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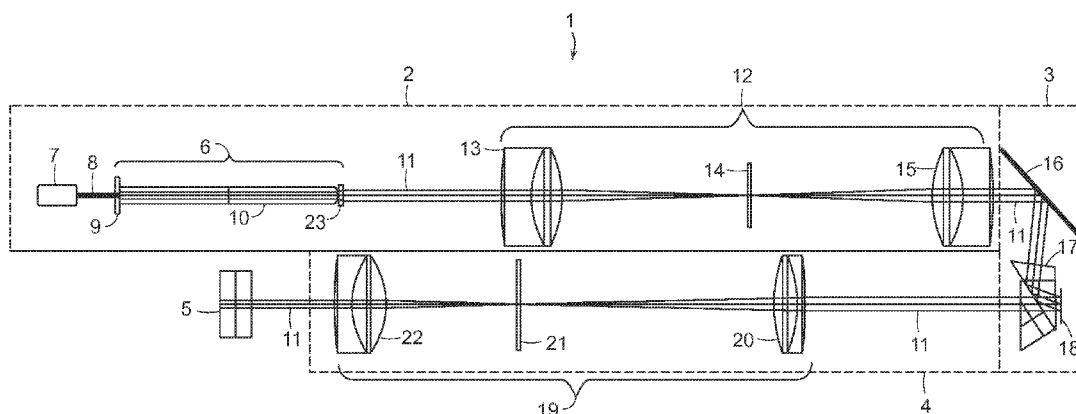


FIG. 1

(57) Abstract: The present invention includes methods and systems for forming an object in a volume of a photohardenable composition wherein the methods and systems preferably include telecentric illumination optics and/or telecentric projection optics.



INTERNATIONAL SEARCH REPORT

International application No.

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A. CLASSIFICATION OF SUBJECT MATTER

IPC - INV. G03F 7/004, C09J 11/08, C09J 133/06 (2022.01)

ADD. G03F 7/028 (2022.01)

CPC - INV. G03F 7/004, C09J 11/08, C09J 133/06

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According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2021/154897 A1 (Quadratic 3D, Inc.) 5 August 2021 (05.08.2021) pg. 1, ln 21-25, pg 2, ln 14-23, pg 5, ln 36-37, pg 22, ln 10, pg 24, ln 4-26,	1-86
Y	WO 2018/136062 A1 (Innovations In Optics, Inc.) 26 July 2018 (26.07.2018) pg 1, ln 5-6, pg 2, ln 11-28, pg 5, ln 17-18, pg 6, ln 9-14, pg 10, ln 8-16, pg 11, ln 19-23, pg 12, ln 5-9, pg 19, ln 27-28, Figs. 2 and 6A,	1-86
Y — A	US 2020/0122394 A1 (Texas Instruments, Incorporated) 23 April 2020 (23.04.2020) para [0005], para [0028], para [0030], para [0032], para [0043], para [0050], Fig. 1, 2, 12	2-3, 6-8, 10-11, 14-16, (17-22)/(10, 14), 23-24, (25-28)/(10, 14), 29-30, (31-33)/(6, 14), 34-38, 44-46, 50-54, 60-61, 63-70, 81-82
		87-89
Y	WO 2020/245456 A1 (Xolo GmbH) 10 December 2020 (10.12.2020) pg 1, ln 3-4, pg 9, ln 7-23, pg 12, ln 15-22,	26-28, 71, 74
Y	US 2019/0014243 A1 (National Security Technologies, LLC) 10 January 2019 (10.01.2019) para [0004], para [0051],	50-51, 65-66
A	US 2015/0015866 A1 (LumeJet Holdings Limited) 15 January 2015 (15.01.2015) para [0114],	1-2, 6, 9-10, 14, 29, 30/(10, 14), 39-40, 44-46, 50-51, 56-57, 60-61, 63-66, 68-70

☒ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"D" document cited by the applicant in the international application

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 22/39766

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

—see supplemental box—

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 22/39766

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2018/0126646 A1 (Nexa3D, Inc.) 10 May 2018 (10.05.2018) para [0070],	3, 8, 11, 16, 34
A	US 2021/0041228 A1 (Nippon Steel Corporation) 11 February 2021 (11.02.2021) para [0115],	23-24, 35, 54, 69-70, 81-82
A	US 2017/0293217 A1 (Woods Hole Oceanographic Institution) 12 October 2017 (12.10.2017) para [0052], para [0087],	36, 38
A	WO 2021/154895 A1 (Quadratic 3D, Inc.) 5 August 2021 (05.08.2021) pg 7, ln 6-8, pg 8, ln 14-15, pg 10, ln 36-37, pg 11, ln 26-37, pg 12, ln 32-36,	87-94
A	US 2014/0306380 A1 (Global Filtration Systems, a dba of Gulf Filtration Systems) 16 October 2014 (16.10.2014) para [0064], para [0075], para [0079], para [0105],	87-94
A	US 2021/0016496 A1 (Northwestern University) 21 January 2021 (21.01.2021) para [0086],	87, 90
A	WO 2019/194798 A1 (Ford Global Technologies) 10 October 2019 (10.10.2019) para [0022], para [0041], para [0066],	90-94

Bx. IV (Lack of Unity)

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I: Claims 1-38 is directed toward a method of forming an object in a volume of a photohardenable composition, the method comprising: (a) providing a volume of the photohardenable composition included within a container wherein at least a portion of the container is optically transparent so that the photohardenable composition is accessible by excitation light; (b) projecting at least two optical projections of excitation light from one or more projection systems into the volume of the photohardenable composition to one or more selected locations in the volume, the at least two optical projections comprising a first optical projection including first excitation light including light having a first wavelength and a second optical projection including a second excitation light including light having a second wavelength, wherein the second optical projection is projected from a projection system including a projection device and at least one of: (i) telecentric illumination optics positioned in the optical illumination path of the excitation light for illuminating the projection device for projecting at least one of the one or more optical projections and (ii) telecentric projection optics in the optical projection path between the projection device for projecting the at least one of the one or more optical projections and the volume of the photohardenable composition, wherein the photohardenable composition is at least partially hardened at the one or more selected locations in the volume; and (c) optionally repeating step (b) one or more times until the object is partially or fully formed.

Group II: Claims 39-94 is directed toward a system for forming an object in a volume of a photohardenable composition, the system comprising: a container adapted to include the volume of the photohardenable composition wherein at least a portion of the container is optically transparent so that the photohardenable composition is accessible by excitation light; and one or more projection systems configured for receiving excitation light and projecting two or more optical projections into the volume included in the container, the two or more optical projections including a first optical projection including first excitation light having a first wavelength and a second optical projection including second excitation light having a second wavelength, wherein at least one projection system includes a projection device and one or more telecentric optics arrangements positioned in: (a) the optical illumination path of the second excitation light for illuminating a projection device for projecting the second optical projection and/or (b) the optical projection path between the projection device for projecting the second optical projection and the volume of the photohardenable composition included in the container.

The inventions listed as Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1 because, they lack the same or corresponding special technical features for the following reasons:

Special Technical Features:

The invention of Group II includes the special technical feature of a system, wherein at least one of the projection systems includes an optical arrangement for generating a light sheet, the optical arrangement including a collimated light source, one or more optical elements for receiving collimated light from the light source and generating a fan of light rays, a first cylinder lens for receiving the fan of light rays, and a second cylinder lens for receiving the light passing through the first cylinder lens, wherein the first cylinder lens includes an axis of nonzero curvature in the direction of the fan of light rays for collimating the fan of light rays into a substantially constant height plane of light and the second cylinder lens includes an axis of nonzero curvature orthogonal to the axis of the first cylinder lens to focus the orthogonal collimated direction of light output from the collimated light source into the volume of the photohardenable composition for control of plane width; and a system comprising two or more projection systems configured for receiving excitation light and projecting one or more optical projections to intersect at one or more selected location in the volume of the photohardenable composition to at least partially harden, polymerize, or crosslink the photohardenable composition to at least partially form one or more objects, wherein the one or more projection systems include a first projection system including an optical arrangement for generating a first optical projection comprising a light sheet, the optical arrangement including one or more optical elements for receiving excitation light and projecting the light sheet to the one or more selected locations in the volume, the optical elements including a an element to generate the light sheet from excitation light and a first cylinder lens and a second cylinder lens configured for adjusting the dimensions of the light sheet, wherein the first cylinder lens includes an axis of nonzero curvature in the direction of the height of the light sheet and the second cylinder lens includes an axis of nonzero curvature orthogonal to the axis of nonzero curvature of the first cylinder lens, not required by Group I.

Continuation of Supplemental Box

Bx. IV (Lack of Unity)

Shared Technical Features:

The inventions of Groups I-II share the technical features of a forming an object in a volume of a photohardenable composition, comprising: (a) providing a volume of the photohardenable composition included within a container wherein at least a portion of the container is optically transparent so that the photohardenable composition is accessible by excitation light; (b) projecting at least two optical projections of excitation light from one or more projection systems into the volume of the photohardenable composition to one or more selected locations in the volume, the at least two optical projections comprising a first optical projection including first excitation light including light having a first wavelength and a second optical projection including a second excitation light including light having a second wavelength, wherein the second optical projection is projected from a projection system including a projection device and at least one of: (i) telecentric illumination optics positioned in the optical illumination path of the excitation light for illuminating the projection device for projecting at least one of the one or more optical projections and (ii) telecentric projection optics in the optical projection path between the projection device for projecting the at least one of the one or more optical projections and the volume of the photohardenable composition, wherein the photohardenable composition is at least partially hardened at the one or more selected locations in the volume.

However, these shared technical features do not represent a contribution over prior art, because the shared technical feature is being obvious over WO 2021/154897 A1 to Quadratic 3D, Inc. (hereinafter "Quadratic") in view of WO 2018/136062 A1 to Innovations In Optics, Inc. (hereinafter "Innovations").

Quadratic teaches a method of forming an object in a volume of a photohardenable composition (pg 2, In 14-15, there is provided a method of forming a three-dimensional object in a volume of a photohardenable composition), the method comprising: (a) providing a volume of the photohardenable composition included within a container wherein at least a portion of the container is optically transparent so that the photohardenable composition is accessible by excitation light (pg 2, In 15-18, the method comprising: (a) providing a volume of the photohardenable composition included within a container wherein at least a portion of the container is optically transparent so that the photohardenable composition is accessible by excitation light); (b) projecting one or more optical projections of excitation light from one or more projection systems into the volume of the photohardenable composition to one or more selected locations in the volume (pg 2, In 18-21, (b) directing excitation light in the first range of wavelengths into the volume of the photohardenable composition, wherein the excitation light has an excitation intensity so that local hardening of the photohardenable composition is achieved at a selected location within the volume of the photohardenable composition; and pg 24, In 9-10, the container may be stationary while a beam or optical projection of excitation light is being directed into the photohardenable composition; and pg 24, In 24-26, Examples of sources of the excitation light source for use in the methods described herein include laser diodes, such as those available commercially, light emitting diodes, DMD projection systems), the optical projection including first excitation light including light having a first wavelength (pg 2, In 18-21, (b) directing excitation light in the first range of wavelengths into the volume of the photohardenable composition), wherein the photohardenable composition is at least partially hardened at the one or more selected locations in the volume (pg 2, In 18-21, (b) directing excitation light in the first range of wavelengths into the volume of the photohardenable composition, wherein the excitation light has an excitation intensity so that local hardening of the photohardenable composition is achieved at a selected location within the volume of the photohardenable composition), wherein at least one of the one or more optical projections is projected from a projection system including a projection device (pg 24, In 4-6, the container may be rotated to provide additional angles of illumination or projection of excitation light into the volume of photohardenable composition contained therein; and pg 24, In 24-26, Examples of sources of the excitation light source for use in the methods described herein include laser diodes, such as those available commercially, light emitting diodes, DMD projection systems; A DMD is a projection device; see instant specification, pg 55, In 33 - pg 56, In 2, Examples of projection devices for use in the methods and systems described herein may include, but are not limited to...a digital micromirror device (also referred to herein as "DMD"); and (c) optionally repeating step (b) one or more times until the object is partially or fully formed (pg 2, In 21-23, and (c) optionally repeating step (b) at the same or a different selected location within the volume of the photohardenable composition until the three-dimensional object is formed), but does not teach the method comprising (b) projecting at least two optical projections of excitation light from one or more projection systems into the volume of the photohardenable composition to one or more selected locations in the volume, the at least two optical projections comprising a first optical projection including first excitation light including light having a first wavelength and a second optical projection including a second excitation light including light having a second wavelength, wherein the second optical projection is projected from a projection system including a projection device and at least one of: (i) telecentric illumination optics positioned in the optical illumination path of the excitation light for illuminating the projection device for projecting at least one of the one or more optical projections and (ii) telecentric projection optics in the optical projection path between the projection device for projecting the at least one of the one or more optical projections and the volume of the photohardenable composition.

-----Continuation of Supplemental Box-----

Bx. IV (Lack of Unity)

Innovations teaches a UV LED digital micromirror device (DMD) illuminator using a three way telecentric optical imaging system (pg 2, In 11-12, A UV LED digital micromirror device (DMD) illuminator according to embodiments of the invention uses a three way telecentric optical imaging system), the illuminator being configured to illuminate a photocurable material (pg 1, In 5-6, The invention relates to high radiance Ultraviolet (UV) sources of illumination coupled to projection systems for selectively exposing photocurable materials); wherein the illuminator is provided with two different LED wavelength bins to be used to provide a broader spectrum (pg 10, In 8-15, Another embodiment of the system uses the same lens system, housing and LED board but is designed for the 1024 by 768 by 0.70 in. diagonal Texas Instruments? DMD device and is comprised of a proportionally smaller taper and a three by four die array of UV LEDs. The typical LED die is approximately 1,000 microns square by about 100 microns in thickness with two each wire bond pads per die. There are two sets of wire bond traces on top and bottom of the central trace where the LED die are attached on the diamond substrate 92. The two sets allow for two different LED wavelength bins to be used to provide a broader spectrum); and the telecentric optical imaging system including (ii) telecentric projection optics in the optical projection path between a light source in the projection device for projecting the at least one of the one or more optical projections and an outlet aperture of the projection device (pg 2, In 25-26, Embodiments of the invention described herein include a high radiance UV LED illuminator that projects onto a DMD as a source of high radiance UV energy; and pg 3, In 3-9, an optical system for a digital micromirror device illuminator includes a LED array, a tapered non-imaging collection optic, a reflective aperture stop and a telecentric lens system. The tapered non-imaging collection optic has an input aperture and an output aperture. The input aperture is in optical communication with the LED array to receive optical energy emitted by the LED array. The telecentric lens system is disposed between the tapered non-imaging collection optic and the reflective aperture stop along an optical axis defined between the LED array and the reflective aperture stop; and pg 12, In 7-9, The system of lenses 54, 58, 64, and 16 are designed to be telecentric in both object (taper output aperture) and image (DMD micromirror plane) space; and pg 19, In 27-28, The small image blur in the middle of the long sides of the image is due to field curvature of the illumination lens system; The optical axis is the optical projection path because the optical energy is projected in the direction of the optical axis; A digital micromirror device (DMD) is a projection device; see instant specification, pg 55, In 33 - pg 56, In 2, Examples of projection devices for use in the methods and systems described herein may include...a digital micromirror device; An arrangement of spherical or aspherical lenses providing telecentricity forms telecentric projection optics; see instant specification, pg 19, In 6-8, The telecentric projection optics can comprise an arrangement of one or more spherical and/or aspherical lenses and/or one or more spherical and/or aspherical mirrors for providing the desired telecentricity; All lenses having a curvature must be either spherical or aspherical).

It would have been obvious to one of ordinary skill in the art to project at least two optical projections of excitation light from the projection system into the volume of the photohardenable composition to one or more selected locations in the volume, the at least two optical projections comprising a first optical projection including first excitation light including light having a first wavelength and a second optical projection including a second excitation light including light having a second wavelength using two different LED wavelength bins as taught by Innovations because providing a broader spectrum of wavelengths is useful for photoinitiators that may change their absorption spectrum throughout the photopolymerization process (Innovations, pg 10, In 14-16. The two sets allow for two different LED wavelength bins to be used to provide a broader spectrum. This is useful for some types of photoinitiators that may change their absorption spectrum throughout the photopolymerization process). Further, it would have been obvious to one of ordinary skill in the art to configure the projection system taught by Quadratic to project the first and/or second optical projection with the telecentric projection optics in the optical projection path between the projection device for projecting the two or more optical projections and the volume of the photohardenable composition because telecentric lenses provide images with a constant magnification regardless of the distance of an object (see US 2015/0045012 A1 to Neuroptics, Inc., para [0025], Telecentric lenses, on the other hand, provide an orthographic projection, providing the same magnification at all distances. An object that is too close or too far from the lens may still be out of focus, but the resulting blurry image will be the same size as the correctly-focused image would be), thereby allowing flexibility for the exact position of the volume of the photohardenable composition, and further because the volume of the photohardenable composition is to be illuminated by the projection system regardless of the placement of the telecentric projection optics (Quadratic, pg 2, In 18-21, (b) directing excitation light in the first range of wavelengths into the volume of the photohardenable composition; and pg 24, In 24-26, Examples of sources of the excitation light source for use in the methods described herein include laser diodes, such as those available commercially, light emitting diodes, DMD projection systems).

As the common features were known in the art at the time of the invention, they cannot be considered special technical features that would otherwise unify the groups.

Therefore, Groups I-II lack unity under PCT Rule 13 because they do not share a same or corresponding special technical feature.

Note: Claims 88-89 lack clarity because they refer to "the method of claim 87"; however, claim 87 teaches a system. For the purposes of this international search, the claims have been assumed to depend on "the system of claim 87".

Note: Claims 91-92 lack clarity because they refer to "the method of claim 90"; however, claim 90 teaches a system. For the purposes of this international search, the claims have been assumed to depend on "the system of claim 90".