NOTES • AND • NEW TECHNIQUES

THE FIRST-ORDER RED COMPENSATOR: AN EFFECTIVE GEMOLOGICAL TOOL

By John Ilmari Koivula

This note deals with some gemological applications for a tool well known to microscopists: the first-order red compensator. In gemological microscopy, the compensator can be useful in locating interference colors and optic figures in birefringent materials and in delineating strain in gemstones. In polarized-light photomicrography, a properly positioned compensator can reduce the exposure time required and thus the risk of film reciprocity failure and of poor-quality images resulting from random vibrations of the microscope and its accessories.

Mineralogists, petrologists, chemical microscopists, and crystallographers are all familiar with the usefulness of a first-order red compensator in locating fast and slow vibration directions of light in crystals, in helping determine the optic character of unknown crystalline compounds, and in defining areas of strain. Use of this microscopist's tool in gemology, however, is virtually unknown.

While exploring potential gemological applications for the classic uses of the first-order red compensator — specifically, enhancing interference colors and determining areas of strain — this article highlights a new use for the compensator, in the field of polarized-light inclusion photomicrography.

WHAT IS A FIRST-ORDER RED COMPENSATOR?

Traditionally, first-order red plates have been constructed of a small, thin (approximately 0.0625 mm), uniform layer of selenite (gypsum), cut par-

allel to the perfect cleavage; or quartz, cut parallel to the c-axis. The plates produce an optical retardation of 530 to 550 nm.

Because of the brittle nature and small size of the ultra-thin gypsum and quartz plates needed to make a first-order red compensator, these compensators were poorly suited for use with a low-power gemological stereo microscope. It was not until the late 1970s, when the Polaroid Corporation introduced large-format first-order red compensators in plastic sheet form, that the application of such a compensator became practical for use with a polarizing gemological microscope. The compensator manufactured by Polaroid is a proprietary product, a plastic laminate of undisclosed nature, that produces an optical retardation of approximately 530 nm.

HOW THE COMPENSATOR WORKS

Several good texts are available that describe the use of the first-order red compensator in the areas of microscopy, optical mineralogy, and optical

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Figure 1. Drawing showing the test subject and compensator plate oriented in subtraction position in a polarized light field when the polarizer and analyzer are in total extinction. Drawing by Christine Wilson, after McCrone et al., 1979.

crystallography (e.g., Phillips, 1971; McCrone et al., 1979). When inserted in a field of polarized light, the compensator basically serves to brighten and enhance an image by the addition or subtraction of optically retarded wavelengths as they pass through the compensator into an optically anisotropic subject. When two anisotropic materials, one being the compensator, are superimposed in a field of polarized light, addition or subtraction of their individual retardations will occur, depending on their orientations to each other and to the polarizer and analyzer. If both the compensator and the subject are oriented in the position of total brightness in the polarized light field (which is 45° away from the vibration directions of the analyzer and polarizer) and their slow vibration directions (corresponding to the higher refractive index) are perpendicular or at right angles to each other (see figure 1), then *subtraction* of retardations occurs, resulting in lower-order interference colors. If, however, the slow vibration directions of the compensator and the test subject are oriented parallel to each other (as in figure 2), then *addition* of retardations occurs, resulting in higher-order interference colors; low-intensity blacks, grays, and whites and very pale yellows, oranges, and reds are enhanced into the more vibrant first- and second-order colors. The Michel Levy chart (McCrone

Figure 2. Drawing showing the test subject and compensator plate oriented in addition position in a polarized light field when the polarizer and analyzer are in total extinction. Drawing by Christine Wilson, after McCrone et al., 1979.

et al., 1979) illustrates the "Newton's Series" sequence of interference colors. If we can enhance, or brighten, low-intensity interference colors either by subtraction from the higher orders or by addition of the lower order, then they will be much easier to locate and observe. The first-order red compensator is well suited to this task.

GEMOLOGICAL APPLICATIONS

The first thing the gemologist notices when using a first-order red plate is the vivid magenta color it produces when it is inserted in the light path between the polarizer and the analyzer when they are in a position of total extinction. The view through the GEM polariscope shown in figure 3 illustrates this effect.

It should be noted that the first-order red compensator plate is not a filter that is red in color as the name might imply. Rather, it is a very pale yellowish, almost colorless, material that gives a first-order red or magenta color to a field of polarized light. The first-order red compensator has a number of practical applications in gemology, as described below.

Observing Interference Colors and Locating the Optic Axis. During orientation of a doubly refractive gemstone in the polariscope or microscope,

Figure 3. View through a polariscope with the first-order red compensator inserted halfway through the polarized light field.

as the gemologist searches for an optic axis, the first-order red plate can prove helpful. Here it serves as a means of brightening interference colors that start to appear as the optic axis direction is approached. Brighter colors are much easier to locate. It follows that if the optic axis interference colors are easier to locate, then the optic axis itself can be found more quickly.

Determining Strain. When present — either as a result of unseen internal disruption, twinning, or

crystalline intergrowth, or as halos surrounding solid included crystals — strain will often reveal itself under polarized light conditions as color anomalies in shades of brown, gray, and black. Because of this lack of color intensity, it is sometimes very difficult to detect. The first-order red compensator can be used to enhance strain colors and patterns (figures 4 and 5), producing more vivid blues and yellows or sometimes reds and greens. Inasmuch as strain is commonly present in diamonds, microscopic examination under polarized light with a first-order red compensator is a helpful method of separating diamonds from substitutes such as cubic zirconia and yttrium aluminum garnet.

Use with Polarized Light Inclusion Photomicrography. When using polarized light to photograph inclusions, the gemological microscopist is commonly confronted with low light intensity and a correspondingly long exposure time that all but makes quality photomicrography impossible. With the first-order red compensator, however, the image is enhanced by a vivid array of bright interference colors and the exposure time required — and, consequently, the effect of vibrations — is greatly reduced.

If we look again at the polariscope image in figure 3, we see how much brighter the magenta side of the polarized light field in this image is. When the compensator is used with a gemological microscope equipped with a light-polarizing system, the difference in brightness is equally obvious and also readily measurable with a light metering system. Light metering showed that the exposure

Figure 4. Left—Included crystal of diamond in diamond, photographed in polarized light without the compensator. Exposure time, 1 minute 25 seconds. Right—the same crystal photographed in polarized light with the first-order red compensator. Exposure time, 22 seconds. Magnified 50×.

Figure 5. Left—Monazite crystal in an African rhodolite garnet in polarized light without the first-order red compensator. Exposure time, 3 minutes, 13 seconds. Right—Monazite crystal but with the first-order red compensator inserted. Exposure time, 25 seconds. Magnified 50 $\times$.

time required to properly expose film with an ASA of 160 when the polarizer and analyzer are in 90° extinction is over 10 hours. With insertion and proper orientation of the first-order red compensator in the field between the polarizer and analyzer, the exposure time is cut to less than one minute. The brighter the image is the less the required exposure time will be.

Although the above-mentioned difference in exposure time is dramatic, no inclusion subject was present in the light path to demonstrate the true value of the compensator plate to the gemologist-photomicrographer. To illustrate the point, three test subjects showing a wide range of optical properties — a diamond, a garnet, and a rock crystal quartz, all with inclusions — were selected.

The first subject, the diamond, has an inclusion of another diamond that shows only partial interfacing, making some of the edges virtually invisible as they blend with their host of the same refractive index. The diamond within a diamond was photographed first using only the polarizer and analyzer in extinction. The photograph, shown in figure 4 (left), reveals a great deal of lattice strain in and around the inclusion. The exposure time was one minute and 25 seconds. The strain colors in this photomicrograph are all of low intensity and the image is quite dark. With insertion of the

first-order red compensator into the field, the inclusion picture (figure 4, right) is immediately decorated by an array of vivid strain colors and the exposure time reduced to 22 seconds.

The second subject, a rhodolite garnet, plays host to a euhedral monoclinic crystal of transparent yellow monazite. As shown in figure 5 (left), taken under polarized light without compensator, strain in low-intensity colors is visible around the radioactive monazite. The exposure time was three minutes and 13 seconds. In figure 5 (right), taken with the compensator in place, the image is now alive with bright interference colors; time for the exposure was only 25 seconds.

The last test subject, a colorless quartz, contains a number of small, noninterfaced, unoriented, slightly distorted quartz crystals. Without polarized light (figure 6, top), only a few faint areas of the quartz inclusions are visible because they have virtually no interfacial separation and the same refractive index as their host. This transmitted light image was recorded in one second. In figure 6 (bottom left), under polarized light, all of the quartz crystal inclusions are now visible. However, the exposure time was 18 seconds. With the first-order red compensator (figure 6, bottom right), the included crystals are still vivid but the exposure time was reduced to 8 seconds.

Figure 6. Top—These inclusions of rock crystal quartz in rock crystal quartz are virtually invisible in transmitted light. Exposure time, 1 second. Bottom left—The same inclusions of quartz in quartz shown above become visible under polarized light. Exposure time, 18 seconds. Bottom right—Use of the first-order red compensator reduced the exposure time in polarized light for the image shown at left to 8 seconds. Magnified 20 $\times$.

CONCLUSION

Comparing the photographic images with their corresponding exposure times shows that the first-order red compensator has something to offer the gemologist who is interested in polarized light photomicrography. The technique is easily adapted to any standard stereo gemological microscope and the results can be worth the effort.

Additionally, the first-order red plate enhances strain colors, making strain areas more easily visible and thereby simplifying the location of strain centers. In many instances, the compensator also

aids efforts to locate an optic axis direction in a doubly refractive gemstone by making the location of interference colors, as an optic axis is approached, much easier.

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