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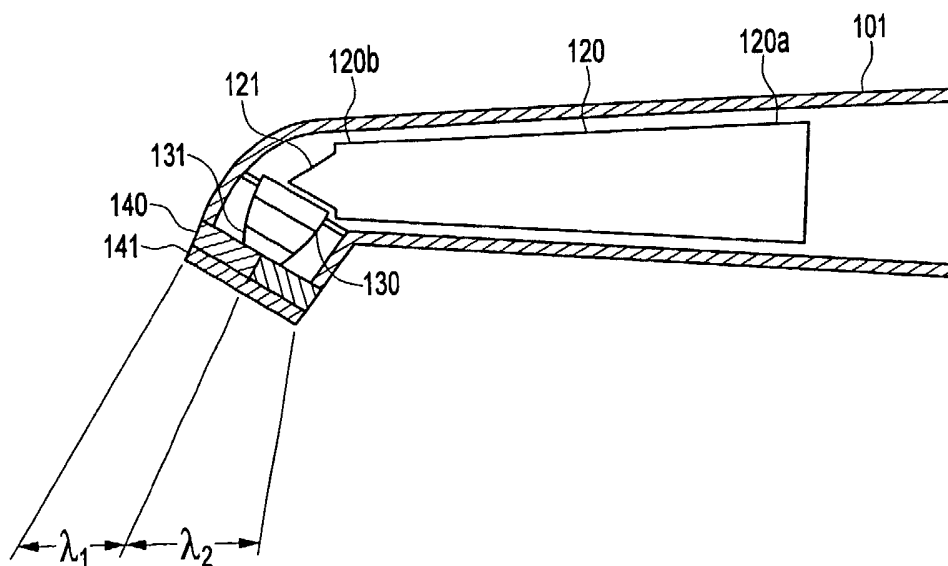
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(54) Title: CURING LIGHT CAPABLE OF MULTIPLE WAVELENGTHS



(57) Abstract: The present invention relates to a curing light having at least one wavelength transformer for transforming a shorter wavelength suitable for curing a dental composite into a longer wavelength also suitable for curing a dental composite. The wavelength transformer may be made of materials including organic dyes, inorganic dyes, pigments, nanocrystals and combinations thereof. The wavelength transformer can be of many different configurations. The curing light also includes at least one heat sink which can be made of a material including at least one phase change material.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Curing Light Capable of Multiple Wavelengths

Field of the Invention

[0001] This invention relates to curing light devices for use in dentistry. Specifically, this invention relates to curing light devices for activating the curing of composite materials in dentistry.

Background of the Invention

[0002] In the field of tooth restoration and repair, dental cavities are often filled and/or sealed with compounds that are photosensitive to visible and/or ultraviolet light. These compounds, commonly known as light-curable compounds, are placed within dental cavity preparations or onto dental surfaces and are cured when exposed to light from a dental curing light device.

[0003] Many light-curing devices are configured to be handheld devices. Some of them are constructed with fiber optic light wands designed for directing light from the light sources into the patient's mouths. The light sources may be lamps, halogen bulbs or light-emitting diodes (LED). One end of the light wand may be placed close to the light source so that the light emitted from the light source may be directed into the light wand. Some of the light wands are not configured to capture all the light that is generated by the light sources, particularly light that is emitted from LEDs, which may be emitted at angles of up to about 120°. This inefficiency in capturing most of the available light output may contribute to excessive heat generation, which may lead to limited run times for the curing devices.

[0004] One method for overcoming the limitations of light

capture disclosed in the prior art is to improve the efficiency of the curing devices by placing the light source(s) of the light-curing devices at the tip of the light-curing devices, so that all of the light generated by the light source(s) may be directed towards a desired location within the patients' mouths. This, however, does not overcome the run time problem mentioned above. At the same time, this method may create the problem of having the light source too close to the patient's mouth, causing discomfort to the patient if the hot tip of the curing device happens to come in contact to the sensitive tissues of the patient's mouth.

[0005] One way of overcoming the problem of having excessive heat from coming too close to the patient's mouth is to mount the light source(s) on a heat sink that may generally conduct the heat away from the tip of the light-curing device. This, however, only minimally solves the runtime problem mentioned above.

[0006] In addition, multiple light sources used in making a curing light capable of multiple wavelengths may further add to excessive heat generation problems if the light sources generate a wide spectrum of light, leading to more heat that needs to be diverted away from the light source. Even with light sources generating just the desired wavelength for composite curing, heat generation is still a problem. Consequently, elaborate cooling systems are needed to handle heat, possibly creating a large, heavy and expensive curing light.

[0007] Accordingly, there remains a need for a device capable of curing restorative compounds containing different initiators.

Summary of the Invention

[0008] The present invention relates to a dental curing device suitable for curing light curable dental composite material. The device includes a light module housing having a substantially cylindrical shape including a substantially hollow interior with at least one heat sink, located in the light module housing. The heat sink includes at least one surface or mounting platform for locating, positioning or mounting a light source, for example, a lamp, an arc lamp such as a halogen light source, semiconductor light emitting devices, light-emitting chips such as an LED, a solid state LED, an LED array, a fluorescent bulb, and so on. Light emitted by the light source has an emission spectrum including at least one wavelength capable of initiating curing of a composite. A device situated in the proximity of the light source includes at least one wavelength transformer for capturing substantially all the light in its path emitted by the light source and transforming at least a portion of the captured light into a longer wavelength, which is also capable of initiating a chemical reaction to cure the dental composite material.

[0009] At least one wavelength transformer includes at least one absorber/emitter having at least a portion that is substantially transparent to the incident light, and at least one portion capable of absorbing the incident light and emitting light having a longer wavelength. In one embodiment, at least one wavelength transformer is configured or positioned to capture substantially all the emitted light and to transform only a portion of the capture light into a longer wavelength. In another embodiment, at least one wavelength transformer is configured or positioned to capture at least a portion of the light emitted by the light source and to transform all captured light into a longer wavelength. In one

aspect, at least one wavelength transformer is stationary. In another aspect, at least one wavelength transformer is adapted for rotation about a longitudinal axis of the light module housing.

[0010] In one other embodiment, the light source includes an emitting surface. In another embodiment, the light source includes at least one emitting edge.

[0011] In a further embodiment, at least one wavelength transformer may be in a direct path of the emitted light. In a yet further embodiment, at least one wavelength transformer may be at an oblique angle to the direct path of the light emitted by the light source.

[0012] The present invention also relates to a dental curing device suitable for curing light curable dental composite materials. The curing device includes a light module housing having a substantially cylindrical shape including a substantially hollow interior with at least one heat sink located in the light module housing. The heat sink includes at least one surface or, mounting platform for locating, positioning or mounting at least one light source, as noted above. Light emitted by the light source includes a wavelength suitable for curing light curable dental composite materials. In one aspect, a light source includes at least one wavelength transformer for capturing at least a portion of the light emitted by the light source and transforming all captured light into a longer wavelength, which is also suitable for curing light curable dental composite material. In another aspect, the light source includes at least one wavelength transformer for capturing all light emitted by the light source and transforming at least a portion of it into a longer wavelength such that the resultant light directed at

the light curable dental composite material includes a portion having the emitted wavelength and a portion having a longer wavelength.

[0013] The present invention further relates to a dental curing light suitable for curing light curable dental composite materials. The curing device includes a light module housing having a substantially cylindrical shape including a substantially hollow interior with at least one heat sink located in the light module housing. The heat sink includes at least one surface or mounting platform for locating, positioning or mounting a light source, as noted above. Light emitted by the light source includes a wavelength suitable for curing light curable dental composite materials. A device situated in the light path of the light source includes at least one wavelength transformer for transforming at least a portion of the light emitted by the light source into a longer wavelength. The wavelength transformer includes at least one beam splitter and at least one absorber/emitter including a chemical capable of absorbing the incident light and emitting light having a longer wavelength.

[0014] In one embodiment, at least one wavelength transformer is configured or positioned to substantially capture one beam coming from the beam splitter. In another embodiment, at least one wavelength transformer is at an oblique angle to the emitted light path. In a further embodiment, at least one wavelength transformer is at substantially right angles to the emitted light path.

[0015] In one embodiment, the heat sink includes at least one elongated heat sink located in the light module housing, with the proximal end of the heat sink being situated close to a proximal end of the housing and at least one surface or

mounting platform located at the proximal end of the elongated heat sink.

[0016] In another embodiment, at least one of the heat sinks may be of any shape situated close to a proximal end of the housing and at least one surface or mounting platform located at the proximal face or portion of the heat sink.

[0017] Furthermore, the present invention relates to a dental curing light capable of generating light of more than one wavelength suitable for curing light-curable dental composite material. The curing light includes at least one wavelength transformer capable of transforming at least a portion of light emitted by a light source, as disclosed above, into a longer wavelength which is also suitable for curing light activatable composites. In one embodiment, at least one wavelength transformer includes at least one absorber/emitter having at least a portion that is substantially transparent to the light incident on it, and at least one portion including a chemical capable of absorbing the incident light and emitting light having a longer wavelength. In one aspect, at least one wavelength transformer is configured or positioned to capture substantially all of the emitted light. In another aspect, at least one wavelength transformer is configured or positioned to capture at least a portion of the light emitted by the light source. In a further aspect, at least one wavelength transformer is stationary. In still another aspect, at least one wavelength transformer is adapted for rotation about a longitudinal axis of the light module housing.

[0018] Still furthermore, the present invention relates to a dental curing light capable of generating light of more than one wavelength suitable for curing light curable dental

composite material. The curing light includes at least one wavelength transformer for transforming at least a portion of the light emitted by the light source into a longer wavelength which is also capable of activating a light activatable composite. At least one wavelength transformer includes at least one beam splitter and at least one absorber/emitter includes a chemical capable of absorbing the incident light and emitting light having a longer wavelength.

[0019] In one embodiment, at least one wavelength transformer is configured or positioned to capture one beam coming from the beam splitter. In another embodiment, at least one wavelength transformer is at an oblique angle to the emitted light path. In a further embodiment, at least one wavelength transformer is at substantially right angles to the emitted light path.

[0020] Yet furthermore, the present invention relates to a dental curing light capable of generating light of more than one wavelength suitable for curing light curable dental composite materials. The curing light includes at least one wavelength transformer for transforming the shorter wavelength portion of the light emitted by a light source, described above, which is unsuitable for curing composites, into a longer wavelength, both the longer wavelength portion of the emitted light and transformed light are capable of activating light activatable composites. At least one wavelength transformer includes at least one filter including an absorber/emitter capable of absorbing substantially all the shorter wavelength of light emitted by the light source, and transforming it into a longer wavelength. In one aspect, the emitter/absorber is capable of absorbing a relatively broad spectrum, below about, for example, 400 nm, and transforming it into a relatively broad spectrum at a higher wavelength,

for example, about 450 nm. In another aspect, the emitter/absorber is capable of absorbing a relatively broad spectrum, below about, for example, 400 nm, and transforming it into a relatively narrow spectrum at a higher wavelength, for example, about 470 nm. In yet another aspect, the emitter/absorber is capable of absorbing substantially all wavelengths, below about, for example, 400 nm, and transforming them into a higher wavelength, for example, about 470 nm. In still yet another aspect, the emitter/absorber is capable of absorbing substantially all wavelengths, below about, for example, 400 nm, and transforming them into a relatively broad spectrum at a higher wavelength, for example, about 450 nm. In still yet a further aspect, the absorber/emitter is capable of absorbing a relatively narrow spectrum at a low wavelength and transforming it to a relatively narrow spectrum at a higher wavelength. In one embodiment, at least one wavelength transformer is stationary. In another embodiment, at least one wavelength transformer is adapted for rotation about the longitudinal axis of the light module housing.

[0021] The light module housing of any of the above disclosed curing lights may include at least one reflecting surface. In one embodiment, the at least one reflecting surface may be present in the direct path of the emitted light. In another embodiment, the at least one reflecting surface may be present in an oblique angle to the emitted light.

[0022] The light source of any of the above disclosed curing lights may include a primary and a secondary heat sink. The heat sink may include a material that can more efficiently remove or divert heat from a curing light device when a reduced weight of heat sink material is used for better

portability.

[0023] In one aspect, the heat sink may have a reflective surface. In another aspect, the heat sink may include a surface or a mounting platform. The surface or mounting platform may also have a reflective surface.

[0024] In one embodiment of the above disclosed invention, the heat sink includes a material that can more efficiently remove or divert heat from a light source or sources with a given weight of heat sink material when compare to a heat sink made of a solid block of thermally conductive material such as metal.

[0025] In another embodiment of the above disclosed invention, the heat sink includes at least one suitable phase change material including organic materials, inorganic materials and combinations thereof. These materials can undergo substantially reversible phase changes, and can typically go through a large, if not an infinite number of cycles without losing their effectiveness.

[0026] In a further embodiment of the above disclosed invention, the output of the light spectrum from the curing device may include of multiple discrete peaks.

[0027] In yet a further embodiment of the above disclosed invention, the output of the light spectrum from the curing device may be substantially a continuum.

[0028] The wavelength transformers of the present invention may be positioned at any distance from the light source. In one embodiment, the transformer maybe formed directly on the light source. In another embodiment, the transformer may be

positioned at a few mm away from the light source.

[0029] In one embodiment, a light source may include edge emitting LEDs or LED arrays. In one aspect, the wavelength transformer capable of transforming all captured light in its path may be formed onto at least one edge of the emitting edges. In another aspect, the wavelength transformer capable capturing all light in its path and transforming portions of it may be formed onto all emitting edges.

[0030] The curing lights of the present invention may include a light transport device at the proximal end of the housing. In one aspect, the light transport device may be a light guide. In another aspect, the light transport system may comprise a focusing dome that may also be capable of varying the beam diameter of the light exiting the curing light device. In a further aspect of the invention, the light transport system may be a tacking tip. In a further aspect, the light transport device may be a positioning light guide adapted for positioning the curing light to a target.

Brief Description of the Drawings

[0031] FIG. 1 shows a cross-sectional view of the curing light of the present invention.

[0032] FIG. 2 shows another cross-sectional view of an embodiment of the present invention, depicting the arrangement of the mounting platform and the wavelength transformer of the present invention.

[0033] FIG. 3A shows a cross-sectional view of another embodiment of the arrangement of the mounting platform and

wavelength transformer.

[0034] FIG. 3B shows a perspective view of an alternative embodiment of a wavelength transformer including a patterned absorber/emitter.

[0035] FIG. 3C shows a perspective view a further alternative embodiment of a wavelength transformer according to principles of the invention.

[0036] FIG. 4 shows a cross-sectional view of yet another embodiment of the present invention including a mounting platform, beam splitter and wavelength transformer.

[0037] FIG. 5 shows a cross-sectional view of still yet another embodiment of the present invention including an arrangement of the mounting platform, beam splitter and wavelength transformers.

[0038] FIG. 6 shows a cross-sectional view of an embodiment of the curing light module using a reflector for reflecting portions of the light.

[0039] FIG. 7 shows a cross-sectional view of an embodiment of the curing light module including a reflector equipped with a wavelength transformer.

[0040] FIG. 8 shows a perspective view of an embodiment of the curing light device having a light transport system such as a light guide or an optically conductive cable.

[0041] FIG. 9A shows a perspective view of a light guide that may serve to position the light source in the mouth of a patient.

[0042] FIG. 9B shows a perspective view of a light guide mated to a lip retractor according to principles of the invention;

[0043] FIG. 9C shows the light guide and lip retractor of FIG. 9B supporting a curing light according to principles of the invention.

[0044] FIG. 10 shows a perspective view of an embodiment of a light source including a protective dome or cover with wavelength transformer.

[0045] FIG. 11 shows a perspective view of an embodiment of the curing light device having a tacking tip.

[0046] FIG. 12 shows a handgrip having coupling means for coupling to the light guide.

[0047] FIG. 13 shows a cross-sectional view of an embodiment of the curing light device having a plurality of LEDs mounted on a heat sink in a manner that the emitted light passes through a wavelength transformer and is collected by a reflector apparatus and focused by a lens means.

[0048] FIG. 14A shows a cross-sectional view of an embodiment of the curing light device having a plurality of LEDs, each having its own heat sink, that the emitted light passes through a wavelength transformer and is collected by a reflector apparatus and focused by a lens.

[0049] FIG. 14B shows a cross-sectional view of a curing light according to one embodiment of the invention.

[0050] FIG. 15 shows a cross-sectional view of an embodiment of the curing light device where the elongated heat sink has a curved structure for positioning an LED array.

[0051] FIG. 15a shows a cross-sectional view of an embodiment of the curing light device where the heat sink has a well structure for mounting LEDs.

[0052] FIG. 16 shows a cross-sectional view of an embodiment of the curing light device where the elongated heat sink has a planar mounting platform for positioning a light source.

[0053] FIG. 17 shows a perspective view of a curing light device according to principles of the invention.

[0054] FIG. 18 shows a battery charger module suitable for use with the present invention.

[0055] The detailing description set forth below is intended as a description of the presently preferred embodiments provided in accordance with aspects of the present invention and is not intended to represent the only forms in which the present invention may be prepared or utilized. It is to be understood, however, that the same or equivalent functions and components may be accomplished by difference embodiments that are also intended to be encompassed within the spirit and scope of the invention.

[0056] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which this invention belongs. Although any methods, devices and materials similar or equivalent to those described herein may be used in the

practice or testing of the invention, the exemplified methods, devices and materials are now described.

[0057] A dental curing light useful for curing or activating light-activated materials is disclosed. The present invention has applications in a variety of fields, including but not limited to medicine and dentistry, where light-activated materials including a photoinitiator or photoinitiators are used. As an example, a photoinitiator absorbs light of a particular wavelength and initiates the polymerization of monomers into polymers.

[0058] In an exemplary embodiment, light-activated materials including a single photoinitiator or multiple photoinitiators may be applied to a surface of, such as a tooth, and later cured by light of a wavelength or wavelengths that activates the photoinitiator or photoinitiators. The light used not only is of a wavelength to which the photoinitiator is sensitive, but also of a power level to cause curing for certain durations of time. Although the light used to activate the photoinitiator is of a wavelength to which a photoinitiator is sensitive, the light may come from a variety of sources, including a lamp, an arc lamp such as a halogen light source, semiconductor light emitting devices, light-emitting chips such as an LED, a solid state LED, an LED array, a fluorescent bulb, and so on. The present invention discloses, for example, light systems that use semiconductor chips as their source of light for a compact curing light device.

[0059] The typical photo-sensitizers used in composite curing include Camphorquinone (CQ), which absorbs light at about 465 nm, and phenyl-propanedione (PPD), which absorbs light at about 390 nm. Dental curing lights having multiple wavelengths suitable for curing curable composites usually include output

wavelengths encompassing the absorbing wavelengths of these two typically used photo-initiators. The output is generally a composite spectrum generated by LEDs or LED arrays emitting different wavelengths. The present invention includes a curing light capable of curing all composites by means of a light source as mentioned above, emitting a single peak wavelength. The light source may include an emitting surface or at least one emitting edge such as an edge emitting chip noted above.

[0060] FIG. 1 shows the cross-section of a curing light 100 having a light module housing 101 having a distal end 111, a proximal end 112, a handle 102 towards its distal end and a neck and head portion 103 on its proximal end at an angle to the handle portion 102. The light module housing 101 includes a substantially cylindrical shape having a substantially hollow interior 101a with at least one heat sink 120 located in the light module housing 101. The heat sink 120 includes at least one surface or mounting platform 121 for locating, positioning or mounting a light source 130, as noted above.

[0061] The light module housing may include a wavelength transformer 140. The wavelength transformer 140 may be present in the emitting surface of the light source 131, in front of the light source 130 towards the proximal end 112 of the light module housing, or at least one emitting edge of an edge emitting source, or in the light path of the light source, as shown in FIG. 1.

[0062] For example, in FIG. 2, the light source 130 may include a single LED 131, emitting light, for example, in the blue range, suitable for curing light activatable composites. Also as shown in FIG. 2, the heat sink 120 has an elongated shape, though any other shape is also useful. The elongated heat sink 120 includes a distal end 120a and a proximal end 120b, and

is positioned such that the proximal end 120b is situated towards the proximal end 112 of the light module housing 101. One surface or mounting platform 121, as shown, is located towards the proximal end 120b of the elongated heat sink 120. In other embodiments, one mounting platform 121 may be present towards the distal end 120a of a heat sink 120, if the heat sink 120 is an elongated heat sink, as shown for example in Figure 5, or on a proximal face or portion of the heat sink 120 if the heat sink 120 is of any other shape, as shown for example in Figure 4.

[0063] Light emitted from the LED 131 includes an emission spectrum including at least one wavelength capable of initiating curing of a composite. A device situated in the light path of the LED includes at least one wavelength transformer 140 for transforming at least a portion of the light emitted by the LED 131 into a longer wavelength, which is also capable of initiating a chemical reaction to cure the dental composite material.

[0064] The wavelength transformer 140 includes at least one absorber/emitter. The absorber/emitter may be of any substances that absorbs electromagnetic waves, for example, in the blue wavelength range, and then luminesce, in particular fluoresce, when optically excited. Such chemical compounds may include organic and inorganic dyes or pigments.

[0065] Organic dyes may include any fluorescent dye having at least one amine moiety substituted with at least two aryl groups, and compounds having N-aryl substituents which exhibit reduced pH sensitivity and enhanced stability to protonation. Examples of an aryl group include phenyl, naphthyl, anthracenyl, dinaphthyl, ditolyl, bis(p-methylphenyl), dianthracenyl, mixed aryl groups such as phenylnaphthyl and

phenyltoluyl, or substituted aryl groups such as toluy, some of these are disclosed in U.S. 6,627,111, "Organic light emitting displays and new fluorescent compounds", incorporated herein by reference.

Some embodiments include dyes that absorb between about 350 to about 430 nm and emit between about 450nm and to about 500 nm, for example, DAPI (4',6-Diamidino-2-phenylindole, 2HCl, absorbing at about 359 nm and emitting at about 461 nm); HOE 33258 (2-[2-(4-Hydroxyphenyl)-6-benzimidazolyl]-6-(1-methyl-4-piperazyl)-benzimidazole, 3HCl), absorbing at about 346 nm and emitting at about 460 nm; HOE 33342 (2'-(4-Ethoxyphenyl) -5-(4-methyl-1-piperazinyl)-2,5'-bi-1H-benzimidazole, 3HCl), absorbing at about 346 nm and emitting at about 460 nm; 7-Diethylamino-3-(4-maleimidylphenyl)-4-methylcoumarin, absorbing at about 387 nm and emitting at about 465 nm; 2-(4'-(Dimethylamino)phenyl)-6-methylbenzothiazole 6-Methyl-BenzoThiazole-Aniline-2-Methyls, absorbing at about 356 nm, and emitting at about 437 nm, and combinations thereof.

[0066] Useful inorganic dyes may include, for example, elements from the group of lanthanides, including the element Y, La, Ce, Pr, Nd, Sm, Yb or Lu. Some examples may include phosphors such as yttrium aluminum garnet doped with praseodymium and cerium (YAG:Pr+Ce), strontium sulfide doped with europium (SrS:Eu), strontium thiogallate, or any other suitable phosphor. Other examples of such dyes are disclosed in the German Patent Document DE 37 03 495 A1, incorporated herein by reference.

[0067] The dyes may also be, for example, in pigment form. Some examples of commercially available ones include Lumogen® dyes (available from BASF AG, Ludwigshafen), Lumilux® pigments

(available from Riedel de Haen GmbH, Seelze), or mixtures thereof.

[0068] The wavelength transformer 140 includes at least one absorber/emitter 141 having at least a portion that is substantially transparent to the incident light, and at least one portion capable of absorbing the incident light and emitting light having a longer wavelength. In the embodiment exemplified in FIG. 2, at least one wavelength transformer is configured or positioned to capture substantially all of the emitted light while transforming only a portion of the capture light into a longer wavelength.

[0069] The absorber/emitter 141 may be positioned at any distance away from an emitting surface, from a few μm to a few mm, including right at the light source or emitting surface or edge, or incorporated therewith into the construction of the emitting surfaces or edges. Such incorporation of the absorber/emitter may be accomplished by sputtering, thin film deposition, vapor deposition, lithographic printing, coating, or other techniques known in the art.

[0070] In one aspect, the light source emits a narrow band and the portion of light being transformed may be of a wavelength that is suitable for activating the curable composite. In another aspect, the light source emits a broader band of wavelengths and the portion of light being transformed may be of a shorter wavelength than that is suitable for activating the curable composite.

[0071] In another embodiment, as shown in FIG. 3A, at least one wavelength transformer including an absorber/emitter may be configured or positioned to capture at least a portion of the light emitted by the light source and transforming all

captured light. The absorber/emitter 141 may be positioned at any distance away from an emitting surface, from a few μm to a few mm.

[0072] FIG. 3B shows an alternative embodiment of the wavelength transformer 140 including an absorber/emitter. The absorber/emitter in this alternative embodiment has a checkerboard pattern of absorbing/emitting material deposited on a clear substrate, such as glass. The pattern in this embodiment may be deposited using photoresist techniques or by various thin film deposition techniques including sputtering. The present invention is not limited to the patterning techniques listed here. Further alternate embodiments include patterns other than checkerboard.

[0073] For an absorber/emitter capable of capturing all of the emitted light and transforming only a portion of it into a longer wavelength, the dye, pigment or mixtures thereof, may be present in at least a portion of the absorber/emitter. In one embodiment, the absorber/emitter has a matrix of domains including dyes, pigments or mixtures thereof, surrounded by domains that are substantially transparent to the incident light. The domains may be of any size, including domains of the size of a few molecules, to domains that may be almost half the size of the entire absorber/emitter. In another embodiment, the configuration of the absorber/emitter may have two separate portions, one portion including a dye, pigment or mixtures thereof, capable of absorbing a shorter wavelength and emitting a longer wavelength and the other portion being transparent to the incident light. In one other embodiment, the configuration of the absorber/emitter may have a matrix of domains of any shape and size, some of which may include a dye, pigment or mixtures thereof, capable of absorbing a shorter wavelength and emitting a longer wavelength and the

others being transparent to the incident light. In a further embodiment, the configuration of the absorber/emitter may have a matrix of stripes having a dye, pigment or mixtures thereof, interposed with stripes of having no dye or pigment. The coating of dye, pigment or mixtures thereof may be deposited in a variety of patterns including, straight line patterns such as parallel longitudinal lines, parallel transverse lines; rectangular patterns; circular or arcuate patterns; dot patterns such as symmetrical or unsymmetrical patterns of dots, and combinations thereof. The patterns may be formed by any of a number of coating methods including slot coating, pattern coating, and rotogravure coating and the like. Suitable methods for applying selected patterns include, for example, slot coating, transfer coating, and rotogravure coating, may be used.

[0074] For the absorber/emitter capable of capturing at least a portion of the emitted light and transforming substantially all of the captured light into a longer wavelength, the dye, pigment or mixtures thereof may be present in substantially all regions of the absorber/emitter.

[0075] An organic dye, pigment or mixtures thereof may be used as an absorber/emitter in a wavelength transformer. Examples are discussed in, for example, U.S. Pat. No. 5,126,214 to Tokailin et al. (which discloses a fluorescent material part that emits in a visible light range from red to blue); and U.S. Pat. No. 5,294,870 to Tang et al. (which makes reference to the use of both organic and inorganic dye materials), the contents of which are incorporated herein by reference.

[0076] An absorber/emitter capable of capturing at least a portion of the light emitted by the light source and transforming all captured light, the absorber/emitter may have

a matrix of a uniform coating or layer of a dye, pigment or mixtures thereof in its entirety.

[0077] In one aspect of the invention, at least one wavelength transformer may be fixed in the light path of the light source. In another aspect, at least one wavelength transformer is adapted for rotation about the longitudinal axis of the light module housing. In a further aspect, at least one wavelength transformer may be, for example, in the form of an interchangeable filter disk, permanently or reversibly connected to a light guide. One embodiment of a light guide may be as shown in FIG. 10.

[0078] In one embodiment, the wavelength transformer includes a substrate, an absorber/emitter matrix capable of absorbing a lower wavelength of light and transforming or re-emitting that light at a longer wavelength, and a cover element.

[0079] The dye, pigment or mixtures thereof, may be coated on any substrate such as a sheet or a plate of glass, a polymer film such as polymethylmethacrylate (PMMA), polyethylene (PE), polypropylene (PP), polystyrene (PS), polycarbonate (PC), polyvinylchloride (PVC), polyester terephthalate (PET) or combinations thereof, to form the absorber/emitter matrix.

[0080] In one embodiment, the wavelength transformer 140 may be capable of capturing substantially all of the light emitted by the emitting source, and may be positioned directly over at least a portion of the emitting source and transforming all of the captured light. In another embodiment, the wavelength transformer 140 may be capable of capturing substantially all of the light emitted by the emitting source, and may be positioned directly over the emitting source and transforming at least a portion of the captured light.

[0081] In one embodiment, the emitting source 131 may include an edge emitting chip. In one aspect, the absorber/emitter 141 is electrophoretically deposited, stenciled, screen printed, coated or sputtered directly onto at least one of the emitting edges so that at least one of the emitting edges include a wavelength transformer 140. In another aspect, the absorber/emitter 141 may be directly deposited, coated or sputtered onto the emitting edges so that at least a portion of each emitting edge includes a wavelength transformer 140. In a further aspect, the absorber/emitter 141 may be positioned directly over at least one of the edges or all of the emitting edges, depending on whether the transformer is capable is transforming all or apportion of the light it captures.

[0082] In the present invention, a handheld curing device is desirable. Such devices tend to have restricted spaces. Hence thermal management is important. Heat generation tends to cause run-time problems. Multiple light sources used in making a curing light capable of multiple wavelengths might further add to excessive heat generation problems, particularly if the light sources generate a wide spectrum of light that is then passed through filters and/or bandwidth adjusters to remove some of the light that is outside of the wavelength ranges suitable for activating light curable composites, leading to more heat that needs to be diverted away from the light source or sources. Even with light sources that generate just the desired wavelength for composite curing, heat generation may still present a problem, leading to the need for elaborate cooling systems. Multiple LEDs such as arrays emitting one wavelength may also present problems if the materials used for absorber/emitter have broad emission photoluminescence spectra that require additional optical filters for spectra

correction. These additional optical filters may also introduce additional loss of intensity. Thus, the efficiency of a wavelength transformer may depend on the broadness of the emission spectra of the absorber/emitter, i.e., how much light that is emitted by components of the wavelength transformer is outside of the usable ranges of the photoinitiators employed in the curing composites. The more desirable ones are those capable of re-emitting a narrower spectrum of light at a longer wavelength, or re-emitting a broad spectrum having a portion that overlaps another usable wavelength range.

[0083] The present invention also includes wavelength transformers including absorber/emitters capable of absorbing light at wavelengths lower than those suitable for curing activatable composites and transforming them into longer wavelengths useful for curing activatable composites. This type of wavelength transformers may accommodate light sources emitting a broader spectrum, for example, having a portion of light outside the wavelength suitable for curing light activatable composites, for example, on the shorter wavelength side. For these wavelength transformers, some of them are capable of emitting a narrow band or a broader band, all within the suitable range for activating a light curable composite. The wavelength transformer can make use of substantially all emitted light and therefore help solve at least a portion of the heat problem generally present in light sources emitting a wide spectrum, as noted above.

[0084] In one embodiment, a wavelength transformer 140 may include an organic dye, alone or in combination with organic dyes pigments or combinations thereof, for example, an inorganic-based material that provides a narrower photoluminescence emission spectrum when optically stimulated

by a lower wavelength photon energy source. An example of such inorganic-based materials includes semiconductor nanocrystals.

[0085] In another embodiment, the absorber/emitter 141 includes matrices having, for example, semiconductor nanocrystals uniformly dispersed in a transparent organic binding material. The wavelength of the re-emitted light may be tunable by altering the size or the size distribution of the semiconductor nanocrystals.

[0086] The excitation of some of these nanocrystals is apparently unaffected by the excitation wavelengths, thus enabling a choice of emission spectrum wavelengths by the use of a single excitation wavelength, for example, an LED emitting at a wavelength capable of initiating curing of a dental composite.

[0087] Examples of semiconductor nanocrystals, such as passivated CdSe crystal, in the size range of about 10 to about 200 Angstroms, are known to be widely tunable to emit up through the visible spectrum, as disclosed in U.S. Patent No. 6,608,439, incorporated herein by reference. They may also be controllably fabricated with narrow size distributions from scalable colloidal precipitation and other techniques known in the art.

[0088] It is also known that a layer or layers containing the semiconductor nanocrystals may be fabricated into a stable film or films by patterned photolithographic techniques. The absorber/emitter 141 may include at least one layer. As noted before, the absorber/emitter 141 may also be positioned at any distance away from an emitting surface, from a few μm to a few mm, or even directly over the emitting source.

[0089] The semiconductor nanocrystals may include, for example, the group of the semiconductor compounds CdS, CdSe, CdTe and mixtures of two or more of the semiconductor compounds. Organic binding material for use with nano-crystals may be the same material disclosed above in relationship to the substrate, or other polymers, oligomers, monomers or a mixture of them.

[0090] The benefits of using semiconducting nanocrystals are related to their fundamental properties, as described in the available research literature, for example, a review presented by A. P. Alivisatos in "Semiconductor clusters, nanocrystals, and quantum dots," Science 271 (Feb. 16, 1996) 933-937; and an article by C. B. Murray, D. J. Norris and M. G. Bawendi, "Synthesis and characterization of nearly monodisperse CdE (E=S, Se, Te) semiconductor nanocrystallites," J. Am. Chem. Soc. 115 (1993) 8706-8715, contains detailed art about the synthesis and properties of nanocrystals from the cadmium family.

[0091] Methods of fabricating semiconductor nanocrystals can be found in U.S. Pat. No. 5,559,057 to Goldstein (disclosing the method of manufacturing thin films from nanocrystal precursors); and U.S. Pat. No. 5,525,377 to Gallagher et al. (disclosing the method of making doped encapsulated semiconductor nanocrystallites for use in thin films for electroluminescent displays), both of which are incorporated herein by reference.

[0092] In a further embodiment, a combination of nanocrystals and an organic transport layer maybe used as a wavelength transformer. Examples of semiconductor nanocrystals in combination with an organic electron transport layer to transform wavelengths are disclosed in U.S. Pat. No. 5,537,000

to Alivisatos et al., all of which are incorporated herein by reference.

[0093] For example, organic electron transport layers may be multifunctional linking agents such as, for example, difunctional thiols, and linking agents containing a thiol group and a carboxyl group. In particular, dithiols described are those having the formula H-S-R-S-H , where R is an organic group which provides sufficient spacing between the sulfur atoms at the opposite ends of the molecule to permit the respective thiol groups on the opposite ends of the molecules to respectively bond to adjacent nanocrystals, or to a nanocrystal at one end and a substrate or support surface on the other end. Thus, R may include an organic moiety, such as an alkylene or an arylene, containing from 4 to 8 carbon atoms. Examples of such dithiol organic compounds include 1,4-dithiol n-butane; 1,5-dithiol n-pentane; 1,4-dithiol cyclohexane; 1,6-dithiol n-hexane; 1,7-dithiol n-heptane; and 1,8-dithiol n-octane. Such shorter chain molecules are more desirable over longer chain molecules to prevent or inhibit the linking agent from doubling back to adhere on both ends to the material to which the semiconductor nanocrystals is being bonded. However, it may be possible to also use longer chain linking agents in some instances, particularly when multiple monolayers of the nanocrystals are being applied over a support media.

[0094] The wavelength transformer may be fabricated in any shape that is suitable for use in the curing light, such as a rectangular, triangular, circular or elliptical flat film; a curve film having a concave or convex shape; a lens form having a concave or convex shape, or other configurations that may be designed for capturing a portion or all of the emitted light.

[0095] As noted above, despite the discussion for desiring dyes or pigments or nanocrystals capable of re-emitting narrower spectra, the desirable wavelength transformers include those capable of absorbing light at wavelengths lower than those suitable for curing activatable composites and transforming them into longer wavelengths useful for curing activatable composites. The desirable absorber/emitter also includes those that emit a narrow spectrum or a broader spectrum including wavelengths suitable, for example, for activating both CQ and PPD in the composites. This embodiment of the absorber/emitter may be used alone or in combination with the embodiments described above. Combinations of this embodiment of absorber/emitter may also be used.

[0096] Coating concentration of the dye, pigment, and/or nanocrystals may range from, for example, about 0.005 to about 5% by weight, further for example, about 0.01 to about 1% by weight, based on the weight of the substrate. As noted, they may also be directly deposited coated or sputtered onto the emitting source or some edges of the emitting source.

[0097] In a further embodiment, the wavelength transformer may also include a prism.

[0098] The housing 101 may be made of any polymeric material, including any polymer that may be molded or cast; or a metal or metallic alloy. Suitable polymers include polyethylene, polypropylene, polybutylene, polystyrene, polyester, acrylic polymers, polyvinylchloride, polyamide, or polyetherimide like ULTEM®; a polymeric alloy such as Xenoy® resin, which is a composite of polycarbonate and polybutyleneterephthalate or Lexan® plastic, which is a copolymer of polycarbonate and isophthalate terephthalate resorcinol resin (all available

from GE Plastics), liquid crystal polymers, such as an aromatic polyester or an aromatic polyester amide containing, as a constituent, at least one compound selected from the group consisting of an aromatic hydroxycarboxylic acid (such as hydroxybenzoate (rigid monomer), hydroxynaphthoate (flexible monomer), an aromatic hydroxyamine and an aromatic diamine, (exemplified in U.S. Patent Nos. 6,242,063, 6,274,242, 6,643,552 and 6,797,198, the contents of which are incorporated herein by reference), polyesterimide anhydrides with terminal anhydride group or lateral anhydrides (exemplified in U.S. Patent No. 6,730,377, the content of which is incorporated herein by reference) or combinations thereof.

[0099] In addition, any polymeric composite such as engineering prepregs or composites, which are polymers filled with pigments, carbon particles, silica, glass fibers, conductive particles such as metal particles or conductive polymers, or mixtures thereof may also be used. For example, a blend of polycarbonate and ABS (Acrylonitrile Butadiene Styrene) may be used for the housing 101a.

[00100] Generally, examples for the housing 101 include, for example, polymeric materials or composites having high temperature resistance.

[00101] Suitable metal or metallic alloys may include stainless steel; aluminum; an alloy such as Ni/Ti alloy; any amorphous metals including those available from Liquid Metal, Inc. or similar ones, such as those described in U.S. Patent No. 6,682,611, and U.S. Patent Application No. 2004/0121283, the entire contents of which are incorporated herein by reference.

[00102] A liquid crystal polymer or a cholesteric liquid crystal polymer, one that can reflect rather than transmit light energy, may be used, for example, as a coating in the interior 101 of the light module housing 101, to minimize the waste of light energy generated by the light source, as described, for example, in U.S. Patent Nos. 4,293,435, 5,332,522, 6,043,861, 6,046,791, 6,573,963, and 6,836,314, the contents of which are incorporated herein by reference.

[00103] Light emitted from the light source 130 having, for example, LED 131 includes an emission spectrum including at least one wavelength λ_1 capable of initiating curing of a composite. At least a portion of the light, for example, one half of the light as shown in FIG. 3A, may be captured and transformed into a longer wavelength, λ_2 , also capable of initiating a chemical reaction to cure the dental composite material by at least one wavelength transformer 140 situated in the direct path of the light emitted by the LED 131, as shown in FIG. 3A. The wavelength may be at an oblique angle to the longitudinal axis of rotation of the light module, or any other angle that is most efficient at capturing at least a portion of the light coming from the light source 130.

[00104] Figure 3C shows an exemplary light emitting diode 350 according to one embodiment of the invention. The diode 350 includes a first region of doped semiconductor material 352 of a first "type." The diode 354 also includes a second region of doped semiconductor material 354 on a second opposite "type." As would be understood by one of skill of the art, the "type" of semiconductor material is established during manufacturing of the diode 350 by adding respective quantities of electron donor and/or acceptor atoms. During operation of the diode, electrons and holes from the first 352 and second 354 regions combine near a junction 356 between the

first and second regions. The combination of electrons and holes produces photons which are emitted, in the illustrated embodiment, substantially coplanar with a plane of the junction 356. Accordingly, the photons generated at the junction 356 emerge from the diode 350 through the four edges 360, 362, 364 and 366 of the diode. According to one embodiment of the invention, edges 362 and 366 each may include a respective coating or film of absorber/emitter material 368, 370. The absorber/emitter material may be disposed such that light escaping from the edges 352, 366 passes through the respective absorber/emitter material 368, 370. As is discussed above and will be discussed in additional detail below, a portion of the light passing through the absorber/emitter material 368, 370, may be absorbed by the absorber/emitter material. This absorption process energizes electrons within the absorber/emitter material and results in the emission of light of a longer wavelength when the energized electrons return to their respective lower energy states. Consequently, the absorber/emitter material acts as a wavelength transformer with respect to some or substantially all of the light being emitted through edges 362 and 366. Notably, light emitted through edges 360 and 364 that does not pass through the absorber/emitter material 368, 370, and consequently no wavelength transformation takes place with respect to this light. As a result, a portion of the light produced by the diode 350 has a wavelength within a first spectral distribution, and a further portion of the light produced by the diode 350 has a wavelength within a second, transformed, spectral distribution.

[00105] One of skill of the art will appreciate that the arrangement of coated edges shown in diode 350 of figure 3C is only one of a wide variety of possible configurations intended

by the inventor to fall within the scope of the invention. For example, one edge alone of the diode, rather than the illustrated two edges, may include the absorber/emitter material. In another embodiment, three of the four edges may have the absorber/emitter material disposed thereupon. In still another embodiment, the diode may include a different number of edges, such as, for example 3 for a triangular diode, five for a pentagonal diode, six for a hexagonal diode, and so on. In each case, the particular number and arrangement of coated sides may be selected according to the requirements of a particular application.

[00106] In another embodiment, the absorber/emitter material may be present as a bulk material or window, rather than a deposited or absorbed film. In still another embodiment, more than one absorber/emitter material may be disposed on respective edges of a diode, so as to produce a particularly desired spectral distribution of light.

[00107] Still other embodiments of the invention may include an absorber/emitter material that is disposed on a diode edge with a particular geometric pattern or random distribution, such that light of both transformed and un-transformed wavelengths is emitted from that edge.

[00108] FIG. 4 depicts another embodiment of the present invention including a beam splitter 150 positioned in the direct path of the light emitted by the light source 130 to split the beam into two beams. Positioned in the path of one of the beams includes at least one wavelength transformer 140 capable of capturing substantially all of the light and transforming it into a longer wavelength λ_3 . The wavelength transformer may be positioned in the direct path of the beam of light coming from the beam splitter, as shown here.

[00109] In addition, more than one wavelength transformers may be used, as shown in FIG. 5. In FIG. 5, wavelength transformers 141 and 142 are positioned at oblique angles to the light path of the light source 130 so as to capture any light not captured by the beam splitter 150 or the other wavelength transformer 140. These other wavelength transformers, 141 and 142 may be of the same type as 140 or of a type that transforms only a part of the emitted wavelength.

[00110] Additionally, as shown in FIG. 6, at least one reflector 160 may be positioned about the mounting 121 for the LED 131. In this embodiment, the reflector is conical and may include a surface adapted to reflect and direct substantially all stray light emitted by the LED 131 towards the proximal end 112 of the handle 102. At least one wavelength transformer 140 is positioned in the path of the light coming both from the LED and the reflector 160, as shown in FIG. 7.

[00111] In another embodiment, the walls of a curved heat sink, as shown in FIG. 15, may also act as a reflector.

[00112] In other embodiments, the inside surface 101a of the light module housing 101 may include reflecting surfaces, adapted also for reflecting and directing substantially all stray light emitted by the LED 131 towards the proximal end 112 of the light module housing 101. At least one wavelength transformer 140 is positioned in the path of the light coming both from the LED and the reflector.

[00113] The reflector may include an opening through which light passes through.

[00114] In one aspect, the reflecting surface is present

towards the proximal end 112, near the head and neck portion 103 of the housing 101. In another aspect, the reflecting surface may be present in substantially most of the interior of the proximal end 112 of the light module housing.

[00115] The reflecting surface of the reflector 160, the curved walls of a heat sink 120, or the interior 101a includes, for example, a reflective metal, a highly polished metal, or a non-specular paint. A reflective metal, for example, a metal having a reflectivity greater than 90% may improve the yield of light collected by the curing light by, may be 50%. Examples of suitable metals include silver, aluminum, rhodium, gold or combinations thereof. The reflective metal may also be selected based on, for example, the substrate the reflective layer is to be deposited, or the wavelength of the light it is to reflect. For example, it is known that gold is highly reflective of light in the red or infra-red wavelength ranges.

[00116] Other embodiments of the reflecting surfaces include anodized aluminum, and surfaces formed by vapor deposition of dielectric layers onto metallic layers, or polymeric layers, for example, a metallic layer on an anodized surface as the base reflection layer, followed by deposition of a low refractive index and then a high refractive index dielectric layer, such as those available from Alanod, Ltd. of the United Kingdom.

[00117] In addition, the reflector 160 may also include a liquid crystal polymer, one that reflects rather than transmits light energy, either as a surface coating for the reflecting surface or as a main ingredient of the reflector 150. The liquid crystal polymer may include that as described, for example, in U.S. Patent Nos. 4,293,435;

5,332,522; 6,043,861; 6,046,791; 6,573,963; and 6,836,314, or other materials with similar properties. Also, a reflector usable in the present invention includes various reflectors having various different configurations, and may, for example, be of a parabolic one, capable of directing the light emitted by the LED towards the proximal end of the handle.

[00118] At least one reflector 160 may also be integral to the light source, either formed on or attached to it. This reflector 160 may also be, for example, of a parabolic shape, again capable of directing the light emitted by the LED towards the proximal end of handle.

[00119] In FIG. 7, light emitted from the LED 131 includes an emission spectrum having at least one wavelength capable of initiating curing of a composite. A device situated in the light path of the emitting LED includes at least one wavelength transformer 140 for transforming at least a portion of the light emitted by the LED 131 into a longer wavelength, which is also capable of initiating a chemical reaction to cure the dental composite material, and at least one reflector capable of reflecting substantially all light in its path towards the wavelength transformer. The light in the path of the reflector may be substantially all of the light or a portion of the light emitted by the light source 130, or it may also be either all or a portion of the light coming from the beam splitter (not shown in FIG. 7). As is discussed above, more than one wavelength transformer and/or more than one reflector may be present in the light path.

[00120] Thus, the beneficial properties of the wavelength transformers of the present invention, either including organic or inorganic dyes, pigments, semiconductor nanocrystals as disclosed above, or combinations thereof,

capable of emitting narrower spectra; capable of absorbing wavelength lower than those suitable for activating curable composites and emitting a broader spectrum including wavelengths useful for curing composites; capable of absorbing wavelength shorter than those suitable for activating curable composites and emitting a narrow spectrum including a longer wavelength useful for curing composites; or combinations thereof; may go to alleviate thermal management problems present in the confined space of a portable curing light device.

[00121] Use of a light transport device such as a light guide 170, as shown in FIG. 8, may be a means of keeping heat away from the target surface and its surroundings, such as a patient's mouth, and may also help in terms of run time and thermal management of the system. The light guide may help to diffuse, rather than concentrate the point of heat generation. The light guide 170 may be of an elongated shape, as shown, and may be in the form of a substantially hollow tube, pipe or an optically conductive cable, having a distal end 171, attached to the proximal end 112 of the light module housing 101, and a proximal end 172 having a cover 173. The cover 173 may include a focusing dome, or lens 174 for focusing the light towards the target surface, as shown in FIG. 10. The cover, in an alternative embodiment, may include a tip, such as a tacking tip 175, as shown in FIG. 11, for molding, shaping or compacting the curable composite. The focusing dome or lens 174 may also act as a means for varying the size of the light beam exiting the proximal end 112 of the handle 102, in order to more correctly directing the beam of light, either at a small target area or over a wider target area. The varying diameter feature may be accomplished by means of different focusing domes or lens, or a dome or lens may have an adjusting mechanism to vary the beam diameter.

[00122] In another embodiment, the light guide 170 may be the head and neck portion 103 of the housing, as described above.

[00123] In yet another embodiment, the light guide may be a device for aiding the positioning of the curing light, and an example of such a light guide is shown in FIG. 9A. The light guide includes a distal end 171 having at least one formation, adapted to be coupled to a light source 130, having a formation, for example, a support structure at the proximal end 112 of the housing 101, and a proximal end 172 having at least one formation adapted to be coupled, additionally or in turn, to a lip retracting device 500, as shown in FIG. 9B, which is adapted to draw the soft tissue of the lips away from the teeth of a subject patient so as to provide an unobstructed path between the proximal end of the light guide and a tooth surface of the subject patient. The lip retracting device includes at least one formation, for example, a wing-like member, adapted for coupling it to the at least one formation of the light guide. The lip retracting device is described in U.S. Patent Application No. 60/641,461, the contents of which are incorporated herein by reference.

[00124] The light guide 170 as shown, includes an elliptically tubular member having an axial cavity 179 disposed between a front aperture 176 and a rear aperture 178. As shown in the illustrated embodiment, a first edge 181 of the tubular member defines a substantially elliptically saddle shaped curve having a convex form in relation to a generally horizontal portion 180 thereof and a concave form in relation to a generally vertical portion 182 thereof. In addition, edge 181 includes first and second substantially horizontal slots 184, 186. According to one embodiment of the invention,

the slots 184, 186 are disposed substantially coplanar with respect to one another and are disposed substantially coincident with a major axis of the elliptically saddle shaped curve that defines edge 181.

[00125] As shown in the illustrated embodiment, a rim 188 extends radially inwardly from the edge 181 to a second substantially elliptically saddle shaped curved edge 190 (also referred to as the "second edge"). The second edge 190 is disposed in substantially constant space relation to edge 181, whereby the rim 118 has a substantially uniform radial dimension over the length of edge 181. Edge 190 defines an outer periphery of the front aperture 186.

[00126] At the rear end of the embodiment of figure 9A, a third edge 200 defines another curve that is of an approximately elliptically saddle shape. Edge 200 may be substantially concave in form in relation to a generally horizontal portion 132 thereof and is generally convex in form in relation to a generally vertical portion 234 thereof. The detailed description of the light guide is found in U.S. Provisional Patent Applications No. 60/641,468 and 60/647,580; Co-pending U.S. Patent Application entitled "Light Guide for Dentistry Applications", to be filed concurrently with this case, and U.S. Design Patent Application No. 29/220,680 incorporated herein by reference in their entirety.

[00127] The light guide 170 may be made of similar material as that of the light module housing 102 as described above. Also, biodegradable or biocompostable polyesters such as a polylactic acid resin (comprising L-lactic acid and D-lactic acid) and polyglycolic acid (PGA); polyhydroxyvalerate/hydroxybutyrate resin (PHBV) (copolymer of 3-hydroxy butyric acid and 3-hydroxy pentanoic acid (3-hydroxy valeric acid) and polyhydroxyalkanoate (PHA) copolymers; and

polyester/urethane resin are also suitable, especially if single-use.

[00128] Additionally, like the light module housing 101, a cholesteric liquid crystal polymer, one that reflects rather than transmits light energy, may be used, either as a coating or as the main ingredient of the light guide to minimize escape of light energy, as described, above, for example.

[00129] Also, the structure of the light guide, for example, may include a UV-inhibiting material in order to protect the patient's skin from ultra-violet light exposure.

[00130] The handle 102 of the curing light may be fitted with a hand grip device 300 having coupling pin 301, for coupling the curing light to the light guide 170, as shown in FIG. 12.

[00131] The handle 102 may also be adapted to rest on the horizontal portion of the light guide structure 170 during use, to help to support the curing light. For example, as shown in figure 9B, the light guide 170 may be coupled to a lip retracting device 500 by coupling together the respective slots 186 of the light guide and wings 502 of the lip retracting device 500. According to one embodiment, the light guide 170 includes a pedestal 504 disposed therein. The pedestal may have, according to an exemplary embodiment, an upper surface 506 with a vertical bore 508. In one embodiment, the vertical bore 508 may be adapted to receive a coupling pin 301 (as illustrated in Fig. 12). This arrangement allows the ready coupling and decoupling of the curing light and light guide, when the light guide is used to support the curing light.

[00132] Figure 9c shows another embodiment of the invention in which the curing light is merely rested on the upper surface 506 of the pedestal 504 within the light guide 170.

[00133] The positioning light guide may help to fix the position between the light source and the target area, so that any accidental movement by the operator does not also result in the curing light being pointed in an undesirable location, leading to potential tissue damage.

[00134] The heat sink 120 may also play a big part in thermal management in the present invention. In the embodiment depicted in FIG. 13, multiple LEDs or LED arrays 131 may be mounted on the mounting platforms 121 of one heat sink 120. FIG. 13 shows the emitted light passing through at least one wavelength transformer and being collected by a reflecting apparatus and focused by a lens.

[00135] In another embodiment of the invention, as is shown in FIG. 14A, each of the LEDs or LED arrays 131 may be formed on or attached to a primary heat sink 120a which may be mounted to the mounting platform 121 on a secondary heat sink, such as an elongated heat sink 120. The primary heat sinks 120a are smaller in overall volume than the secondary heat sink 120. In another aspect, no secondary heat sink is present. In yet another aspect, the secondary heat sink may be an air gap, an air jacket, a fan or combinations thereof as exemplified, for example, by the embodiment of Figure 14B.

[00136] Figure 14B shows, in cross section, a portion 400 of a curing light according to one embodiment of the invention. The curing light includes a light source 401 including an array of light emitting diodes 402 disposed on a substrate 404. The light source is supported on a proximal surface of a heat sink 406. An electric motor 410 is coupled to, and

supported by, a distal surface of the heat sink 406. The motor 410 includes a motor housing 412 and a rotatable shaft 414.

[00137] Rotatable shaft 414 may be substantially fixedly coupled to a fan 416, such as a centrifugal or vane-axial fan, such that operation of the motor 410 causes rotation of the fan 416.

[00138] During operation of the curing light 400, the motor 410 is operated to cause rotation of the fan 416. The motor 410 may be operated intermittently, cyclically, or continuously, according to the design of a particular embodiment of the invention. As the fan 416 is rotated, air is ejected from the fan blades or vanes through one or more exhaust ports 420 disposed in the housing of the curing light 400. As air is ejected from the exhaust ports 420, ambient air pressure causes a flow of external cooling air inwardly through one or more intake ports 422. The cooling air flows more or less axially past the light source 401 and past one or more surfaces of the heat sink 406. According to the illustrated embodiment, the cooling air also flows past one or more surfaces of the housing 412 of the motor 410, such that the light source 401, the heat sink 406 and the motor 410, each gives up excess heat to the cooling air. In this way, the light source 401 and motor 410 are maintained within respective specified operating temperature ranges.

[00139] In still another embodiment of the invention, the at least one LED located in the mounting platform located towards the proximal end 112 of the housing 110 may have, at the proximal end, a reflector formed by the LED carrier 130 disposed through a heat reflector having a length for example 140 which may be capable of reflecting a the light emitted by the LED towards the proximal end 112 of the housing 101.

apparatus 160 and focused by a focusing means 165.

[00141] The reflector apparatus includes at least one reflector 160 which may be in any of the shapes described above, for example, a parabolic one, adapted for reflecting light towards the proximal end 112 of the handle 101.

[00142] The focusing means 165 may be fixed or removable and may be located towards the proximal end of the light module housing 101 and may include a focusing lens for focusing the light towards the target surface. The focusing means may also be a cover 173 which may include a focusing dome, or lens 174. The cover may also include a tip, such as a tacking tip 175, for molding, shaping or compacting the curable composite. The tacking tip may be a removable attachment. The focusing dome or lens 174 may also act as a means for varying the size of the light beam exiting the proximal end 112 of the handle 102, in order to more correctly directing the beam of light, either at a small target area or over a wider target area, as noted before.

[00143] As noted, the heat sink may be an elongated heat sink, but it may also be of any other shape. The primary heat sinks, if present, may be attached to the LEDs, either by integral forming such as molding, or by attachment means, such as an adhesive. The mounting platform 121 may include a well in the surface of the heat sink which may also act as a reflecting surface.

[00144] A heat sink 120 may also include a deep well, as shown in FIG. 15a, which depicts a cross-sectional view. In this embodiment, the elongated heat sink 120 has a deep well having side walls with the proximal end 120a being at the top

of the well and the distal end 120b at the bottom of the well. At least two mounting platforms 121 may be located towards the proximal end 120a, and at least one mounting platform 121 may be located towards the distal end 120b of the elongated heat sink. On each of the mounting platforms 121 may be mounted at least one LED 131. The LED 131 may be capable of emitting same or different wavelengths. This curing light construction may be capable of more effective heat dissipation by not concentrating the heat product at one location.

[00145] At the distal end 120b, there may be a smaller primary heat sink 150 or an LED having a smaller primary heat sink 150 mounted thereon. The smaller primary heat sink may also comprise a well, which may also act as a reflector if it includes a reflecting surface, to reflect all stray light towards the target area.

[00146] The elongated heat sink 120 as shown may also have a planar mounting platform 121 on its distal end (not shown) for mounting light sources such as LEDs or arrays 131, or the platform may include a reflector. Though the heat sink 120 is shown as an elongated shape, it may also be of other shapes, as desired, for rapid heat dissipation or transfer away from the light sources.

[00147] Heat management is important, especially for a compact and/or hand held curing light. If heat transfer and dissipation are not handled adequately, damage to the LEDs or LED arrays 131 may result, or light output of the LEDs or LED arrays may be diminished or compromised.

[00148] Different geometric shapes facilitate the arrangements of the light sources for improved runtime

efficiency. This along with higher efficiency heat sinks may lead to a better curing light.

[00149] In one embodiment, the light module housing 101 may be separated from the heat sink 120 by a buffer layer or an insulating means 163. The heat sink 120 may occupy less than about 50%, less than about 60% of the length of the light module housing 101. Electrically conductive wires 164 are also provided to power the light sources such as the LEDs or LED arrays 131. A buffer layer or an insulation means 163 is there to separate the heat sink 120 from the housing 101 to facilitate heat dissipation, and may be in the form of an insulation tape, an air space, an air jacket, or any material that will provide spacing and distance between the heat sink 120 and the light module housing 101 to form an air jacket in between to permit air circulation, ventilation and heat dissipation. The insulation means may also include rubbers, silicones, plastics or other materials.

[00150] The housing 101 may also have one or more vents or holes 161a to permit or encourage air to travel from outside the casing 161 into the air jacket 163, and/or to permit or encourage air from the air jacket 163 to travel outside of the housing 161. This air exchange may assist in cooling the light module 101, especially during the resting or recharging cycle of the device. The air jacket 163 may thus assist in avoiding a buildup of heat in the device that could result in short run time or even cause user discomfort.

[00151] As an exemplary embodiment of the heat sink 120, FIG. 15 shows the heat sink as an elongated heat sink having a curved structure for positioning an LED or array 131 at its proximal end 120b. There may be a smaller primary heat sink 120' or an LED having a smaller primary heat sink 120' mounted thereon.

[00152] As another exemplary embodiment, the elongated heat sink 120 as shown in FIG. 16 may have a planar mounting platform 121 on its proximal end 120b for mounting a light source such as LEDs or arrays 131. In addition, the LED or LED array 131 may be covered by a protective cover, dome or a focus lens 139. In one embodiment, the protective cover, dome or focus lens may also include a wavelength transformer 140. This may potentially improve the efficiency of the system and decrease the amount of heat needed to be diverted or conducted away from the light sources 130.

[00153] Though the heat sink 120 is shown as an elongated shape, it may also be of other shapes, as desired, for rapid heat dissipation or transfer away from the LEDs or arrays 131.

[00154] The heat sink may be made of any material that has good thermal conductivity, including metal blocks of copper, aluminum or similar. In another embodiment, the cooling system includes heat pipes. In another embodiment, the cooling system includes phase change materials, some embodiments and material are exemplified as is described in U.S. Application No. 60/585,224, "Dental Light Devices With Phase Change Material Filled Heat Sink", filed on 7/2/2004, the contents of which are incorporated herein by reference.

[00155] For example, the heat sink may include a block of thermally conductive material such as a metal having a bore or void space which is at least partially filled with a phase change material.

[00156] The heat sink may includes a material that can more efficiently remove or divert heat from a curing light device

when a reduced weight of heat sink material is used for better portability.

[00157] In one embodiment, the heat sink may include a phase change material that is more efficient in removing or diverting heat from a light source or sources with a given weight of heat sink material when compare to a heat sink made of a solid block of thermally conductive material such as metal.

[00158] In another embodiment, the heat sink may include at least one suitable phase change material including organic materials, inorganic materials and combinations thereof. These materials can undergo substantially reversible phase changes, and can typically go through a large, if not an infinite number of cycles without losing their effectiveness.

[00159] In other embodiments, the heat sink may include compressed air cartridges which may be easily installed and replaced. The housing may be constructed with a support platform, similar to that for mounting a battery pack, for mounting cartridges. The cartridges may contain sufficient cooling for each cycle or multiple cycles.

[00160] As another example, the heat sink maybe of a thermoelectric cooling type, also called "the Peltier Effect," which is a solid-state method of heat transfer through dissimilar semiconductor materials. The semiconductor materials are N and P types, with the N-type having more electrons than necessary to complete a perfect molecular lattice structure, and the P-type not having enough electrons to complete a lattice structure. The extra electrons in the N-type material and the holes left in the P-type material are called "carriers" and they are the agents that move the heat

energy from the cold to the hot junction. Heat absorbed at the cold junction is pumped to the hot junction at a rate proportional to carrier current passing through the circuit and the number of couples.

[00161] The cold junction or evaporator surface becomes cold through absorption of energy by the electrons as they pass from one semiconductor to other semiconductor material or materials with dissimilar characteristics which are connected electrically in series and thermally in parallel, so that two junctions are created.

[00162] Good thermoelectric semiconductor materials such as bismuth telluride greatly impede conventional heat conduction from hot to cold areas, yet provide an easy flow for the carriers. In addition, these materials have carriers with a capacity for transferring more heat.

[00163] For a thermoelectric type heat sink, heat maybe transferred by the usual modes of conduction, convection, and radiation.

[00164] The heat sink may be constructed, for example, by hollowing out a thermally conductive material, such as metal, and at least partially filling the void with at least one phase change material prior to capping it to secure the phase change material inside, such that the at least one phase change material is substantially contained or surrounded by a thermally conductive material such as metal normally used in the construction of a conventional metal heat sink.

[00165] As another example, the heat sink may be cast or machined out of a thermally conductive material such as metal walls surrounding a bore or void. The bore or void is

partially filled with at least one phase change material prior to capping it to secure the material inside. If desired, a heat sink may also have fins or other outer surface modifications or structures to increase surface area and enhance heat dissipation.

[00166] Other or additional features may also be included in the curing light of the present invention. For example, FIG. 17 shows a perspective view of a curing device. A switch 108a is provided on the top of the housing 101, while a second switch 108b is provided on the side of the housing 101. These switches 108a and 108b are means for turning the light emission of the light on and off and may take the form of such as a button or trigger. A timer 109 (including, for example, increment 550 and decrement 552 buttons and a miniature time remaining display 554) may also be provided to control the duration of time that the light is on. Other control buttons such as to set and adjust the timer (not shown) can also be present on the handle.

[00167] An audible indicator or beeper may be provided in some lights to indicate when light emission from the light module begins and ends. In one embodiment, this may be a voice alert system, verbally relating the stage and progress of the operation. In another embodiment, this may be a voice alert system, verbally relating the stage and progress of the operation as well as an auto shut off of the light source at the end of the cycle.

[00168] An indicator 210 for indicating low battery power may be located on the housing 101 in a location that is easily visible to the dental professional during use concerning the status of the battery power of the battery powered curing light, as shown in FIG. 17. A second indicator 210a may also

be located on the housing in a visible location in order to indicate to the user that the battery is being charged. These indicators may also be LEDs.

[00169] There is also a main on/off switch 230 provided at the rear or proximal end 112 of the housing 101. An optional wavelength selector (not shown) may also be provided in some curing lights so that the dental professional may select the wavelength of light that he/she wishes to emit from the light, depending on the wavelength sensitivity of the photoinitiator in the light-activated material that he is using. The user may also select a combination of two or more wavelengths of light to be emitted together in some lights.

[00170] A separate battery charger module 220 may be included in order to receive AC power from a traditional wall socket and provide DC power to the light system for both charging the batteries and powering the light source and control circuitry when the batteries if desired, as shown in FIG. 18. The battery charger module 221 has a cable 221a and a plug 221b for plugging into a receptacle or connector 222 on the distal end 111 of the light module housing 101. The battery charger module 221 includes circuitry 221c for controlling battery charging of batteries (not shown).

[00171] The battery charger may also have a built in heat dissipation means for drawing heat away from the curing light while the battery is being charge or simply while the curing light is being rested between use cycles. In one embodiment, the heat dissipation means may include a fan. In another embodiment, the heat dissipation means may include compressed air.

[00172] Having described the invention by the description

and illustrations above, it should be understood that these are exemplary of the invention and are not to be considered as limiting. Accordingly, the invention is not to be considered as limited by the foregoing description, but includes any equivalents.

Claims

1. A dental curing light suitable for curing light curable dental composite materials comprises:

a light module housing having at least one heat sink therein, said heat sink comprising at least one mounting platform for mounting a light source; and

a device proximate the light source comprising at least one wavelength transformer for transforming light of a shorter wavelength suitable for curing light activatable composites into light of a longer wavelength comprising at least a portion that is suitable for curing light activatable composite.

2. The dental curing light of claim 1 wherein said wavelength transformer is capable of capturing substantially all light in its path and transforming at least a portion of the captured light into a longer wavelength.

3. The dental curing light of claim 1 or 2 wherein said wavelength transformer comprises one absorber/emitter having at least a portion that is substantially transparent to an incident light, and at least a portion capable of absorbing an incident light and emitting light having a longer wavelength.

4. The dental curing light of claim 1 or 2 wherein at least one wavelength transformer is positioned to capture substantially all light in its path and transforming only a portion of the captured light into a longer wavelength.

5. The dental curing light of claim 1 or 3 wherein at least one wavelength transformer is configured to capture at least a portion of the light emitted by the light source and transforming all of it into a longer wavelength.

6. The dental curing light of any of the preceding claims wherein said wavelength transformer comprises an absorber/emitter comprising a material selected from the group consisting of an organic dye, a pigment, an inorganic dye, a semiconductor nanocrystal and combinations thereof.

7. The dental curing light of claim 6 wherein said organic dye comprises any fluorescent dye, any compound having an N-aryl substituent and mixtures thereof.

8. The dental curing light of claim 7 wherein said the N-aryl substituent selected from the group consisting of phenyl, naphthyl, anthracyl, dinaphthyl, ditoluylyl, bis(p-methylphenyl), dianthracenyl, mixed aryl groups, substituted aryl groups and combinations thereof.

9. The dental curing light of claim 6 wherein said organic dye absorbs between about 350 nm to about 430 nm and emits between about 450 nm and about 500 nm.

10. The dental curing light of claim 6 wherein said inorganic dye comprises at least one element selected from the lanthanides.

11. The dental curing light of claim 6 wherein said semiconductor nanocrystals are selected from the group consisting of CdS, CdSe, CdTe and mixtures thereof.

12. The dental curing light of claim 1 wherein said light source comprises a cover comprising a wavelength transformer, an emitting surface or combinations thereof.

13. The dental curing light of claim 12 wherein said

emitting surface comprises an absorber/emitter.

14. A dental curing light capable of generating light of a multiple wavelength suitable for curing light curable dental composite materials comprises:

a light module housing; and

at least one heat sink located in the light module housing, said heat sink includes at least one mounting platform for mounting at least one light source comprising at least one wavelength transformer for transforming at least a portion of light emitted by the light source suitable for curing light activatable composites into a longer wavelength suitable for curing light activatable composites.

15. The dental curing light of claim 14 wherein said wavelength transformer is capable of capturing at least a portion of the light emitted by the light source and transforming all captured light into a longer wavelength.

16. The dental curing light of claim 14 wherein said wavelength transformer is capable of capturing all light emitted by the light source and transforming at least a portion of it into a longer wavelength.

17. The dental curing light of claim 14, 15 or 16, wherein said light source comprises a cover comprising a wavelength transformer.

18. The dental curing light of claim 14, 15 or 16, wherein said light source comprises an emitting surface.

19. The dental curing light of claim 18 wherein said wavelength transformer is present on a portion of the emitting surface.

20. The dental curing light of any of claims 14-19, wherein said light source comprises an edge emitting source comprising at least one edge.

21. The dental curing light of claim 20 wherein said wavelength transformer is present on at least one emitting edge.

22. A dental curing light capable of generating light of more than one wavelength suitable for curing light curable dental composite material comprises at least one wavelength transformer capable of transforming at least a portion of light emitted by a light source suitable for curing a dental composite into a longer wavelength suitable for curing a composite.

23. The dental curing light of claim 22 wherein said at least one wavelength transformer comprises at least one absorber/emitter having at least a portion that is substantially transparent to incident light, and at least one portion comprising a chemical capable of absorbing incident light and emitting light having a longer wavelength.

24. The dental curing light of claim 22 or 23 wherein said at least one wavelength transformer is configured to capture substantially all light emitted by the light source.

25. The dental curing light of claim 22 or 23 wherein said at least one wavelength transformer is configured to capture at least a portion of light emitted by the light source.

26. The dental curing light of any of the preceding

claims wherein said wavelength transformer comprises a beam splitter.

27. A dental curing light suitable for curing light curable dental composite materials comprises:

a light module housing having at least one heat sink located therein, said heat sink comprising at least one mounting platform for mounting at least one light source; and

a device positioned in the light path of the light source comprising at least one wavelength transformer for transforming at least a portion of the light emitted by the light source suitable for curing light activatable composites into a longer wavelength suitable for curing light activatable composites.

28. The dental curing light of claim 27 wherein said wavelength transformer comprises at least one beam splitter and at least one absorber/emitter comprising a chemical capable of absorbing incident light and emitting light having a longer wavelength.

29. The dental curing light of claim 27 or 28 wherein said at least one heat sink comprises a well having side walls.

30. The dental curing light of claim 29 wherein at least a portion of the side walls is reflective.

31. The dental curing light of claim 28, 29 or 30, wherein said at least one wavelength transformer is configured to capture substantially one beam coming from the beam splitter.

32. The dental curing light of any of claims 27-31

wherein said at least one wavelength transformer is positioned at an oblique angle to the emitted light path.

33. A curing light system capable of generating light of more than one wavelength suitable for curing light curable dental composite materials comprises:

a light module housing having at least one heat sink therein, said heat sink comprising at least one mounting platform for mounting a light source;

a device positioned proximate the light source comprising at least one wavelength transformer for transforming light of a shorter wavelength suitable for curing light activatable composites into light of a longer wavelength suitable for curing light activatable composites; and

a light guide comprising a formation adapted for supporting the curing light at a target position.

34. The curing light system of claim 33 wherein said system further comprises a lip retracting device comprising wing-like members.

35. The curing light system of claim 33 or 34 wherein said formation is adapted to couple the light guide to the wing-like members of the lip retracting device.

36. The curing light system of claim 35 wherein said light module housing comprises a support means for supporting the curing light on said light guide.

37. The dental curing light of any of the preceding claims wherein said wavelength transformer comprises an absorber/emitter capable of absorbing a relatively broad spectrum and transforming it into a relatively broad spectrum at a longer wavelength.

38. The dental curing light of any of the claims 1-36 wherein said wavelength transformer comprises an emitter/absorber capable of absorbing a relatively broad spectrum and transforming it into a relatively narrow spectrum at a longer wavelength.

39. The dental curing light of any of the claims 1-36 wherein said wavelength transformer comprises an emitter/absorber capable of absorbing substantially all wavelengths below about 400 nm, and transforming them into a relatively narrow spectrum at a longer wavelength.

40. The dental curing light of any of claims 1-36 wherein said wavelength transformer comprises an emitter/absorber capable of absorbing substantially all wavelengths below about 400 nm, and transforming them into a relatively broad spectrum at a higher wavelength.

41. The dental curing light of any of claims 1-36 wherein said wavelength transformer comprises an emitter/absorber capable of absorbing a relatively narrow spectrum at a low wavelength and transforming it to a relatively narrow spectrum at a higher wavelength.

42. The dental curing light of any of the preceding claims wherein light from the curing light comprises multiple discrete peaks.

43. The dental curing light of any of claims 1-41 wherein light from the curing light comprises a continuum between about 390 nm to about 500 nm.

44. The dental curing light of claim 27 or 33 wherein said light source comprises an edge emitting source comprising at least one edge comprising at least one wavelength transformer.

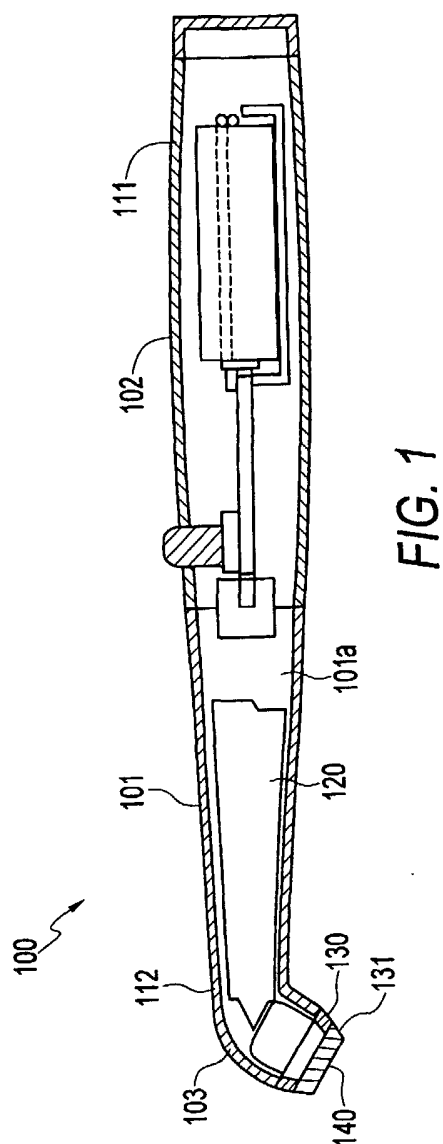
45. The dental curing light of any of the preceding claims wherein said at least one heat sink comprises a phase change material.

46. The dental curing light of any of the preceding claims wherein said device comprises a reflector.

47. The dental curing light of any of the preceding claims wherein said light module housing comprises a reflecting surface.

48. The dental curing light of any of the preceding claims wherein said at least one heat sink comprises a reflecting surface.

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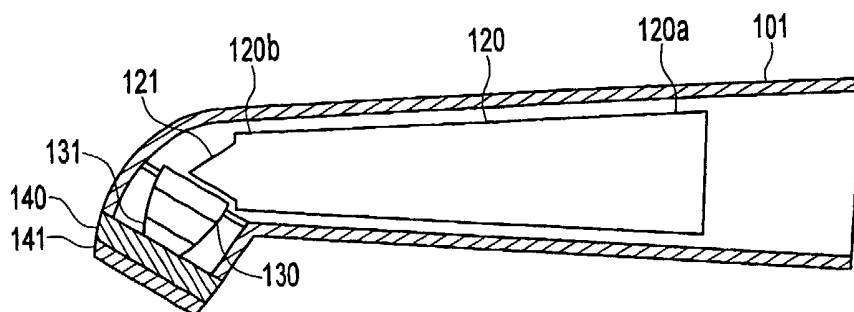


FIG. 2

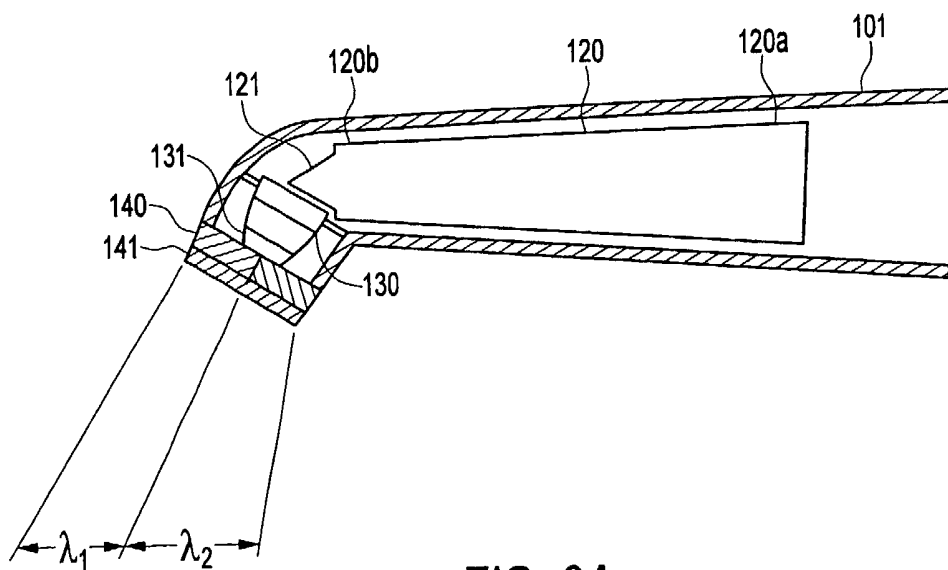


FIG. 3A

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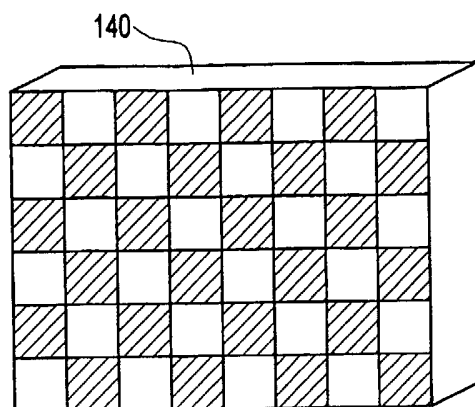


FIG. 3B

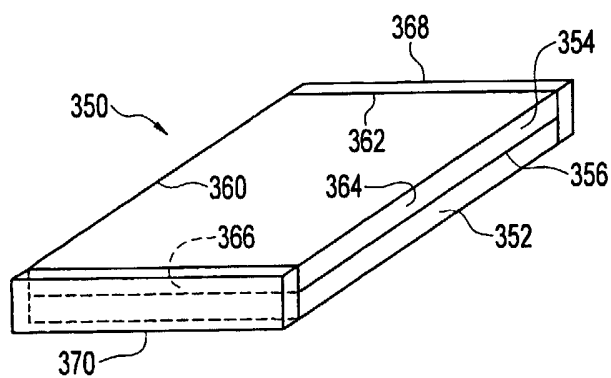


FIG. 3C

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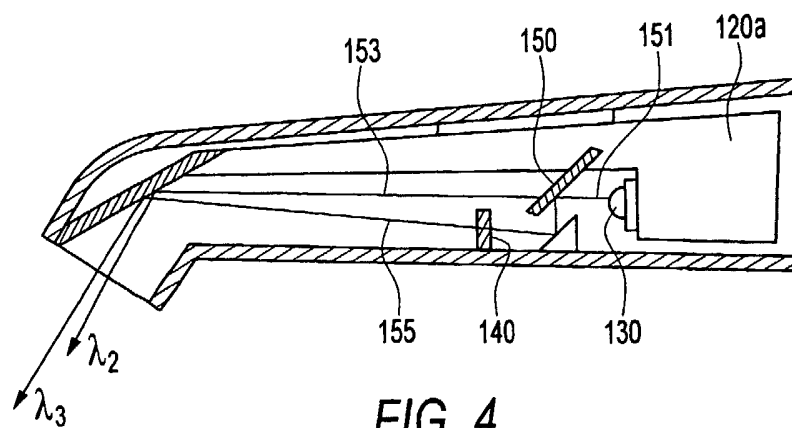


FIG. 4

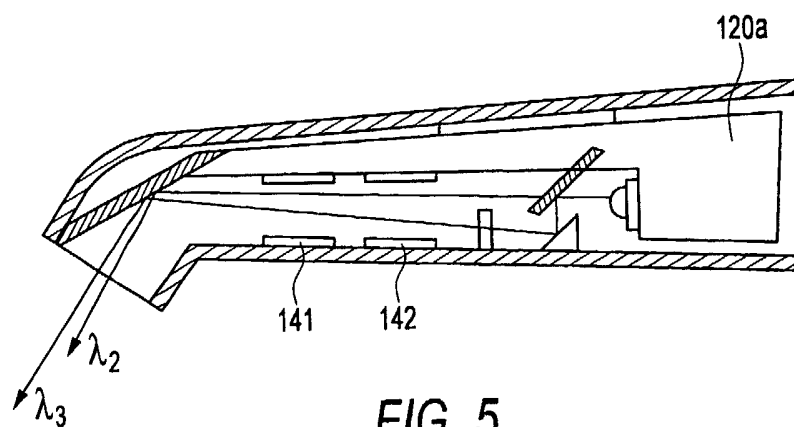


FIG. 5

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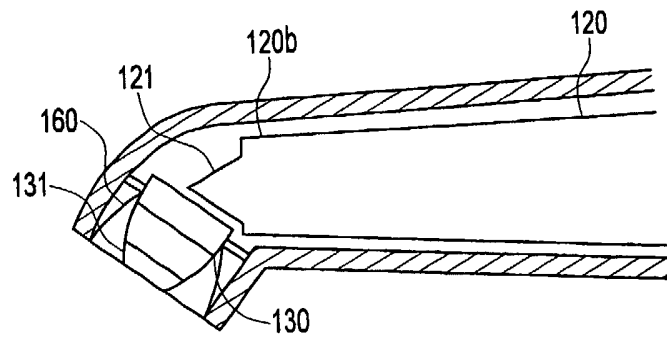


FIG. 6

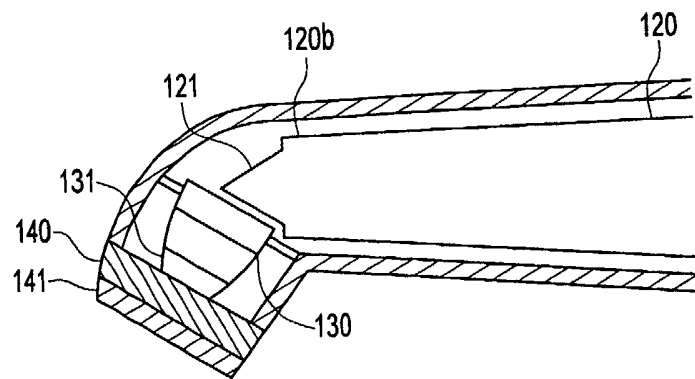


FIG. 7

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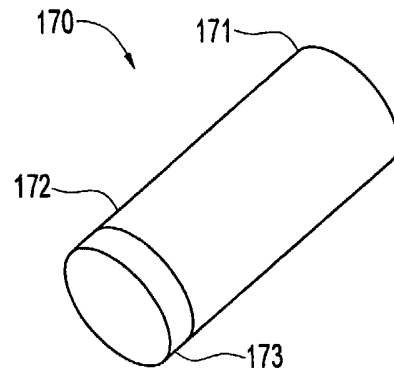


FIG. 8

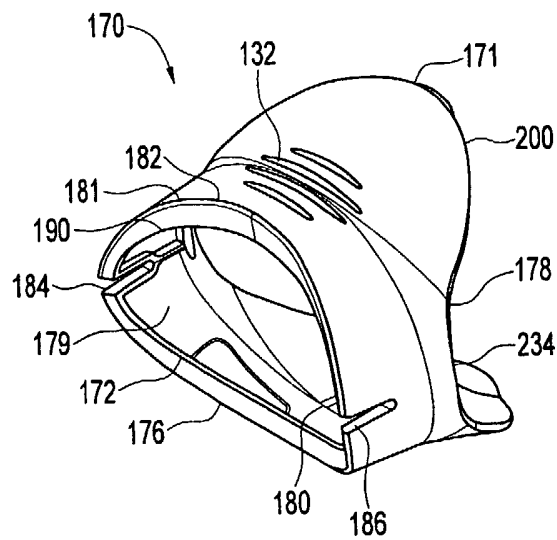


FIG. 9A

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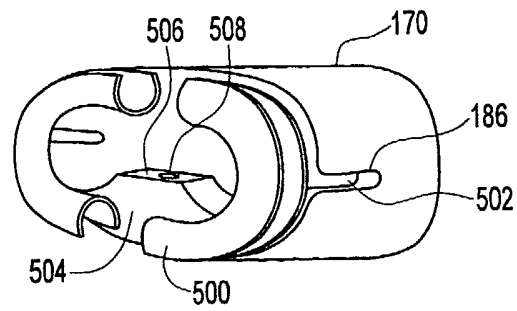


FIG. 9B

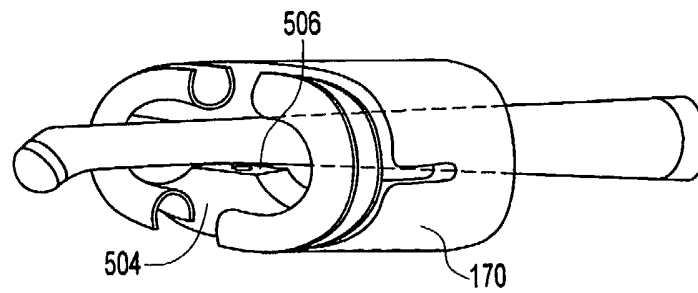


FIG. 9C

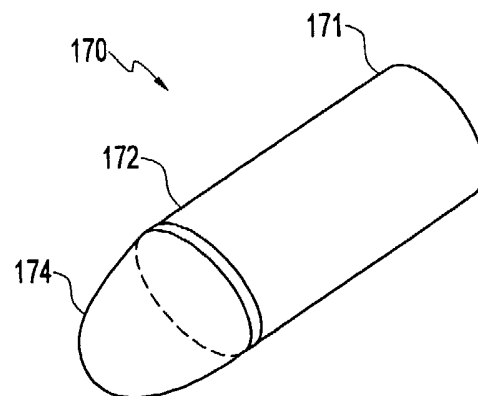


FIG. 10

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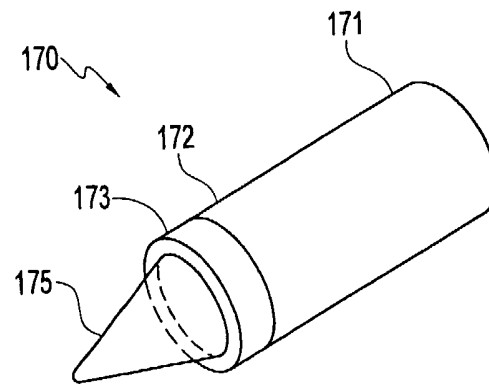


FIG. 11

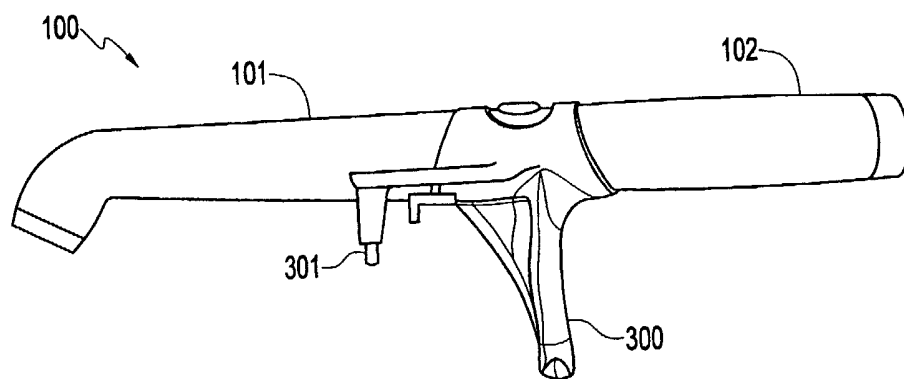


FIG. 12

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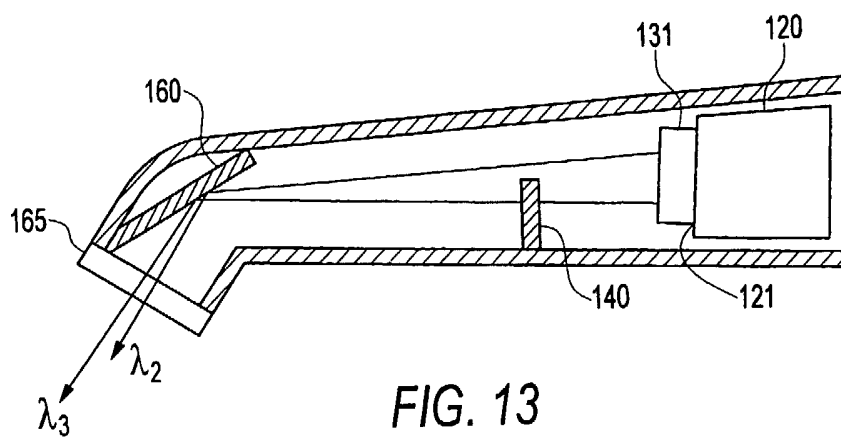


FIG. 13

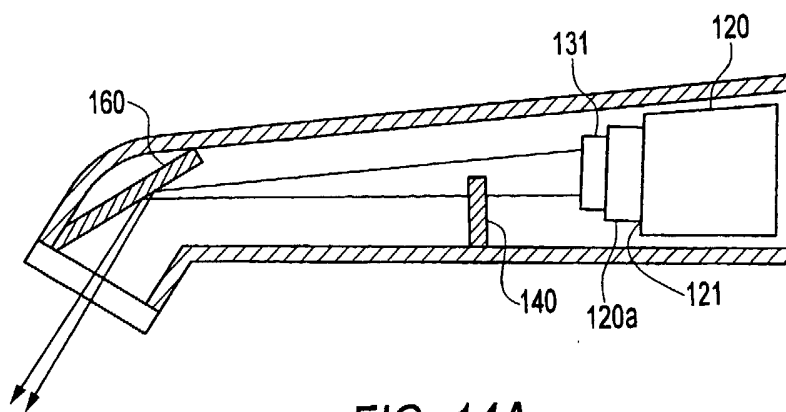


FIG. 14A

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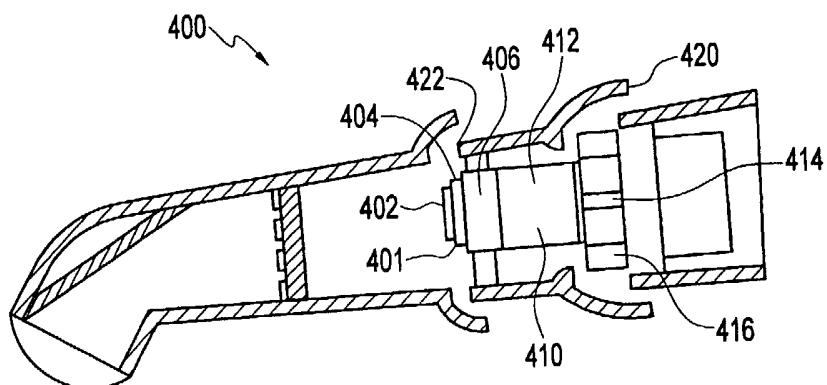


FIG. 14B

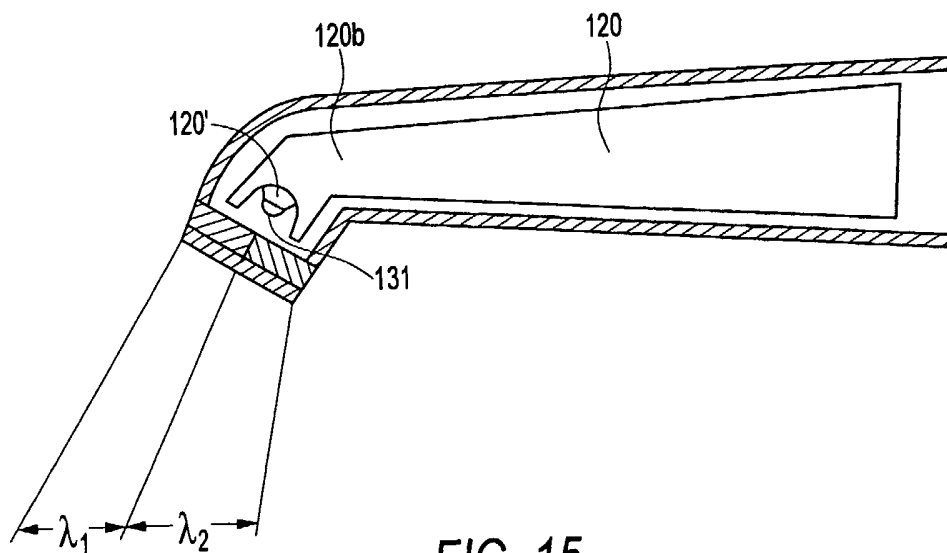


FIG. 15

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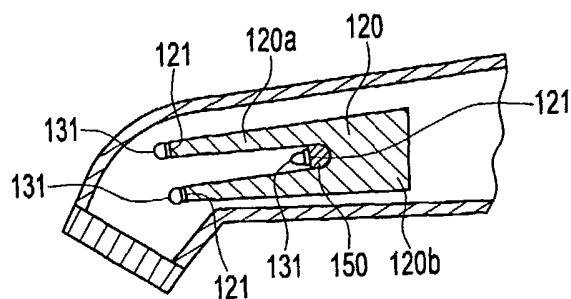


FIG. 15A

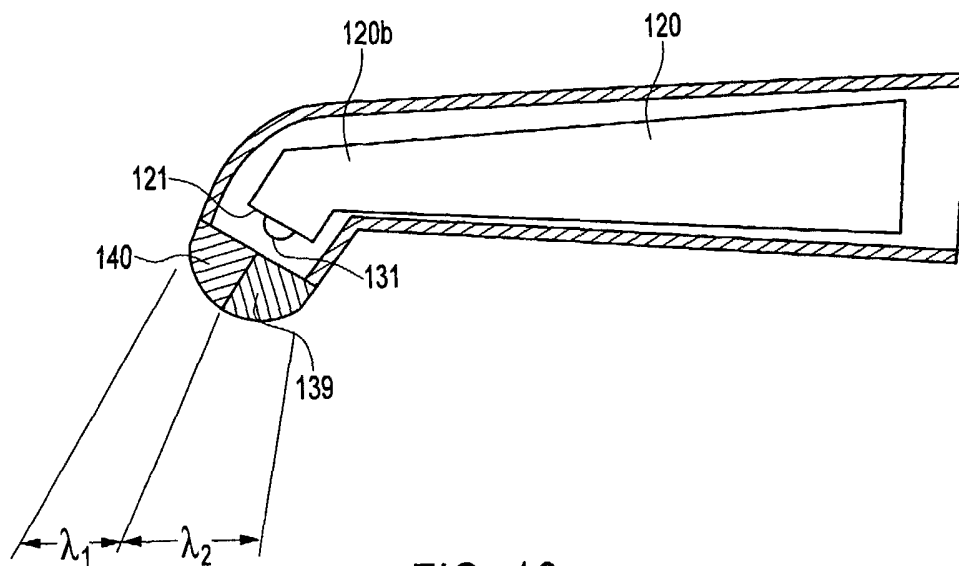


FIG. 16

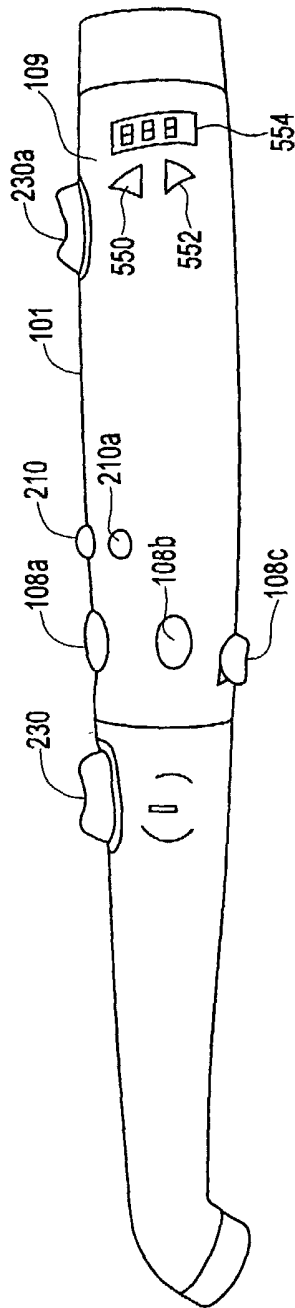


FIG. 17

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