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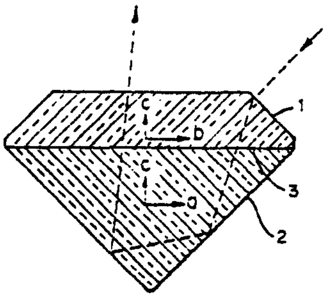
(54) Multiple element display objects.

(57) Multi-element gem stones and other display objects comprising pleochroic materials are provided which evidence enhanced colors or other unusual optical properties, based on the pleochroic behavior of the material. Doublet stones, comprised of two pleochroic materials, and triplet stones, comprised of two pleochroic materials separated by an optical rotator, are described.

FIG. 2



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BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to gem stones and other display objects and, more particularly, to multiplet gem stones, such as doublets and triplets, which incorporate pleochroic materials.

2. Description of the Prior Art

Many of the well-known gem minerals are pleochroic. That is, a single piece of such a material will exhibit various colors, depending on the direction of viewing and/or the polarization direction of the illuminating light. The fundamental effect is due to the polarization direction of the light. The viewing angle dependence in unpolarized light arises due to the elimination of light polarized parallel to the viewing direction, since light waves are purely transverse excitations. Such effects occur in non-cubic, optically uniaxial and biaxial crystals due to the influence of the anisotropic host crystal structure on the transitions between electron energy levels of the impurity ions which give rise to the color.

Some well-known gem crystals which exhibit pleochroism to a greater or lesser extent include alexandrite, andalusite, axinite, beryl, chrosoberyl, cordierite, emerald, epidot, kyanite, peridote, ruby, sinnalide, spodumene, tourmaline and zoisite.

In the course of cutting crystals of these minerals to obtain faceted gem stones, it is well-known that one must often control the crystallographic orientation of the stone to obtain the desired color in the finished gem stone, or alternatively, that the color of the finished gem may be varied to some extent by varying the crystallographic orientation. This is particularly important, for example, in the faceting of certain types of tourmaline which, if cut with the table (top) facet parallel to the "c" plane, may appear nearly opaque or black, while the same stone, if cut with the table facet perpendicular to the "c" plane, would exhibit a desirable blue or green color. Similarly, certain cordierites may appear nearly colorless in certain orientations and deep blue in others.

Multiplet element gem stones have been used in the past for various purposes. For example, D'Esposito in U.S. Patent 1,745,607, issued February 4, 1930, describes doublet stones in which two components made of natural beryl are cemented together with a transparent cement incorporating an appropriate coloring agent so as to produce a composite stone exhibiting the color of emerald. In this case, the refractive properties of beryl, which resemble those of emerald, are combined with the color properties of the central colored film. Other doublet constructions may combine the hardness properties of a material, such as sapphire, with the refractive and dispersive properties of a soft material, such as strontium titanate, to produce a robust composite stone visually resembling a diamond. See, e.g., Jones, U.S. Patents 3,528,261 and 3,808,836, issued Sept. 15, 1970 and May 7, 1974, respectively. Or, a hard colorless cap may be used to mechanically protect a fragile but visually attractive stone such as opal.

Other attempts to alter or control the optical properties of gem stones have also been employed. For example, in highly doped natural or synthetic alexandrite, the daylight green color is often obscured by red overtones, especially in thicker sections. Cline et al. in U.S. Patent 3,912,521, issued Oct. 14, 1975, disclose addition of iron as an impurity as a means of improving the daylight green coloration of highly doped synthetic crystals of larger size. However, we have observed that this method is not totally effective.

SUMMARY OF THE INVENTION

The present invention is directed to the improvement or modification of the color displayed by certain of the above-mentioned pleochroic materials, either alone or in various combinations, by constructing multiple element display objects, including gem stones, in such a way as to exploit the natural pleochroic behavior of the material. As used herein, pleochroic material refers to either natural or synthetic mineral, that is, a crystalline, inorganic oxide, for example, which evidences pleochroic behavior.

In accordance with one aspect of the invention, a display object is disclosed comprising at least two optically oriented elements of at least one pleochroic material, said elements either fixed or disposed in continuously variable rotational configuration with respect to each other. Such display objects may be used to provide a varying range of colors pleasing to the eye, the particular colors depending on the particular pleochroic materials and optical orientations selected.

In accordance with another aspect of the invention, a multi-element transparent gem stone is disclosed comprising at least two optically oriented elements of at least one pleochroic material, said oriented elements being either physically rotated with respect to each other over a range of about 20° to 160° or separated by an optically active rotator plate.

The gem stones of the invention evidence enhanced colors and other unusual optical properties over those obtained in singlet construction. In the case of either synthetic or natural alexandrite, the red overtones which obscure the daylight green color are substantially eliminated by rotating two alexandrite stones, which have been cut parallel to the "c" crystal plane, by, e.g., 90° to produce a clear intense blue-green color. The stones are then cemented together to produce a doublet having a color pleasing to the eye. Alternatively, triplet constructions comprising an optical rotator plate sandwiched by at least one pleochroic material may be used to obtain the enhanced colors and other unusual optical properties.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1, on coordinates of absorption in cm^{-1} and wavelength in μm, is a plot of the absorption spectrum of synthetic alexandrite in polarized light; and

FIG. 2 is a diagrammatic sectional view of a doublet gem stone construction.

DETAILED DESCRIPTION OF THE INVENTION

One of the most spectacular of the pleochroic minerals is alexandrite, $BeAl_2O_4$, containing chromium (Cr^{3+}) as an impurity. It is one of the few trichroic minerals, that is, exhibiting three distinct colors corresponding to the three possible polarization directions of light traveling through its orthorhombic crystal structure. These will be described here for later reference. We use the crystal lattice parameter assignment of Farrell et al. in American Minerologist, 48, 804-810 (1963), where a = 9.404 Å, b = 5.476 Å and c = 4.427 Å. A polished cube of alexandrite containing about 0.05 to 0.1 atomic percent chromium substituted for aluminum and having dimensions of about 1 cm on an edge, when viewed in transmission in unpolarized daylight, will appear blue or purplish-blue in the "a" direction, orange or reddish-orange in the "b" direction and green or reddish-green in the "c" direction. If the same cube is viewed in transmission, illuminated by linearly polarized white light, it will appear a clear yellow color for light polarized with the electric vector parallel to the "a" direction (i.e., $E \| a$) for all directions of viewing except, of course, "a", since as mentioned above, light is a purely transverse disturbance and therefore light traveling along a certain direction can have no component of polarization in that direction. Similarly, for $E \| b$, the color is blue-green and for $E \| c$, the color is violet. Thus, when viewing, for example, through the "c" direction in unpolarized light, both the $E \| a$ (yellow) and $E \| b$ (blue-green) beams are seen simultaneously, and the resulting color is green.

The polarized absorption spectra which give rise to these observed colors are shown for a typical piece of synthetic alexandrite in FIG. 1.

In the present invention, as it applies to a multiplet gem stone which incorporates pleochroic materials, the function of the pleochroic materials is to act as spectrally selective polarizers by absorbing light of particular polarizations and in particular spectral regions in order to modify aspects of the color of the resulting gem. In certain instances of the invention, all of the elements of the multiplet are of the same material, while in other instances, it is desirable to combine elements of different pleochroic materials in the same gem.

Display objects incorporating the teachings herein are also contemplated. Such display objects, like the gem stones of the invention, comprise at least two optically oriented elements of at least one pleochroic material. The doublet and triplet constructions set forth below may be advantageously employed to produce display objects having colors pleasing to the eye. The optically oriented elements of the display objects may be fixed with respect to each other in a manner similar to that described below for gem stones. For example, a simple cube comprising appropriately cut and oriented plates which are then cemented together may be fabricated. Alternatively, the elements of the display objects may be disposed in continuously variable rotational configuration with respect to each other. For example, two single cubes comprising appropriately cut and oriented elements rotationally mounted on the same axis may be fabricated.

1. Doublet Gem Stones

A doublet gem stone is schematically depicted in FIG. 2, which shows, in cross-section, a top or crown portion 1 which is disposed in effectively permanent secured relation, as by cementing, to a lower or pavillion member 2. Interface or mating surfaces 3 of parts 1 and 2 are first lapped and polished prior to cementing or otherwise bonding portions 1 and 2 together. The actual gem cut may be any of the type usually employed, such as brilliant-cut, emerald-cut, and the like, or other cuts employing facets producing a stone pleasing to the eye.

One useful application of the present invention is the enhancement of the color change properties of the gem alexandrite. In highly doped natural or synthetic alexandrite, the daylight green color is often obscured by red overtones, especially in thicker sections.

In accordance with one aspect of the invention, the alexandrite crystal section (natural or synthetic) to be fabricated into a facet gem, say an optically dense, highly doped crystal, is first oriented by means of visual inspection, optical methods or X-ray diffraction so that the three crystal directions, "a", "b" and "c", are known. The crystal is then sawed in half parallel to the "c" crystal plane (i.e., perpendicular to the "c" direction). The mating sawed surfaces are polished flat and placed in contact in their original orientation. The stone, now in two pieces, is viewed in transmission in a direction perpendicular to the saw cut. One of the pieces is then rotated with respect to the other. It will be found that this rotation produces a dramatic change in the color displaced from a reddish or reddish-green color with no rotation to a clear blue-green color which will be most intense with a rotation of 90°. The stone is then rotated by some angle θ so as to produce the desired degree of color change in the composite, and the two mating polished surfaces are cemented together using a suitable bonding agent. This may be any transparent, colorless, strong glue, such as epoxy, Canada balsam, polymethyl methacrylate, cyanoacrylate or other satisfactory material. Other agents requiring the application of heat, such as low melting point glasses or polymers, may also be used. The angle θ producing the blue-green color may range from about 20° to 160°. The most intense coloration is produced over the range of about 60° to 120°, and accordingly, such rotation angle is preferred.

The doublet crystal so formed is then fabricated into the desired finished form by conventional methods of lapidary art. The faceting is done in such a way that the planar glue joint generally lies in the stone parallel to the table facet and at a position near the firgle of the stone. Some care may be required during facet grinding and polishing to avoid damage to the glue joint from excessive heat or mechanical force, since the joint may not in general be as strong or heat resistant as the original material.

Alternatively, the separation of the stone into two components may be made parallel to the "a" crystal plane, in which case a relative rotation of the two halves around an axis normal to the "a" plane will produce a deep pure blue color. The angle of rotation again may vary from about 20° to 160°. The most intense coloration is produced over the range of about 60° to 120°, and accordingly, such rotation angle is preferred. However, if the same method is followed by separating the stone parallel to the "b" plane, little or no color change will result from rotation, an observation which will be explained below.

In general, the two components of a pleochroic doublet gem, namely, the crown (the upper or top) component and the pavillion (the lower or back) component, are best made from crystals containing different levels of doping. This is because in most standard gem cuts, to which the present invention is primarily addressed, the crown section of the stone is thinner than the pavillion section and therefore requires deeper coloring to produce an optimum balanced coloring of the finished gem stone.

It is also sometimes desirable to combine "a" and "c" axis plates in the same stone. In this case, the color will vary between blue-green, when the "b" directions of the two plates are at 90° from each other, to violet, when the "b" directions are parallel.

The daylight green color of alexandrite can be enhanced most effectively by using two natural or synthetic "c" axis alexandrite plates as described above, in which the upper or crown plate contains from 1 to 5 times as much chromium as the bottom plate, and the angle of relative rotation, θ (measured between similar crystallographic directions in the upper and lower plates) lies between 20° and 160°. The chromium concentration of the alexandrite crystals should, in general, be in the range of from about 0.005 to 1.0 atomic percent substitution of chromium for aluminum ions. The preferred concentrations for gems with final dimensions of about 0.2 to 2 cm in diameter are about 0.02 to 0.2 atomic percent chromium in the pavillion element and about 0.06 to 0.6 atomic percent in the crown element. In general, the smaller stones require the higher chromium concentration to produce intense colors.

Natural or synthetic alexandrite doublet gem stones constructed according to the method of the present invention exhibit a strikingly pure daylight green coloration while still possessing the characteristic raspberry or columbine red color of alexandrite when illuminated by incandescent light or light from a wood fire, oil lamp or candle.

Furthermore, high doping levels, up to 1.0 atom percent and higher (substitution of Cr^{3+} for Al^{3+} in $BeAl_2O_4$) can be used to obtain very deep green colors. Such high concentration levels inevitably cause serious or complete degradation of the green color in conventional singlet alexandrite gems.

Thus, the method of the present invention can be used to produce natural or synthetic alexandrite gems possessing unprecedented color change properties not equalled by conventionally cut singlet stones of whatever origin or detailed chemical composition.

The principles by which the pleochroic doublet functions can be illustrated using the alexandrite example by reference to the polarized absorption curves shown in FIG. 1 and the schematic doublet shown in FIG. 2. If one considers, for example, a "c" axis plate of alexandrite viewed in transmission parallel to the "c" direction (i.e., at right angles to the plate), the unpolarized light passing through the plate will be resolved by the crystal into two orthogonally polarized beams, one with $E \parallel a$ and the other $E \parallel b$.

Viewed separately (as with a polarizer), the $E||b$ beam appears deep blue-green by virtue of the relatively strong absorption of this polarization in the yellow-orange spectral region (λ = 0.6-0.65 μm). The $E||a$ beam, viewed separately, appears yellow-orange by virtue of the relatively low absorption in this spectral region combined with the peak in human visual spectral response, which occurs near the same spectral region. One notes that both polarizations transmit with little absorption in the far red spectral region ($\lambda >$ 0.65 μm). Upon leaving the plate, the two beams recombine and, in thin sections, the color sensation produced is green. As the section thickness (or dopant concentration) is increased, however, the composite color becomes increasingly orangish, due, for the most part, to orange light (λ = 0.6-0.65 μm) transmitted by the $E||a$ beam with an absorption coefficient, α, lower than that for either beam in the blue-green transmission band centered near λ= 0.5 μm.

The intensity of the transmitted light depends exponentially on the product of the absorption coefficient and the section thickness; that is, $I/I_o = e^{-\alpha x}$, where I_o is the incident intensity, I is the transmitted intensity, α is the absorption coefficient and "x" is the section thickness. Thus, the ratio of green to orange light transmitted also varies exponentially with the thickness section "x". If a second "c" axis plate is now placed parallel to the first and oriented with both "a" (or "b") directions parallel, the effect is that of a simple increase in section thickness. If, however, the second plate is rotated by 90° relative to first plate around the "c" axis, as shown in FIG. 2, the polarizations of the two transmitted beams are now interchanged as they pass from one plate into the other. That is, the E a beam in the first plate, which was transmitted with relatively low absorption in the orange spectral region, becomes the E b beam in the second plate, and as such experiences strong absorption of its orange spectral components. Since neither polarization experiences strong absorption in the blue-green transmission band centered near $\lambda = 0.5$ μm or in the far red ($\lambda > 0.65$μm), these colors now dominate the composite transmitted spectra, and the stone appears either green under illuminations such as skylight or fluorescent light, which are rich in green, or red under illuminations such as candlelight or incandescent light, which are rich in the red and poor in the green-blue spectral regions. Thus, the classical alexandrite illumination-dependent color change effect is somewhat flawed by the relatively low absorption coefficients of $E||c$ and $E||a$ polarizations in the spectral region of $\lambda = 0.6$-0.65 μm (orange to red) which causes the effect to become obscured in thick sections or deeply colored stones. This flaw is corrected by the method of the present invention by the controlled total or partial absorption of this $E||a$ transmission by rotational transformation of this beam to a different polarization.

We have found, in the course of a detailed study of rotated doublet effects in pleochroic minerals, that a number of desirable color modifications similar in origin to those described above in alexandrite can be effected by the method of the present invention.

One such case involves doublets constructed by cementing together one plate of "c" or "a" axis alexandrite with another plate of tourmaline cut so that the tourmaline "c" axis lies in the plane of the plate. Certain varieties of tourmaline, which exhibit an undesirable yellowish-green color alone can be made to change to a deep pure emerald green color by varying the angle of rotation of the tourmaline-alexandrite doublet, the strongest effect occurring when the tourmaline "c" axis lies parallel to the alexandrite "b" axis.

Similarly, certain other tourmaline varieties, known collectively as watermelon tourmaline because they contain regions of both red and green color in the same crystal, can be combined in the doublet configuration with the "a" or "c" axis alexandrite plates in such a way as to increase the depth and contrast of their unique coloration. This is particularly useful in the case of lightly colored material which is otherwise of good quality but appears pale and low in color contrast. Again, the effect is maximized when the tourmaline "c" axis lies parallel to the alexandrite "b" axis.

The color tint of certain varieties of aquamarine, morganite, beryl and ruby can be adjusted by combining them with dichroic plates of tourmaline or cordierite in doublet configurations as described above, with the rotation angle being adjusted to produce the desired color.

2. Triplet Gem Stones

Triplet gem stones accomplishing the effects discussed above for pleochroic doublets can be produced using the variation of the present invention as described below. This variation relies on the known optical rotatory power or optical activity of α-quartz (and certain other compounds of the same crystal structure, such as berlinite) to rotationally transform the polarization directions of light beams traveling in the pleochroic multiplet gem stone. A beam of linearally polarized light traveling parallel to the "c" axis in a crystal of α-quartz will suffer a progressive rotation of its plane of polarization, depending on the distance traveled and the wavelength of the light. In general, due to the so-called rotatory dispersion, light of shorter wavelength will suffer more rotation in a given path length than light of a longer wavelength.

The example of the alexandrite-quartz-alexandrite triplet will be used to illustrate this aspect of the present invention. It will be recalled that the alexandrite doublet functions by transformation of the $E||a$ beam in one element into the $E||b$ beam in the other element through appropriate relative orientation of the pleochroic doublet components and the consequent absorption of light in the λ = 0.6-0.65 m spectral region which would otherwise be transmitted by single sections. In the present variation, the rotational transformation is accomplished by the use of a quartz "c" axis plate interposed between two plates of similarly oriented alexandrite. The thickness of the quartz plate is adjusted so as to produce a rotation of approximately 90° in the spectral region of $\lambda = 0.6-0.65\ \mu m$. The rotatory power in this region is about 20° per mm, so the required thickness for a full 90° of rotation is about 4.5 mm. In practice, we have found that thinner quartz plates (0.5 mm and up) can also be used if the balance of the rotation required is made up by physical rotation of the alexandrite elements of the triplet. As a practical matter, the maximum thickness for a quartz plate employed in triplet gem stones is about 10 mm. The preferred position of the quartz plate in the finished gem is generally near the girdle, and the chromium concentration ranges and ratios discussed above in connection with alexandrite doublets also apply.

In addition to effecting the color variations produced by doublets, we find that striking interference effects are produced by pleochroic material-quartz triplets such that the color of the stone changes rapidly with slight shifts in viewing angle.

EXAMPLES

Example 1

An alexandrite doublet gem was constructed as follows. Two polished "c" axis plates of synthetic alexandrite, one containing 0.3 atomic percent chromium and the other containing 0.1 atomic percent chromium, were cemented together using epoxy glue (formula), with a 90° relative rotation such that the "a" axis in one plate lay parallel to the "b" axis in the other plate. After allowing adequate time for the epoxy glue to cure, the composite was formed into a standard brilliant-cut gem by conventional lapidary diamond grinding and polishing techniques. Using the traditional crown and pavillion angles for chrysoberyl or alexandrite, the upper or crown plate, containing 0.3 atomic percent Cr^{3+}, had a final thickness in the finished gem of 1.53 mm, and the pavillion or back plate, containing 0.1 atomic percent Cr^{3+}, had a final maximum thickness (at the culet or point) of 4.58 mm. The glue joint in the finished gem was placed parallel to the table or top facet and at the level of the girdle or widest diameter of the gem. The finished gem had a girdle diameter of 9.8 mm, a total height, from table to culet, of 6.1 mm and a weight of approximately 4 carats (0.8 g). The color of the finished gem was deep green by daylight or fluorescent light and deep raspberry red when illuminated by an incandescent bulb or candlelight.

Example 2

Two standard emerald cut alexandrite gems were produced following the general procedures outlined in Example 1. In this case, both the crown and pavillion elements were "c" axis synthetic alexandrite plates containing 0.05 atomic percent Cr^{3+}. Both stones had final width and length dimensions of 10 and 12 mm, respectively. In the first stone (stone A), the "a" axis of the pavillion or bottom plate was parallel to the width dimension of the finished gem, as was the "b" axis of the crown plate. In the second stone (stone B), the "b" axis of the pavillion element and the "a" axis of the crown element were both parallel to the width dimension, i.e., the reverse of stone A. Both stones appeared raspberry red under incandescent light or candlelight and green in daylight. The daylight tint of stone A, however, was decidedly bluish-green, while that of stone B was more of a pure green.

Example 3

In this example, a doublet combining two pleochroic materials to produce a unique effect is described. Two elements, one of a dichroic natural andalusite crystal and one of a crystal of the blue, strongly pleochroic variety of cordierite (also known as iolite or dichroite) were placed together such that the surface perpendicular to the orange-appearing direction in the andalusite crystal (containing the optical X direction) contacted the surface perpendicular to the blue-appearing direction in the cordierite crystal (also containing the optical X direction). (The optical X direction is the polarization direction of light with the smallest index of refraction.) Rotation of the elements such that the optical X directions of both crystals were parallel produced a violet color by daylight illumination, which changed to red under incandescent light. Thus, an illumination color change effect was produced.

A standard emerald-cut gem stone measuring 6 x 5 mm is produced using the general procedures outlined in Example 1. The crown plate is formed from the andalusite crystal with the polished surface perpendicular to the orange-appearing direction in the crystal so that the polished surface contains the optical X direction. The pavillion plate is formed from the cordierite crystal in such a way that the optical X direction of the crystal again lies in the plane of the plate. The plates are cemented together so that the optical X directions of both crystals lie parallel in the finished gem and along the long dimension. The finished gem is a pleasing violet color by daylight illumination, which changes to red under incandescent light.

Example 4

In this example, a quartz rotator plate is used to accomplish a part of the rotational transformation of polarizations in an alexandrite-quartz-alexandrite triplet. Two cubes of alexandrite, 8 mm on edge, with edges oriented parallel to the "a", "b" and "c" directions, were placed on either side of a 4 mm thick "c" axis α-quartz plate such that the surface perpendicular to the "c" axes of the cubes contacted the surface perpendicular to the "c" axis of the plate. Alignment of the cubes such that their "a" axes were parallel produced the characteristic green color under daylight illumination and the characteristic raspberry red color under incandescent illumination, when viewed along the "c" axis. When viewed at angles slightly off the "c" axis, color fringes appeared, and the color changed to reddish-orange under daylight illumination.

A standard brilliant-cut gem stone is prepared as follows. A crown plate of "c" axis synthetic alexandrite containing 0.15 atomic percent chromium is cemented to one side of a 2 mm thick "c" axis α-quartz plate. To the other side of the quartz plate is cemented a pavillion plate of "c" axis synthetic alexandrite containing 0.05 atomic

4a

percent chromium and oriented with its "a" axis rotated 45° from the "a" axis of the crown plate in a direction producing the characteristic color change (the direction of rotation required will depend on whether right or left-handed rotating quartz is used). The composite so produced is then fabricated into a 15 mm diameter brilliant-cut gem stone, with the quartz plate parallel to the table facet and lying at a depth such that it is centered at the girdle plane.

The resulting gem appears the characteristic green color in daylight when viewed at right angles to the table facet, but changes to reddish-orange if rotated by a slight angle. Under incandescent illumination, there is a decided color change to the characteristic raspberry red color.

We claim:

1. A multiple element transparent optical display object comprising a gem stone having at least two optically oriented elements of at least one pleochroic material, said oriented elements being either physically rotated with respect to each other over a range of about 20° to 160° or separated by an optically active rotator material.

2. A multiple element transparent display object comprising at least two optically oriented elements of at least one pleochroic material, said oriented elements being either fixedly mounted with respect to each other such that one element is rotated with respect to the other by an angle ranging from about 20° to 160° or disposed in continuously variable rotational configuration with respect to each other.

3. A display object according to either of claims 1 and 2, in which said at least one pleochroic element is selected from alexandrite, andalusite, axinite, beryl, chrysoberyl, cordierite, dichroite, emerald, epidot, kyanite, peridot, ruby, sinhalite, spodumene, tourmaline or zoisite.

4. A display object according to any one of claims 1 to 3, comprising two elements of at least one pleochroic material physically rotated with respect to each other.

5. A display object according to claim 4, in which said two elements comprise alexandrite, each element containing chromium in the concentration range of about 0.005 to 1.0 atom percent substitution for aluminum, said elements being oriented substantially parallel to crystal planes which contain the "b" crystal direction and rotated with respect to each other over a range of about 20° to 160°.

6. A display object according to claim 4, in which one element comprises tourmaline oriented at right angles to the "c" plane and the second element comprises either "a" axis or "c" axis alexandrite.

7. A gem stone according to either of claims 1 and 3 comprising three elements, two of which comprise at least one pleochroic material

and the third an optically active rotator material interposed between said two elements.

8. A display object according to claim 2, additionally comprising an optically active rotator material disposed between said at least two elements.

9. A gem stone according to either of claims7 and 8, in which said rotator material comprises α-quartz.

FIG. 1

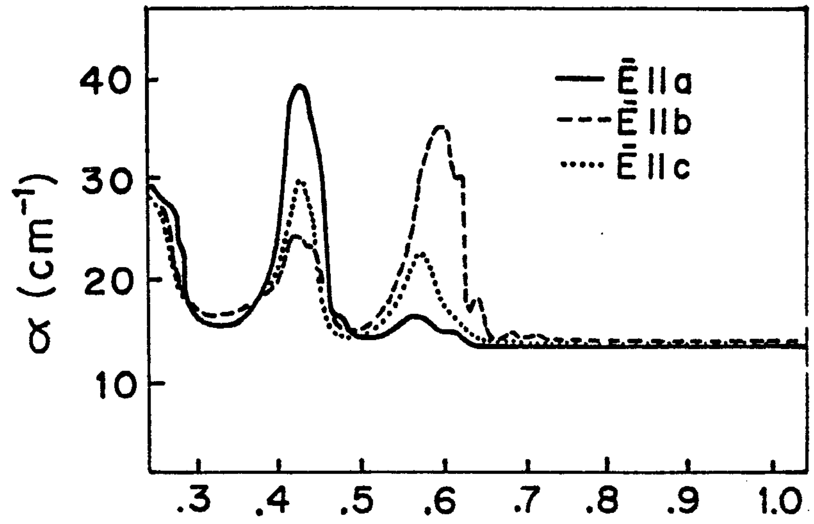

FIG. 2