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(54) **LIGHT COLORING SYSTEM**

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This patent is subject to a terminal disclaimer.

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(60) Provisional application No. 60/931,308, filed on May 21, 2007.

(51) **Int. Cl.**

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**G02B 26/02** (2006.01)  
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*G02B 5/22* (2013.01); *G02B 7/006* (2013.01); *G03F 7/0007* (2013.01); *Y10T 29/49* (2015.01)

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**362/293**

See application file for complete search history.

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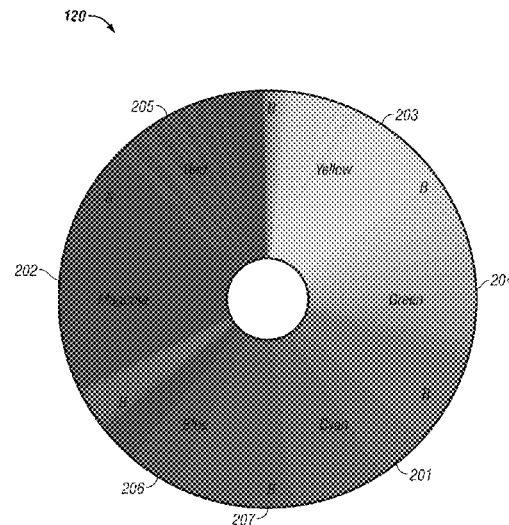
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*Assistant Examiner* — Colin Cattanach

(57)

**ABSTRACT**

A rainbow wheel that colors light that is passed there-through. The wheel can be formed using a photolithographic process. Another supermagenta wheel can be used to increase the number of colors that can be obtained.

**24 Claims, 8 Drawing Sheets**



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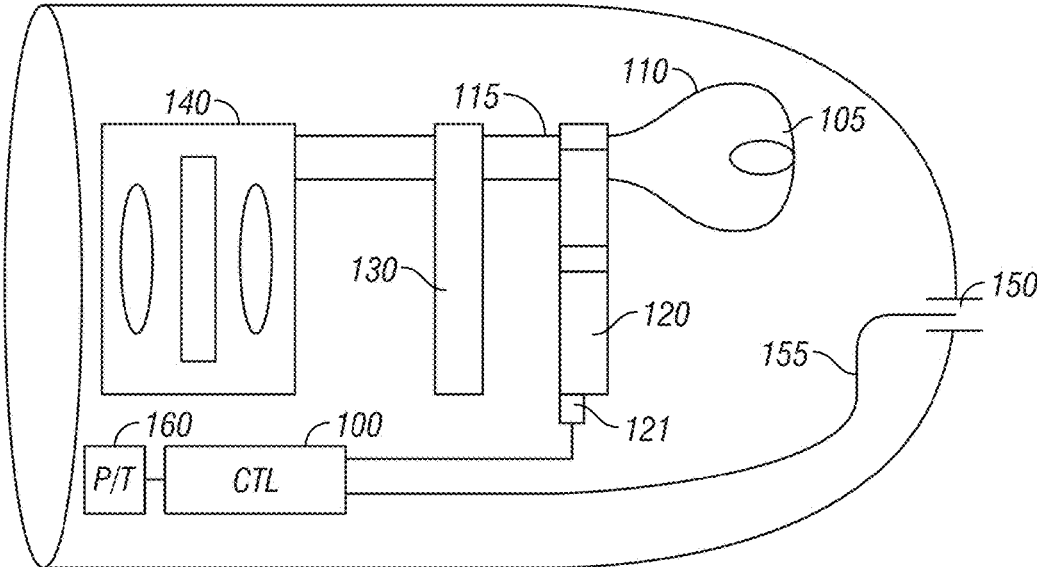


FIG. 1

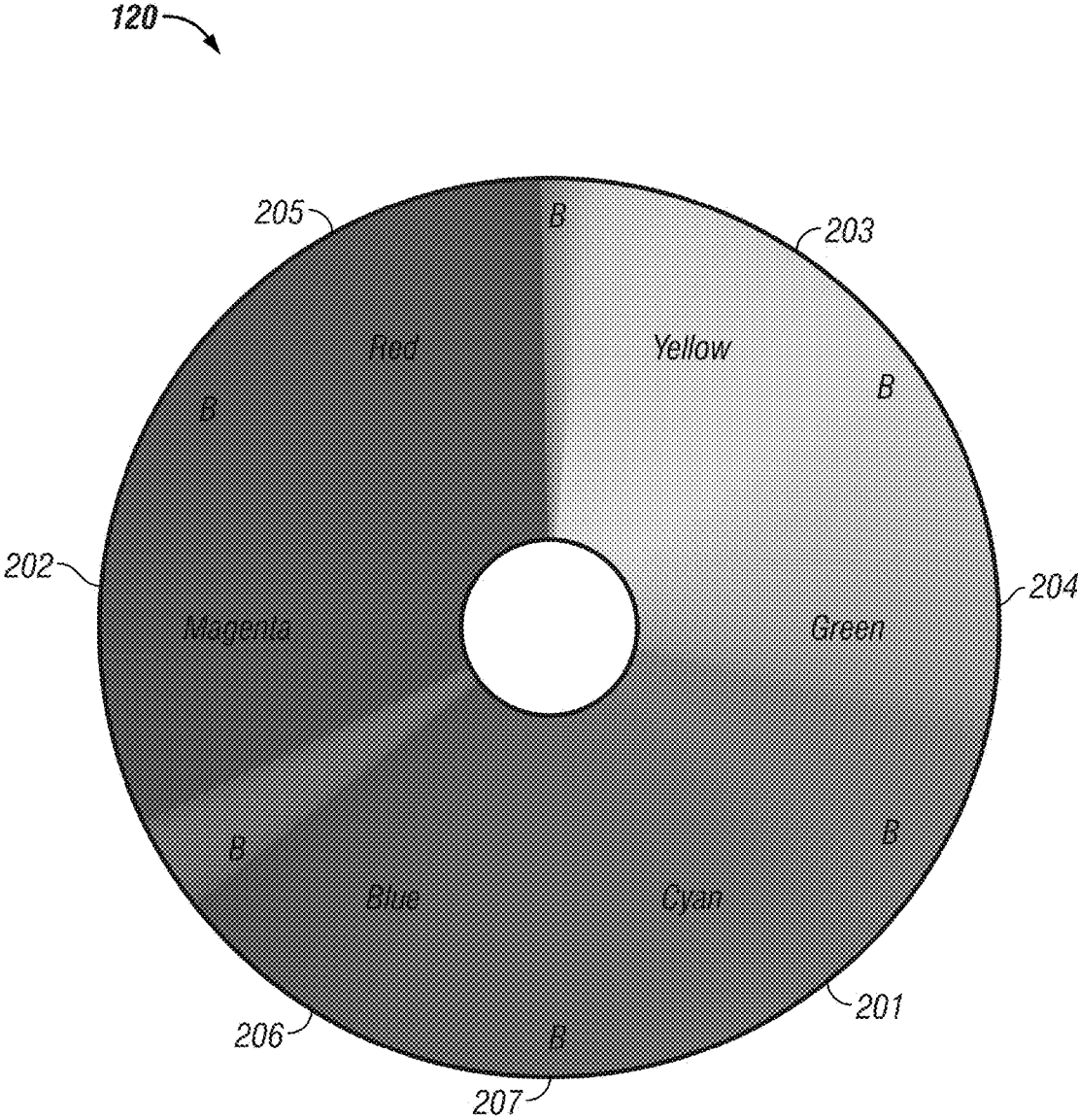


FIG. 2

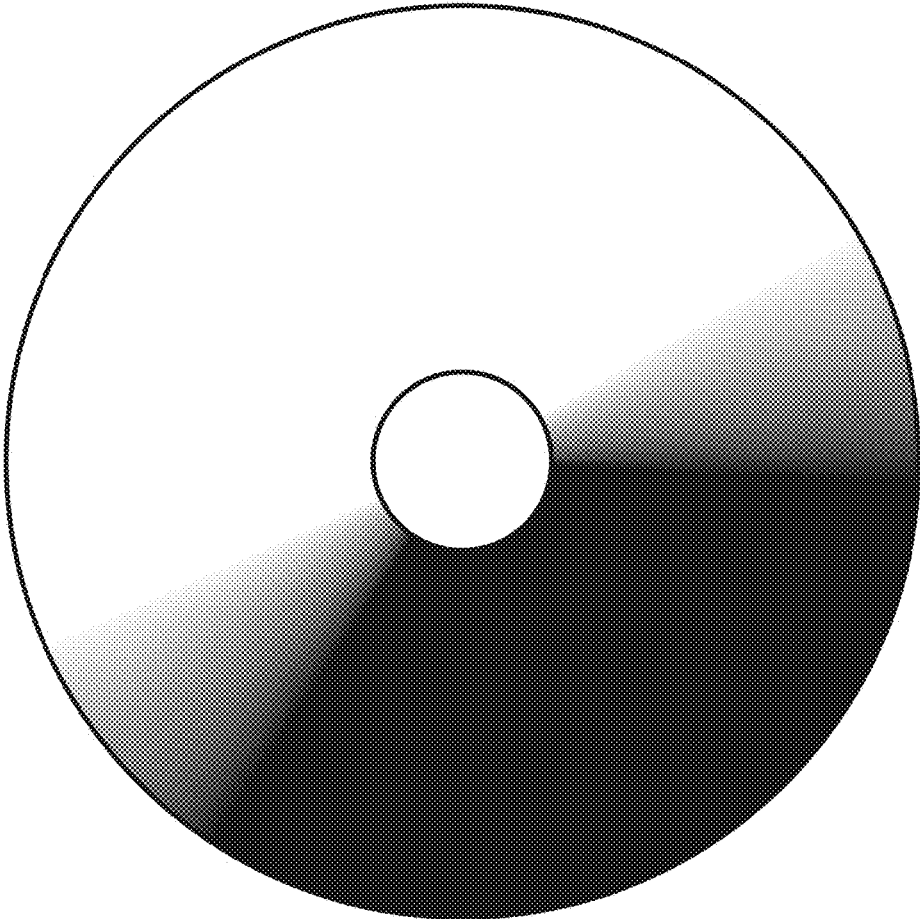


FIG. 3

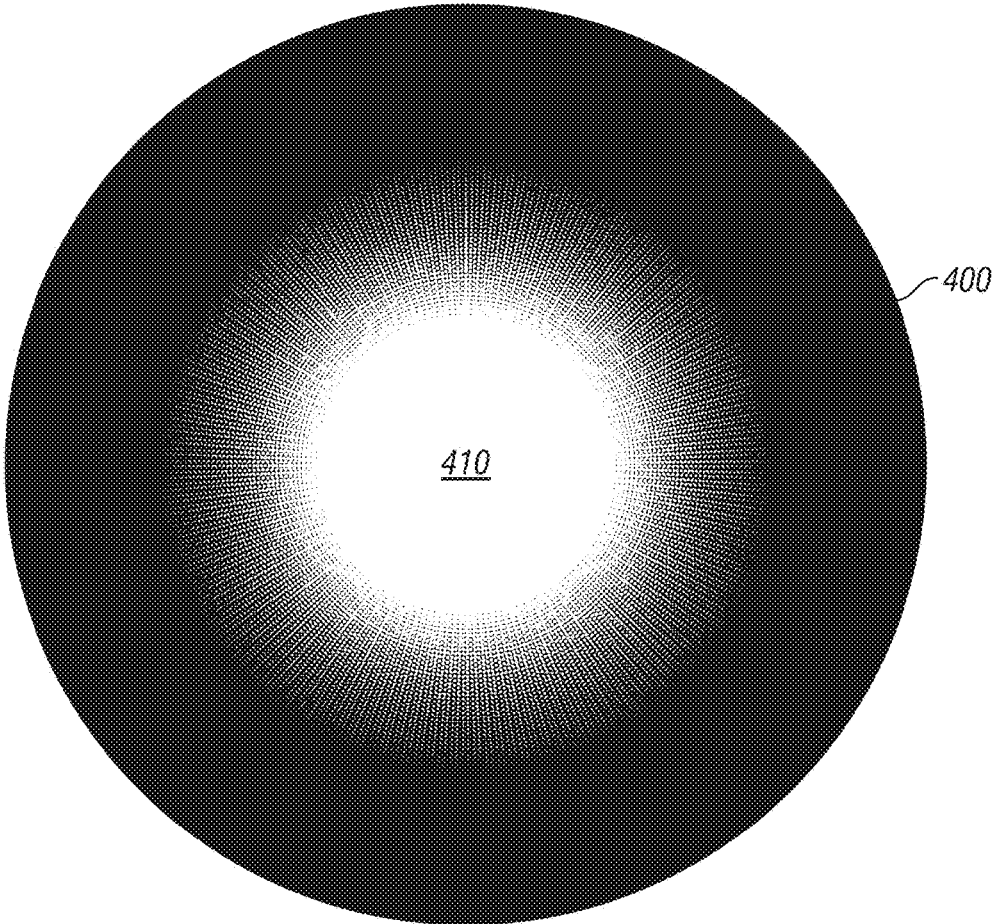


FIG. 4

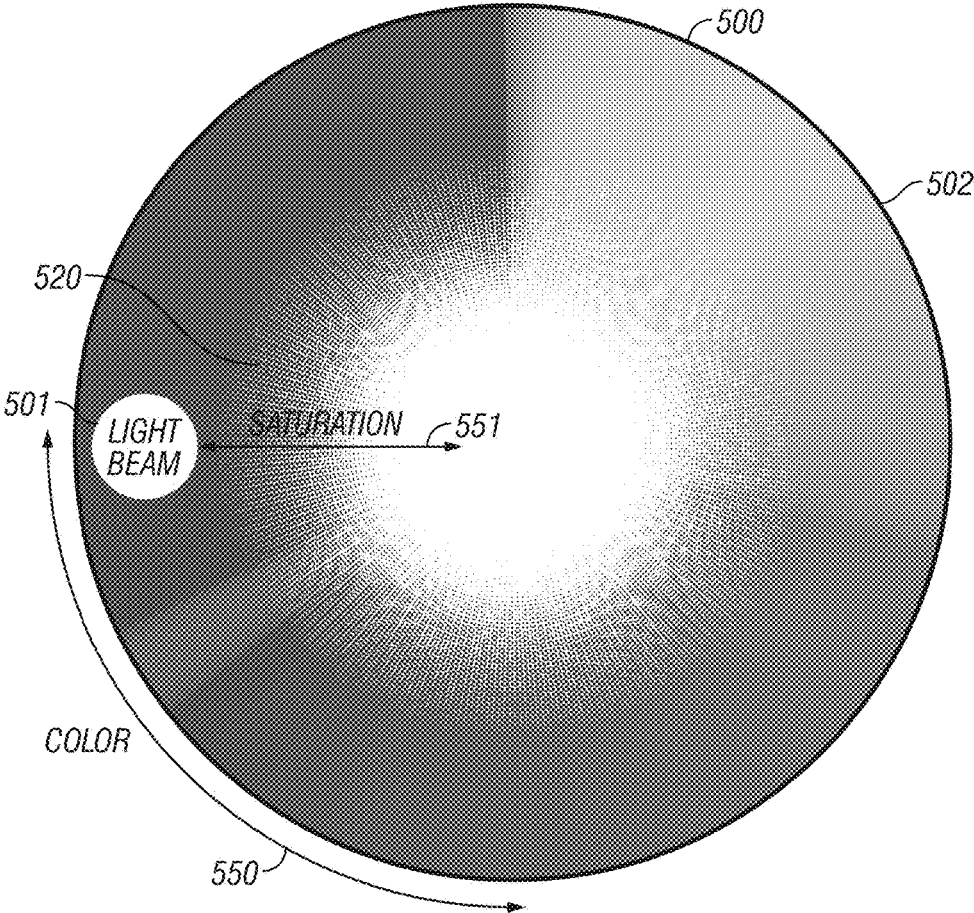


FIG. 5

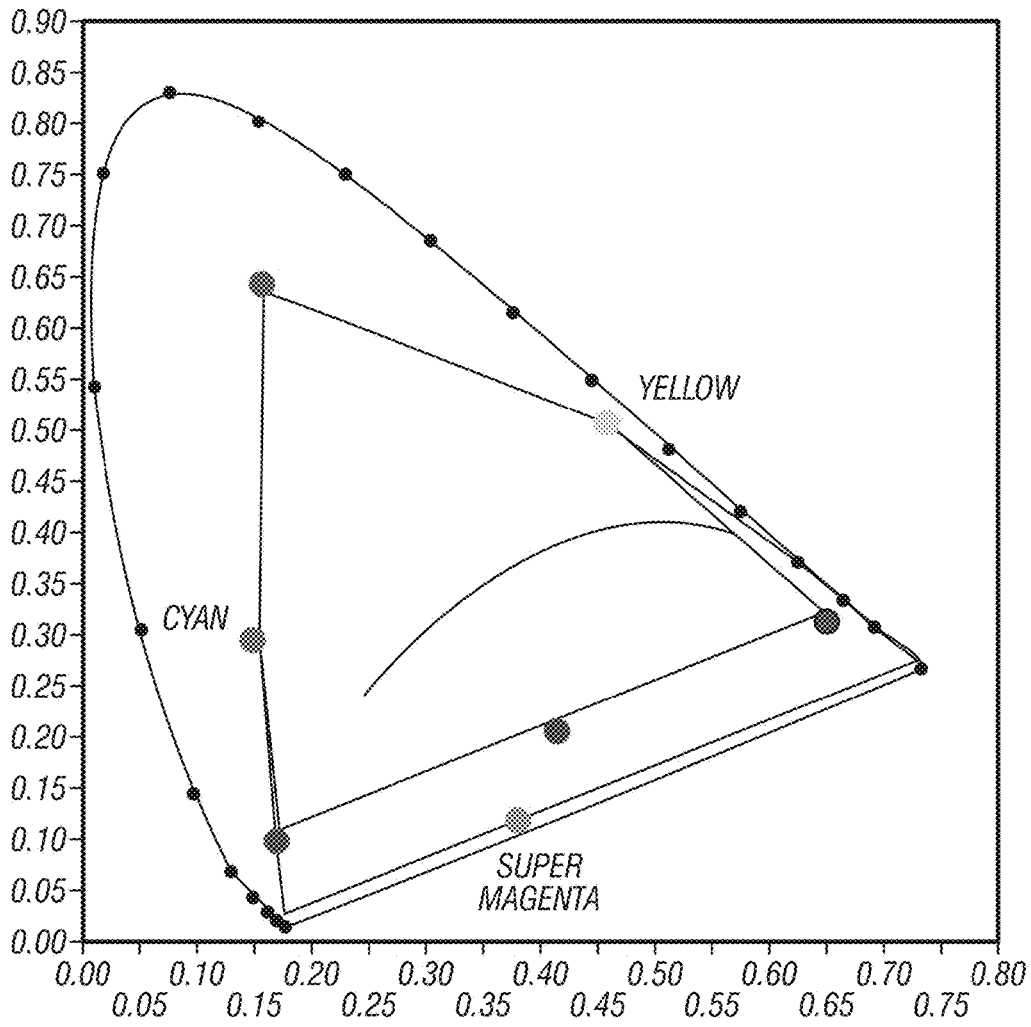


FIG. 6

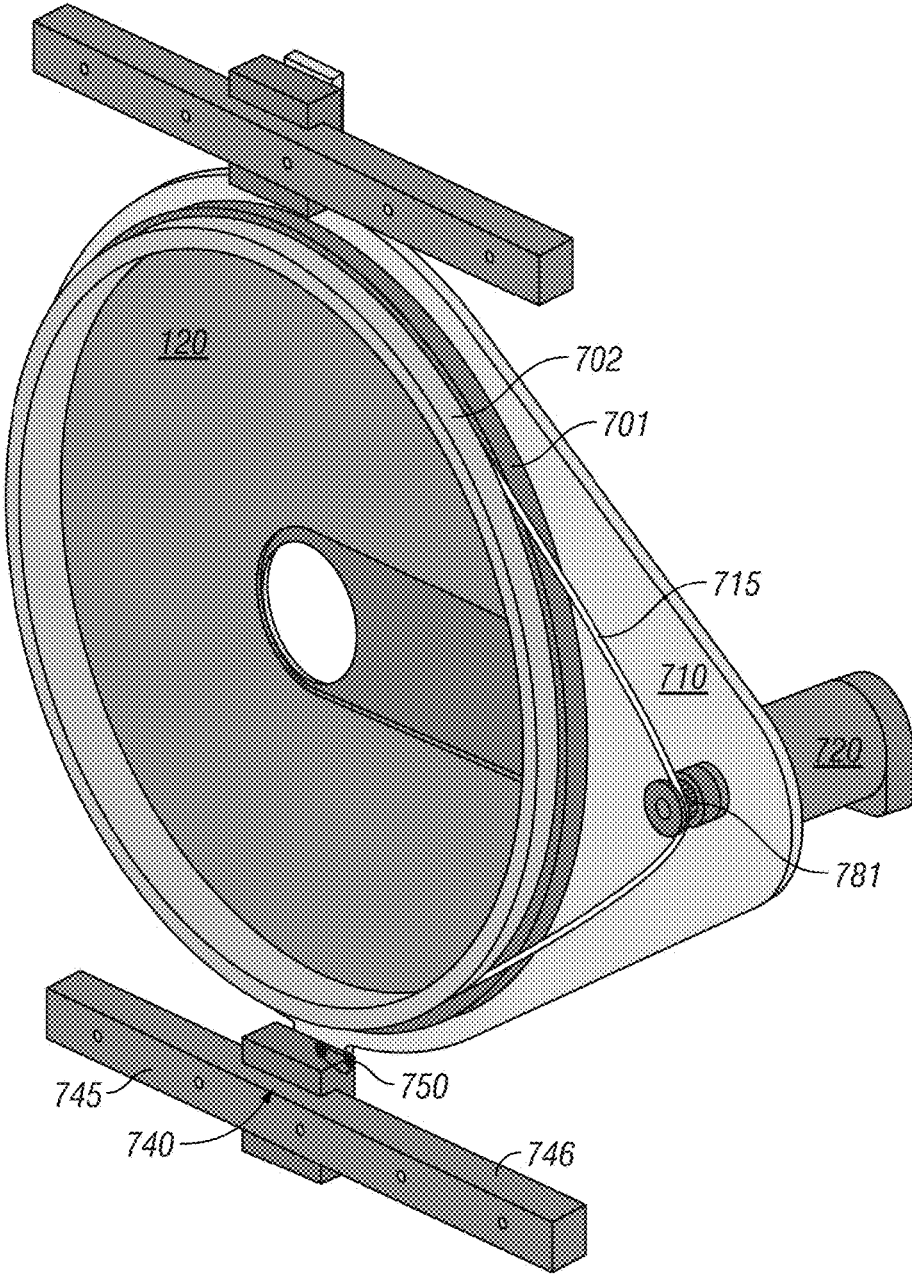
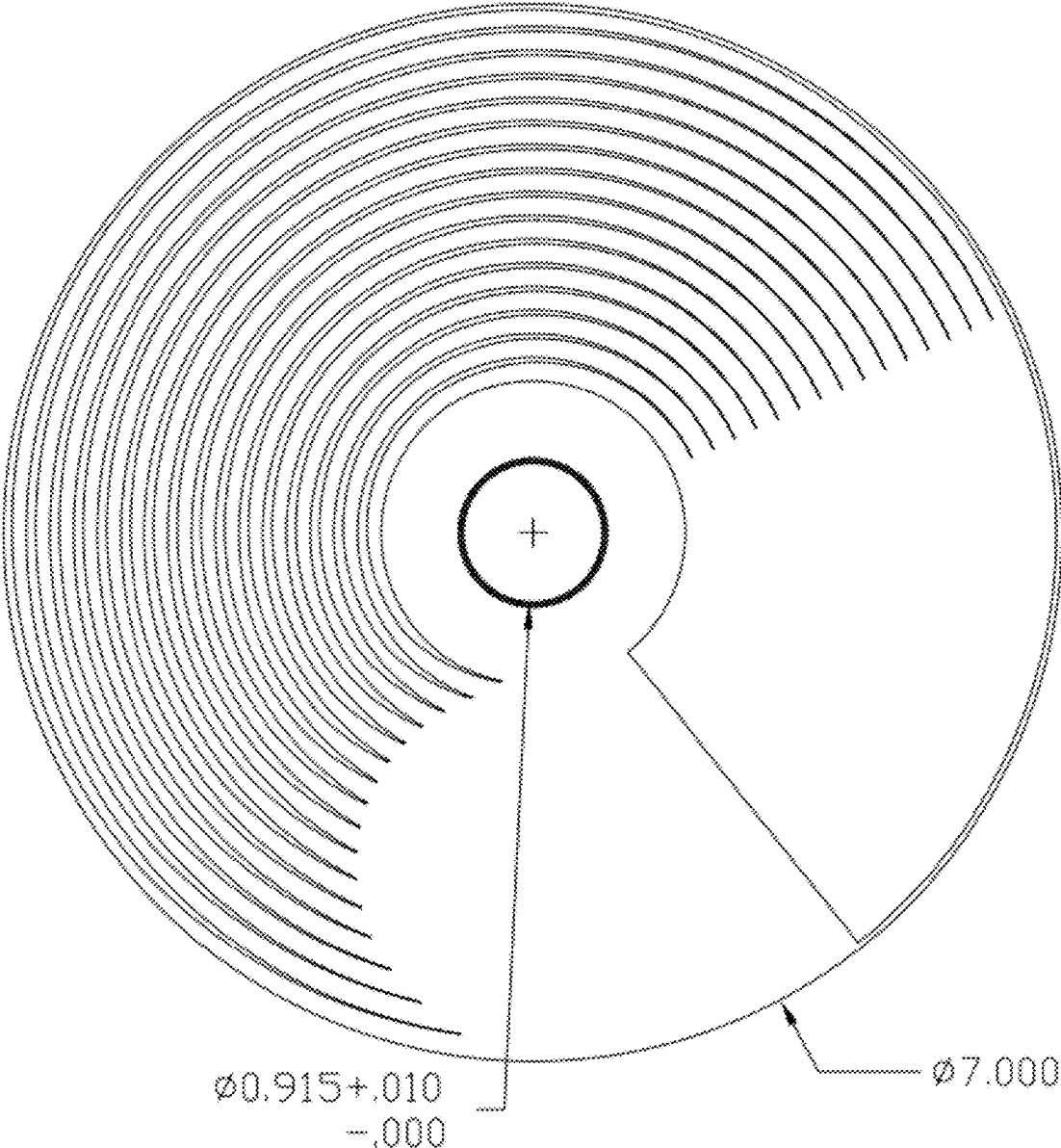


FIG. 7

FIGURE 8



## LIGHT COLORING SYSTEM

## CROSS-REFERENCE

This application is a continuation application of U.S. Ser. No. 13/302,338 filed Nov. 22, 2011, now U.S. Pat. No. 8,220,969 issued Jul. 17, 2012, which is a continuation application of U.S. Ser. No. 12/123,679 filed May 20, 2008, now U.S. Pat. No. 8,061,874 issued Nov. 22, 2011, which claims priority to provisional application Ser. No. 60/931,308 filed May 21, 2007, the disclosure of which is herewith incorporated by reference in their entirety.

## BACKGROUND

U.S. Pat. No. 4,392,187 (hereinafter '187), having a common inventor to the present application, describes a stage lighting system that is used to project a high intensity beam of light having certain variable characteristics such as shape, color and position. In '187, a high intensity discharge lamp provides a compact source of white light. The white light is colored by a dichroic color changing system that allows producing a large range of different colors. The colors, as well as other properties of the light, can be controlled using a digital control architecture. The digital control architecture allows transmitting commands from a central control console to the light.

Different kinds of light and colors of light can be produced by this kind of system.

## SUMMARY

The present application describes a new and continuously variable color changing system that can be used to color light.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows an embodiment including how the color wheels of the embodiments are used;

FIG. 2 illustrates a color wheel showing the effect of the combination of the three patterned films;

FIG. 3 illustrates a typical pattern used for the photolithographic etch process;

FIG. 4 illustrates a typical radial saturation gradient with white at the center;

FIG. 5 shows how the finished rainbow wheel may look;

FIG. 6 illustrates the CIE color domain for two different color wheels disclosed as embodiments;

FIG. 7 illustrates an exemplary holder for the wheels; and

FIG. 8 illustrates a circumferential saturation gradient used for the photolithographic etch process;

## DETAILED DESCRIPTION

The general structure and techniques, and more specific embodiments which can be used to effect different ways of carrying out the more general goals, are described herein.

Different kinds of coloring systems may be used to color light in a controllable high intensity lighting system, such as a stage lighting system. The term 'stage lighting system' is used to describe these lights, but it should be understood that these can be used in other venues, such as stores, and architectural lighting. The lights are preferably lights with high intensity bulbs, e.g., greater than 200 watts, 500 watts or 700 watts.

It is possible to use a system of multiple different color wheels, such as three color wheels, all arranged in series within the light beam. Such a system might use multiple openings near the periphery of each wheel, for example each wheel having eight openings through which light can be passed. Seven of those eight openings may be fitted with a multilayered dielectric interference filter that provides color to the beam. The last hole is open so that white light can be passed through that wheel, thereby enabling more variety in the final colored light.

The filters may be arranged in families on each wheel to interact with each other to create a large variety of colors. If three wheels are fitted with 21 discrete filters, over 60 unique colors can be generated.

Another color system may take advantage of the unusual and generally disadvantageous property of dichroics, that a filter characteristic may change based on the angle of incidence of the light on the filter. A continuously variable color changing system may be created based on this effect. Such a filter may use a multilayer interference filter that builds a continuously variable color changing system, allowing colors to be gradually faded from one color to the next color. This fading eliminates the drastic changing color that might occur with the multiple analog color wheels. However, if a CYM color filter is used, it may not be continuously variable throughout its entire range. Rather, such a filter often has a piecewise continuously variable color. A system similar to this was used in the Vari-Lite VL3 luminaire.

Another color system may use an optical coating technology to deposit a variable thickness coating stack. These variable thickness or wedged coatings may change the optical properties across the coated substrate to create a continuum of color. The Vari-Lite VL7 luminaire used two of these color plates. The first plate used two linearly variable bandpass coatings which were capable of producing all of the colors in the rainbow on the single plate.

The inventor notes, however, that human color perception includes not only the colors of the rainbow, but also the ability to detect a range of complex colors such as magentas, lavenders and purples that are a mix of various percentages of red and blue wavelengths. The VL7, for example, used a variable notch filter in order to create and expand the range of continuous color.

These color systems may be expensive, and also may create a complex optical system to homogenize the projected color. Such a system was also arranged along the long axis of a rectangular plate. Changing from one end of the color system to the other (usually red to blue) required that the colors passed through interim colors (green) during the movement. Many observers find this interim color to be undesirable.

A CYM mixing system can be formed using three patterned color wheels that subtractively create color in a way that is similar to that used by the print industry. Three cylindrical circular glass wheels are each coated, respectively, with cyan, magenta, and yellow, e.g. using a dichroic filter stack. The wheels are patterned using photolithographic and chemical etch techniques to remove parts of the filter coating and selected areas. The completed wheel has a completely uncoated area that allows white light to pass. At the opposite extreme, the wheel has a completely coated area that fully saturates the color of the beam. A density patterned area is in between the two, which has a variable saturation gradient.

The wheels may be used in pairs or in triples to create partial color limited continual color range. For example, the

magenta wheel may be used in combination with the yellow wheel, to generate the entire range of yellow to orange to red to magenta colors.

While this system produces good color, the inventor has recognized that this system is inherently limited in the color space it can produce. A color space is defined by the cyan, yellow and magenta filters. The color space can be modified by selecting different color points for the filters, but the space remains limited.

The inventor recognized that this is particularly weak in producing saturated colors.

The inventor recognized another disadvantage of this system: that it is sometimes difficult to fade between two different colors, especially when three wheels are involved in creating the color. Getting from red to green requires that the magenta wheel be moved to the white area, while the cyan wheel moves to full saturation and the yellow wheel stays fixed. The transitioning can create unwanted interim colors.

An embodiment disclosed herein may use a dichroic coated color altering device that can individually produce all the colors of a CYM system. A second color altering device is used in conjunction with the rainbow wheel to increase the saturation capability of the color combination.

An embodiment is shown in FIG. 1. A luminaire **100** has a housing as shown, and a high intensity lamp **105** that shines a light beam **110** along an optical path shown generally as **115**. One or both of a first color wheel **120** and second color wheel **130** are arranged in series in the path of the optical beam **115**. Additional optics **140** may further be used to homogenize and/or shape the beam. A wire connection **150** may provide power for the light, and may also provide a control signal **155** that is received by a controller, that controls different functions of the light including positions of the color wheels **120** and **130**. 2-dimensional pan and tilt motor(s) **160** may also control the position of the light.

In the embodiment, the wheel **120** is a rainbow wheel, and the wheel **130** is a special saturation-inducing wheel.

The wheel **120** is illustrated in FIG. 2. The wheel has sections of pure saturated colors as well as sections of subtractive secondary colors. For example, approximately 30 degrees of the wheel is developed for each of the pure subtractive primary colors: the cyan section **201**, the magenta section **202**, and the yellow section **203**. The primary colors overlap to create regions of subtractive secondaries, with a green section **204**, a red section **205**, and a blue section **206**. These subtractive secondaries may also be sectors of approximately 30 degrees.

The six 30 degree sectors account for approximately half the wheel. The remaining half of the wheel is taken up by six interleaved 30 degree regions, where the primaries and secondaries blend together. For example, section **207** is a blend from the cyan portion **201** to the blue portion **206**. These blended regions allow a smooth transition when crossfading between different wheel parts.

The fabrication of the wheel **120** may use a round glass disk with a clear central portion **210**. First, the disk is coated with a magenta dichroic layer. This coating is selectively patterned using the density mask of FIG. 3 to remove portions in a way that creates a circumferential saturation gradient.

After the patterning, a second coating process is used to overlay a yellow dichroic film. That yellow film is again patterned and removed. The resulting overlaying patterned film creates a circumstantial color continuum ranging from yellow to orange to red to magenta.

This process is repeated for a third time using a cyan patterned coating. This eventually produces a wheel that has all saturated colors that are defined by the color points of the three cyan, yellow and magenta primary filters.

FIG. 3 illustrates a typical pattern that may be used for the photolithographic etch process. This pattern may be repeated every 120 degrees to form the 30 degree sequence of colors going around the wheel. A half tone or stochastic or any other pattern blend may therefore be formed in 120 degree increments.

The above embodiment describes the colors being arranged symmetrically around the wheel. However, according to another embodiment, the colors may be laid out on the wheel using any color distribution scheme. For example, other colors may be added to the system, and different links can be applied for the transitions, more transitions can be provided, and other arrangements can be used. In addition, other embodiments may eliminate some of the colors, and may expand the areas of other one of the colors. The designer may want, for example, a wheel where red is right next to green. The color arrangement may be developed on any computer using graphics software. Satisfactorily arranged colors can be converted into a set of CYM separations using standard print media software. These separations may then be formed into film negatives that are used to expose a photoresist that controls the overall etching process.

The embodiment described above shows a rainbow color wheel that has all possible CYM colors at full saturation. Another embodiment may include areas of softer colors or less saturated colors as part of the wheel. These unsaturated colors may be used to enhance the color of an object, such as a costume or scenery.

In an extended embodiment, a second radial pattern may be overlaid on the first circumferential pattern during the wheel fabrication. The radial gradient shown in FIG. 4 may be used as a pattern for the overlay. This pattern creates a saturation gradient, where there is less saturation towards the center in the area **410** than there is at the outer portion area **400**. This saturation gradient in FIG. 4 may be combined with the color gradients of FIG. 3, and incorporated into a single pattern for each of the three photolithographic etch process.

In an enhanced embodiment, the most saturated colors may reside at the outer periphery of the wheel. The wheel may have its parts positioned so that the color gradient across the light beam area may be minimal. For example, the saturated portion, shown as the black outer portion **400** in FIG. 4, may be at least as wide as a light beam.

Less saturated colors are provided towards the clear center **420** of the beam. This may be an area where the coating is applied, for example, in a speckled patten as shown. The center portion may be clear white, to thereby allow pure white light to be projected.

An example of the finished rainbow wheel which uses the saturation gradient may be as shown in FIG. 5. The light beam **501** is shown in the area of full saturation, with the saturation gradient area **520** illustrated as an inner portion.

In order to use a system of this type with a clear center portion, the color wheel **500** may be mounted in a carrier that supports the outer edges **502** of the color wheel only. The carrier allows the color wheel to rotate within the light beam to select the color by moving along the arrow **550**. The carrier also allows the color wheel to move in the axis of the arrow **551**, to adjust the saturation of the rainbow wheel. Hence, this arrangement allows for movement in two different dimensions, where linear movement (e.g. left to right)

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adjusts saturation; rotational movement adjusts color. This may facilitate the control implementation. In an embodiment two different control knobs may remotely adjust color and saturation independently on the single wheel. In the FIG. 1 embodiment, the control signal 155 may contain control information from a remote console, which is passed to the control part 121 that controls the movement of the color changer. In this embodiment, all of that movement to the entire available color scheme, can be controlled with only two controls, e.g., two knobs. This compares with the control that would be necessary for a CYM system, in which three knobs, one for each of the cyan wheel, the yellow wheel and the magenta wheel, would be necessary.

Another embodiment may use a second color wheel to expand the range of the domain of colors available from the CYM color wheel. A second color wheel 130 is shown in FIG. 1. This second color wheel is coated with a super-magenta saturated color. The super-magenta coating has a wider rejection band than the magenta layer that is formed on the rainbow wheel, and hence is a more saturated magenta than the magenta on the rainbow wheel.

The super-magenta color wheel is patterned using a similar circumferential saturation gradient shown in FIG. 8. As in FIG. 4, the super-magenta wheel includes a region of full saturation where none of the coating is removed. The super-magenta wheel also has a graded saturation area, and a clear area which allows light to pass unfiltered.

FIG. 1 illustrates how the super-magenta wheel 130 can be used in an embodiment. The super-magenta wheel is placed optically in series with the rainbow wheel within the light beam. Because the super magenta color is composed of a deeper blue and a deeper red color concentration than the corresponding magenta in the rainbow wheel, these deeper colors may be gradually used to modify the rainbow wheel colors. The effect is that the blue color range generated by the rainbow wheel can be expanded to include the very deep blues when the super magenta wheel is used in conjunction with the rainbow wheel.

The same effect is true for the reds. The red that is generated by the rainbow wheel alone, like many CYM reds, is slightly on the orangey side. When the rainbow wheel red is altered by the super magenta wheel, the resulting light is adjusted to a very deep and saturated red.

The rainbow magenta is naturally a pinkish magenta since this hue provides the most variety of colors when used in combination with the cyan and yellow filters. However, the super magenta wheel adjusts the rainbow magenta to a more purplish hue, allowing a more dramatic color shift.

FIG. 6 illustrates the CIE color domain for the two different wheels. The color points for the CYM filter are shown as the inner domain, illustrated as a five-sided polygon that is bounded by the different colors in the wheel. The super-magenta color wheel allows expanding this region considerably, to the outer expansion portion shown. The red outline shows the more saturated region of the color domain that is achievable with the combination of the two wheels. This can also be controlled in a similar way to that discussed above with respect to the rainbow wheel. While the rainbow wheel can be controlled with two different knobs, the combination of the rainbow wheel with the super-magenta color wheel can expand the realm of hue and saturation, e.g. using an additional two knobs.

FIG. 7 illustrates an exemplary holder for the rainbow wheel. The wheel 120 is supported in a ball bearing carrier 701 that itself is supported on a mounting plate 710. A second supporting ring 702 may be used for rotating the wheel. For example, 702 may have timing teeth on its outer

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diameter, and may interface with a drive belt shown as 715. The drive belt itself may be driven by a drive motor 720 that transmits its rotational force to a driving pulley 781. The pulley 781 may be transmitted via the belt to the pulley 702. Alternatively, the driving mayor may not connect directly to the pulley 702.

The mounting plate itself 710 may translate left to right on linear bearings shown as 740 that themselves translate on a mounting rails 745. The plate 710 can move left to right via motion between bearing 740 in the rail 745. The rail may have a slot shown as 746 which accommodates the translation across the beam.

A lead screw nut 750 may control the movement of the device 745. The lead screw nut 750 may include a motor that moves the mounting plate 710 in the left and right direction.

Although only a few embodiments have been disclosed in detail above, other embodiments are possible and the inventors intends these to be encompassed within this specification. The specification describes specific examples to accomplish a more general goal that may be accomplished in another way. This disclosure is intended to be exemplary, and the claims are intended to cover any modification or alternative which might be predictable to a person having ordinary skill in the art. For example, while the above has described the form of those systems being a wheel, it should be understood that other forms for the coloration can be used. For example, the outer shape of the device can be rectangular instead of round.

Also, the inventor intends that only those claims which use the words "means for" are intended to be interpreted under 35 USC 112, sixth paragraph. Moreover, no limitations from the specification are intended to be read into any claims, unless those limitations are expressly included in the claims.

This system can be used in the light of the type shown in FIG. 1 which can be controlled by a remote console, that communicates with the light over wired or wireless protocols such as DMX 512. Both the console and the light can include computers therein. The computers described herein may be any kind of computer, either general purpose, or some specific purpose computer such as a workstation. The computer may be an Intel (e.g., Pentium Core 2 duo) or AMD based computer, running Windows XP or Linux, or may be a Macintosh computer. The computer may also be a handheld computer, such as a PDA, cellphone, or laptop.

The programs may be written in C or python, or Java, Brew or any other programming language. The programs may be resident on a storage medium, e.g., magnetic or optical, e.g. the computer hard drive, a removable disk or media such as a memory stick or SD media, wired or wireless network based or Bluetooth based Network attached Storage (NAS), or other removable medium.

The programs may also be run over a network, for example, with a server or other machine sending signals to the local machine, which allows the local machine to carry out the operations described herein.

Where a specific numerical value is mentioned herein, it should be considered that the value may be increased or decreased by 20%, while still staying within the teachings of the present application, unless some different range is specifically mentioned. Where a specified logical sense is used, the opposite logical sense is also intended to be encompassed.

What is claimed is:

1. A lighting device, comprising:
  - a high intensity bulb, creating light along a path;

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- a first color altering device, along said path, having a coloring surface, divided into a plurality of primary sections, including a first primary section having a first primary color section and a second primary color section, and a third primary color section, where said primary color sections include cyan, magenta and yellow,
- said coloring surface also including a plurality of secondary sections, including a first secondary section having a first secondary color section and a second secondary color section, and a third secondary color section, where said secondary color sections include red, green and blue;
- a plurality of mixing sections in between two adjacent color sections, such that a first said mixing section is between said first primary color section and said first secondary color section, said first said mixing section corresponding to a color that corresponds to a subtractive combination of said first primary color section and said first secondary color section; and
- a second color altering device used in conjunction with the first color altering device, said second color altering device having a magenta color, that is more deeply magenta saturated than any magenta color on said first color altering device to increase a saturation of multiple different colors of light as altered by both the first color altering device and the second color altering device.
2. The lighting device as in claim 1, wherein said coloring surface further includes an additional plurality of mixing color sections, each mixing section between a primary color section and a secondary color section.
3. The lighting device as in claim 1, wherein said second color altering device increases saturation of both blues and reds from said first color altering device.
4. The lighting device as in claim 1, wherein each of said primary and secondary sections each take up substantially a same angular space on the color altering device.
5. A device as in claim 1, wherein the color altering device includes patterned coatings of magenta, yellow, and cyan, one over the other, each of said coatings selectively patterned to create a circumferential saturation gradient.
6. The device as in claim 5, wherein said patterned coatings are dichroic coatings.
7. The device as in claim 5, wherein said patterned coatings each use the same pattern, which repeats in 120° increments.
8. A lighting device, comprising:  
 a high intensity bulb, creating light along a path;  
 a first color altering device, along said path, having a coloring surface, divided into a plurality of sections, each of a different color, wherein the color altering device includes patterned coatings of magenta, yellow, cyan, one over the other, each of said coating selectively patterned to create a circumferential saturation gradient, wherein said patterned coatings each use the same pattern, which repeats in 120° increments to form said different colors; and  
 a second color altering device along said path used in conjunction with the first color altering device to increase a saturation capability of a color combination using colors on the first color altering device, said second color altering device having a magenta color, that is more deeply magenta saturated than any magenta color on said first color altering device to increase a saturation of multiple different colors of light as altered by both the first color altering device and the second color altering device.

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9. The lighting device as in claim 8, wherein said first color altering device includes sections which are all of magenta, yellow, cyan, red, green and blue.
10. The lighting device as in claim 9, wherein said sections each take substantially a same amount of area on said first color altering device.
11. The lighting device as in claim 8, wherein said first color altering device includes sections with each of three subtractive primary colors and three additive primary colors.
12. The lighting device as in claim 11, wherein said sections include a subtractive primary color adjacent and additive primary color.
13. The lighting device as in claim 12, further comprising a plurality of mixing sections in between two adjacent additive primary color and subtractive primary color.
14. The device as in claim 8, wherein said patterned coatings are dichroic coatings.
15. The lighting device as in claim 9 including a mixing section between said cyan section and said blue section.
16. The lighting device as in claim 15 including a mixing section between said yellow section and said green section.
17. The lighting device as in claim 16 including a mixing section between said magenta section and said red section.
18. The lighting device as in claim 8, wherein said second color altering increases saturation of both blues and reds from said first color altering device.
19. A lighting method, comprising:  
 producing light along an optical axis;  
 moving a first color changing structure, located along said axis, so that different portions of said first color changing structure intersect with said optical axis;  
 said first color changing structure including a plurality of areas defined thereon, including first, second and third primary color areas, each primary color area defining a specified area on the color changing structure, and said first color changing structure further including fourth, fifth and sixth areas of subtractive colors, where said subtractive areas are formed at an overlap between said primary areas, and are physically between said primary color areas; and  
 using a second color changing structure having a second color arrangement different than the color arrangement of said first color changing structure and having a magenta color that is more deeply saturated than any magenta on said first color changing structure to further adjust color of light that has passed through said first color changing structure in a way that increases a saturation of light passing through the first color changing structure and the second color changing structure, said second color altering structure having a magenta color, that is more deeply magenta saturated than any magenta color on said first color altering structure to increase a saturation of multiple different colors of light as altered by both the first color altering structure and the second color altering structure.
20. A method as in claim 19, wherein said primary colors are red, green and blue, and said subtractive colors are magenta, yellow and cyan.
21. A method as in claim 19, further comprising areas with blended colors between said primary areas and said secondary areas.
22. A method as in claim 19, wherein said first color changing structure is a disk shaped altering device.
23. A method as in claim 19, wherein said second color altering structure increases saturation of both blues and reds from said first color altering structure.

24. A method as in claim 23, wherein said less saturated part includes a portion where coloring agent is applied in a speckled pattern that does not cover the entire area.

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