US 20240319422A1

(19) **United States**

(12) **Patent Application Publication**

Lu et al.

(10) **Pub. No.: US 2024/0319422 A1**

(43) **Pub. Date: Sep. 26, 2024**

(54) **OPTICAL FILM AND DISPLAY SYSTEM INCLUDING SAME**

(71) Applicant: **3M INNOVATIVE PROPERTIES COMPANY**, St. Paul, MN (US)

(72) Inventors: **Yu Hsin Lu**, Dacun Township (TW); **Chiu-Hsing Lin**, Taoyuan City (TW); **Ryan T. Fabick**, Shoreview, MN (US); **Masaki Yamamuro**, Tokyo (JP)

(21) Appl. No.: **18/579,434**

(22) PCT Filed: **Jul. 18, 2022**

(86) PCT No.: **PCT/IB2022/056590**

§ 371 (c)(1),
(2) Date: **Jan. 15, 2024**

Related U.S. Application Data

(60) Provisional application No. 63/227,787, filed on Jul. 30, 2021.

Publication Classification

(51) **Int. Cl.**

G02B 5/28 (2006.01)

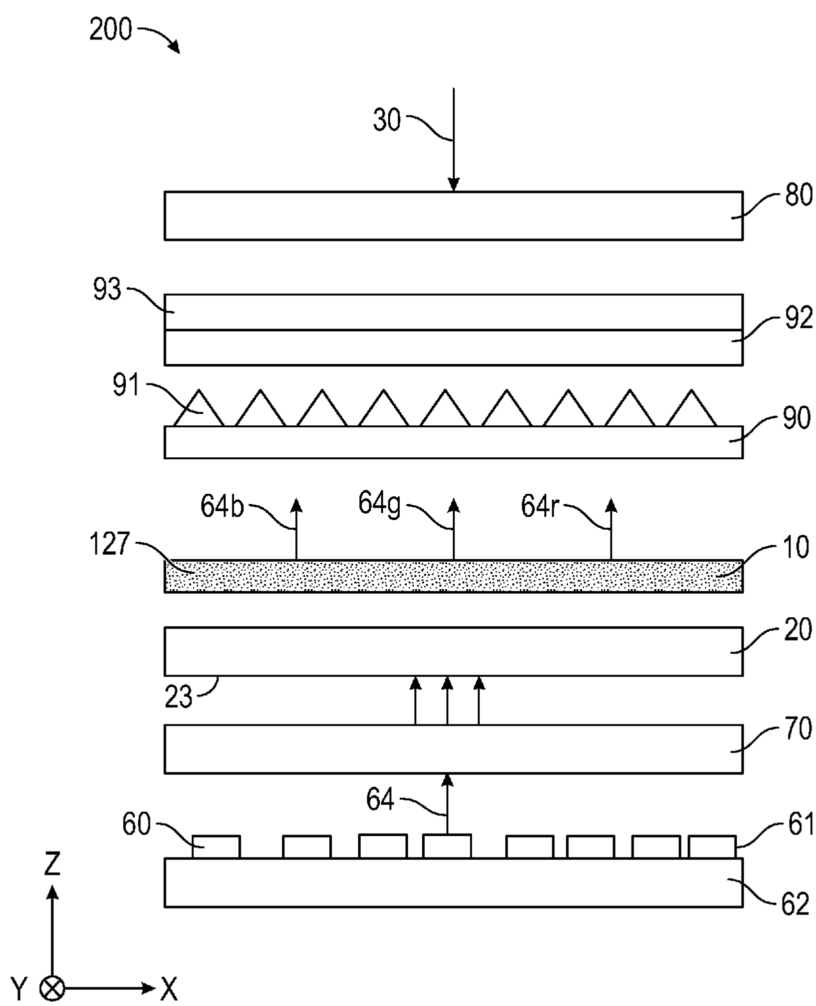
H01L 25/075 (2006.01)

(52) **U.S. Cl.**

CPC ***G02B 5/287*** (2013.01); ***H01L 25/0753*** (2013.01)

(57) **ABSTRACT**

An optical film includes a plurality of polymeric layers, such that a transmittance of the polymeric layers versus wavelength includes: a left band edge separating a wavelength range where the polymeric layers has a transmittance of greater than about 60% from a wavelength range where the polymeric layers has a reflectance of greater than about 80%; and a mid-wavelength corresponding to a transmittance of about 50% along the left band edge. A display system includes a light converting film having green and red emission spectra including respective green and red emission peaks with respective green and red full width at half maxima (FWHMs); and includes the optical film disposed on the light converting film. For each of the FWHMs, the mid-wavelength is less than or equal to a shortest wavelength of the FWHM or greater than the shortest wavelength by no more than about 30% of the FWHM.



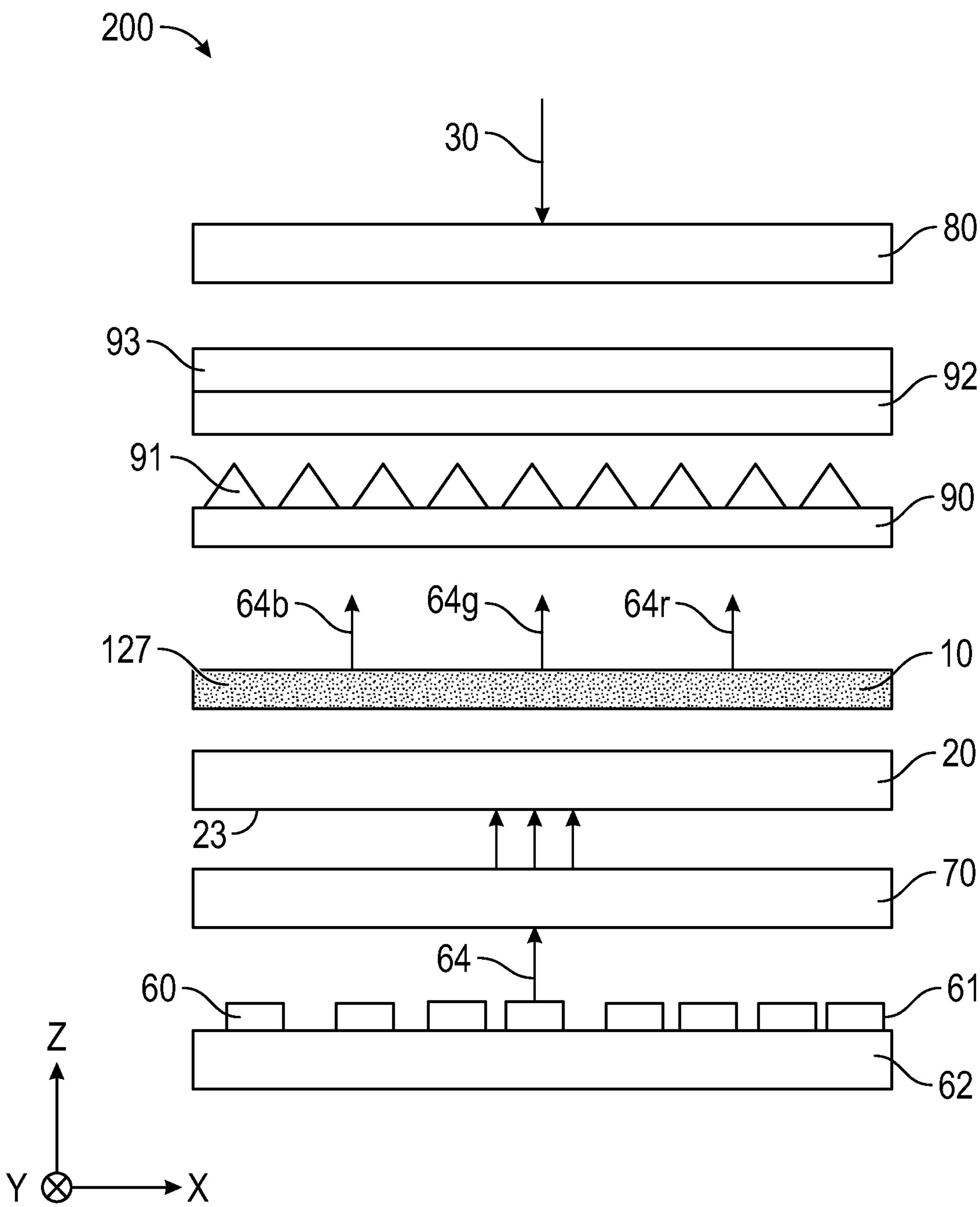


FIG. 1

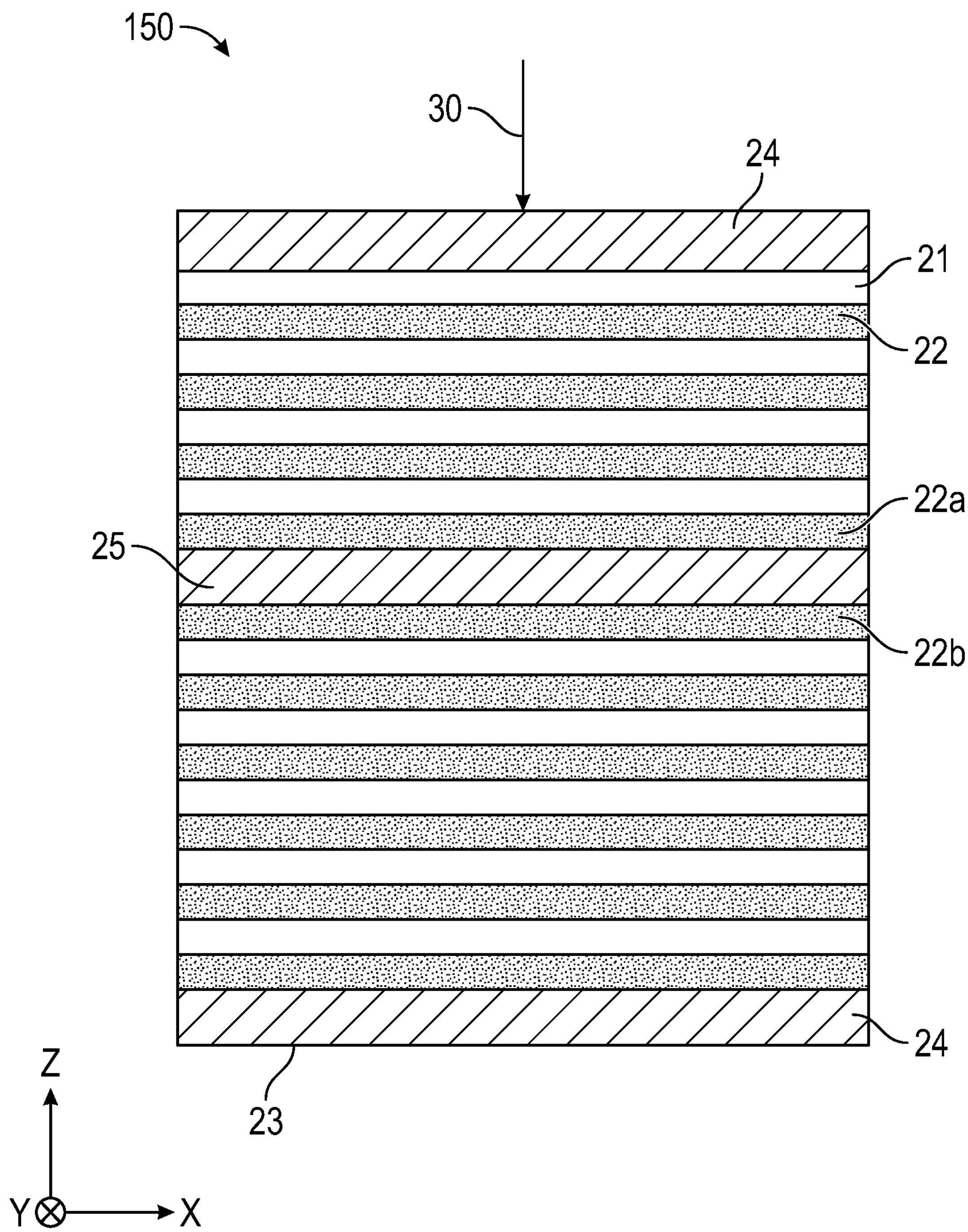


FIG. 2A

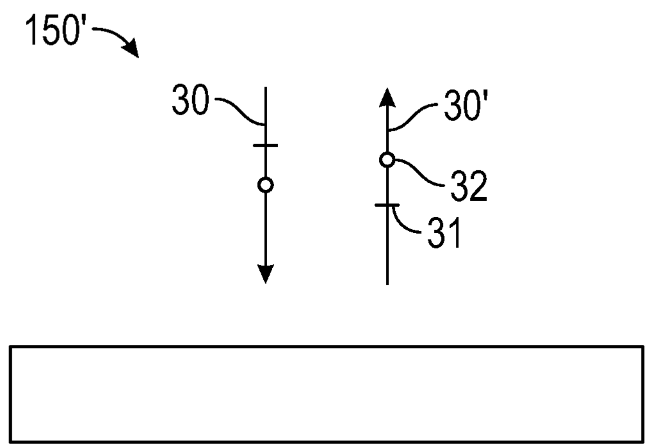


FIG. 2B

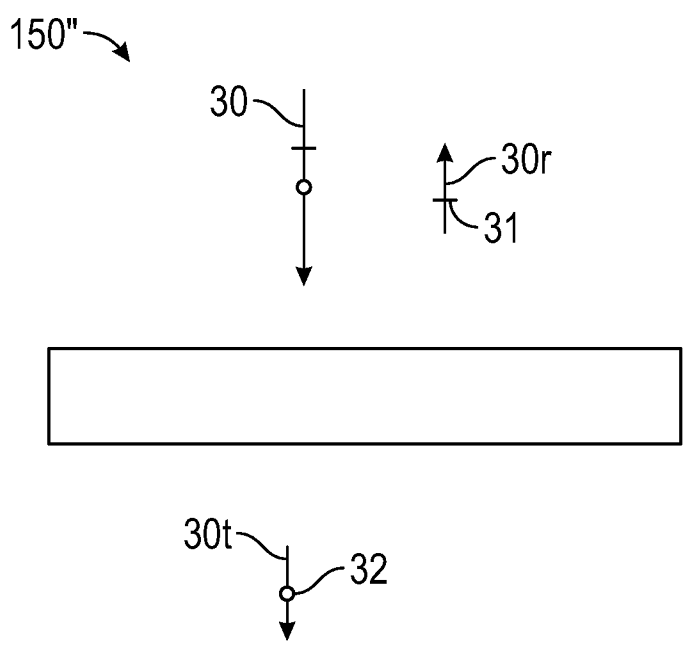


FIG. 2C

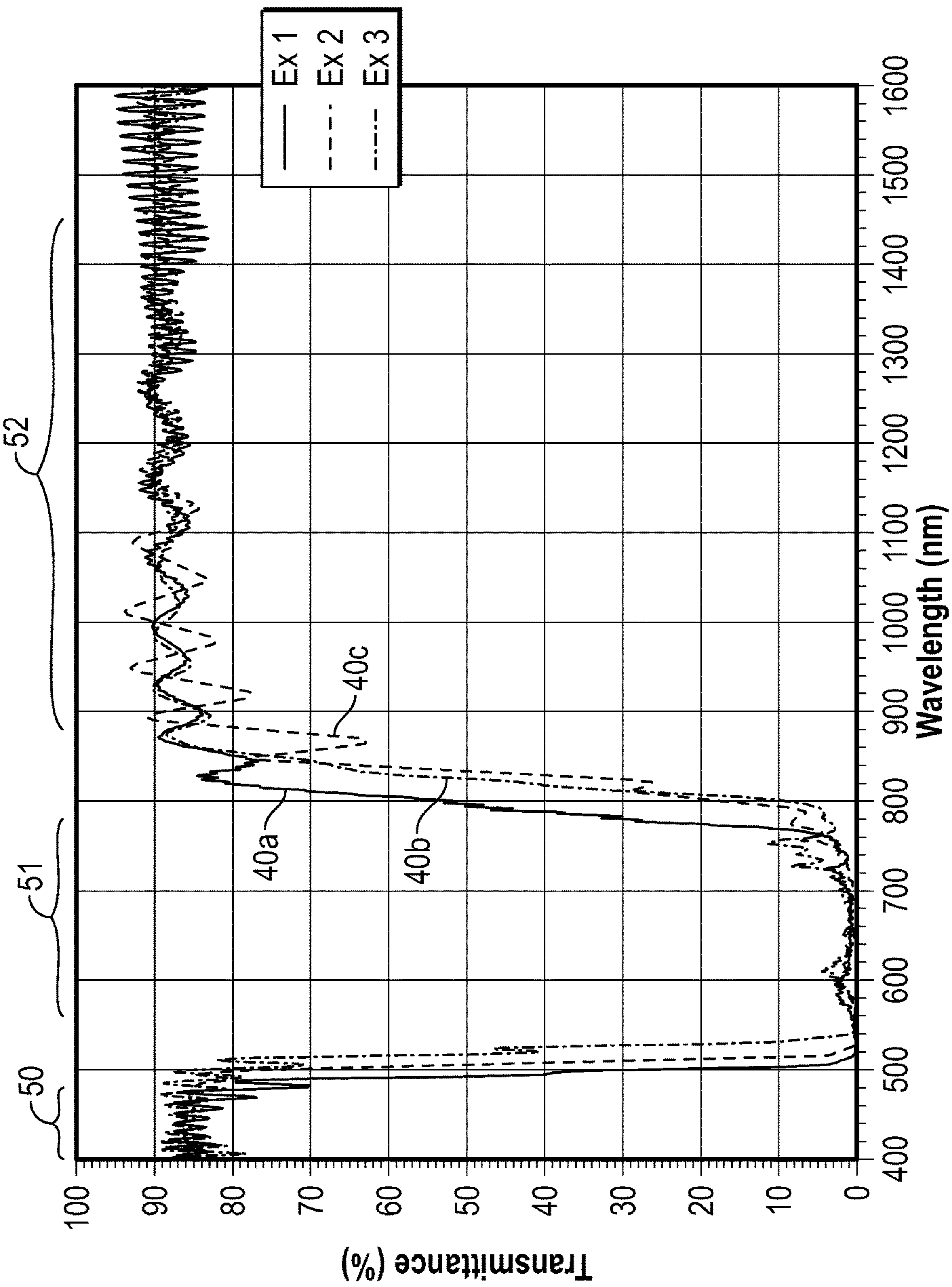

Transmittance (%)
100
90
80
70
60
50
40
30
20
10
0
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
Wavelength (nm)
Ex 1
Ex 2
Ex 3
50
51
52
40a
40b
40c

FIG. 3A

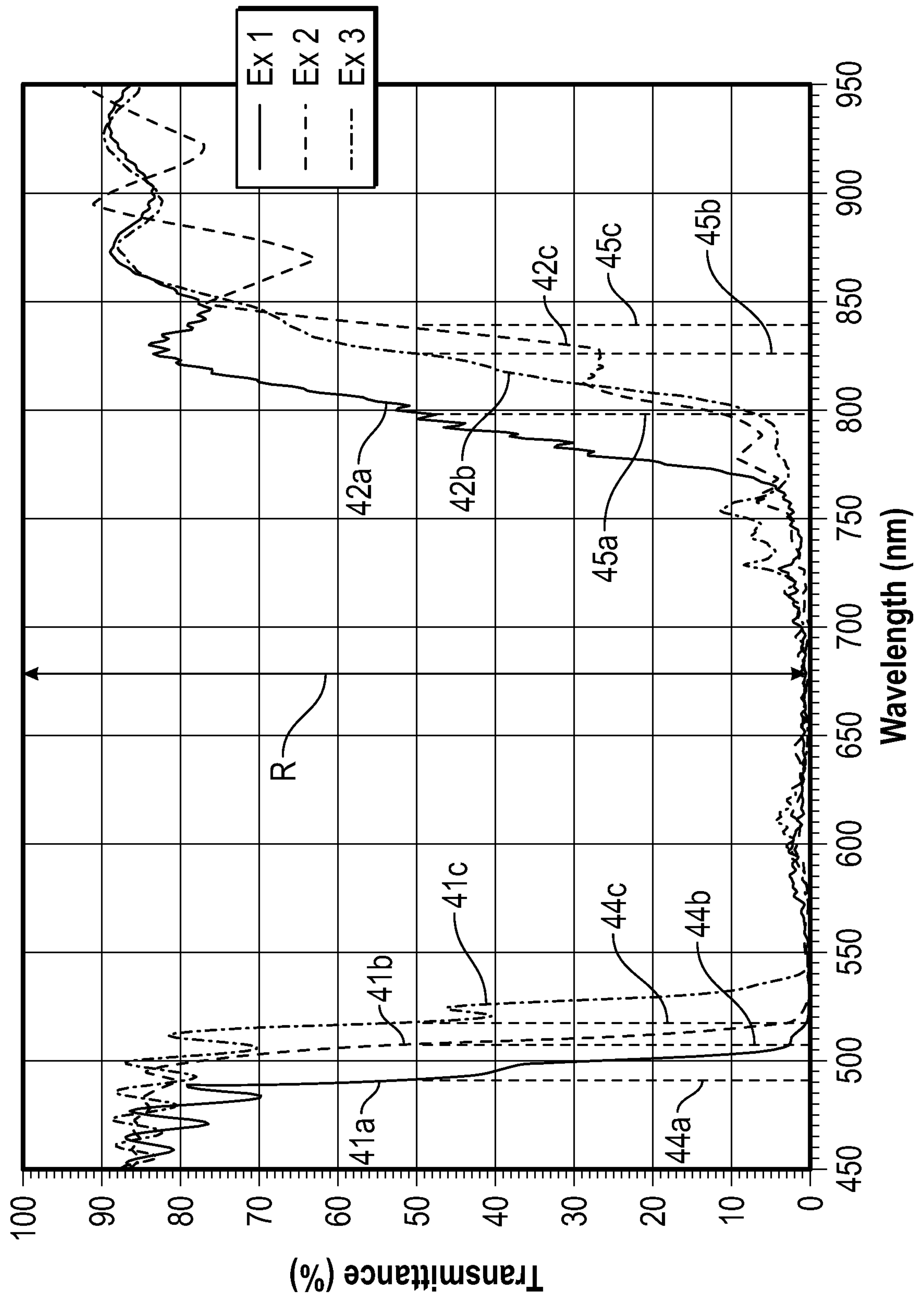

Ex 1
Ex 2
Ex 3
Transmittance (%)
Wavelength (nm)
100
90
80
70
60
50
40
30
20
10
0
450
500
550
600
650
700
750
800
850
900
950
41a
41b
41c
44a
44b
44c
42a
42b
42c
45a
45b
45c
R

FIG. 3B

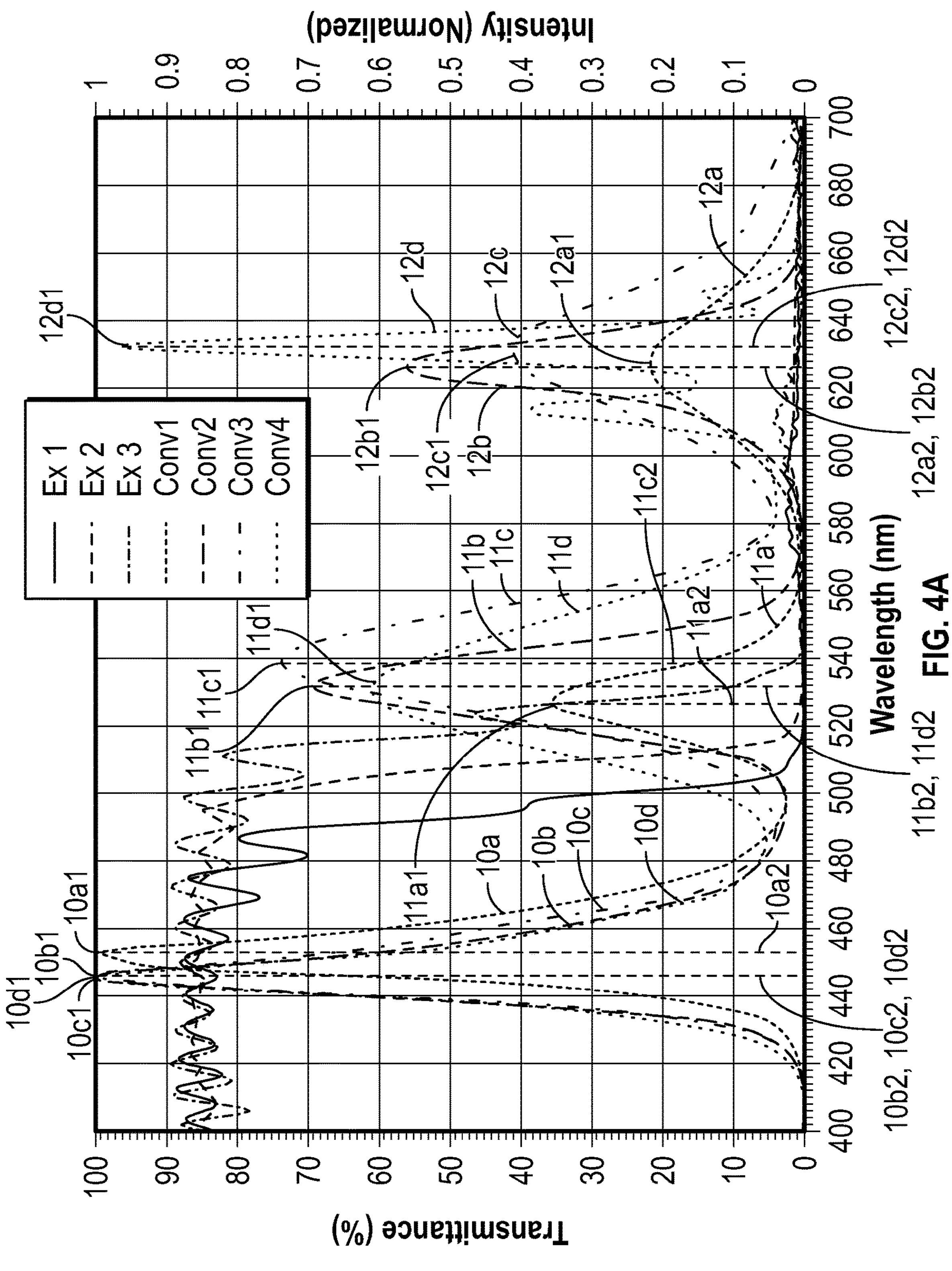

Intensity (Normalized)
Transmittance (%)
Wavelength (nm)
Ex 1
Ex 2
Ex 3
Conv1
Conv2
Conv3
Conv4
100
90
80
70
60
50
40
30
20
10
0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
400
420
440
460
480
500
520
540
560
580
600
620
640
660
680
700
10a
10b
10c
10d
10a1
10b1
10c1
10d1
10a2
10b2, 10c2, 10d2
11a
11b
11c
11d
11a1
11b1
11c1
11d1
11a2
11c2
11b2, 11d2
12a
12b
12c
12d
12a1
12b1
12c1
12d1
12a2, 12b2
12c2, 12d2

FIG. 4A

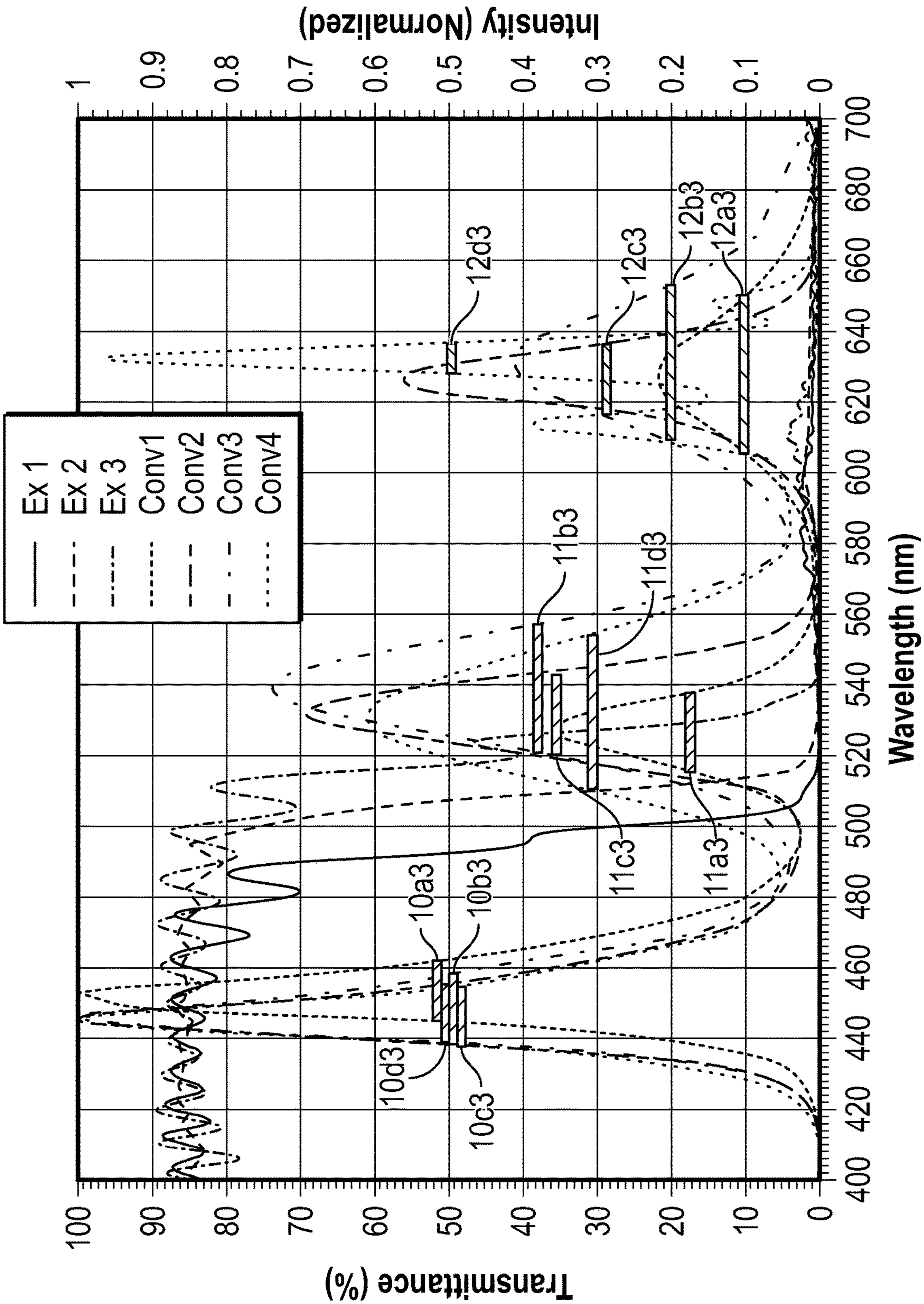

Intensity (Normalized)
Transmittance (%)
Wavelength (nm)
Ex 1
Ex 2
Ex 3
Conv1
Conv2
Conv3
Conv4
10a3
10b3
10c3
10d3
11a3
11b3
11c3
11d3
12a3
12b3
12c3
12d3
400
420
440
460
480
500
520
540
560
580
600
620
640
660
680
700
0
10
20
30
40
50
60
70
80
90
100
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

FIG. 4B

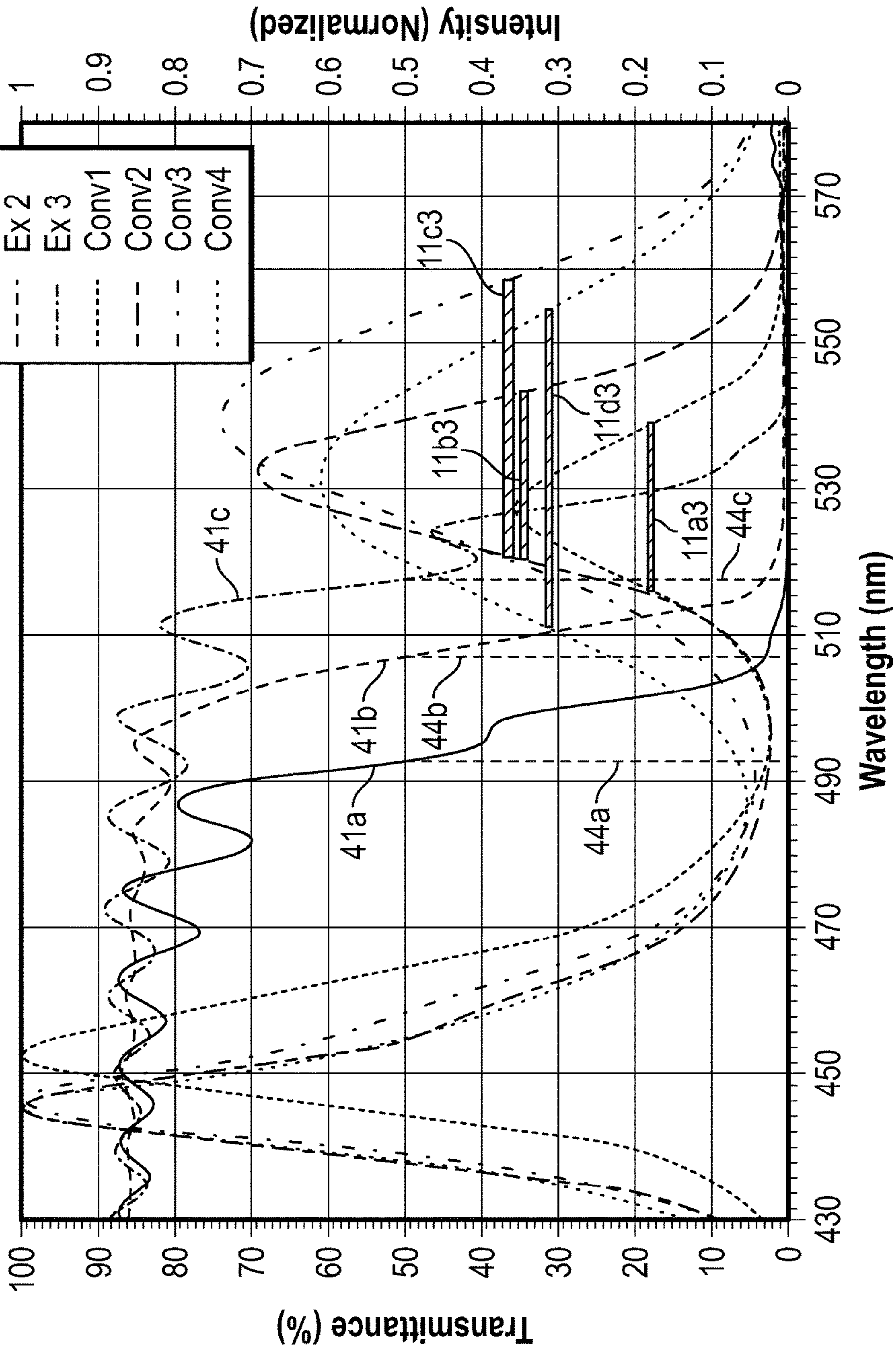

Intensity (Normalized)
Transmittance (%)
Wavelength (nm)
Ex 1
Ex 2
Ex 3
Conv1
Conv2
Conv3
Conv4
41a
41b
41c
44a
44b
44c
11a3
11b3
11c3
11d3
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50
60
70
80
90
100
430
450
470
490
510
530
550
570

FIG. 4C

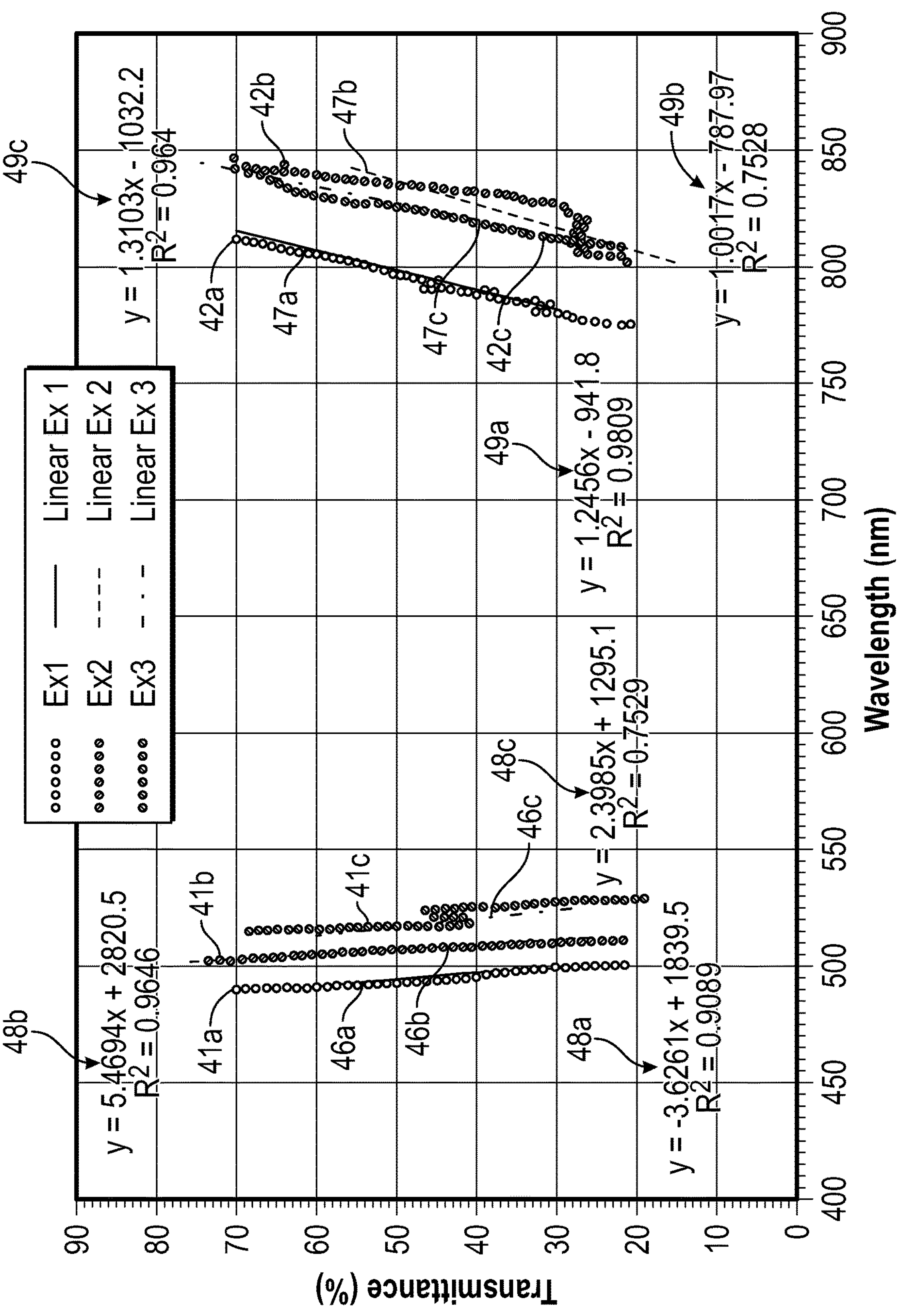

Ex1
Linear Ex 1
Ex2
Linear Ex 2
Ex3
Linear Ex 3
Transmittance (%)
Wavelength (nm)
48b
y = 5.4694x + 2820.5
R2 = 0.9646
48a
y = -3.6261x + 1839.5
R2 = 0.9089
48c
y = 2.3985x + 1295.1
R2 = 0.7529
49a
y = 1.2456x - 941.8
R2 = 0.9809
49c
y = 1.3103x - 1032.2
R2 = 0.964
49b
y = 1.0017x - 787.97
R2 = 0.7528
41a
41b
41c
46a
46b
46c
42a
42b
42c
47a
47b
47c

FIG. 5

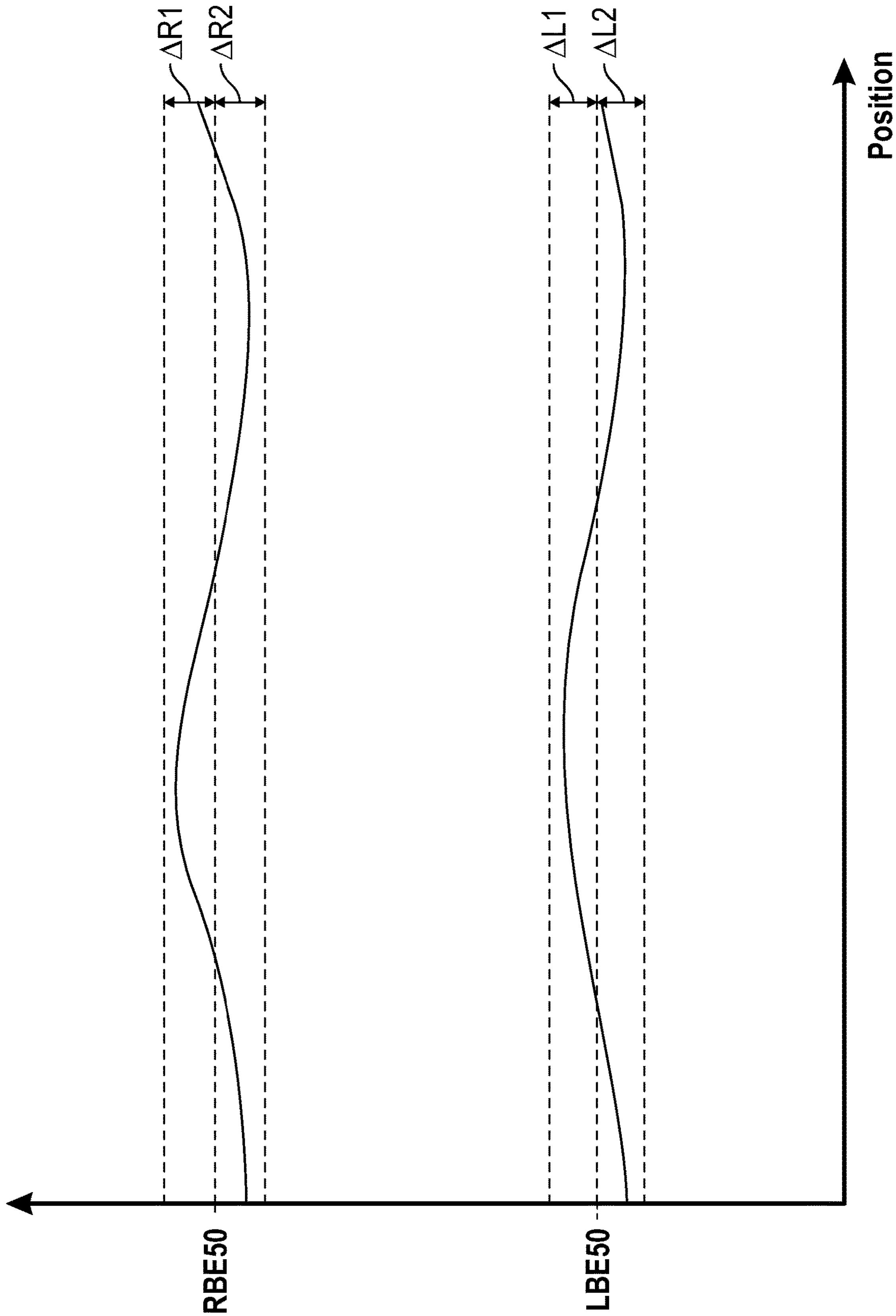


FIG. 6

OPTICAL FILM AND DISPLAY SYSTEM INCLUDING SAME

SUMMARY

[0001] According to some aspects of the present description, a display system is provided. The display system includes a light converting film including one or more light converting materials having green and red emission spectra including respective green and red emission peaks at respective green and red peak wavelengths with respective green and red full width at half maxima (FWHMs). Each of the FWHMs extends from a lower first wavelength to a higher second wavelength. The display system includes a first optical film disposed on the light converting film and including a plurality of first polymeric layers numbering at least 10 in total where each of the first polymeric layers having an average thickness of less than about 500 nm, such that for a substantially normally incident light and for at least a first polarization state, an optical transmittance of the plurality of first polymeric layers versus wavelength includes: a left band edge separating a shorter wavelength range where the plurality of first polymeric layers has an optical transmittance of greater than about 60% from a middle wavelength range where the plurality of first polymeric layers has an optical reflectance of greater than about 80%, and a right band edge separating the middle wavelength range from a longer wavelength range where the plurality of first polymeric layers has an optical transmittance of greater than about 60%; and a mid-wavelength corresponding to an optical transmittance of about 50% along the left band edge. For each of the FWHMs, the mid-wavelength is less than or equal to the lower first wavelength of the FWHM or greater than the lower first wavelength by no more than about 30% of the FWHM.

[0002] According to some aspects of the present description, an optical film including a plurality of polymeric layers numbering at least 10 in total is provided. Each of the polymeric layers has an average thickness of less than about 500 nm, such that for a substantially normally incident light and for at least a first polarization state, an optical transmittance of the plurality of first polymeric layers versus wavelength includes: a left band edge separating a shorter wavelength range where the plurality of first polymeric layers has an optical transmittance of greater than about 60% from a middle wavelength range where the plurality of first polymeric layers has an optical reflectance of greater than about 80%, and a right band edge separating the middle wavelength range from a longer wavelength range where the plurality of first polymeric layers has an optical transmittance of greater than about 60%; and first and second mid-wavelengths corresponding to optical transmittances of about 50% along the respective left and right band edges. Across at least 80% of the optical film, the first mid-wavelength has an average value LBE50 between about 480 nm and about 530 nm with a maximum value that is greater than LBE50 by no more than about 4% and a minimum value that is less than LBE50 by no more than about 4%, and the second mid-wavelength has an average value RBE50 between about 820 nm and about 870 nm with a maximum value that is greater than RBE50 by no more than about 1% and a minimum value that is less than RBE50 by no more than about 5%. Best left and right linear fits to the respective left and right band edges at least across wavelength ranges where the optical transmittance changes from about 70% to about 20% have respective left and right slopes, where a ratio of a magnitude of the left slope to a magnitude of the right slope is greater than about 1.2.

[0003] These and other aspects will be apparent from the following detailed description. In no event, however, should this brief summary be construed to limit the claimable subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. **1** is a schematic exploded cross-sectional view of a display system, according to some embodiments.

[0005] FIG. **2**A is a schematic cross-sectional view of a multilayer optical film, according to some embodiments.

[0006] FIG. **2**B is a schematic cross-sectional view of a mirror film, according to some embodiments.

[0007] FIG. **2**C is a schematic cross-sectional view of a reflective polarizer, according to some embodiments.

[0008] FIGS. **3**A-**3**B are plots of optical transmittances of a plurality of polymeric layers versus wavelength, according to some embodiments.

[0009] FIGS. **4**A-**4**C are plots of optical transmittances of a plurality of polymeric layers and intensity of light emitted from a light conversion film versus wavelength, according to some embodiments.

[0010] FIG. **5** is a plot of band edges of optical transmittances of a plurality of polymeric layers versus wavelength, according to some embodiments.

[0011] FIG. **6** is a schematic plot of band edge wavelengths versus position, according to some embodiments.

DETAILED DESCRIPTION

[0012] In the following description, reference is made to the accompanying drawings that form a part hereof and in which various embodiments are shown by way of illustration. The drawings are not necessarily to scale. It is to be understood that other embodiments are contemplated and may be made without departing from the scope or spirit of the present description. The following detailed description, therefore, is not to be taken in a limiting sense.

[0013] Display systems can include blue light emitting diodes (LEDs) and a color converting film (e.g., a quantum dot film or a phosphor film) disposed to receive light from the blue LEDS and convert portions of the blue light to green and red light while transmitting a portion of the blue light. An optical film having a blue reflection band can be placed between the color converting film and the blue LEDs to recycle light from the LEDs in order to improve efficiency. However, it has been found that overlap between the green emission spectra and a left band edge of the blue reflection band can create undesired color mura. According to some embodiments of the present description, it has been found that the position of the left band edge of the blue reflection band of the optical film relative to the smallest wavelength of a full width at half maximum of the green emission spectra can be selected to reduce the color mura. Moreover, it has been found that the optical film can be made such that the blue reflection band has band edges that are substantially uniform over the optical film so that the left band edge of the blue reflection band has a substantially constant position relative to the smallest wavelength of the full width at half maximum of the green emission spectra so that color mura is reduced for substantially any portion of the optical film used in a display.

[0014] FIG. **1** is a schematic exploded cross-sectional view of a display system **200** including a light converting film **10** and a first optical film **20** disposed on the light converting film **10**, according to some embodiments. The display system can include a plurality of discrete spaced apart light emitting sources **60**, where the first optical film **20** is disposed between the light converting film **10** and the light emitting sources **60**, such that emission surfaces **61** of the light emitting sources **60** face a major surface **23** of the first optical film **20**. The plurality of discrete spaced apart light emitting sources **60** can be configured to emit light **64** having wavelengths of less than about 490, or 480, or 470, or 460, or 455, or 450 nm. The emitted light can be primarily in a range of about 410 nm to about 490 nm (e.g., greater than 50% or 60% or 70% of the emitted light intensity can be in this wavelength range), for example. The light emitting sources **60** can be disposed on a common substrate **62**. The light converting film **10** may be configured to convert portions of the light **64** into green and red lights **64***g* and **64***r* and to transmit a portion of the light **64** as a blue light **64***b*.

[0015] The display system **200** can further include optical elements conventionally included in a liquid crystal display, for example. The display system **200** can include an optical diffuser film **70** disposed between the first optical film **20** and the light emitting sources **60** and configured to receive and scatter the emitted light **64**. The diffuser film **70** may be included for defect hiding, for example. The display system **200** can include a reflective polarizer **80**, where the light converting film **10** is disposed between the reflective polarizer **80** and the first optical film **20**. The reflective polarizer **80** can be included for polarization recycling, for example. The display system **200** can include a first prismatic film **90** disposed between the reflective polarizer **80** and the light converting film **10**. The first prismatic film **90** can include a plurality of first prisms **91** extending along a first longitudinal direction (e.g., y-direction). The display system **200** can include a second prismatic film **92** disposed between the reflective polarizer **80** and the first prismatic film **90**. The second prismatic film **92** can include a plurality of second prisms **93** extending along a second longitudinal direction (e.g., x-direction) different than the first longitudinal direction. The second longitudinal direction can be substantially orthogonal to the first longitudinal direction. The prism film(s) can be included to enhance on-axis brightness, for example. Suitable prism films include Brightness Enhancement Film (BEF) available from 3M Company, St. Paul, MN.

[0016] FIG. **2**A is a schematic cross-sectional view of a multilayer optical film **150**, according to some embodiments. The multilayer optical film **150** may be a mirror film as schematically illustrated in FIG. **2**B for optical film **150'** which may correspond to optical film **150**, or may be a reflective polarizer as schematically illustrated in FIG. **2**C for optical film **150"** which may correspond to optical film **150**. In FIG. **2**B, the optical film **150'** substantially reflects the substantially normally incident light **30** for each of orthogonal first and second polarization states **31** and **32** as reflected light **30'**. In FIG. **2**C, the optical film **150"** substantially reflects the substantially normally incident light **30** having the first polarization state **31** as reflected light **30***r* and substantially transmits the substantially normally incident light **30** having the second polarization state **32** as transmitted light **30***t*. The first optical film **20** and/or the reflective polarizer **80** may be as schematically illustrated for multilayer optical film **150**. The optical film **20** may be as schematically illustrated for optical film **150'**, for example, and the reflective polarizer **80** may be as schematically illustrated for optical film **150"**.

[0017] As is known in the art, multilayer optical films including alternating polymeric layers can be used to provide desired reflection and transmission in desired wavelength ranges by suitable selection of layer thicknesses and refractive index differences. Multilayer optical films and methods of making multilayer optical films are described in U.S. Pat. No. 5,882,774 (Jonza et al.); 6,179,948 (Merrill et al.); 6,783,349 (Neavin et al.); 6,967,778 (Wheatley et al.); and 9,162,406 (Neavin et al.), for example.

[0018] In some embodiments, the first optical film **20** includes a plurality of first polymeric layers **21**, **22** numbering at least 10, 20, 50, 75, 100, 150, 200, 250, 300, 350, or 400 in total. The plurality of first polymeric layers **21**, **22** may number up to 1500 or 1000 in total. For example, the plurality of first polymeric layers **21**, **22** may number from 10 to 1500 or from 20 to 1000 in total. In some embodiments, each of the first polymeric layers has an average thickness of less than about 500, 400, 350, 300, 250, or 200 nm. The average thickness may be at least about 20 nm or at least about nm. For example, each of the first polymeric layers has an average thickness in a range of about nm to about 500 nm or about 40 nm to about 400 nm. The optical film **20** can include other layers such as protective boundary layers (intermediate layers) between packets of the first polymeric layers **21**, **22** and/or skin layers as outer layers of the optical film. In some embodiments, the first optical film **20** includes at least one skin layer **24** having an average thickness of greater than about 500. In some embodiments, the first optical film **20** further includes at least one intermediate layer **25** disposed between two of the first polymeric layers (**22***a*, **22***b*) and having an average thickness of greater than about 500 nm. The at least one skin layer **24** and/or the at least intermediate layer **25** can have an average thickness greater than about 750, 1000, 1500, or 2000 nm, for example. The average thickness can be up to about 30 micrometer or up to about 20 micrometers, for example.

[0019] In some embodiments, the reflective polarizer **80** includes a plurality of second polymeric layers **21**, **22** numbering at least 10 in total. The total number of second polymeric layers can be in any of the ranges described for the first polymeric layers. In some embodiments, each of the second polymeric layers has an average thickness of less than about 500 nm, such that for a substantially normally incident (e.g., within about 30, 20, 10, or 5 degrees of normally incident) light **30**, the plurality of second polymeric layers reflect more than about 60% of the incident light having the first polarization state **31** and transmit more than about 60% of the incident light having an orthogonal second polarization state **32**. Each of the second polymeric layers can have an average thickness in a range described for the first polymeric layers. The reflective polarizer **80** may include skin and/or intermediate layer(s) as described for the first optical film **20**. In some embodiments, the plurality of second polymeric layers reflect more than about 70%, 80%, or 90% of the incident light having the first polarization state **31**. In some embodiments, the plurality of second polymeric layers transmit more than about 70%, 80%, or 90% of the incident light having the second polarization state **32**. The reflection and/or transmission may be in any of the above ranges for at least one wavelength in a visible wavelength range or the average reflection and/or transmission over a visible wavelength range may be in any of these ranges. The visible wavelength range may be 400 nm to 700 nm or 420 nm to 680, for example.

[0020] FIGS. **3**A-**3**B are plots of optical transmittances **40***a*-**40***c* of a plurality of polymeric layers **21**, **22** versus wavelength, according to some embodiments. The optical transmittances **40***a*-**40***c* are for respective optical films Ex**1**, Ex**2**, and Ex**3**. The optical transmittances **40***a*-**40***c* have respective left band edges **41***a*-**41***c* and corresponding first mid-wavelengths **44***a*-**44***c* where the optical transmittance is about 50% and respective right band edges **42***a*-**42***c* and corresponding second mid-wavelengths **45***a*-**45***c* where the optical transmittance is about 50%. Average optical transmittances in various wavelength ranges are reported in the table below.

Wavelength range (nm)	Ex1	Ex2	Ex3
420-480	84.3	85.8	85.9
490-520	18.4	49.3	74.0
530-680	1.08	0.96	1.53
900-1400	88.5	88.3	88.6

[0021] The optical films of FIGS. **3**A-**3**B were made by co-extrusion and biaxial orientation as generally described in U.S. Pat. Appl. Pub. No. 2001/0013668 (Neavin et al.), with exceptions as follows. The films included alternating first (**21**) and second (**22**) optical layers (layers having a thickness less than about 500 nm so that the layers can reflect and transmit light primarily by optical interference) having a layer thickness profile giving the optical transmittance of FIGS. **3**A-**3**B. The first optical layers were comprised of polyethylene terephthalate (PET) homopolymer. The second optical polymer layers were a copolymer of poly(methyl methacrlatemethacrylate) or coPMMA available from Plaskolite, Columbus, OH, USA under the tradename OPTIX. The polymer used for the skin layers were comprised of the same material used in the first optical layers. The materials were fed from separate extruders to a multilayer coextrusion feedblock, in which they were assembled. The skin layers were added to the construction in a manifold specific to that purpose, resulting in a final construction having 429 layers. The multilayer melt was then cast through a film die onto a chill roll, in the conventional manner for polyester films, upon which it was quenched. The cast web was then stretched in a commercial scale biaxial tenter at temperatures and draw profiles similar to those described in U.S. Pat. Appl. Pub. No. 2001/0013668 (Neavin et al.). The resulting films were measured for physical thickness by a capacitance gauge. The average thickness was approximately 54.9 μm as measured using an Ono-Sokki DG-925 Micrometer. It has been found that the resulting optical films can have left and right band edge wavelengths that are substantially uniform over substantially a total area of the optical film. The optical films Ex**1**, Ex**2**, and Ex**3** are different film samples made using the same process and can represent different portions of a same film made using the same process. Other suitable polymers that can be used for the various layers of the optical films are described in U.S. Pat. No. 5,882,774 (Jonza et al.); 6,179,948 (Merrill et al.); 6,783,349 (Neavin et al.); 6,967,778 (Wheatley et al.); and 9,162,406 (Neavin et al.), for example.

[0022] FIGS. **4**A-**4**C are plots of optical transmittances of FIGS. **3**A-**3**B superimposed on a plot of intensity of light emitted from a light conversion film **10** versus wavelength when illuminated with light from a blue light emitting diode (LED), according to some embodiments. The intensity is shown for four light conversion films labeled Conv**1**-Conv**4**. Conv**1** and Conv**2** are quantum dot films available from Showa Denko K. K. (Tokyo, Japan), Conv**3** is a quantum dot film available from Inno QD (Korea), and Conv**4** is a phosphor film available from Dexerials Corporation (Tokyo, Japan).

[0023] In some embodiments, a display system **200** includes a light converting film **10** including one or more light converting materials **127** having green (**11***a*-**11***d*) and red (**12***a*-**12***d*) emission spectra including respective green (**11***a***1**-**11***d***1**) and red (**12***a***1**-**12***d***1**) emission peaks at respective green (**11***a***2**-**11***d***2**) and red (**12***a***2**-**12***d***2**) peak wavelengths with respective green (**11***a***3**-**11***d***3**) and red (**12***a***3**-**12***d***3**) full width at half maxima (FWHMs). The FWHMs are schematically represented by the widths of horizontal bars in FIGS. **4**B-**4**C. Each of the FWHMs extend from a lower first wavelength to a higher second wavelength. In some embodiments, a first optical film **20** can be disposed on the light converting film **10** and includes a plurality of first polymeric layers **21**, **22** such that for a substantially normally incident light **30** and for at least a first polarization state (**31** and/or **32**), an optical transmittance (**40***a*-**40***c*) of the plurality of first polymeric layers versus wavelength includes: a left band edge (**41***a*-**41***c*) separating a shorter wavelength range **50** (e.g., about 400 or 420 nm to about 480 nm) where the plurality of first polymeric layers has an optical transmittance of greater than about 60% from a middle wavelength range **51** (e.g., about 530 nm to about 680 or 760 nm) where the plurality of first polymeric layers has an optical reflectance (e.g., the optical reflectance R schematically illustrated in FIG. **3**B) of greater than about 80%, and a right band edge **42***a*-**42***c* separating the middle wavelength range **51** from a longer wavelength range **52** (e.g., about 880 nm to about 1450 nm or about 900 to about 1400 nm) where the plurality of first polymeric layers has an optical transmittance of greater than about 60%; and a mid-wavelength **44***a*-**44***c* corresponding to an optical transmittance of about 50% along the left band edge. In some embodiments, for each of the FWHMs, the mid-wavelength **44***a*-**44***c* is less than or equal to the lower first wavelength (e.g., for **11***b***3**, **11***c***3**) of the FWHMs or greater than the lower first wavelength (e.g., for **11***a***3**, **11***d***3**) by no more than about 30% of the FWHM. Here, 30% of the FWHM means 30% of the total width (difference between the higher second wavelength and the lower first wavelength) of the FWHM. In some embodiments, for each of the FWHMs, the mid-wavelength **44***a*-**44***c* is no greater than the first wavelength plus 0.3, or 0.2, or 0.1 times a difference between the second wavelength and the first wavelength. In some embodiments, the mid-wavelength **44***a*-**44***c* is greater than (e.g., by at least 20 nm, or at least 30 nm) a peak emission wavelength (e.g., **10***b***1**-**10***d***1**) of the light emitting sources **60** or greater than (e.g., by at least 20 nm, or at least 30 nm) a blue peak transmission wavelength (e.g., **10***a***1**-**10***d***1**) of the received light **64** transmitted by the light converting film **10**.

[0024] In some embodiments, the plurality of first polymeric layers has an optical transmittance (e.g., the optical transmittance for at least one wavelength in the shorter wavelength range **50**, or the optical transmittance for each wavelength in the shorter wavelength range **50**, or for an average of the optical transmittance in the shorter wavelength range **50**) of greater than about 60%, 65%, 70%, 75%, or 80% in the shorter wavelength range **50**. In some embodiments, the plurality of first polymeric layers has an optical reflectance (e.g., the optical reflectance for at least one wavelength in the middle wavelength range **51**, or the optical reflectance for each wavelength in the middle wavelength range **51**, or for an average of the optical reflectance in the middle wavelength range **51**) of greater than about 80%, 85%, 90%, 95%, 96%, or 97%, 98%, or 98.5% in the middle wavelength range **51**. In some embodiments, the plurality of first polymeric layers has an optical transmittance (e.g., the optical transmittance for at least one wavelength in the longer wavelength range **52**, or the optical transmittance for each wavelength in the longer wavelength range **52**, or for an average of the optical transmittance in the longer wavelength range **52**) of greater than about 60%, 65%, 70%, 75%, 80%, or 85% in the longer wavelength range **52**. In some embodiments, the optical transmittance and/or optical reflectance is in any of these ranges for each of orthogonal first (**31**) and second (**32**) polarization states.

[0025] In some embodiments, the light emitting sources **60** are configured to emit light primarily in the shorter wavelength range **50**. In some embodiments, the light converting film **10** is configured to receive the emitted light **64** from the light sources **60** and convert at least: a first portion (corresponding to the green emission peak **11*a*1**-**11*d*1**) of the received emitted light to a green light **64*g*** having a green wavelength disposed within the green FWHM of the green emission spectra of the light converting film **10**; and a second portion (corresponding to the red emission peak **12*a*1**-**12*d*1**) of the received emitted light to a red light **64*r*** having a red wavelength disposed within the red FWHM of the red emission spectra of the light converting film **10**. In some embodiments, the light converting film **10** is configured to transmit a third portion (corresponding to the blue transmission peak **10*b*1**-**10*d*1** or the transmitted portion of the peak **10*a*1**) of the received emitted light **64** as a blue light **64*b***. In some embodiments, the light converting film **10** (e.g., light converting films Conv**2**-Conv**4**) substantially transmits a third portion of the received emitted light **64** as a blue light without substantially shifting a blue peak wavelength of the received emitted light **63**. In some embodiments, the light converting film **10** (e.g., light converting film Conv**1**) substantially transmits a third portion of the received emitted light **64** as a blue light having a longer blue peak wavelength than that of the received emitted light **63**.

[0026] FIG. **5** is a plot of band edges of optical transmittances of a plurality of polymeric layers versus wavelength, according to some embodiments. Left band edges **41*a*-41*c*** and respective right band edges **42*a*-42*c*** are shown for the optical transmittances of the respective optical films Ex**1**-Ex**3** and best linear fits to the band edges are also shown. A high band edge slope (e.g., greater than about 2%/nm, or greater than about 3%/nm, or greater than about 3.5%/nm) may be desired for the left band edges so that there is a sharp transition in optical transmittance between blue and green emission wavelengths while the right band edge may have a lower slope (e.g., less than about 1.4%/nm, or less than about 1.3%/nm, or less than about 1.25%/nm). The left band edge can be sharpened by using additional optical layers providing reflection at wavelengths near the left band edge. Such band edge sharpening techniques are known in the art and are described in U.S. Pat. No. 6,967,778 (Wheatley et al.), for example. In some embodiments, best left (**46*a*-46*c***) and right (**47*a*-47*c***) linear fits to the respective left and right band edges at least across wavelength ranges where the optical transmittance changes from about 70% to about 20% have respective left (**48*a*-48*c***) and right (**49*a*-49*c***) slopes, where a ratio of a magnitude of the left slope to a magnitude of the right slope is greater than about 1.2, 1.5, 1.8, 2, 3, 4, or 5, for example. The ratio can be up to about 10, 8, or 6, for example. In some embodiments, the ratio of the magnitude of the left slope to the magnitude of the right slope is in a range of about 1.5 to about 6, for example. The best linear fits can be linear least squares fits as is known in the art. Such fits minimize the sum of squares of residuals where a residual is the difference between data and the fitted line. The least squares analysis allows the r-squared value (R^2), sometimes referred to as the coefficient of determination, to be determined. The r-squared value for the best left (**46*a*-46*c***) and/or right (**47*a*-47*c***) linear fits may be greater than about 0.7, 0.75, 0.8, 0.85, or 0.9, for example.

[0027] FIG. **6** is a schematic plot of band edge wavelengths versus position, according to some embodiments. The position can be the cross-web location, for example. In some embodiments, the band edge wavelengths are substantially uniform across at least 80% of the optical film **20**. Across at least a specified percentage of an optical film means across at least the specified percentage by area of the optical film, unless indicated differently. In FIG. **6**, the optical film has a left band edge mid-wavelength having an average value LBE50, a maximum value greater than LBE50 by no more than AL**1**, a minimum value less than LBE50 by no more than AL**2**, and the optical film has a right band edge mid-wavelength having an average value RBE50, a maximum value greater than RBE50 by no more than AR**1**, a minimum value less than RBE50 by no more than AR**2**. In some embodiments, LBE50 is between about 460 nm and about 540 nm, or between about 480 nm and about 530 nm, or between about 490 nm and about 520 nm. In some such embodiments, or in other embodiments, RBE50 is between about 770 nm and about 880 nm, or between about 800 nm and about 875 nm, or between about 820 nm and about 870 nm. In some embodiments, each of AL**1** and AL**2** is no more than about 5% or no more than about 4% of LBE50. In some embodiments, each of AR**1** and AR**2** is no more than about 5% or no more than about 4% of RBE50.

[0028] In some embodiments, across at least 80%, 85%, 90%, 95%, 98%, or 99% of the (first) optical film **20**, the (first) mid-wavelength **44*a*-44*c*** (see, e.g., FIG. **3**B) has an average value LBE50 between about 480 nm and about 530 nm with a maximum value that is greater than LBE50 by no more than about 4% and a minimum value that is less than LBE50 by no more than about 4%. In some embodiments, the maximum value is greater than LBE50 by no more than about 3.5% or no more than about 3%. In some embodiments, the minimum value is less than LBE50 by no more than about 3.5% or no more than about 3%. In some embodiments, across at least 80%, 85%, 90%, 95%, 98%, or 99% of the (first) optical film **20**, the second mid-wavelength **44*a*-44*c*** (see, e.g., FIG. **3**B) has an average value RBE50 between about 820 nm and about 870 nm with a maximum value that is greater than RBE50 by no more than about 1% and a minimum value that is less than RBE50 by no more than about 5%. In some embodiments, the maximum value is greater than RBE50 by no more than about 0.9%, 0.8%, 0.7%, or 0.6%. In some embodiments, the minimum value is less than RBE50 by no more than about 4.5%, 4%, 3.8%, or 3.6%.

[0029] Terms such as "about" will be understood in the context in which they are used and described in the present description by one of ordinary skill in the art. If the use of "about" as applied to quantities expressing feature sizes, amounts, and physical properties is not otherwise clear to one of ordinary skill in the art in the context in which it is used and described in the present description, "about" will be understood to mean within 10 percent of the specified value. A quantity given as about a specified value can be precisely the specified value. For example, if it is not otherwise clear to one of ordinary skill in the art in the context in which it is used and described in the present description, a quantity having a value of about 1, means that the quantity has a value between 0.9 and 1.1, and that the value could be 1.

[0030] Terms such as "substantially" will be understood in the context in which they are used and described in the present description by one of ordinary skill in the art. If the use of "substantially" with reference to a property or characteristic is not otherwise clear to one of ordinary skill in the art in the context in which it is used and described in the present description and when it would be clear to one of ordinary skill in the art what is meant by an opposite of that property or characteristic, the term "substantially" will be understood to mean that the property or characteristic is exhibited to a greater extent than the opposite of that property or characteristic is exhibited.

[0031] All references, patents, and patent applications referenced in the foregoing are hereby incorporated herein by reference in their entirety in a consistent manner. In the event of inconsistencies or contradictions between portions of the incorporated references and this application, the information in the preceding description shall control.

[0032] Descriptions for elements in figures should be understood to apply equally to corresponding elements in other figures, unless indicated otherwise. Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that a variety of alternate and/or equivalent implementations can be substituted for the specific embodiments shown and described without departing from the scope of the present disclosure. This application is intended to cover any adaptations, or variations, or combinations of the specific embodiments discussed herein. Therefore, it is intended that this disclosure be limited only by the claims and the equivalents thereof.

1. A display system comprising:

a light converting film comprising one or more light converting materials comprising green and red emission spectra comprising respective green and red emission peaks at respective green and red peak wavelengths with respective green and red full width at half maxima (FWHMs), each of the FWHMs extending from a lower first wavelength to a higher second wavelength; and

a first optical film disposed on the light converting film and comprising a plurality of first polymeric layers numbering at least 10 in total, each of the first polymeric layers having an average thickness of less than about 500 nm, such that for a substantially normally incident light and for at least a first polarization state, an optical transmittance of the plurality of first polymeric layers versus wavelength comprises:

a left band edge separating a shorter wavelength range where the plurality of first polymeric layers has an optical transmittance of greater than about 60% from a middle wavelength range where the plurality of first polymeric layers has an optical reflectance of greater than about 80%, and a right band edge separating the middle wavelength range from a longer wavelength range where the plurality of first polymeric layers has an optical transmittance of greater than about 60%; and

a mid-wavelength corresponding to an optical transmittance of about 50% along the left band edge, wherein for each of the FWHMs, the mid-wavelength is less than or equal to the lower first wavelength of the FWHM or greater than the lower first wavelength by no more than about 30% of the FWHM.

2. The display system of claim **1** further comprising a plurality of discrete spaced apart light emitting sources configured to emit light having wavelengths of less than about 490 nm, the first optical film disposed between the light converting film and the light emitting sources, such that emission surfaces of the light emitting sources face a major surface of the first optical film.

3. The display system of claim **2**, wherein the light converting film is configured to receive the emitted light from the light sources and convert at least:

a first portion of the received emitted light to a green light having a green wavelength disposed within the green FWHM of the green emission spectra of the light converting film; and

a second portion of the received emitted light to a red light having a red wavelength disposed within the red FWHM of the red emission spectra of the light converting film.

4. The display system of claim **3**, wherein the light converting film is configured to transmit a third portion of the received emitted light as a blue light.

5. The display system of claim **2** further comprising an optical diffuser film disposed between the first optical film and the light emitting sources and configured to receive and scatter the emitted light.

6. The display system of claim **2**, wherein the light emitting sources are disposed on a common substrate.

7. The display system of claim **1**, further comprising a reflective polarizer, the light converting film disposed between the reflective polarizer and the first optical film, the reflective polarizer comprising a plurality of second polymeric layers numbering at least 10 in total, each of the first polymeric layers having an average thickness of less than about 500 nm, such that for a substantially normally incident light, the plurality of second polymeric layers reflect more than about 60% of the incident light having the first polarization state and transmit more than about 60% of the incident light having an orthogonal second polarization state.

8. The display system of claim **7** further comprising a first prismatic film disposed between the reflective polarizer and the light converting film and comprising a plurality of first prisms extending along a first longitudinal direction.

9. The display system of claim **8** further comprising a second prismatic film disposed between the reflective polarizer and the first prismatic film and comprising a plurality of second prisms extending along a second longitudinal direction different than the first longitudinal direction.

10. The display system of claim **1**, wherein the first optical film further comprises at least one skin layer having an average thickness of greater than about 500 nm.

11. The display system of claim **1**, wherein the first optical film further comprises at least one intermediate layer disposed between two of the first polymeric layers and having an average thickness of greater than about 500 nm.

12. The display system of claim **1**, wherein across at least 80% of the first optical film, the mid-wavelength has an average value LBE50 between about 480 nm and about 530 nm with a maximum value that is greater than LBE50 by no more than about 4% and a minimum value that is less than LBE50 by no more than about 4%.

13. An optical film comprising a plurality of polymeric layers numbering at least 10 in total, each of the polymeric layers having an average thickness of less than about 500 nm, such that for a substantially normally incident light and for at least a first polarization state, an optical transmittance of the plurality of first polymeric layers versus wavelength comprises:

a left band edge separating a shorter wavelength range where the plurality of first polymeric layers has an optical transmittance of greater than about 60% from a middle wavelength range where the plurality of first polymeric layers has an optical reflectance of greater than about 80%, and a right band edge separating the middle wavelength range from a longer wavelength range where the plurality of first polymeric layers has an optical transmittance of greater than about 60%; and

first and second mid-wavelengths corresponding to optical transmittances of about 50% along the respective left and right band edges, wherein across at least 80% of the optical film, the first mid-wavelength has an average value LBE50 between about 480 nm and about 530 nm with a maximum value that is greater than LBE50 by no more than about 4% and a minimum value that is less than LBE50 by no more than about 4%, and the second mid-wavelength has an average value RBE50 between about 820 nm and about 870 nm with a maximum value that is greater than RBE50 by no more than about 1% and a minimum value that is less than RBE50 by no more than about 5%,

wherein, best left and right linear fits to the respective left and right band edges at least across wavelength ranges where the optical transmittance changes from about 70% to about 20% have respective left and right slopes, wherein a ratio of a magnitude of the left slope to a magnitude of the right slope is greater than about 1.2.

14. The optical film of claim **13**, wherein the ratio of the magnitude of the left slope to the magnitude of the right slope is in a range of about 1.5 to about 6.

15. A display system comprising:

a light converting film comprising one or more light converting materials comprising green and red emission spectra comprising respective green and red emission peaks at respective green and red peak wavelengths with respective green and red full width at half maxima (FWHMs), each of the FWHMs extending from a lower first wavelength to a longer second wavelength; and

the optical film of claim **13** disposed on the light converting film, wherein for each of the FWHMs, LBE50 is less than or equal to the lower first wavelength of the FWHM or greater than the lower first wavelength by no more than about 30% of the FWHM.

* * * * *