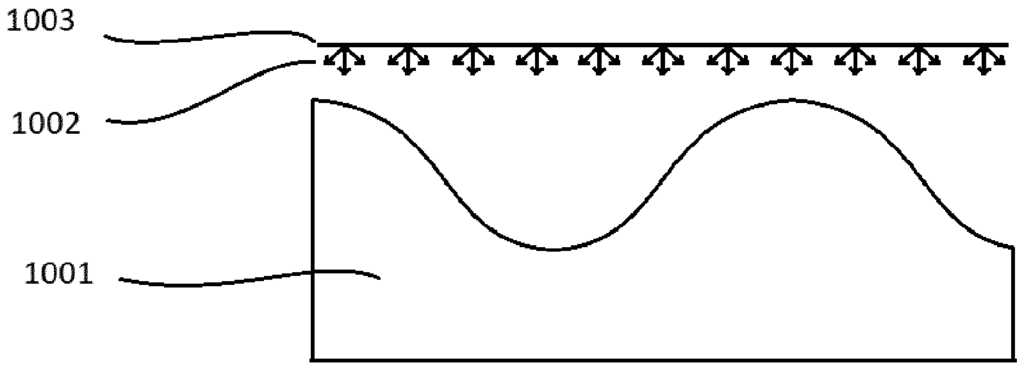
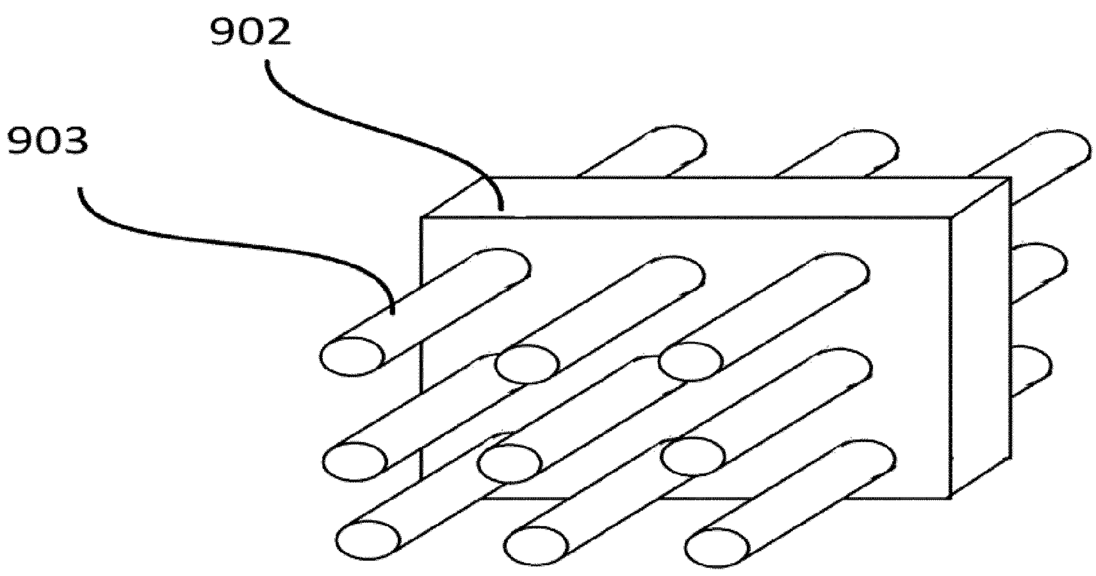


Figure 14



Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 17 19 4235

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 2 543 472 A1 (ROLLS ROYCE PLC [GB]) 9 January 2013 (2013-01-09) * paragraph [0001] * * paragraph [0062] * * paragraph [0068] - paragraph [0071] * * paragraph [0162] - paragraph [0171]; figures 12-14 *	1,2,4-9, 11-17	INV. H05B3/44
X	US 2016/007412 A1 (BUSCHE MATTHEW [US] ET AL) 7 January 2016 (2016-01-07) * paragraph [0005] * * paragraph [0021] * * paragraph [0026] - paragraph [0028]; figure 2 * * figures 3A,3B,4A,4B *	1,2,4,5, 10-12	
X	JP 2002 147762 A (FUJI PHOTO FILM CO LTD) 22 May 2002 (2002-05-22) * paragraph [0017] * * paragraph [0022] - paragraph [0023]; figures 1(a),1(b) *	1,3-5,11	
			TECHNICAL FIELDS SEARCHED (IPC)
X	US 6 713 713 B1 (CALDWELL SCOTT [US] ET AL) 30 March 2004 (2004-03-30) * column 1, line 6 - line 8 * * column 3, line 32 - column 4, line 8; figures 1-2 * * column 4, line 9 - line 49; figures 3-5 *	1,4,5, 11,12	H05B

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	5 March 2018	Barzic, Florent

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 17 19 4235

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

05-03-2018

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 2543472	A1	09-01-2013	EP	2543472	A1	09-01-2013
			US	2013009060	A1	10-01-2013
US 2016007412	A1	07-01-2016	CN	106471609	A	01-03-2017
			JP	2017522730	A	10-08-2017
			KR	20170024058	A	06-03-2017
			TW	201602667	A	16-01-2016
			US	2016007412	A1	07-01-2016
			WO	2016003633	A1	07-01-2016
JP 2002147762	A	22-05-2002	NONE			
US 6713713	B1	30-03-2004	CN	1508586	A	30-06-2004
			DE	10361353	A1	08-07-2004
			JP	2004195552	A	15-07-2004
			US	6713713	B1	30-03-2004

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82