Crossed filters revisited

Dr D B Hoover FGA[1] and Bear Williams CG[2]

1. 1274 E. Crystal Wood Ln., Springfield Mo., U.S.A.
2. P.O. Box 104504, Jefferson City, MO., U.S.A.

Abstract: *The crossed filters technique, introduced to gemmologists by Basil Anderson, has not found extensive use due, in part, to the cumbersome excitation filter he used. The commercialisation of new solid state sources, and ready availability of a variety of coloured glasses now makes possible simple and inexpensive means for practice of this fluorescence method.*

Keywords: *crossed filters, chrome-bearing gems, fluorescence, gem testing*

"These instruments and appliances to be of any practical value must be simple and substantial, as cheap as possible, and such that determinations made with their aid can be as well performed by the working jeweller as by a trained mineralogist."
Max Bauer (1904, p.561), writing about instruments for identification of gems.

Introduction

The crossed filters technique in gemmology, was first introduced in 1953 by Basil Anderson in a paper in the *Gemmologist* and later included in the sixth edition of his text *Gem Testing* (Anderson, 1959). The technique is well known to British gemmologists, but appears to be underutilised. In part, this reflects the bulky filter that Anderson used with his light source, a glass Florence flask filled with about 1 litre of copper sulphate solution. More recent mention of the technique in reference works offers little more help, repeating Anderson's filter choices or simply calling for a blue and a red filter (Harding, 1994; Hughes, 1997) giving no specifics. Hughes (1997) does state: "There is no better technique of observing fluorescence in ruby---", with which the authors agree. This paper looks at the history of the method, and offers practical and low cost means for implementing the technique which the gemmologist can easily accomplish.

As implemented in the past, the crossed filters technique principally provided a means of testing for chromium present within several gem materials. It is based on fluorescence due to the chromium ion (Cr^{3+}) present in gems such as ruby, emerald, spinel and alexandrite. The fluorescence is excited not only by ultraviolet light, but also by wavelengths in the visible region. Hoover and Theisen (1993) published excitation-emission spectra for a number of chromium-bearing gems with excitation in the range of 270 to 600 nm. Their results show that the predominant chrome excitation occurs in a blue band and a green-yellow band; the blue centred near 440 nm, and the broader green band centred at or below 600 nm. A central minimum is around 480 nm. Details vary among the various gem species and individual gems. As might be expected the excitation bands correspond approximately to the absorption bands seen in the spectroscope. Ruby shows a much broader excitation band than emerald for example. Their data also show a band in the UV from about 260 to 360 nm which is not very effective at exciting fluorescence.

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Iron quenching increases the wavelength at which fluorescence starts at the UV-violet excitation end. The effect of iron on emission spectra is mostly in an overall reduction in the strength of emission. For emeralds examined, a change of 2 orders of magnitude is seen, and for ruby about 1 order. These data are important in selection of a light source and excitation filter for detection of chromium in gems. The data suggest the optimum source should be broad and extend at least to the orange.

To determine the optimum viewing (emission) filter, the fluorescence spectra of chrome-bearing gems need examination. Most gemmologists are familiar with the 693-694 nm doublet in ruby, and the 'organ pipe' lines of red spinel, principally at 675, and 686 nm. Data from Hoover and Theisen (1993) show that very little emission due to chromium occurs at wavelengths shorter than 650 nm, but that much occurs well into the near-infrared, between 700 and 800 nm. In fact many of these gems have their emission peaks, and most of their emission, in the near infrared. Chrome tourmaline, chrome diopside, chrome grossular, and emerald are examples. Thus, the ideal viewing filter would have a very sharp cutoff near 650 nm, passing the longer wavelengths.

The problem for the practising gemmologist is whether he/she can find practical, inexpensive, light sources and colour filters to implement the technique. This paper presents several possibilities, but the basic requirements given above permit anyone to improve or to modify the details as new sources and filters become available.

A short history

Although the crossed filters technique for use in gemmology is due to Anderson, it was first used many years ago by Sir G.G. Stokes (1819–1903) for determination of very weak fluorescing materials. A dense cobalt glass combined with a thin signal green glass was used as an excitation filter, or a solution of ammoniacal copper sulphate. A yellow glass, or solution of potassium dichromate (yellow) was used for the viewing filter (Wood, 1934). Anderson (1959) mentions Stokes's work, and the possibility of filters similar to those that Stokes used for gemmological work. However, he substituted a simple copper sulphate solution for the blue filter, and, because only red fluorescence is involved with chrome gems, a red gelatine filter was used for viewing. This red gelatine filter was commonly used in photo processing at that time. With good filters the effect is quite pronounced.

Anderson describes it as "like glowing coals against a dead-black background- a sight so beautiful that it still delights the author after years of repetition." (Anderson,1959, p.168). He notes that it was first used as a lecture demonstration, but goes on to say that he found it so sensitive and useful in gem testing that it was constantly in use in the London laboratory. Anderson (1959), and Harding (1994) provide explanations of the use of fluorescence in gem testing, and for which gems crossed filters are most useful.

Another fluorescent effect described by Wood (1934) is important in practice of the crossed filters technique, but not normally mentioned. Fluorescence is principally a surface phenomenon, because the excitation light incident on the surface is absorbed to give the fluorescence. Wood presents an elegant experiment showing that the observed intensity of fluorescence is found to be many times brighter if viewed in a direction perpendicular to the surface, than if viewed through the material. The intensity difference can be greater than thirty times. The implication for the gemmologist would be in general to face the table of a gem towards the blue/UV source so as to present the greatest surface area of the stone to excitation light. Then he/she should view the fluorescence looking towards the girdle, as indicated in *Figure 1*. This also minimises the small amount of direct light that might get through the crossed filters, from transmission through the stone or by reflection from facets. With practice or common use, one will come to recognise the difference between the fluorescence, and light due to

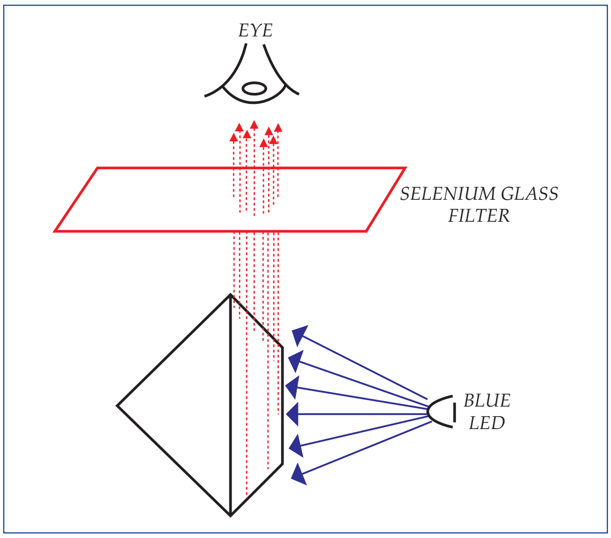

Figure 1: *Schematic diagram showing optimum illumination and viewing orientation for examination of a weakly fluorescing gem.*

simple reflection from facets. For strongly fluorescing gems there will be little need for orientation. It should also be noted that fluorescence from some solids is polarised. This can be seen in ruby by observing the change in the fluorescing image while rotating a polaroid plate during observation of the gem.

Modern sources and filter materials

Technology has given today's gemmologist a much wider range of light sources and advanced filter materials than Anderson had in his day, opening the possibility that simpler and perhaps less expensive components might be used for implementing a crossed-filters inspection unit. The authors are continuing to look at a number of possibilities with the prime motivation to keep costs low. For this reason, modern interference filters which can be tailored to almost any pass/block range have not been examined in detail, because they would make for rather expensive equipment. The focus was on keeping cost low enough for any gemmologist to be able to get materials and set up a simple viewing unit.

With the popularity of hobby stained glass work, a wide variety of coloured glass is now available everywhere. This was an obvious source for filter material. Two common glasses available to the hobbyist are blue cobalt and red selenium glasses (*Figure 2(a)*), whose spectra are given in Gem-A's introductory course, since they are used in glass simulants. The selenium glass with only a pass band in the red cutting at 630 nm makes a good viewing filter if an appropriate source-excitation filter combination can be found. *Figure 2(b)* shows the transmission spectra of selenium, cobalt and a green glass used by the authors. All spectra shown were obtained with an Oceans Optics S-2000 spectrometer and software running on a personal computer. Light from the cobalt glass has some red components that would pass the selenium glass, so a means of limiting this is needed. A green glass, similar to Stokes's signal green, was found at a local stained glass shop, and this was found to cut some of the red that passed the cobalt glass (*Figure 2*). This also passed more light in the green where greater fluorescence should occur. Other green to violet glasses were also tested.

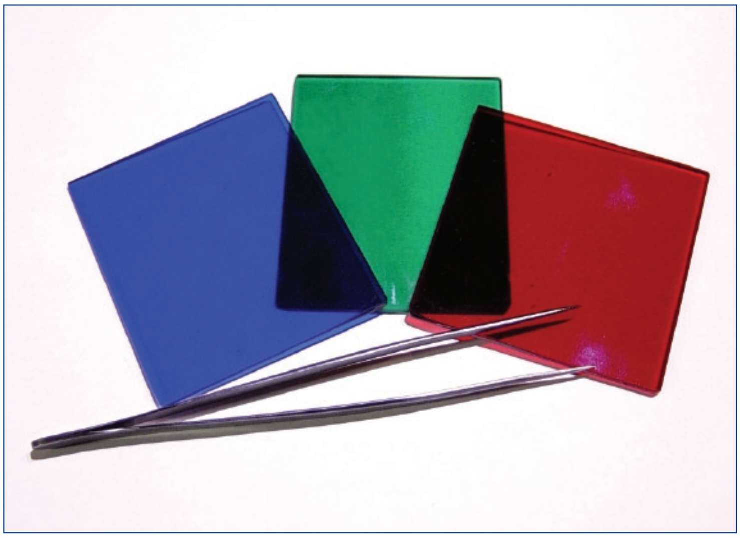

Figure 2a: *Photograph of the glass filters used in this investigation with gem tweezers for scale.*

The coloured glasses were all 2.5 mm thick, and had no patterning so that one could read print through a sheet. A single pane of selenium glass for viewing, and one and two thicknesses of the cobalt and green glasses were tested for minimum transmission using an incandescent source.

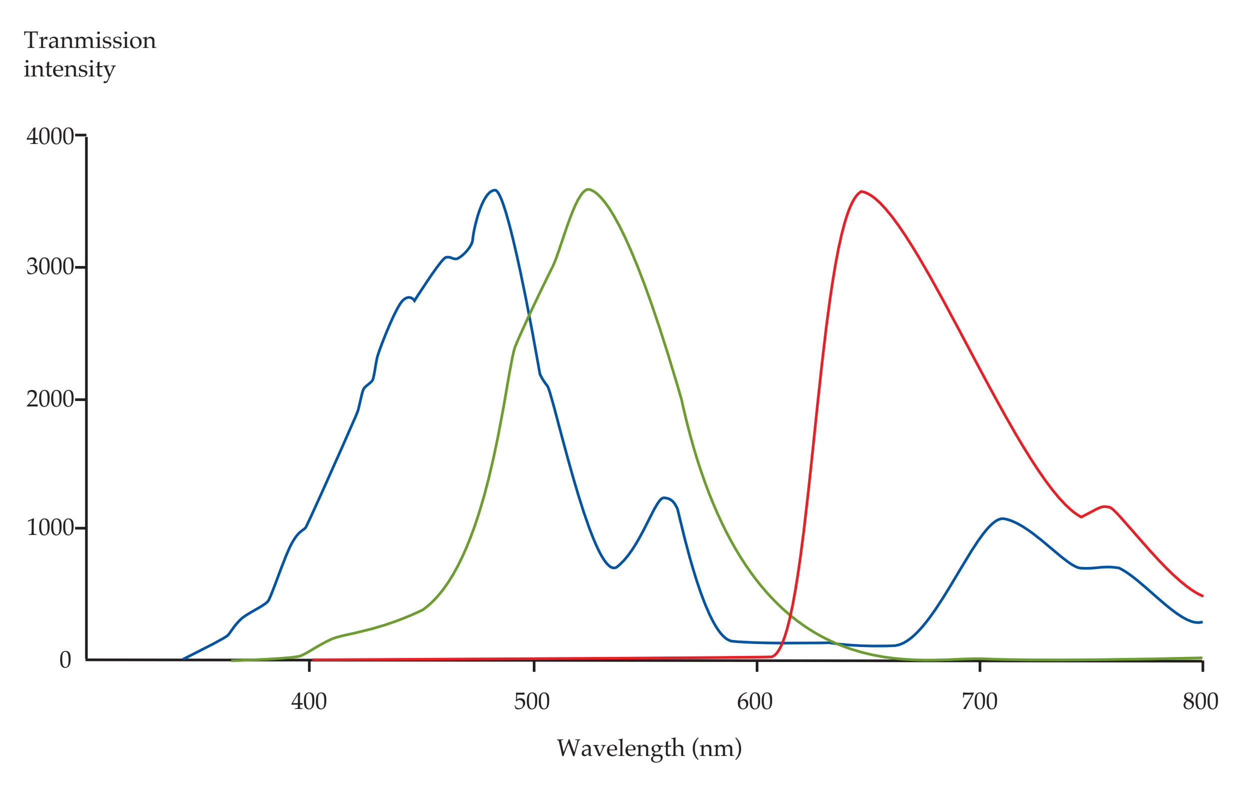

Figure 2b: *Transmission spectra of green (green curve), cobalt (blue curve) and selenium (red curve) glasses taken with an incandescent source.*

The bulb filament could be seen in all cases, but other light was not evident. In use, the double pane cobalt filter appeared to give the best viewing when testing with a synthetic ruby. This appears to give adequate results for a simple crossed-filters apparatus, and is quite simple and inexpensive.

Also tested was a fluorescent light source using cool white bulbs which produced little light at wavelengths below 650 nm. This source, with two panes of the cobalt or green filters, produced better results than with an incandescent source. The cobalt glass is better than the green, producing an essentially black background against which the ruby appears as Anderson described it, "a glowing coal". Thus, the crossed filters technique can easily be implemented by any gemmologist for a few dollars. Comparison illumination spectra for an incandescent, a cool white fluorescent source, and a white Light Emitting Diode (LED) source, all with the cobalt glass filter are shown in *Figure 3*. The disadvantage of an incandescent source used with a cobalt glass filter is seen by the relatively large amount of red light present in such an excitation source.

The applicability of solid-state sources was also investigated. Recently available are LED sources in various colours including a bright blue and green, sold as miniature flashlights (torches), in addition to white LED torches. The blue produces little emission in the red, and from *Figure 3* is very near to the excitation provided by a white LED and cobalt glass excitation filter. All these LED sources are quite intense, and inexpensive. We also tested a three-element LED white source, using one pane of cobalt glass for an excitation filter (*Figure 3*), and found this excellent as well. The high brightness of the LED sources gives increased fluorescence from a gem. While a 'white' LED source may be used effectively with a cobalt glass filter the authors strongly recommend that the blue LED discussed below be used due to the simplicity of not needing a separate excitation filter.

Various blue LED units and one green unit have also been tried by the authors and appear very similar in effectiveness. Tests were made with these sources, and with no

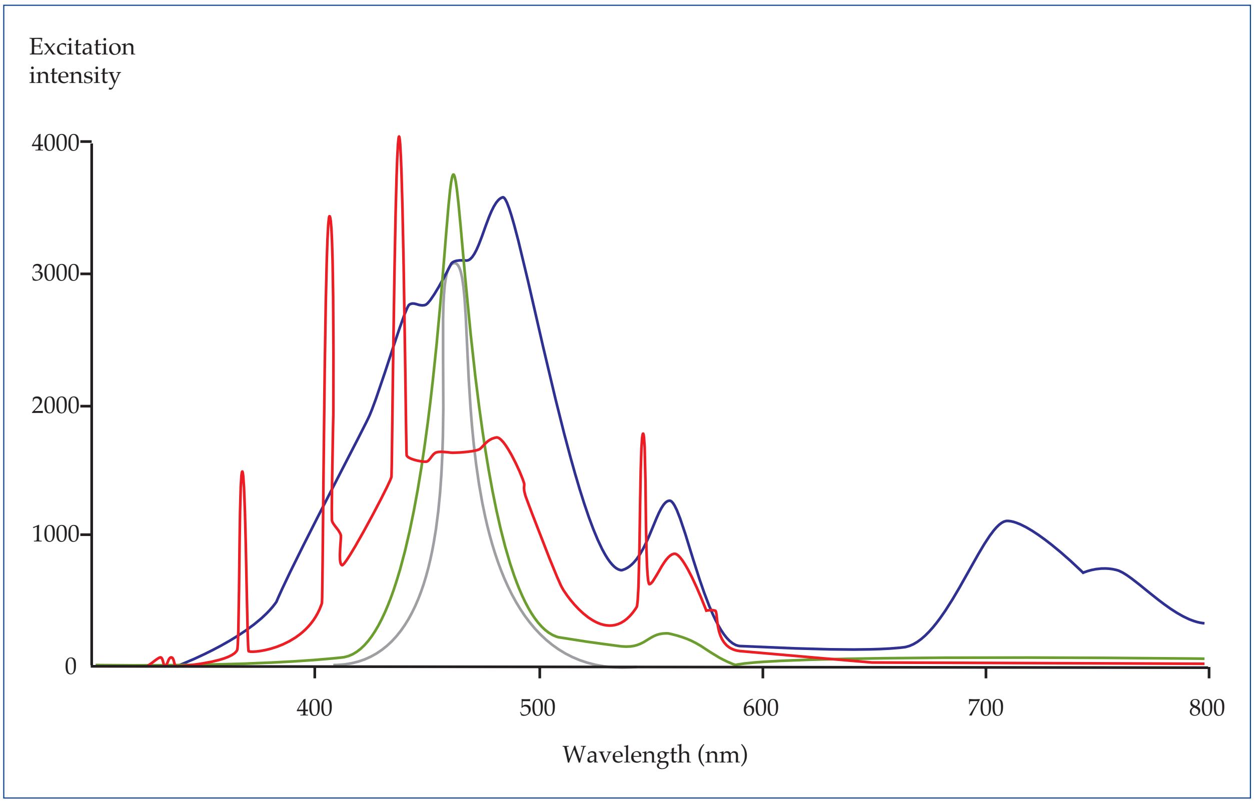

Figure 3: *Excitation spectra for a cobalt glass filter with incandescent (blue curve), fluorescent (red curve) and white LED (green curve) sources, and a blue LED (black curve) source.*

source filter on synthetic ruby. The results were truly amazing when the source was within a centimetre of the stone, which appeared almost alive (*Figure 4*). For ruby and red spinel the green source gave stronger fluorescence, as would be expected from the results of Hoover and Theisen (1993). However, there was too much transmission in the red for it to be considered as effective for weakly fluorescing gems. The authors will continue to investigate green sources, but for this paper will concentrate on the blue LED source. Readers are encouraged to experiment further.

For simplicity of use, effectiveness and cost (under $10) the blue LED source and single pane of selenium glass are recommended as the most practical, and best, way to implement the crossed filters technique. The equipment will fit in a shirt pocket or purse, and one is ready to test anywhere, especially when buying in the field, where it would be easy to test a parcel of stones quite rapidly.

Note should be made of the potential for extending the utility of the technique

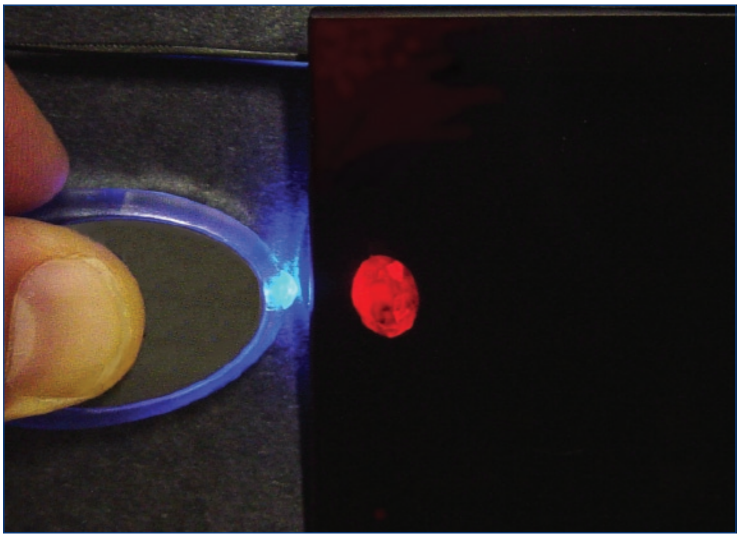

Figure 4: *Photograph of a synthetic ruby fluorescing using the crossed filters technique. Excitation with a blue LED source, and viewed with a selenium glass viewing filter. The selenium filter only covers the ruby.*

to those chrome-bearing gems fluorescing at wavelengths in the near infrared range, longer than 700 nm (emerald, jadeite, kyanite, chrome tourmaline, chrome diopside, chrome grossular, and probably others) by the use of infrared sensors, such as night vision devices, or cameras. Viewing should extend to

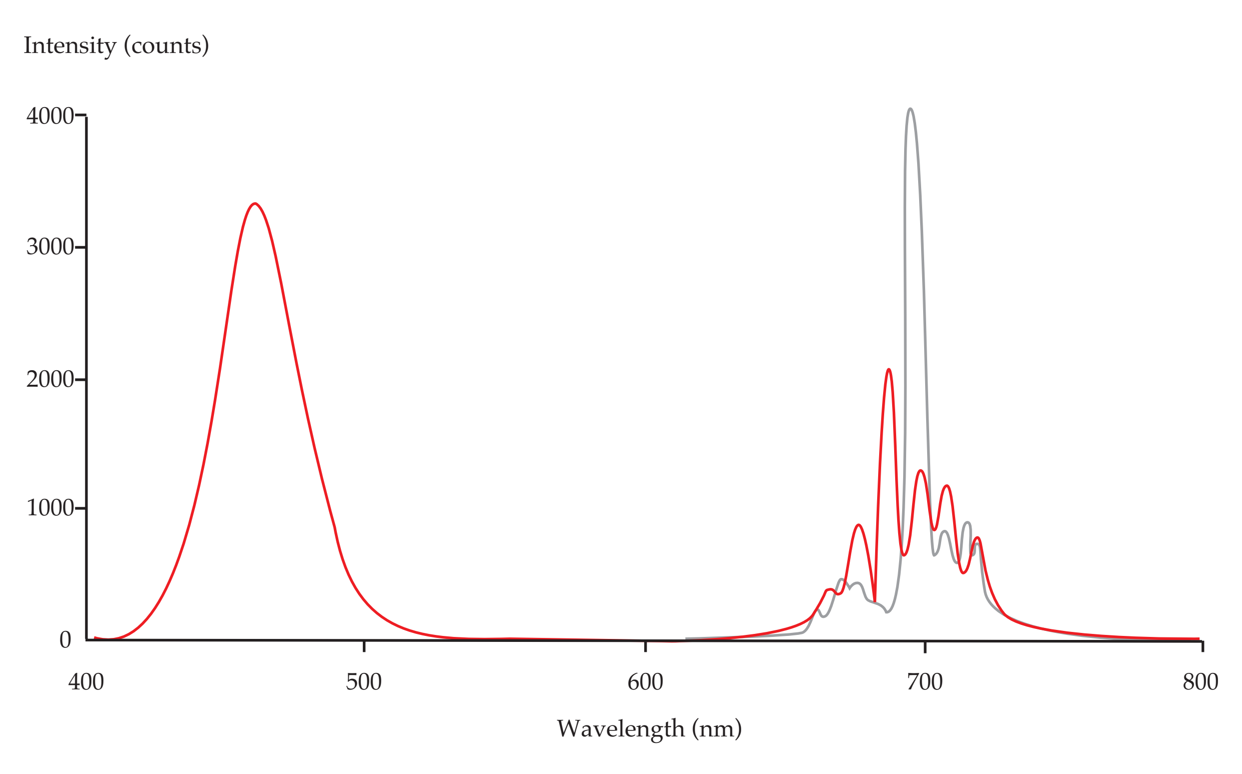

Figure 5: *Emission spectra of ruby (blue curve) and red spinel (red curve) from Myanmar using a blue LED for excitation. In the case of the spinel (red curve) the excitation curve of the blue LED has been superposed on the spinel emission, and shows as the prominent band between 400 and 500 nm.*

800 nm for best results. Harding (1994) notes that Mitchell used a photographic infrared filter in place of the conventional red viewing filter, but evidently his eye was the sensor. His vision range would have been limited to a very narrow band near 700 nm, but Mitchell does note that synthetic emeralds were much more brilliant than natural stones with this combination. The fluorescent emission spectra of ruby and red spinel from Myanmar are shown in *Figure 5*, and for Sri Lankan sinhalite, mottled Myanmar jadeite jade, and Colombian emerald in *Figure 6*. The latter especially show that much emission occurs at wavelengths longer than 700 nm, and is a convincing illustration of the potential for examination of this region.

Comments on practical application

Gems that fluoresce strongly can be viewed in a normally lit room by limiting the amount of extraneous light entering the test region. For some gems the fluorescence is evident even without a selenium glass viewing filter. However, for best results crossed-filters testing should be done in a darkened room, eyes dark-adapted, and with the gems to be tested placed on dead black paper. This is essential for very weakly fluorescing gems such as sinhalite which, the authors discovered, may be separated from peridot in this simple manner. An added advantage of using visible light for excitation is that common glass lenses may be used to focus the blue or green light to a small intense spot if needed.

The authors have not done extensive testing either on large quantities of gems, or on gems from numerous sources. The applications for crossed filters given by Anderson (1959) and Harding (1994) are in general confirmed by our testing. However, the reader should remember that the excitation wavelengths we used are somewhat different than those produced by an incandescent source and a copper sulphate filter, so emissions may differ as well. This corresponds to the differences

Harding (1994) cautions about between different ultraviolet sources and illustrates in his figure 36.10. Harding also comments that comparison of luminescent response between two or three different illuminants can greatly increase the value of fluorescence in diagnostic testing. Having a simple means for crossed-filter testing adds another dimension to discrimination by traditional ultraviolet excitation methods. The authors have noted that in general the longer the wavelength of excitation light used the stronger the emission. Results reported below are from preliminary testing using a blue torch. Much additional testing is needed before the full capability of this variation on crossed-filters is known.

Results using a blue source

Looking at chromium-bearing gems, it is clear that there is a large variation in the strength of fluorescence of natural stones of one type, even from one source. In the following we will summarise what we have observed from limited observations.

All rubies observed fluoresce, the strongest being synthetic stones and natural rubies from Myanmar. Thai stones give a weak to moderate response, as expected from their iron contents. The strong emission at 694 nm is visible as the dominant emission in *Figure 5*.

Sapphires for the most part don't respond, although some light-coloured stones, light blue, pink, yellow or colourless, of varied provenance give a moderate to good response.

Red, and some lilac to purple spinels show good to poor responses. Myanmar stones fluoresce strongly. *Figure 5* shows the 'organ pipe' lines of red spinel extend well beyond 700 nm.

Chrysoberyl is inert except for alexandrite although this varies according to source. From Minas Gerais, Brazil and India, alexandrites respond well to a blue light, in contrast to no response for the deep coloured cabochon material from Carnaiba, Bahia, Brazil.

Natural emeralds from different sources also show different responses, ranging from a strong response from Colombian stones to no response from Carnaiba, Brazil stones; this is generally similar to Anderson's observations. The good response of Colombian stones may reflect the generally low iron content in comparison with emeralds from other localities (Schwarz, 1987). However, concentration of chromium also determines the intensity of fluorescence and Colombian stones show higher average chrome contents than stones from deposits other than Brazil. This question needs further examination. Because almost all of emerald's fluorescence is in the infrared (*Figure 6*), we suspect that part of the variability in reported visual response is due to differences in human vision, and to differences in excitation spectra.

Jadeite jade from Myanmar was quite variable, ranging from a good response to no response. Mottled green/white cabochons may show red fluorescence with little correlation to visual colour patterning. *Figure 6* shows that the two principal emission peaks are on the high-wavelength side of 700 nm.

Examination of topaz showed that chrome-bearing varieties do fluoresce red, and give a much stronger response to the blue light than they do to LWUV. Brown, colourless, and blue varieties from volcanic or pegmatitic sources were found not to fluoresce. Many samples from the Ouro Preto district, Brazil, do react, with the strongest response from those having pinkish tones in white light, while light coloured to pure yellow stones show very weak to no response. The rare pink topaz from Brumado, Brazil, gives a strong response, as does the amber to pink topaz from Ghundao Hill, Pakistan. This probably reflects low iron contents coupled with significant chrome contents. Surprisingly, the pale yellow Schneckenstein topaz of Germany gave a moderate response from two samples tested. This substantiated the reports of crimson and pale violet topaz from the deposit reported many years ago by Feuchtwanger and Streeter, as mentioned by Hoover (1992).

Demantoid, and tsavorite garnets both gave no visible response – understandable

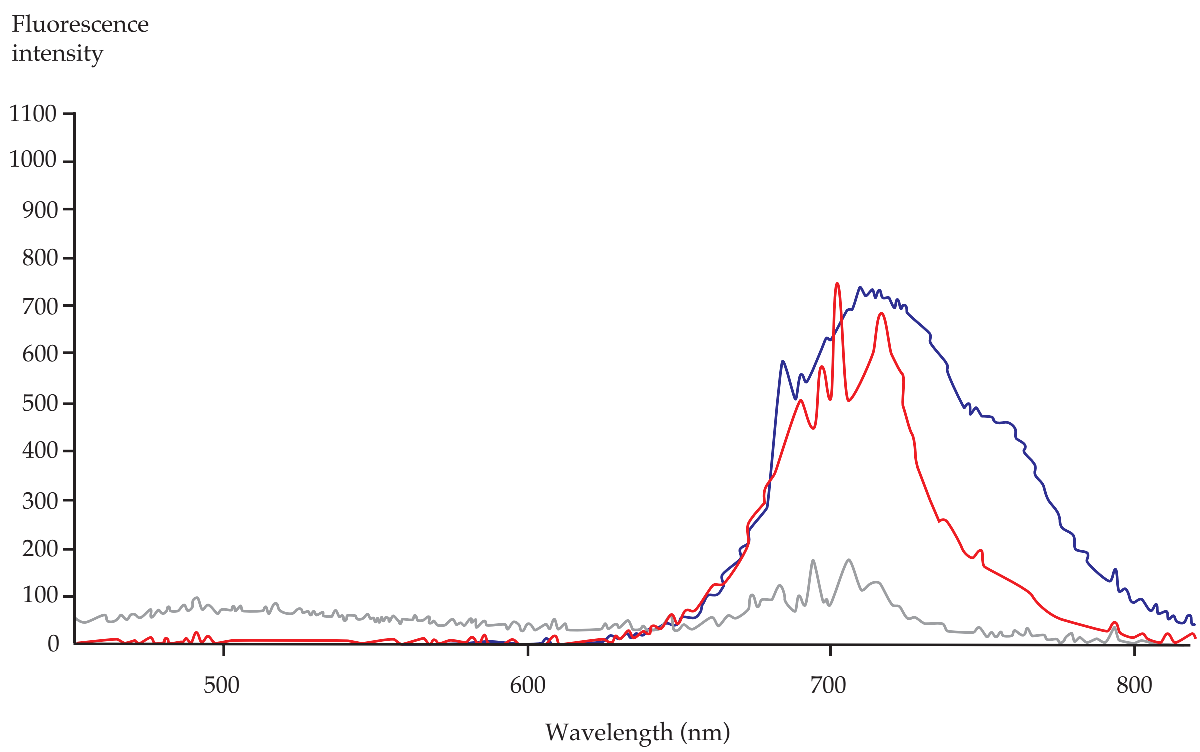

Figure 6: *Emission spectra of Colombian emerald (blue curve), Myanmar jadeite jade (red curve) and Sri Lankan sinhalite (black curve) using a blue LED for excitation.*

because their emissions are weak and too far into the near infrared to be seen.

Because the blue torch/selenium glass combination was so effective for many common chrome-bearing gems, it was tested on a large variety of other stones. The results show that some other UV-fluorescing gems also fluoresce by crossed-filters examination.

Some surprises were found when comparing responses to LWUV and the blue LED crossed-filter technique. Diamonds give different responses to LWUV and to blue excitation. Diamonds that fluoresce blue-white under LWUV show varying strengths of orange to red fluorescence under blue light without a viewing filter, and red with the filter of course. Diamonds fluorescing yellow to whitish-yellow under LWUV, show a varying strength orange without the viewing filter, and red with the filter. In some stones the fluorescence is stronger under blue excitation than under LWUV. In the above tests with diamonds, it was found that a yellow viewing filter such as Stokes used, is a better detector of any response and colour differences due to the better match between the emitted light spectrum and the pass band of the yellow filter.

Other stones tested that fluoresced include: anorthite, Alaska, very weak; light coloured apatites, weak, but blue and green ones gave no response; calcite, some fluorescent varieties good; brown fluorite, Clay Center Ohio, strong, others no; colour-change garnet, Madagascar, fair; kyanite, Nepal, and Brazil, weak; scheelite, weak; sinhalite, Sri Lanka, very weak; sphalerite, weak; spodumene, weak to moderate, with no apparent relation to colour; tugtupite, good.

Of the organic gems, amber, ivory, and red coral all gave fair to good responses. The real surprise was the sinhalite which is considered to be non-fluorescing (Henn, 1994). Although the response is extremely weak, tests on three samples have shown that it can be differentiated from peridot if care is taken with the crossed-filters technique. *Figure 6* shows the emission spectrum of one of the examined sinhalites, suggesting that chromium is present.

Summary

The red selenium glass and blue LED are simple and easy to use. The authors believe that the sources and filters described in this paper provide an important advance in application of the crossed-filters technology because it can be easily implemented by the average gemmologist at very little cost. However, with technology advancing at a rapid pace it would not be surprising if even better sources and/or filters become available in the near future. The information given in this paper should be sufficient for any gemmologist to easily determine which future technical advancements he/she might be able to adapt to the method.

The authors expect that this simple procedure will aid gemmologists in separation and discrimination between a number of gems. However, development and effectiveness of the technique will depend on testing sufficient quantities of stones, looking for differences to assist in distinguishing between synthetics and natural stones, and in distinguishing provenance. We feel that it should supplement conventional UV fluorescence testing. Also, with potential to exploit in the deep red region, it is possible that infrared-sensitive (digital) cameras could extend the limited range of the human eye.

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