SHADOWING: A NEW METHOD OF IMAGE ENHANCEMENT FOR GEMOLOGICAL MICROSCOPY

By John I. Koivula

The shadowing technique employs an opaque, black, nonreflecting light shield that is inserted gradually into the transmitted light path of a gemological microscope between the subject and the light source. Shadowing takes advantage of even very slight differences in refractive index between a gemstone host and its inclusions, casting shadows in certain areas of an inclusion scene and passing light to the microscope objectives in other areas of the image. Thus, shadowing produces a three-dimensionality that seems to lift the inclusion from its surroundings, revealing it in vivid contrast against the now-subdued background of the host. This increase in contrast adds much greater detail to growth zones, included crystals, color zones, and the like, thus greatly aiding the gemologist in his work with the microscope.

Shadowing was developed through a desire to study more closely the apparently "straight" and "angular" growth and color zones that often occur in flux-grown synthetic rubies. The theory is that if these synthetic rubies were grown in a low-pressure, flux-type environment, the apparently straight and sharply angular color zoning seen under normal dark-field and transmitted light conditions might reveal slight, very subtle growth undulations on their otherwise overall straight surfaces. Such growth undulations would prove that the host rubies were synthetic. Although the absence of such growth undulations does not necessarily prove that the ruby is natural (some flux synthetics can show color-growth zoning that appears to be perfectly straight), if color zone undulations are present, the ruby is synthetic.

Microscope techniques used outside the realm of gemology, such as modulation contrast, phase contrast, and interference contrast (McCrone and Delly, 1973; McCrone et al., 1979) employ interference rings, slits, and the like to increase image contrast. However, these various systems, as they currently exist and are often used in the biological sciences and petrography, are not practical for gemological application. The cost of such equip-

ment is very high, and the systems are designed to be used on prepared biological slides and thin sections, where depth of field and working distance are not important factors, and where magnification ranges much higher than those required in gemology are commonly used.

Gübelin (1957) was successful in adopting phase-contrast microscopy to gemology, but, again, the equipment is expensive. The problem that persisted was how to obtain the desired effect of enhanced contrast while retaining the depth of field and long working distance of the gemological microscope without a great expense.

With some experimentation, the author found the key to the solution in the other, even more expensive contrast-enhancement systems. They all incorporate slits, rings, beam splitters, and the like that are built into what is known as a sub-stage condenser. The condenser fits between the light source and the subject, and interferes with the direct passage of light to the subject itself. The main body of the condenser is merely a housing for the convenient control of the phase rings, variable slits, and the like. Remove the housing, and we have certainly cut the cost of such a system. Keeping in mind only the principle of light-path interference, the author in a sense stripped away the condenser housing and started to experiment with an array of various shapes and sizes of opaque, flat, black light shields (see figure 1).

THE TECHNIQUE

The first opaque light shield used was a 6 × 2-cm rectangular piece of flat, black, 16-gauge steel sheet (again, see figure 1); next was the movable black dark-field light shield, and then the iris dia-

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Figure 1. Three opaque light shields used to develop the author's shadowing technique. The crescent-shaped shield provided the best contrast enhancement and control of directionality.

phragm of the Gemolite microscope (Gem Instruments, Santa Monica, CA). All increased contrast in the inclusion subject to a similar, limited extent. At low magnification, $10\times$ to $20\times$, the area of enhancement was quite small, approximately 10% or less of the entire field of view. With higher magnification, the contrast-enhanced area increased proportionately.

The principle behind the light shield is relatively simple. As the edge of the opaque light shield is slowly inserted into the light path, it interferes with the direct upward passage of light, causing it to be diffracted and scattered at the edge. This fanning out of the light (see figure 2) literally causes a transmission of light in certain portions of the inclusion subject while other areas appear to be darkened or shadowed, greatly increasing contrast in and around the inclusion. Theoretically, any inclusion that has a refractive index different from that of its host can be shadowed. However, facets and facet junctions, which often act as mirrors or prisms, can and do greatly reduce the effect of shadowing.

At the interface of the inclusion and its host, in the presence of shadow-scattered light, two things take place to produce the contrast-enhanced image that we see. The scattered light travels through the host unimpaired until it contacts an inclusion of different optical density. Portions of the light are then reflected away from the microscope objective and the observer's eyes,

Figure 2. An exaggerated diagram showing the back-scattering of light as the opaque light shield is gradually inserted into the transmitted light path.

causing those areas that reflected the light to appear dark. Conversely, areas that allowed the light to be transmitted into and refracted through the subject to the observer's eyes appear light. This effect, as illustrated in figure 3, gives rise to the

Figure 3. Simplified theoretical situation illustrating the effect of both reflection and refraction transmission of the back-scattered light as it contacts an included crystal with a refractive index different from that of its host.

increased contrast we observe with the shadowing technique.

DIRECTIONALITY AND ITS CONTROL

When color or growth zones, as in flux-grown synthetic rubies, are the object of study, a problem of directionality arises, particularly if the zones are in essentially parallel straight lines. The author noted that as the opaque edge of the light shield was inserted in the light path, little or no shadowing took place if the color zones ran perpendicular to the edge of the light shield. If, however, the color zones ran parallel to the edge of the shield, then maximum shadowing took place.

This problem of directionality was overcome somewhat by varying the shape and size of the opaque light shield used. A curved arc, measuring only about 1 cm in diameter (see figure 1), proved quite effective in reducing directionality and increasing contrast. A $1 \times 1\text{-cm}^2$ section cut from an old screen door (again, see figure 1) also proved effective in reducing directionality, but the shadowing effect and resulting increase in contrast was somewhat subdued. The curved arc, because it is not as directionally dependent and therefore is easier to control, worked equally well on inclusions such as crystals and on zoning.

SETTING UP FOR SHADOWING

With a standard gemological microscope such as the Gemolite, shadowing can be achieved in the following manner. The iris diaphragm of the microscope is first opened and the dark-field stop (light shield) is rotated out to produce a transmitted light mode in the microscope. The subject to be studied is placed in a stone holder or similar device and oriented so that light is being transmitted through the area of the gemstone that will be shadowed. Then the area of study is brought into sharp focus. Next the shadowing device is very slowly brought into the transmitted light path while the user looks at the image through the microscope. The shadowing shield can be inserted into the light path at any point between the light source and the subject. The author has placed the shadowing shield in the well of the microscope directly on top of the transmitted light diffuser and moved it with a pair of tweezers. He has also placed the shield on a glass slide directly below the subject, almost touching it, with equally good results.

As the shield is inserted, a dark shadow edge will begin to appear at the edge of the microscope's field of view. This is the out-of-focus image of the shadowing shield as it begins to emerge into the field of view. As it gets nearer the inclusion subject the shadowing will begin to take place until, at a particular point, the inclusion seems to almost instantly become three-dimensional, as if it were lifted from the host and placed on its surface. For the beginner, in the initial stages of experimentation with shadowing, the author suggests that perhaps the fixed-position dark-field light stop and/or the built-in iris diaphragm of a microscope like the Gemolite will be much easier to control than free-moving light shields such as those illustrated in figure 1.

With the iris diaphragm, simply stopping it down below the subject and partially blocking the transmitted light will produce a somewhat limited shadowing effect. The built-in dark-field light stop shield can also be used for shadowing either by itself or in combination with the iris diaphragm simply by rotating it gradually into the transmitted light path, producing a dark-field illumination/transmitted light combination. The limitation of both the built-in iris diaphragm and the dark-field stop, however, lies in the fact that they are actual parts of the microscope and cannot be moved about freely to find the optimum direction for shadowing.

The two critical steps in setting up for shadowing are (1) proper initial orientation of the subject, so that light is transmitted through the area to be shadowed; and (2) the slow, careful insertion of the light shield into the light path below the subject while observing the effect through the microscope.

RESULTS

In the opinion of the author, the image enhancement provided by the shadowing technique far outweighs the difficulties encountered in the discovery and early development of the method. In the initial study done on color and growth zones in flux-grown synthetic rubies, the obvious difference between the shadowed image and the unshadowed image, as illustrated in figure 4, was amazing. Slight growth undulations in the otherwise straight color zones became quite apparent in the shadowed view on the right. Without shadowing, as on the left, these same features were invisible.

Figure 4. The growth undulations and slight curving seen in the shadowed color zones of this flux-grown ruby on the right are not seen in the unshadowed image shown on the left. Magnified 60 $\times$.

The author next experimented with transparent included crystals, and found that shadowing worked equally as well. He also determined that the shadowed image of most included crystals could be further enhanced by the use of shadowed polarized light. The three views in figure 5 vividly illustrate the transition from the unshadowed transmitted light image (far left) through the shadowed transmitted light image (center) to the shadowed polarized light image (far right) of these muscovite mica crystals included in beryl.

Other gemstones studied by the shadowing technique also responded favorably. For example,

swirl marks (*schlieren*), an important characteristic of glass (figure 6), can be greatly enhanced by shadowing, as can curved striae, the hallmark of flame-fusion synthetic rubies (figure 7).

CONCLUSION

Shadowing increases contrast in an inclusion scene with no visible loss of resolution, so the quality of the image is greatly enhanced. When viewing a crisper, sharper, more detailed image, the gemologist is less likely to overlook important internal features in a gemstone. Growth and color zones in both natural and synthetic gems

Figure 5. These muscovite mica crystals included in a Brazilian colorless beryl illustrate the effective use of shadowing on transparent included crystals. The view on the left shows the crystals as they appear in transmitted light without shadowing; the center photo shows the same inclusion shadowed. The view on the right shows the crystals illuminated by polarized light in combination with shadowing. Note the great amount of detail revealed in the two shadowed views. Magnified 80 $\times$.

Figure 6. Swirl marks (schlieren) in a green glass appear in sharp contrast under shadowing conditions. Magnified 50 $\times$.

Figure 7. Curved striae, an important internal feature found in synthetic flame-fusion corundum, also respond to the shadowing technique. Here they are shown with typical gas bubbles as well. Magnified 100 $\times$.

are more readily studied, curved striae in flame-fusion rubies and sapphires will often take on a bold, three-dimensional appearance, and included crystals of all different types will look as if they have been taken from their host and laid on its surface.

Shadowing is a micro-technique that is both difficult to master and of admittedly limited application. Learning to use the shadowing tech-

nique takes both time and a great deal of patience. It requires a gemologist who not only is a skilled microscopist but who also has a sound knowledge of both light interference and reflection and refraction for the initial set-up of the host and inclusion subject.

In spite of these drawbacks, the technique of shadowing adds yet another new dimension to gemological microscopy and further increases the flexibility and available methodology, to the gemologist, of the standard gemological microscope. For those gemologists who wish to increase the contrast of an inclusion or study in greater detail otherwise vague and ill-defined internal images while, at the same time, expanding their own abilities with the microscope, the shadowing technique will undoubtedly prove useful.

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