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(54) **SYSTEM AND METHOD FOR A TRANSPARENT COLOR IMAGE DISPLAY UTILIZING FLUORESCENCE CONVERSION OF NANOPARTICLES AND MOLECULES**

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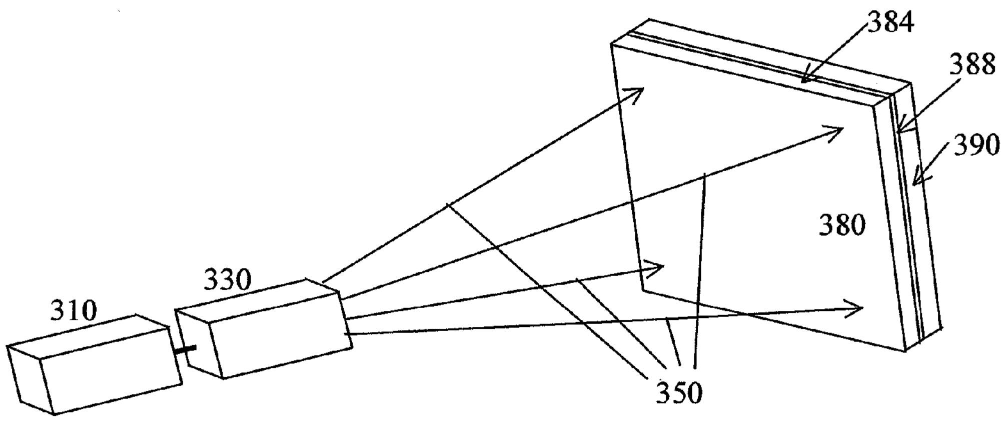
(57) **ABSTRACT**

A system and a method of a transparent color image display utilizing fluorescence conversion (FC) of nano-particles and molecules are disclosed. In one preferred embodiment, a color image display system consists of a light source equipped with two-dimensional optical scanning hardware and a FC display screen board. The FC display screen board consists of a fluorescence display layer, a wavelength filtering coating, and a visibly transparent substrate. In another preferred embodiment, two mechanisms of light excitation are utilized. One of the excitation mechanisms is up-conversion where excitation light wavelength is longer than fluorescence wavelength. The second mechanism is down-conversion where excitation wavelength is shorter than fluorescence wavelength. A host of preferred fluorescence materials for the FC screen are also disclosed. These materials fall into four categories: inorganic nano-meter sized phosphors; organic molecules and dyes; semiconductor based nano particles; and organometallic molecules. These molecules or nano-particles are incorporated in the screen in such a way that allows the visible transparency of the screen. Additionally, a preferred fast light scanning system is disclosed. The preferred scanning system consists of dual-axes acousto-optic light deflector, signal processing and control circuits equipped with a close-loop image feedback to maintain position accuracy and pointing stability of the excitation beam.



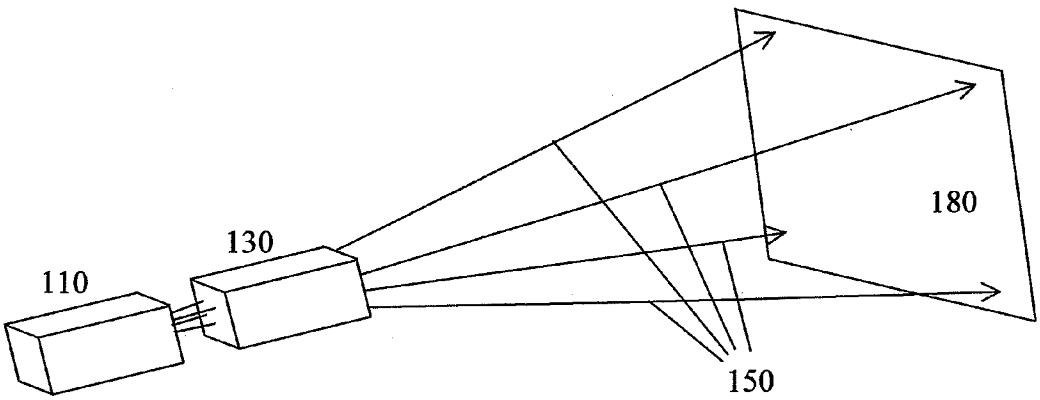


FIG. 1 (PRIOR ART)

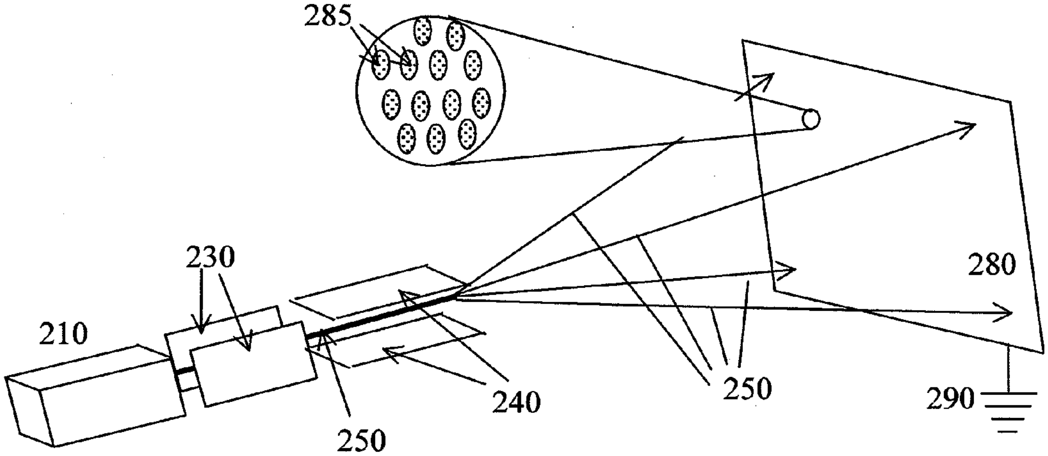


FIG. 2 (PRIOR ART)

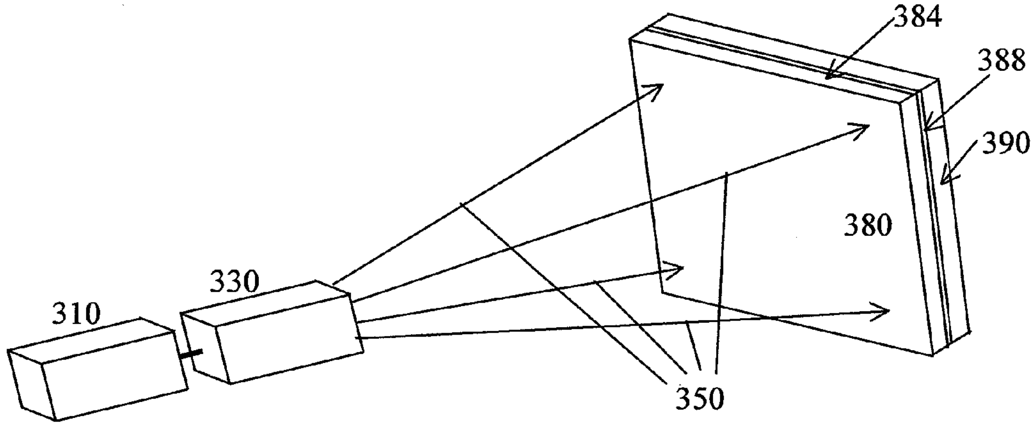


FIG. 3

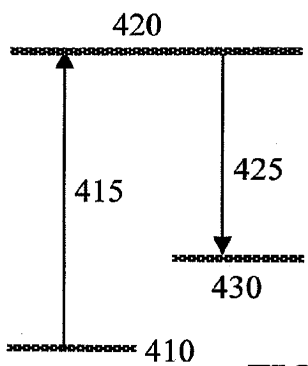


FIG. 4a

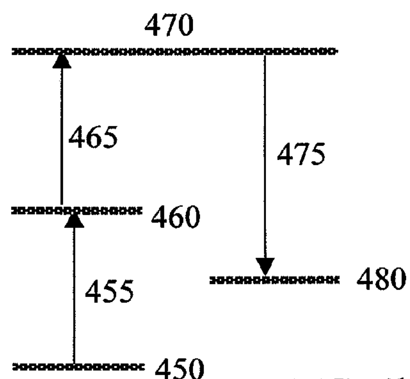


FIG. 4b

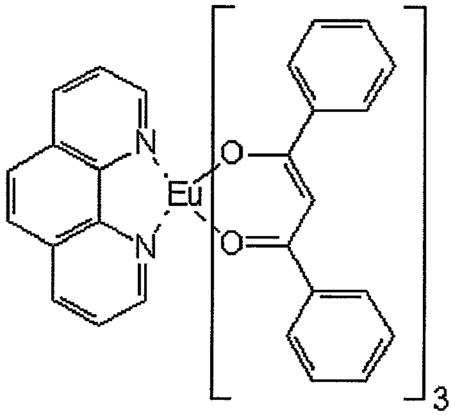


FIG. 5a

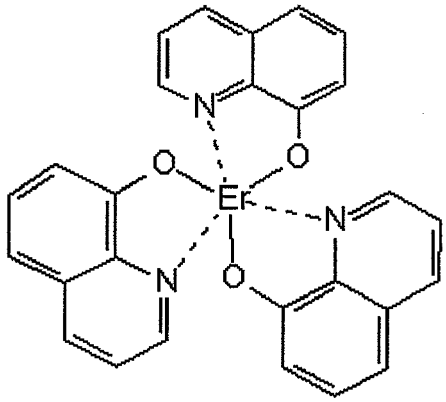


FIG. 5b

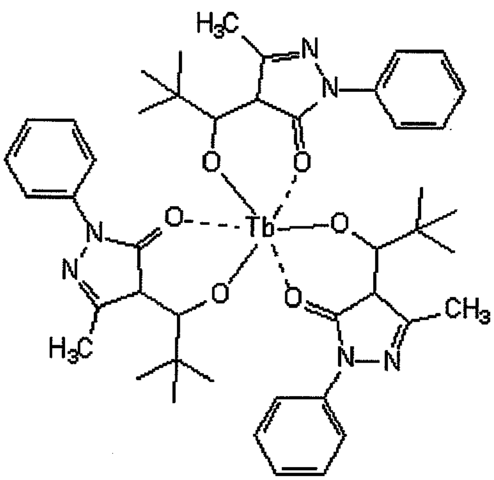


FIG. 5c

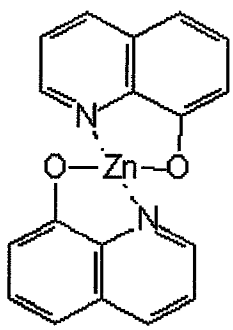


FIG. 5d

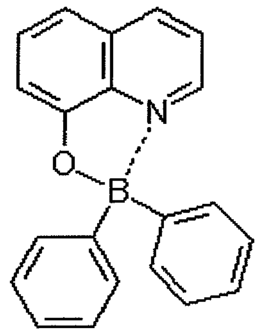


FIG. 5e

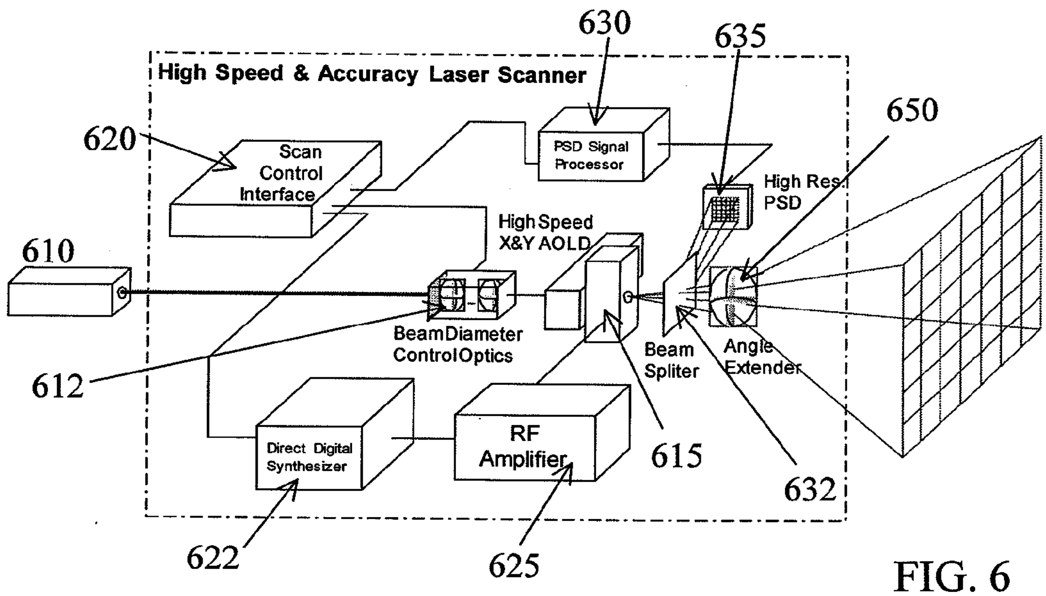

630
635
High Speed & Accuracy Laser Scanner
650
620
Scan Control Interface
PSD Signal Processor
High Res. PSD
High Speed X&Y AOLD
610
BeamDiameter ControlOptics
612
Beam Spliter
Angle Extender
RF Amplifier
Direct Digital Synthesizer
615
632
622
625

FIG. 6

SYSTEM AND METHOD FOR A TRANSPARENT COLOR IMAGE DISPLAY UTILIZING FLUORESCENCE CONVERSION OF NANOPARTICLES AND MOLECULES

[0001] This application claims priority to the provisional application entitled "Advanced laser fluorescent displays", Ser. No. 60/471,968, filed by the same subject inventors and assignee as the subject invention on May 19, 2003.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates generally to displays and more particularly to a system and a method for two-dimensional transparent displays utilizing special laser induced fluorescence media.

[0004] 2. Background Art

[0005] Image display and associated technologies are a fundamental necessity of today's society. Application areas include communication, entertainment, military, medical and health. Traditionally, a display system consists of a source beam, beam masks or deflectors, and a projection screen. Although the basic concept of a display system served us well in the past, new technologies have been developed steadily. As demonstrated in **FIG. 1**, a prior art light beam based display system consists of a collimated light source **110**, a light masking or deflecting unit **130**, and the modified light beam (**150**) strikes a display screen **180**. Typical example of this type of displays are: movie and film display systems, liquid crystal based display, MEMs and liquid crystal based reflective light projection systems for TV and computer. In these light based systems, the image can be viewed on the same side of the projection system as in the case of a movie display, or on the opposite side of the projection system, as in the case of back illuminated large screen projection TV. A common element in these light based display system is that the displaying screen does not change the color (or wavelength) of the illumination light. The screen preferably be opaque to increase scattering of the illuminated light to the viewers. Also the intensity of a particular color component is modulated, and/or the beam position is scanned. In **FIG. 2**, a prior art electron beam based display system is illustrated. These systems are used in Cathode Ray Tube (CRT) based displays for TV and computers and are gradually being replaced by liquid crystal based flat panel displays. A typical CRT display consists of an electron gun **210**, horizontal and vertical beam deflecting conductive plates **230** and **240**, and a conductive screen **280**. A well-collimated electron beam is deflected by periodically changed electrical fields and strikes certain location of the screen at a specified time. The conductive screen is coated with phosphor particles that convert absorbed electrons into photons of a particular color. The intensity of the electron beam is controlled to regulate intensity patterns displayed on the CRT screen. The CRT screen is normally grounded or maintained at certain electrical potential to avoid charge build up. In order to operate properly, these CRT systems are evacuated and sealed in a glass vacuum tube (not shown). In both situations, the display screens are opaque and people cn only see the electronic information on the display surface but can not see through the screens.

[0006] Recently, several research groups have studied the potential of using light conversion as a mean to two- and three-dimensional displays. Of particular interests are the work by E. Downing et. al, as described in an article entitled: "A three-color, Solid-state, Three-dimensional Display" published in Science, vol. 273, pp 1185-89, 1996. The work described in the Science article formed basis for several US patents granted. See for example, U.S. Pat. Nos. 5,684,621; 5,764,403; 5,914,807; 5,943,160; and U.S. Pat. No. 5,956,172 all to Downing. M. Bass and co-workers, at the University at Central Florida, carried out other related research works. Several related US patents were issued. See for example, U.S. Pat. Nos. 6,327,074; 6,501,590; and 6,654,161; to Bass and co-inventors. These patents and article are thereby included herein by ways of reference.

[0007] The research work of Downing et. al, and M. Bass and co-inventors all employed a two color excitation scheme called up-conversion. In an up-conversion process, an absorption center must absorb at least two longer wavelength photons to emit one photon with a shorter wavelength. While Downing et. al, used a solid display material (fluoride ZBLAN glass) doped with rare earth cations, M. Bass and co-workers investigated the use of both dye doped plastics micron particles as well as rare earth cation containing fluoride micron particles ($NaYF_4$) as display medium. The major difference is that the former uses solid glass layers whereas the latter uses solid particle sizes from 0.5 μm to 50 μm. The major drawback for both methods is the use of multiple lasers as the excitation sources. The use of multiple lasers is normally required for the up-conversion process due to the inefficiency of the process. The use of very intense, infrared lasers substantially limits the practical applicability of the research works and may introduce safety hazards for the viewers. For each displaying color, two laser beams with specified laser wavelengths need to be used to generate a particular color. Therefore, in order to realize a three-color display, a three-layered display solid structure doped with three color-specific emitters (rare earth cations, or dyes) together with six excitation lasers have to be used.

[0008] There are several areas that can be improved on these prior art two- and three-dimensional displays. For instance, it is desirable to use a single excitation laser to generate all three colors. Also desirable is methods using one laser for each color instead of the two lasers per color methods used in these prior art displays. Even more desirable is the use of regular safe dark light sources (e.g. Light emitting diodes or arc lamps of UV-blue emission) and a fluorescent "down-conversion" materials for a 2-D display with transparent screen. Inexpensive manufacturing processes are also the key to a practical display technology. There is a need therefore to have improvements to these prior arts such that inexpensive displays with reduced number of laser sources can be made.

SUMMARY OF THE INVENTION

[0009] The present invention discloses an improved system and method, materials and designs of an image display that utilizes fluorescence conversion (FC) process. The disclosed display consists of an excitation light source, a visibly transparent display screen containing fluorescent materials or particles, photo-acoustic light beam steering mechanisms, and a feedback loop. Once illuminated, the fluorescent screen converts the invisible (or less visible) excitation lights into red, green or blue emissions. Rastering or scanning of the excitation beam according to a predefined or a programmed data generates an image on the fluorescent screen.

[0010] Two schemes of FC are disclosed: The first scheme is termed down-conversion, where the excitation wavelength is shorter than fluorescence wavelength; the second scheme is called up-conversion, where laser wavelengths is longer than fluorescence wavelength. In the second case, two or more photons from the laser are necessary to excite the fluorescence particle in order to yield a visible fluorescence photon. A common approach for the first scheme is to apply a UV (or blue) light with wavelength shorter than 500 nm to excite the fluorescence molecules or particles on the image screen; the UV light sources include solid state lasers, semiconductor laser diodes, gas lasers, dye lasers, excimer lasers, and other UV-blue sources including LEDs, Xenon, mercury, or metal halide arc lamps, and other dark lamps familiar to those skilled in the art. A common approach for the second scheme is to apply infrared (IR) lasers with wavelength longer than 700 nm to excite the fluorescence molecules or particles on the Screen. The IR lasers include solid-state lasers, semiconductor laser diodes and other IR sources familiar to those skilled in the art. In both cases, excitation light intensities are modulated to yield visible fluorescence of varying intensity or gray scales.

[0011] To display multiple colors on the screen, fluorescent molecules or nano-particles of different emitting wavelengths are deposited on the displaying screen or dissolved in the screen; multiple excitation light sources of different wavelengths may be combined and illuminated on the screen. Composite displaying colors are obtained through the mixing of three basic fluorescent emitting colors. Molecules or nano-particles with different fluorescent colors are either premixed and deposited as a single layer; or are deposited as a multiple-layered structure on the displaying screen. The molecules and nano-particles are so small that they will not scatter the visible light and block the view through the transparent screen.

[0012] A host of preferred fluorescence materials are also disclosed. These materials fall into four categories: inorganic nano-meter sized phosphors; organic molecules and dyes; semiconductor based nano particles (quantum dots); and organometallic molecules.

[0013] Two methods of image display are disclosed. In the first preferred method, expanded static light beams are applied through a matrix of on-off switches (e.g., a matrix of tiny reflective mirrors), and a fluorescent image is created on the transparent displaying screen. Static images are typically generated from a lookup table. In the second preferred method, a light beam is coupled with a two-dimensional laser scanner (e.g., galvanometer, acousto-optic light deflector (AOLD), and electro-optic light deflector (EOLD)). Electrical signals are applied to steer the light beam to illuminate a particular spot on the screen at a given time. Additionally, signal processing and control circuits are used and equipped with a close-loop image feedback to maintain position accuracy and pointing stability of the laser beam.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The aforementioned objects and advantages of the present invention, as well as additional objects and advantages thereof, will be more fully understood hereinafter as a result of a detailed description of a preferred embodiment when taken in conjunction with the following drawings in which:

[0015] **FIG. 1** illustrates a prior art light beam based image display;

[0016] **FIG. 2** shows the structure of a prior art electron beam based image display;

[0017] **FIG. 3** displays an improved fluorescence conversion image display system;

[0018] **FIGS. 4***a* and **4***b* depict energy level diagrams associated with down-conversion and up-conversion FC schemes;

[0019] **FIGS. 5***a* through **5***e* provide chemical structure information of 5 organometallic molecules that can be used in the fluorescent screen;

[0020] **FIG. 5** illustrates an improved FC image display systems.

DETAILED DESCRIPTION OF THE INVENTION

[0021] The present invention discloses an improved system and method, materials and designs of an transparent image display that utilizes fluorescence conversion (FC) process. The improved display system disclosed herein consists of an excitation light source, a transparent display screen containing fluorescent molecules or nano-particles, photo-acoustic light beam steering mechanisms, and a feed back mechanism. Once illuminated, the fluorescent screen converts the invisible (or less visible) excitation lights into red, green or blue emissions. Rastering or scanning of the excitation beam according to a predefined or a programmed data generates an image on the fluorescent screen.

[0022] The first preferred embodiment of the present invention is illustrated in **FIG. 3**. A radiation source **310** delivers an intense, collimated beam of invisible (or less visible) radiation. The radiation beam passes an optical image processor **330** and the modified radiation beam **350** is projected on to a FC displaying screen **380**. Two methods of image display are disclosed. In the first preferred method, expanded static radiation beams are applied through an image processor **330** contains a matrix of on-off switches (e.g., a matrix of tiny reflective mirrors) to create a dark image, and a fluorescent visible image is created on the displaying screen **380** through fluorescent conversion of the dark image. Static images are typically generated from a lookup table. In the second preferred method, a radiation beam is coupled with an image processor **330** contains a two-dimensional beam scanner (e.g., galvanometer, acousto-optic light deflector (AOLD), and electro-optic light deflector (EOLD)). Electrical signals are applied to steer the radiation beam to illuminate a particular spot of the screen at a given time. The preferred FC screen typically has the following structure: a layer **384** contains fluorescent nano-particles or molecules attached to or dispersed in a uniform medium; a coating **388** reflects the visible emission while transmitting the invisible radiation; and a substrate layer **390** that absorbs the remaining invisible radiation. Alternatively, it comprises of a layer **384** containing fluorescent nano-particles or molecules attached to or dispersed in a uniform medium; a coating **388** absorbing the invisible radiation; and a visibly transparent substrate layer **390**. Self adhesive layer and protective layers such as scratch resistance layer can also be assed to the screen structure.

[**0023**] Two preferred schemes of FC are disclosed and illustrated in **FIGS. 4A and 4B**, respectively. The first scheme is termed down-conversion, where the wavelength of the excitation light is shorter than fluorescence wavelength. **FIG. 4A** illustrates an energy level diagram of the down-conversion molecule or nano-particle. The photon of the shorter wavelength excitation light has more energy and induces a transition **415** from a lower energy level **410** to a higher energy level **420**. The emission involves transition **425** associated with two energy levels with a smaller energy gap. The second scheme is called up-conversion, where excitation wavelengths are longer than fluorescence wavelength. In the second case, two or more photons from a laser are necessary to excite the fluorescence particle in order to yield a visible fluorescence photon. **FIG. 4B** illustrates an energy level diagram of the FC molecules or nano-particles associated with the second scheme. The longer wavelength excitation laser induces two transitions (**455**, **465**) from a lower state **450** to a higher energy state **470** through an intermediate state **460**. The emission involves transition **475** associated with two energy levels with an energy gap that is smaller than energy associated with two laser photons. A common approach for the first scheme is to apply a UV (or blue) light source with wavelength shorter than 500 nm to excite the fluorescence molecules or nano-particles on the image screen; the UV sources include solid state lasers, semiconductor laser diodes, gas lasers, dye lasers, excimer lasers, and other UV light sources familiar to those skilled in the art. A common approach for the second scheme is to apply infrared (IR) lasers with wavelength longer than 700 nm to excite the fluorescence molecules or particles on the Screen. The IR lasers include solid-state lasers, semiconductor laser diodes and other IR sources familiar to those skilled in the art. In both cases, excitation beam intensities are modulated to yield visible fluorescence of varying intensity or gray scales.

[**0024**] A host of preferred fluorescence materials are also disclosed. A common property of these materials is that the size of the fluorescent particles is very small. Typically, nano-particles or molecules with size between 0.5 nm to 500 nm are preferred to have minimum scattering effect that reduce the visible transparency of the screen. These materials fall into four categories: inorganic nano-meter sized phosphors; organic molecules and dyes; semiconductor based nano particles; and organometallic molecules.

[**0025**] For down-conversions the following materials are preferred to form FC displaying screen:

[**0026**] 1. Inorganic or ceramic phosphors or nano-particles, including but not limited to metal oxides, metal halides, metal chalcoginides (e.g. metal sulfides), or their hybrids, such as metal oxo-halides, metal oxo-chalcoginides. These inorganic phosphors have found wide applications in fluorescent lamps and electronic monitors. These materials can covert shorter wavelength photon (e.g. UV and blue) into longer wavelength visible light and can be readily deposited on displaying screens or dispersed in the screen.

[**0027**] 2. Laser dyes and small organic molecules, and fluorescent organic polymers. These can also be used to convert shorter wavelength laser photon (e.g. UV and blue) into longer wavelength visible light and can be readily deposited on a displaying screen. Since they are in the molecular state in the solid, the screen transparency is maintained due to lack of particle scattering.

[**0028**] 3. Semiconductor nano-particles, such as II-VI or III-V compound semiconductors, e.g. fluorescent quantum dots. Again, their addition in the screen does not affect the optical transparency

[**0029**] 4. Organometallic molecules. The molecules include at least a metal center such as rare earth elements (e.g. Eu, Tb, Ce, Er, Tm, Pr, Ho) and transitional metal elements such as Cr, Mn, Zn, Ir, Ru, V, and main group elements such as B, Al, Ga, etc. The metal elements are chemically bonded to organic groups to prevent the quenching of the fluorescence from the hosts or solvents. Such organomettalic compounds filled screen does not scatter light and affect the screen transparency either, unlike the micro-sized particles.

[**0030**] Of the down-conversion FC materials or molecules mentioned above, those that can be excited by lasers of long wave UV (e.g. >300 nm) to blue (<500 nm), and yield visible light emission are preferred for the current invention. For example, the phosphors can be Garnet series of phosphors: $(Y_mA_{1-m})_3(Al_nB_{1-n})_5O_{12}$, doped with Ce; where $0 \leqq m, n \leqq 1$; A include other rare earth elements, B include B, Ga. In addition, phosphors containing metal silicates, metal borates, metal phosphates, and metal aluminates hosts are preferred in their applications to FC displays; In addition, nano-particulates phosphors containing common rare earth elements (e.g. Eu, Tb, Ce, Dy, Er, Pr, Tm) and transitional or main group elements (e.g. Mn, Cr, Ti, Ag, Cu, Zn, Bi, Pb, Sn, Tl) as the fluorescent activators, are also preferred in their applications to FC displays. Finally, some undoped materials (e.g. Metal (e.g. Ca, Zn, Cd) tungstates, metal vanadates, ZnO, etc) are also preferred FC display materials.

[**0031**] The commercial laser dyes are another class of preferred FC display materials. A list of commercial laser dyes can be obtained from several laser dye vendors, including Lambda Physik, and Exciton, etc. A partial list of the preferred laser dye classes includes: Pyrromethene, Coumarin, Rhodamine, Fluorescein, other aromatic hydrocarbons and their derivatives, etc. In addition, there are many polymers containing unsaturated carbon-carbon bonds, which also serve as fluorescent materials and find many optical and fluorescent applications. For example, MEH-PPV, PPV, etc have been used in opto-electronic devices, such as polymer light emitting diodes (PLED). Such fluorescent polymers can be used directly as the fluorescent layer of the transparent 2-D display screen.

[**0032**] In addition, the recently developed semiconductor nanoparticles (e.g., quantum dots) are also a preferred LIF display materials. The terms "semiconductor nanoparticies," refers to an inorganic crystallite between 1 nm and 1000 nm in diameter, preferably between 2 nm to 50 nm. A semiconductor nano-particle is capable of emitting electromagnetic radiation upon excitation (i.e., the semiconductor nano-particle is luminescent). The nanoparticle can be either a homogeneous nano-crystal, or comprises of multiple shells. For example, it includes a "core" of one or more first semiconductor materials, and may be surrounded by a "shell" of a second semiconductor material. The core and/or the shell can be a semiconductor material including, but not limited to, those of the group II-VI (ZnS, ZnSe, ZnTe, CdS, CdSe, CdTe, HgS, HgSe, HgTe, MgS, MgSe, MgTe, CaS, CaSe, CaTe, SrS, SrSe, SrTe, BaS, BaSe, BaTe, and the like) and III-V (GaN, GaP, GaAs, GaSb, InN, InP, InAs, InSb, and the like) and IV (Ge, Si, and the like) materials, and an alloy or a mixture thereof.

[0033] Finally, fluorescent organometallic molecules containing rare earth or transitional element cations are also preferred in the down-conversion fluorescent screens. Such molecules include a metal center of rare earth elements including Eu, Tb, Er, Tm, Ce protected with organic chelating groups. The metal center may also include transitional elements such as Zn, Mn, Cr, Ir, etc and main group elements such as B, Al, Ga. Such organometallic molecules can readily dissolved in liquid or transparent solid host media and form a transparent fluorescent screen for the disclosed 2-D transparent display with minimum light scattering. Some examples of such fluorescent organomettalic molecules include: 1. Tris(dibenzoylmethane) mono(phenanthroline)europium (III); 2. Tris(8-hydroxyquinoline)erbium; 3. Tris(1-phenyl-3-methyl-4-(2,2-dimethylpropan-1-oyl)-pyrazolin-5-one)terbium (III); 4. Bis(2-methyl-8-hydroxyquinolato)zinc; 5. Diphenylborane-8-hydroxyquinolate. Their molecular structures are given in **FIGS. 5***a* through **5***e*.

[0034] Up-conversion phosphors are similar in chemical compositions as the down-conversion fluorescent materials discussed. The up-conversion phosphors for the fluorescent conversion display also include the following choice of materials or molecules:

[0035] 1. Laser dyes, the organic small molecules that can be excited by the absorption of at least two infrared photons with emission of visible light.

[0036] 2. Fluorescent polymers, the class of polymers that can be excited by the absorption of at least two infrared photons with emission of visible light

[0037] 3. Inorganic or ceramic particles or nano-particles, including the conventional up-conversion phosphors (e.g. metal fluorides, metal oxides) that can be excited by the absorption of at least two infrared photons with emission of visible light

[0038] 4. Semiconductor particles, including nano-particles such as III-VI or II-V compound semiconductors, e.g. quantum dots, described in details in the "down-conversion" semiconductors above.

[0039] The fluorescent up-conversion inorganic phosphors include but are not limited to metal oxides, metal halides, metal chalcoginides (e.g. sulfides), or their hybrids, such as metal oxo-halides, metal oxo-chalcoginides. They are usually doped with rare earth elements (e.g. Yb^{3+}, Er^{3+}, Tm^{3+}). Some host examples include, but not limited to: $NaYF_4$, YF_3, $BaYF_5$, LaF_3, La_2MoO_8, $LaNbO_4$, LnO_2S; where Ln is the rare earth elements, such as Y, La, Gd).

[0040] These preferred FC displaying materials may be used to form a variety of FC displaying objects. These objects include: screens, plates, windows, walls, billboards, and other displaying surfaces. There are several means to incorporate these fluorescent molecules or materials onto a displaying surface:

[0041] 1. They can be dissolved (organic dyes) or dispersed (inorganic particles) into solvents (water or organic solvents). The liquid fluorescent formula can be either coated onto a surface and form a solid film or coating after drying, or they can be sandwiched between two surfaces in liquid form.

[0042] 2. They can be dissolved (organic dyes) or dispersed (inorganic particles) into solid hosts, such as glasses, polymers, gels, inorganic-organic hybrid hosts, cloths, papers, films, tapes, etc. and turn the solid into a fluorescent object for laser display.

[0043] 3. Some objects (e.g. cloths, paper, tapes, fluorescent polymers) may already contain fluorescent molecules or luminescent functional groups. In that circumstance, they can be directly used as laser display objects.

[0044] Referring now to **FIG. 6**, a detailed diagram illustrates an additional preferred embodiment of a two-dimensional light beam based FC display subsystem. The excitation source **610** preferably passes through a set of beam-diameter control optics **612** and a 2-D acousto-optical scanner **615**. A scan control interface unit **620** coordinates the functions of a Direct Digital Synthesizer **622**, an RF amplifier **625** and Beam-Diameter Control Optics **612**. The processes image beam is projected on to a FC screen through an angle extender **650**. In order to deliver consistent and stable image on the FC screen, a beam splitter deflects the image into a position sensitive detector **635** and processed through **630**, feedback to **620**. The close-loop image feedback formed by **632**, **635**, **630** and **620** is incorporated to maintain position accuracy and pointing stability of the laser beam.

[0045] It will be apparent to those with ordinary skill of the art that many variations and modifications can be made to the system, method, material and apparatus of FC based display disclosed herein without departing from the spirit and scope of the present invention. It is therefore intended that the present invention cover the modifications and variations of this invention provided that they come within the scope of the appended claims and their equivalents,

We claim:

1. A two-dimensional color image display setup with visibly transparent screen based on fluorescence conversion comprising:

at least one excitation light beam operating in a wavelength range of >700 nm or <450 nm;

an optional imaging processing unit projecting the said light beam to specified positions with specified light intensities;

a displaying screen comprising at least one layer of transparent medium containing at least one type of electromagnetic radiation activated visible light emitting ingredients;

a coating attached to the said layer of transparent medium of the said displaying screen separating the said visible light from the said excitation light;

a covering layer of transparent materials protecting the said transparent layer of medium containing the said visible light emitting particles of the said displaying screen.

2-26. (canceled)

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