PHOTOMICROGRAPHY FOR GEMOLOGISTS

By John I. Koivula

Just because you don't see it, doesn't mean it isn't there.

Many areas in the jewelry industry—education, gemological research, lecturing, publication, and laboratory and inventory documentation, to name a few—either require or benefit from high-quality photomicrography. This article reviews the basic requirements of gemological photomicrography and introduces new techniques, advances, and discoveries in the field. Proper illumination is critical to obtaining the best possible photomicrographs of gemological subjects, as is the cleanliness of the photomicroscope and the area around it. Equally as important is an understanding of the features one sees and the role they might play in the identification process.

This article is dedicated to Dr. Edward J. Gübelin, one of the great pioneers of gemological photomicrography and the first gemologist to truly appreciate the unparalleled beauty of gems in nature's microcosm.

Without photomicrography, gemology as we know it would be virtually nonexistent. The photomicrographer explores the surfaces and interiors of gems with a microscope, and prepares images that record and convey information that is normally hidden from view. Today, nearly all professional gemological researchers take and publish their own photomicrographs. When researchers report the identifying features of new synthetics, treatments, and natural gems from new geographic localities, they include photomicrographs that are instrumental to the jeweler/gemologist in identifying these new materials. One needs only to look through issues of *Gems & Gemology*, or any of the other various international gemological journals, to see how dependent gemology has become on these illustrations of the microscopic features of gems. Via the printed page, these photomicrographs instantly update the reader.

Although the basics of photographing through a microscope are easily learned and applied (see, e.g., "Photomicrography…," 1986–87), high-quality photomicrography is an art-science that is never fully mastered. It only continues to improve over time with much practice, great patience, and at least some imagination. A gemological photomicrographer must understand a subject in order to bring out or highlight any significant details, and to know how the subject will appear on film. That is the science (figure 1). Artistry, however, requires that those details be presented in an eye-pleasing photograph, since along with durability and rarity, beauty is one of the primary virtues of any "gem" (figure 2).

It is neither possible nor feasible to own every beautiful or scientifically interesting gem encountered. With the ability to take photomicrographs, however, one can document any notable or educational micro-features. Over time, it is possible to create a visual media library that can be used as a reference and documentation source in gem identi-

See end of article for About the Authors and Acknowledgments.
Note that all photomicrographs are by the author.
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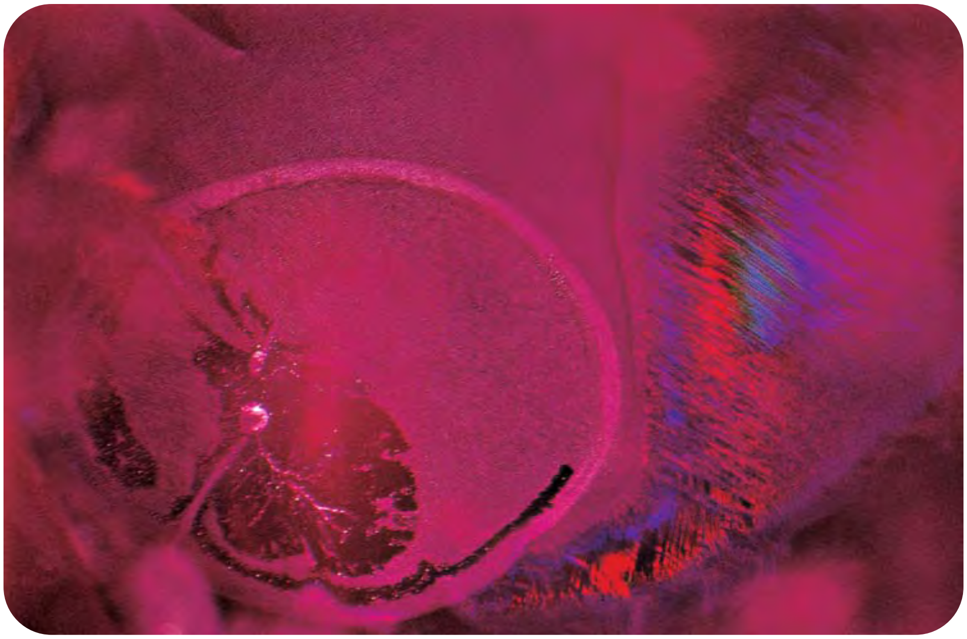


Figure 1. This decrepitation halo surrounding a fluid inclusion in a natural, untreated Thai ruby was captured on film using a combination of darkfield and fiber-optic illumination. A Polaroid analyzer was also used to eliminate image doubling, thereby providing a sharper photo. Magnified 45×.

fication situations. Such a library also can be employed as an independent image resource for lectures and other presentations, and, in the case of certain beautiful photos (figure 3), even as an inspirational form of aesthetically pleasing natural art.

In the pursuit of photomicrography, the cleanliness and stability of the microscope are critical, and the effects of light on the subject inclusion must be fully understood in order to determine what method(s) of illumination will yield the most useful photographic image. In addition, specialized techniques can save film and time while producing top-quality photomicrographs. Although some of these techniques are usually mastered only through decades of experience, it is never too late to start learning and refining what you already know. This article discusses these various factors and techniques, such as the importance of a properly prepared microscope and photographic subject, as well as the control of vibrations and the factor of time itself. It also examines several methods of illumination adaptable to a standard gemological microscope. It is intended not only to introduce readers to gemological photomicrography, but also to show them the possibilities offered by this always interesting and often beautiful realm.

PROPER TERMINOLOGY

The terms *photomicrography* and *microphotography* do not mean the same thing and are not interchangeable. The scientifically correct term for taking pictures through a microscope is *photomicrography* (Bradbury et al., 1989), which has longstanding precedence ("Photomicrograph . . .," 1887). The images produced are properly called *photomicrographs* or simply *photographs. Microphotography* is the technique used to reduce a macroscopic image to one that is too small to be resolved by the unaided eye. For example, microphotography is used in the production of microfilm, where the contents of entire newspapers are reduced to very tiny photographs. These images are called *microphotographs or, in sequence, microfilms.*

DIGITAL VERSUS FILM

All of the images published in this article were produced from 35 mm professional film (with ASA's ranging from 64 to 160). While some gemologists may consider digital photomicrography more "up to date," in my experience the color saturation and resolution obtained on the best digital cameras is not yet as good as can be obtained using a fine-grained professional film. While photomicrographic images obtained from a digital camera may look excellent, if the same subject is photographed on professional film, and two images are placed side-by-side, the superiority of the film image then becomes obvious. The quality of scanners today is such that you still can obtain a better digital image by scanning a slide than if you use digital photomicrography directly. While there is virtually no doubt that digital photomicrography will someday surpass and probably replace film, this has not yet occurred.

SOME REQUIREMENTS

There are three primary steps to effective examination of the external and internal microscopic characteristics of any gem. The first is found in a sound scientific and gemological knowledge of the subject. The second is found in the quality of the microscope's optics, while the third is linked to illumination techniques.

As the first step, the photomicrographer must have a sound working knowledge of inclusions in gems and how they react to various forms of illumination. This knowledge can be gained by reading the technical literature, both journals such as *Gems & Gemology and Journal of Gemmology,* and books such as *The Photoatlas of Inclusions in Gemstones* (Gübelin and Koivula, 1986).

The second step is obtaining the best optics, and there really is no substitute for high quality. With optics, you more-or-less get exactly what you pay for. While there might be a premium for certain well-known brand names, if you choose to spend as little as possible on a photomicroscope, then your talent will quickly surpass your microscope's usefulness, you will quickly outgrow that microscope, and you will never achieve the results you are after. A used photomicroscope with excellent optics is much better than a brand new one with an inferior optical system.

The third step is understanding the various illumination techniques that are available to both best visualize the microscopic feature and best capture it in a photograph. This is discussed in detail below.

There are also a number of other concerns that are intrinsic to the process of photomicrography. How can vibrations be reduced or eliminated? How can exposure time be controlled or reduced? What is the best way to clean the equipment and the stones to be photographed? And so on. What follows is a review of some of these important considerations for photographing inclusions and other features through a microscope, to ensure the most positive experience and the best possible images.

VIBRATION CONTROL

Vibration problems are one of the greatest threats to good photomicrographs. It is, therefore, critical that the photomicrographic unit be protected from unavoidable room vibrations during the entire exposure cycle. Optical isolation benches and air flotation tables have been designed for this specific purpose, but the high cost of such tables (typically several thousand dollars for one 3 × 3 feet [approximately 1 m^2]) is prohibitive for most photomicrographers. Making your own vibration control stage is the logical alternative, and doing so can be relatively easy.

First, if at all possible, find a ground floor or basement location for your photomicroscope, preferably a thick concrete slab that has been poured directly over firm soil or bedrock and covered with a firm finish flooring material such as vinyl or vinyl composition tile. Avoid floating floors and areas subject to frequent harsh vibrations (such as near a manufacturing

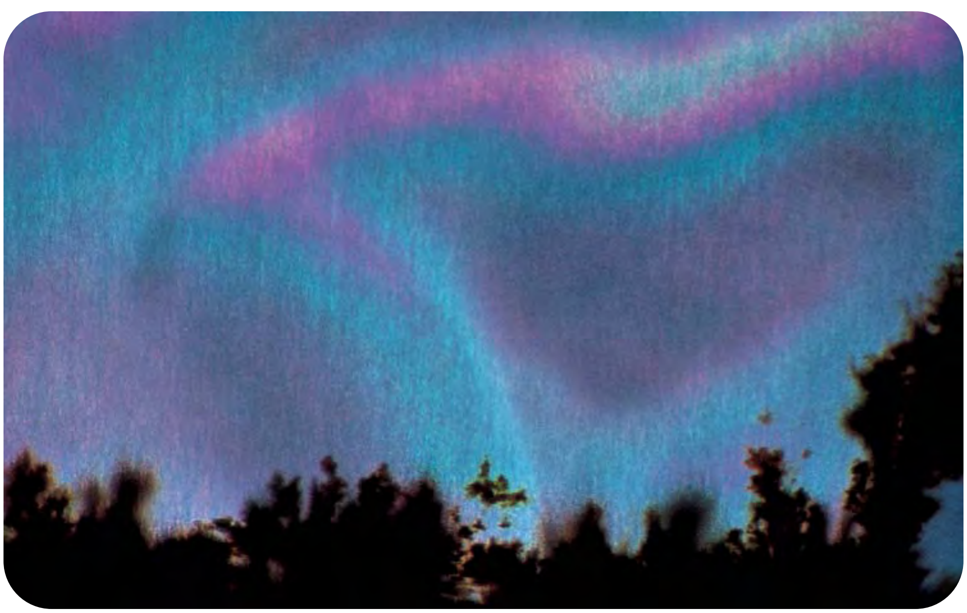


Figure 2. Photomicrographic images can be either soft or bold. A combination of shadowing to bring out the vibrant colors and fiber-optic illumination to highlight the pseudo-vegetation was used to create this soft, imaginative "Aurora Borealis" in a dendritic iris agate carved by Falk Burger. Magnified 4×.

Figure 3. Polarized light and fiber-optic illumination combine to form this bold rainy mountain scene in a quartz faceted by Leon Agee. The patterned colors are caused by Brazil-law twinning, while light reflecting from rutile needles produces the "wind-driven rain." Magnified 5×.

area or a workshop). Then place a soft layer of dense, short-pile carpeting or rubber matting of a neutral color in the immediate area around the photo space in case something is dropped accidentally. The photo room itself need not be large (5 × 6 feet will work), but it should be capable of near-total darkness.

Once the photo room has been chosen, start with a hard, sturdy, thick-surfaced table as a primary base for your microscope, camera, and lighting equipment. To build an anti-vibration "sandwich," place a rubber cushion that is larger than the base of your microscope and about 1/4 inch (6.4 mm) thick on the table. On top of that put a 1/4–1/2 inch (6–12 mm) thick steel plate of the same dimensions as the rubber cushion, and then position a rubber cushion similar to the first over the steel plate. Last, place a 1–3 inch (approximately 2.5–7.5 cm) thick granite (or similar hard rock) slab on the top cushion, which then holds the photomicrographic unit. This set-up eliminates vibrations for virtually all magnifications below about 100–150× (Koivula, 1981), although it is still important to avoid touching the table or any of the equipment during the actual exposure.

MODERN EQUIPMENT

Since there is no substitute for good optics, you should expect to spend several thousand dollars to properly equip a gemological photomicroscope. Obviously the most costly piece of equipment is the microscope itself, followed by the camera and the fiber-optic illuminators. As shown in figure 4, there are two bifurcated illuminators in the set-up I use, which gives a total of four controllable light pipes, two on each side of the microscope. This set-up is highly recommended for its versatility. The fiber-optic illuminators can be purchased through manufacturers such as Dolan Jenner, Nikon, or Zeiss, or from distributors such as GIA Gem Instruments or Edmund Scientific.

The Internet is a great place to start in your search for a photomicroscope. All of the major manufacturers of high-quality optical equipment have Web sites that show the full range of their products, as well as ancillary equipment useful to the photomicrographer. There are also some excellent Web sites that list used microscopes for sale from all of the major manufacturers. Many of these have been very well maintained, with optics in excellent "as new" condition.

Currently, no one manufacturer produces an all-inclusive, ideal photomicroscope for gemology. Such set-ups evolve over time, typically user-assembled hybrids with components designed to handle specific gemological photo situations. For example, the gemological photomicroscope set-up pictured in figure 4 has evolved around a basic, but no longer manufactured, Nikon SMZ-10 zoom stereo trinocular photomicroscope with a built-in double iris diaphragm for depth-of-field control. It rests on a GIA Gem Instruments custom-made base with a built-in darkfield–transmitted light system that incorporates a 150-watt quartz halogen light source. The base itself is mounted to a large steel plate for added stability, and the post that holds the microscope to the base is 10 inches (about 25 cm) longer than a normal post, which allows much larger specimens to be examined and photographed.

Figure 4. Housed in a sturdy protective cabinet, the author's gemological photomicrographic system uses a trinocular arrangement so that the camera remains in place when the system is being used as a binocular microscope. Note that this custom-made darkfield and transmitted light system uses two fiber-optic illuminators (with a white film canister diffuser on the wand that is lit), but it is also easily set up for applications with polarized light, shadowing, and ultraviolet illumination. Photo by Maha Tannous.

As noted in the article "Photomicrography: A 'how-to' for today's jeweler-gemologist" (1986–1987), you can get good, usable photomicrographs by purchasing a camera-to-microscope adaptor that will allow you to mount a 35 mm single-lens-reflex camera on virtually any binocular microscope. Ultimately, you determine how far you go with gemological photomicrography. When putting together a gemological photomicrographic system, it is most important to remember that there is no substitute for high-quality optics, and proper illumination is critical.

TIME, EXPOSURE TIME, AND FILM

Forget film cost and developing. *Your time* is the single most valuable asset you invest when practicing photomicrography. You should use it, and use it wisely. Take the time to clean the subject, position the stone, and select the correct illumination and adjust it appropriately. As you are beginning work in this area, the more time you spend on a photo, the fewer mistakes you will make. As you become more experienced, you will need less time, but it will always be your most important commodity.

Another time consideration in photomicrography is exposure time. While time may be a friend during sample preparation and set-up, with exposure time, shorter is always better. Long exposure times not only can increase the risk of vibration problems, but they also can affect the quality of the color captured by the film.

Exposure time is dictated by the speed of the film you use and the amount of light reaching the film. While it might be tempting to choose a faster film, it is normally better to increase the lighting on the subject, when possible. Slower films use smaller chemical grains to capture the image; exposure times are longer but images are much sharper. Faster films use larger grains that capture images more quickly, but, in general, such larger grains produce grainier photos. If a photograph is to be enlarged in any significant degree, as is usually the case with gemological photomicrographs, the sharpness of the recorded image is an important consideration. It is particularly critical with 35 mm transparencies, because of the smaller format. Likewise, for the same reasons, higher film speed equates to a lower quality of color. Between low-speed, fine-grain 64 ASA tungsten professional film and higher-speed, larger-grain 400 ASA film, you will see an obvious difference in image sharpness, color saturation, and overall richness of the photograph.

STARTING CLEAN

There is no substitute for cleanliness in photomicrography. Oily or greasy smudges on your lenses will produce fuzzy, blurred images, making it virtually impossible to obtain proper focus. Dirt particles block light

Figure 5. Items for cleaning optical equipment as well as gems, such as compressed air, a camel's-hair blower brush, cleaning fluids, a gem cloth, and lens paper, should always be kept close at hand while doing gemological photomicrography. Photo by Maha Tannous.

and can create dark artifacts or spots on photographs. Your camera, microscope, lenses, and other associated components (again, see figure 4), are precision instruments that should be treated with respect and care. They should be covered and stored safely when not in use, and you should never smoke, eat, or drink around them or any other optical equipment.

Even with proper precautions, however, lenses and other photographic equipment will still become dirty through normal use. When this occurs, cleaning requires proper procedures and equipment (figure 5). A quick "dry wipe" will damage a lens's coating and almost guarantees a scratched surface. Cleaning should begin with a blast of compressed air to remove all loose dirt particles. Any stubborn dust can be loosened with a soft camel's-hair brush, followed by another dose of compressed air. Fingerprints, nose prints, and any other greasy smudges can be removed with any of the standard quick-evaporating lens cleaners together with a lint-free lens tissue.

Dust and grease on your photographic subject will cause the same problems they cause on your lenses, so cleaning here is just as important. Even tiny dust particles on a gem can show up as bright hot spots or dark artifacts on the developed film, depending on how the subject was illuminated and the nature and diaphaneity of the "dust" itself. Oily smudges and fingerprints on the surface of the subject will diminish clarity and distort the view of a gem's interior. While wiping the stone with a clean, lint-free gem cloth is often sufficient, very oily or dirty subjects should be cleaned with water or a mild detergent, followed by a lens tissue to clean the surface. Special care should be taken first, however, to ensure that hard particulate matter is not stuck to the surface; wiping such a stone could result in scratching, since the cloth or tissue will serve as a carrier for any small, hard particles. Initial examination at about 5–10¥ with fiber-optic lighting should reveal any such material.

While care should be taken during the cleaning of any gem material, the softer the gem material the more cautious one should be. For example, a ruby with a Mohs hardness of 9 is much less susceptible to scratching than is a faceted fluorite with a Mohs hardness of 4. While both can be scratched, it is considerably more difficult to damage the ruby.

Dust can still settle on or be attracted to your subject even after cleaning, especially if you are working with troublesome dust gatherers such as tourmaline. Pyroelectric gem materials can attract new dust, especially when warmed by the illuminators commonly used in photomicrography. It is particularly important to constantly check for newly arrived dust with such stones. As when cleaning your lenses, canned air and a camel's-hair blower brush are useful; if carefully handled, a fine-point needle probe can also be used to remove small dust particles. The tools you use for routine cleaning of lenses and gemological subjects should be kept nearby while you work. It is also important to check your subject through the camera or microscope before each and every exposure to be sure an unwanted dust particle has not settled in the field of view, or to be sure that neither the lighting nor the subject has shifted position.

ILLUMINATION TECHNIQUES FOR PHOTOMICROGRAPHY

The very first "rule" of photomicrography is: Without proper illumination, you never know what you're missing. A broad collection of photomicrographic lighting accessories that greatly expand the usefulness of a gemological darkfield microscope are shown in figure 6 and described in the sections below.

While sometimes a single illumination technique will be sufficient, more often than not two or more techniques are needed to produce a high-quality gemological photomicrograph. Today, these meth-

Figure 6. This collection of lighting accessories would be found in any complete gemological photomicrographic laboratory. Shown here are a single-wand fiber-optic illuminator; a pinpoint fiber-optic illuminator with two end attachments; two Polaroid plates and a first-order red compensator; a white diffusing plate; two iris diaphragms for shadowing; two modified film cans and two black paper strips for hot spot control; and a shallow glass evaporating dish for partial immersion if needed. Photo by Maha Tannous.

ods include fiber-optic, pinpoint, light "painting," and darkfield illumination, as well as transmitted, diffused transmitted, and polarized light. Among the tools that can be used to maximize the effectiveness of the different illuminants are the first-order red compensator and shadowing. For special situations, photomicrographs may be taken using an ultraviolet unit or with the stone in immersion.

When the first *Gems & Gemology* article on "Photographing Inclusions" was published (Koivula, 1981), darkfield illumination was considered the most useful illumination technique in gemological microscopy. Over the last two decades, that designation has shifted, and fiber-optic illumination is now considered to be the single most useful form of lighting in gemology for photomicrography as well as gem identification. Certainly, darkfield illumination still has its place, especially in diamond clarity grading. Where photomicrography is concerned, however, fiber-optic illumination is without peer, and so we will start there.

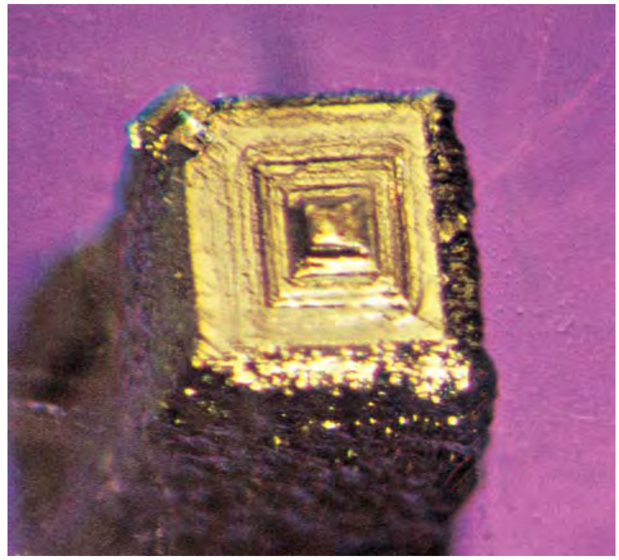
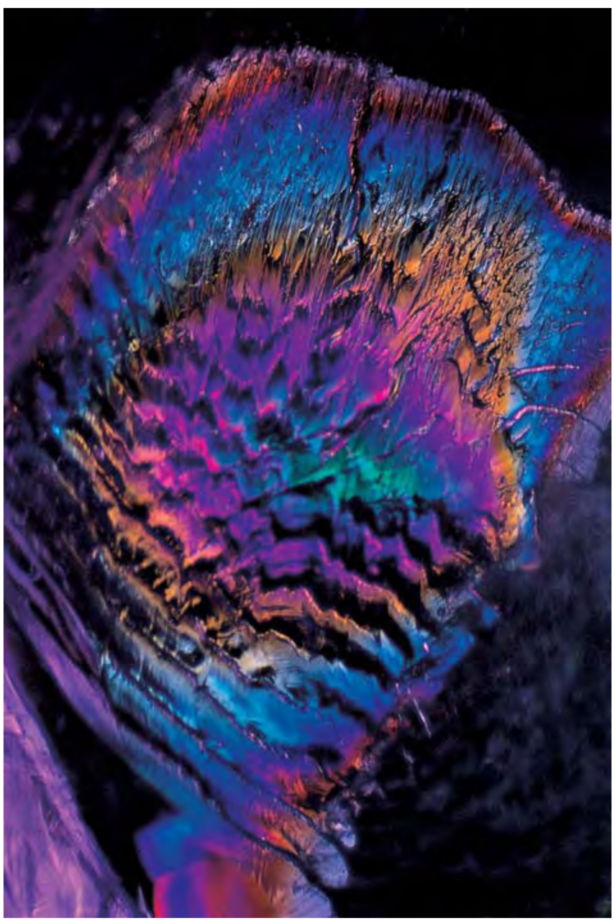


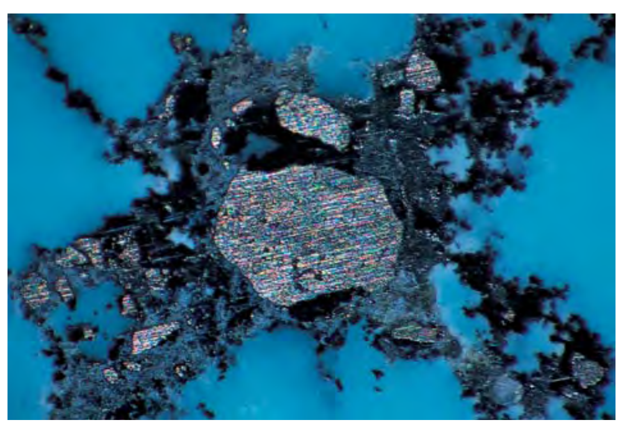
Figure 8. Fiber-optic illumination was used to highlight the surface of this pyrite crystal in fluorite, bringing out growth details that otherwise would be difficult to see. Magnified 10×.

Figure 7. This highly diagnostic "zebra stripe" fracture pattern in natural "iris" amethyst shows vibrant iridescent colors in fiber-optic illumination. Magnified 2×.



Fiber-optic Illumination. The use of fiber-optic illumination in gemology was first introduced in the late 1970s and in *Gems & Gemology* a few years later (Koivula, 1981). A fiber-optic light is not only effective in obtaining a specific effect or viewing a specific feature, but it is also versatile, in that the

Figure 9. Opaque gems, which look essentially black in darkfield, usually respond well to fiber-optic illumination. Pyrite, chalcocite, and quartz are all present in the webbing of this untreated spider-web turquoise. Magnified 10×.



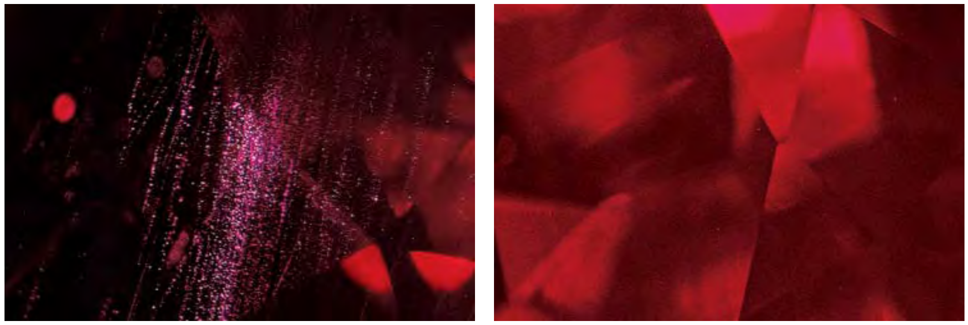


Figure 10. Fiber-optic illumination reveals the rainlike stringers of flux particles in a Kashan synthetic ruby (left). In darkfield conditions, without fiber-optic illumination, the flux "rain" in the same Kashan synthetic ruby is no longer visible (right). Magnified 15×.

object can be illuminated from virtually any angle (again, see figure 4).

Transparent, translucent, and opaque gems all respond well to fiber-optic lighting. The results can be both beautiful and informative. Fractures, cleavages, and ultra-thin fluid inclusions become decorated with vibrant iridescent colors (figure 7). Interfaces surrounding included crystals show details of growth that otherwise elude observation (figure 8), while reflecting back facets return light to the observer's eye, seemingly magnifying the intensity and the richness of color. Opaque gems, which look essentially black in darkfield, often show startling patterns and/or variations of color when explored with fiber-optic illumination (figure 9; "Fiber optic illumination. . .," 1988).

Today, it doesn't seem possible for anyone on the technical side of the gem industry to get along without a fiber-optic illumination system for their microscope. And, indeed, some microscope systems have such a system built in. At the microscopic level, there are internal characteristics in gems that you just cannot see without this form of illumination. One example is the so-called "rain" trails of tiny flux particles that are characteristic of Kashan synthetic rubies (figure 10, left), which often go undetected in darkfield alone (figure 10, right). Another startlingly clear example of the inadequacy of darkfield illumination was recently published in *Gems & Gemology* (Koivula and Tannous, 2001, p. 58). In this example, a beautiful stellate cloud of pinpoint inclusions in diamond was only visible in its diamond host with fiber-optic illumination.

Fiber optics also can be used to examine the surfaces of both rough and faceted gems for irregularities. These might include surface growth or etch features, surface-reaching cracks, or polishing lines. Scanning the surface of the stone with a fiber-optic wand is of tremendous value in the photomicrography of important details on the surfaces of gems and related materials, particularly in the detection of some surface treatments, such as the oiling of emeralds, fracture filling of diamonds, and coatings as on Aqua Aura quartz (figure 11).

If the light is too harsh, or produces too much glare, fiber-optic illumination can be controlled by placing a translucent white diffusing filter over the end of the light pipe. From experience, I have found that a translucent white film canister makes a great diffuser: Simply punch a hole in the lid and push the film canister over the end of the light pipe (again, see figure 4).

Over the years, other forms of fiber-optic illumination have been adopted for use in gemology. Two particularly important ones are pinpoint illumination and light painting.

Pinpoint Illumination. As its name suggests, pinpoint illumination is ideally suited for getting light into tight or difficult places. Pinpoint illumination (Koivula, 1982a) employs a long, very flexible light pipe with interchangeable straight and curved tips of various diameters down to a millimeter (again, see figure 6). An adaptor can be used to convert a standard fiber-optic light source to a pinpoint illuminator.

Figure 11. Details of the gold coating on the surface of an Aqua Aura quartz are clearly visible with shadowed fiber-optic illumination. Magnified 5×.

Figure 12. Pinpoint fiber-optic illumination clearly shows the rupture craters on the surface of a high-temperature heat-treated ruby (left). Without the pinpoint illuminator to highlight the surface, using only darkfield, the surface damage on the heat-treated ruby is not visible (right). Magnified 12×.

With pinpoint illumination, it is possible to highlight specific regions in or on a gem (figure 12, left) that might otherwise go unnoticed (figure 12, right), or quickly locate very small inclusions. It is also possible to effectively illuminate mounted stones no matter how complex the mounting; even those in closed-back settings are easily examined using this technique. Pinpoint fiber-optic illumination is perhaps the most versatile form of ancillary lighting available for gemologists concerned with gem identification or evaluation.

Light Painting. Light painting is a variant of pinpoint fiber-optic illumination. As with all techniques, it takes some practice to use effectively. It is also a technique that will often surprise you with its results, and it probably never can be fully mastered. In light painting, you use a pinpoint fiber-optic wand just as an artist uses a paint brush, in that you keep the wand moving and "stroke" the subject with light from various angles during the exposure cycle. It usually works best on transparent subjects, with the light directed either from below or from the side (figure 13), since the use of light painting from overhead angles will often result in hot spots. It is a supplementary technique to other forms of illumination such as darkfield and transmitted lighting, and can be helpful in reducing exposure times in low-light situations such as those encountered when using polarized or ultraviolet illumination.

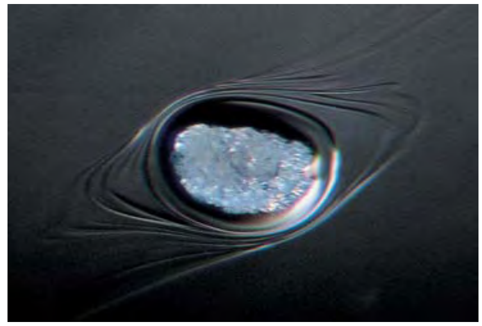
Figure 13. This image showing a comet-like sprig of rutile in quartz was created by light painting using a pinpoint fiber-optic illuminator. Magnified 10×.

Darkfield Illumination. Darkfield illumination, the method used internationally in diamond grading, is the "workhorse" of lighting techniques, the one most gemologists use for colored stones as well as diamonds. Most jewelers and appraisers rely almost entirely on darkfield illumination in their gemological work with a microscope. The primary reasons for this are twofold: Darkfield illumination as married to the gemological microscope is what is taught, and darkfield illumination is what is sold as the "built-in" illumination system on today's advanced gemological microscopes.

Even though it has been surpassed by fiber-optic illumination for gem identification and photomicrography, darkfield still remains an important illumination technique for all gemological applications, including the routine observation and photography of inclusions.

With the darkfield technique, whereby light transmitted from below is reflected around the sides of an opaque light shield by a mirror-like reflector (as illustrated in Koivula, 1981), only light that is scattered or reflected by the inclusions is seen through the microscope and captured on film. The inclusion subjects appear relatively bright against a dark background (figure 14, left). However, if darkfield is the only method employed, significant details may be missed, as shown in figure 14, right—the same image taken with shadowing (see below) in addition to darkfield. Darkfield lighting is most applicable to the study of transparent-to-

Figure 14. Darkfield illumination is designed to show inclusions brightly against a dark background. On the left, a white solid in a manufactured glass is clearly revealed. If shadowing is also used (right), the flow lines in the glass surrounding the white solid can be seen as well. Magnified 30×.



translucent included crystals, small fluid inclusions, and partially healed fissures (figure 15).

While darkfield is an excellent method for lighting the interior of diamonds for commercial grading, it is not the only method that should be applied to diamonds for comprehensive gemological investigation, because it frequently does not reveal all the details. However, when coupled with fiber-optic illumination, a darkfield system is an excellent choice for most gemological applications.

Transmitted Light. Sometimes referred to as transillumination, lightfield, or brightfield, direct (undiffused) transmitted light is produced by allowing light to pass directly up through the gem into the microscope system by removing the darkfield light shield (Koivula, 1981). Because so much of the detail normally seen with fiber-optic or darkfield illumination is lost in direct, undiffused transmitted light—darkly colored or opaque included crystals and fine growth features, for example, are virtually washed out—this method is of limited use. However, some details that are not visible with either darkfield or fiber-optic illumination, such as voids and fluid chambers, often stand out readily in a beam of direct transmitted light. Large negative crystals (figure 16) and fluid inclusions are very easily examined. Color zoning (figure 17) is also easily observed and photographed, as are some large, flat, transparent to translucent mineral inclusions (figure 18).

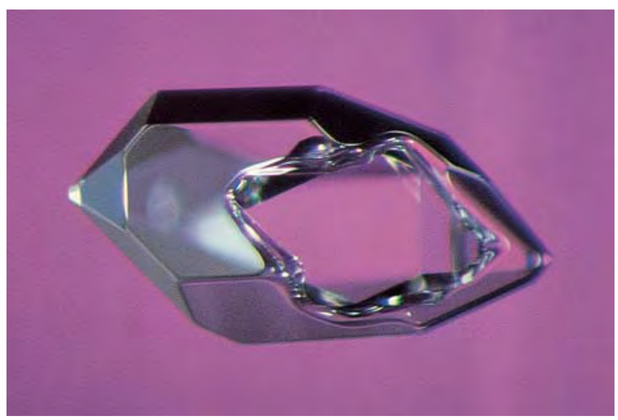
Direct, undiffused transmitted light has other advantages as well. Exposure times are at their shortest, and small dust particles on the surface of the host gem rarely show up on film, since the quantity of light washing around them tends to cancel their ability to interfere with light transmission.

Diffused Transmitted Light. Transmitted light is more useful when it is diffused by adding a translucent white filter between the light source and the subject. With such a filter, strong reflections and glare are essentially eliminated and an evenly illuminated image results.

There are basically two different ways to diffuse transmitted light. The first and most commonly used method utilizes a flat plate of translucent

Figure 15. Darkfield lighting is used to study transparent-to-translucent included crystals, small fluid inclusions, and partially healed cracks, all of which are illustrated in this image of a spessartine garnet in quartz. Magnified 3×.

Figure 16. Transmitted light was used to illuminate this relatively large negative crystal in an amethyst from Mexico. Magnified 10×.



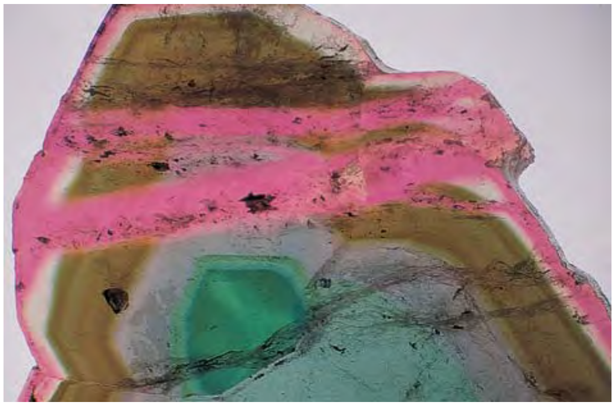


Figure 17. Elaborate color zoning in a cross-section of tourmaline is easily observed and photographed using transmitted light. Magnified 4×.

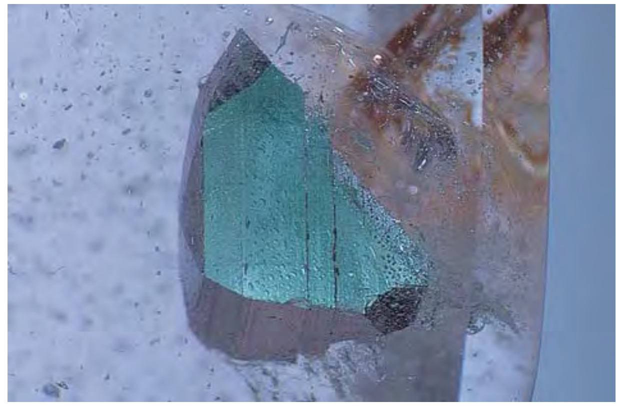


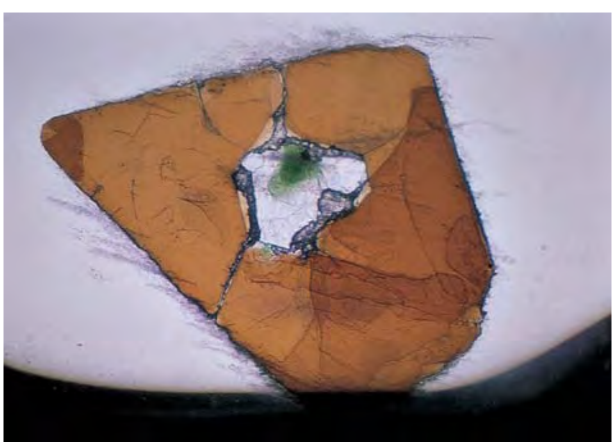
Figure 19. Diffused transmitted light is an excellent way to observe color in transparent-to-translucent mineral inclusions. The green color of this fluorite inclusion in topaz is clearly seen with this technique. Magnified 7×.

white glass or plastic that is placed over the light well of the microscope, just below the subject. High-quality diffuser plates specifically designed to fit in the opening over the well of the microscope are manufactured and sold for this purpose (again, see figure 6).

"Tenting," the second method, is achieved by enveloping the subject from below and on all sides with a custom-made light diffuser so that only diffused light enters the stone. So-called custom-made diffusers ideally suited for this purpose are easier to manufacture than it might seem. A little imagination, a sharp knife or razor blade, and some empty translucent white plastic 35 mm film canisters are all that is needed, the same type previously recommended for use on the ends of fiber-optic illuminators to diffuse their light.

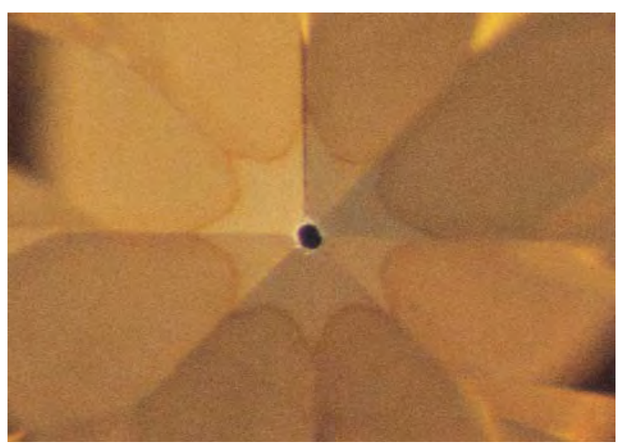
Diffused transmitted light is an excellent way to observe color in transparent-to-translucent mineral inclusions in both faceted (figure 19) and rough stones. With the addition of a polarizing analyzer over the objective lens, above the subject, it also becomes relatively easy to check for pleochroism in colorful crystal inclusions. Diffused transmitted light, particularly tenting, also makes even relatively subtle color zoning easy to observe and photograph (figure 20).

Figure 18. Using transmitted light, three generations of mica—green, colorless, and brown—are readily imaged in their Brazilian quartz host. Magnified 5×.



Polarized Light. Despite its great utility in gemology, polarized light microscopy is often neglected by gemologists, who consider it solely a mineralogist's tool (McCrone et al., 1979). Many important gem

Figure 20. Tenting, a form of diffused transmitted light, was used to resolve the relatively subtle "umbrella effect" color zoning that proves that this diamond has been cyclotron irradiated and heat treated. Magnified 20×.



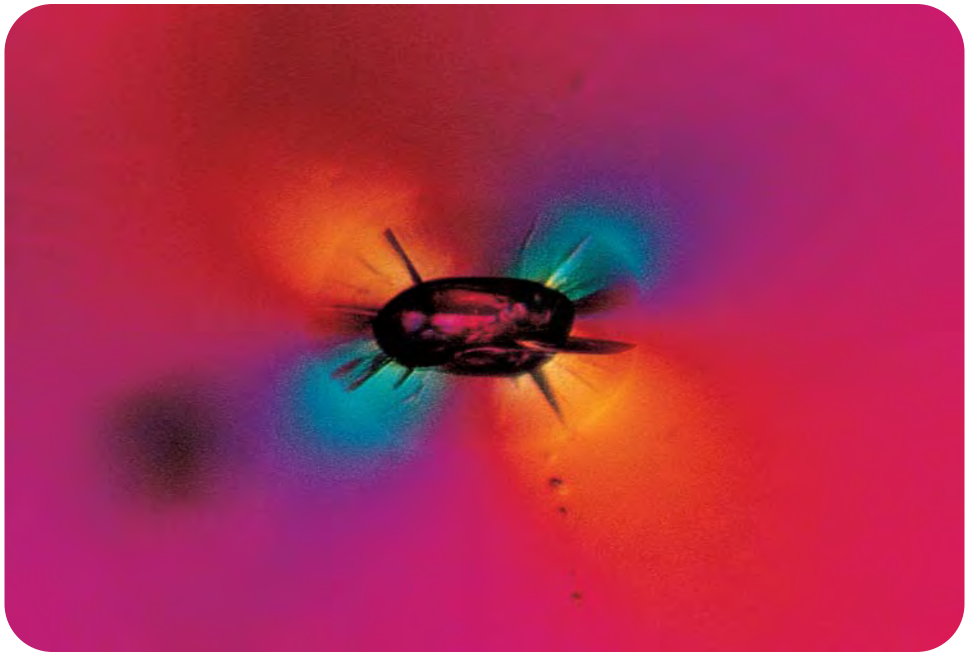


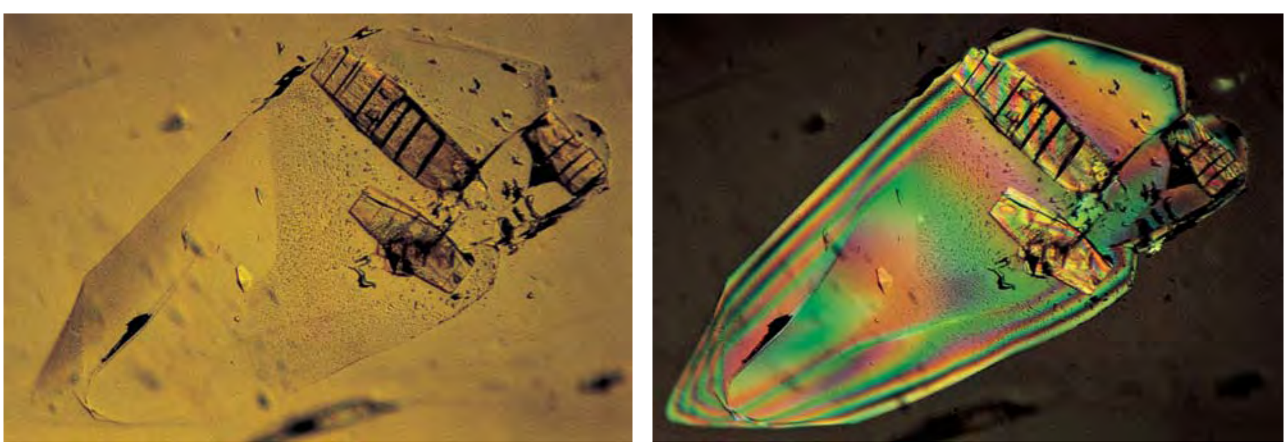
Figure 21. Internal strain around this tiny zircon crystal in a Sri Lankan spinel is made visible using polarized light. Magnified 60×.

features need polarized light for clear viewing, among them internal strain around included crystals (figure 21), crystal-intergrowth induced strain, optically active twinning, and optic figures. Included crystals of a doubly refractive material that otherwise show very low relief are easily seen in polarized light (figure 22). Especially for those employing this technique for the first time, the world of polarized light microscopy can be both startling and beautiful.

Temporarily converting a gemological microscope with transmitted light capabilities to a polarizing microscope is a very simple process. The only requirement is a pair of polarizing plates that can be placed above and below the gem subject (Koivula, 1981). However, while unprotected plastic sheet filters, with their fine scratches and slightly warped surfaces, may be adequate for routine examinations, photomicrography requires polarizing filters of good optical quality.

With the microscope's darkfield light shield removed for direct transmission of light, one plate,

Figure 22. If they are doubly refractive, mineral inclusions of very low relief will stand out readily when polarized light is used. The quartz crystal in this golden beryl (heliodor) shows low relief in transmitted light (left), because the refractive index of the inclusion is near that of the host. The mica inclusions in the included quartz crystal are more visible because they are darker. In polarized light (right), the quartz inclusion lights up with interference colors that make it clearly visible in the beryl host. Magnified 10×.



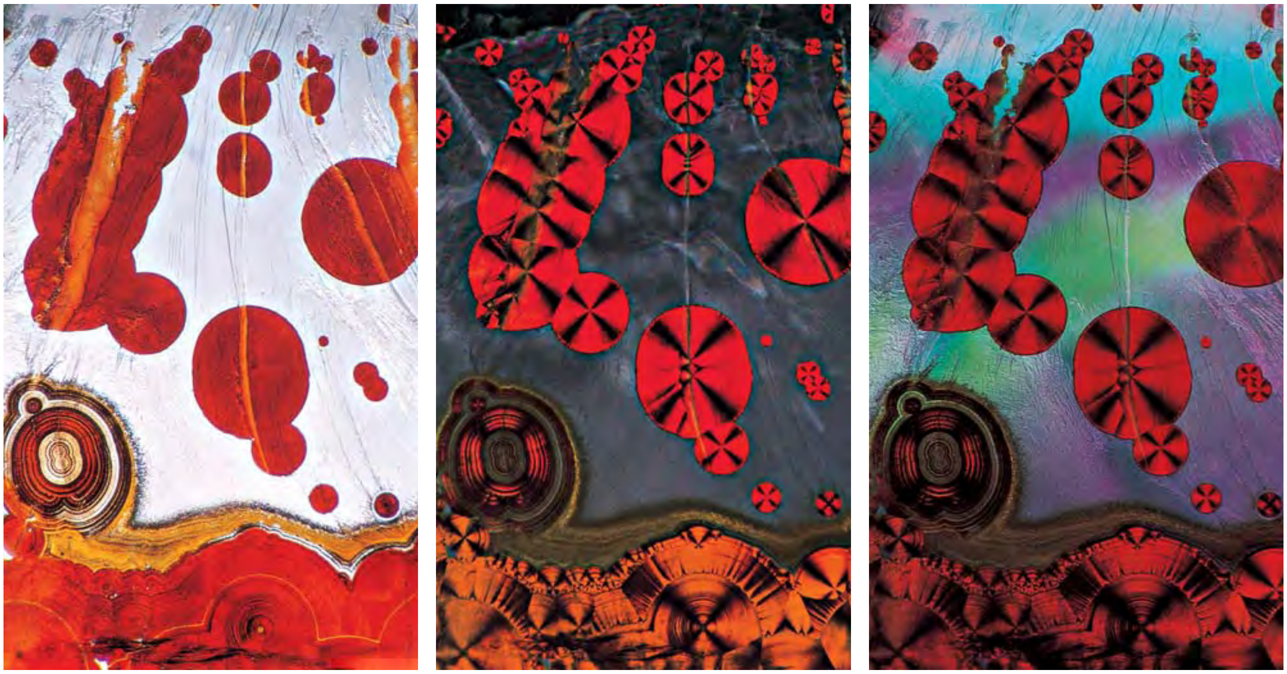


Figure 23. The first-order red compensator not only dramatically reduces the exposure times required to photograph with polarized light, but it creates some very pleasing images as well. This sequence shows epigenetic hematite radial concretions lining a fracture in quartz. The photomicrograph on the left was taken in direct transmitted light, with an exposure time of only 0.94 seconds. The center image, taken in polarized light, reveals extinction crosses in all the hematite concretions, thus showing their radial crystalline structure. The exposure time was 45.31 seconds. When the same internal scene was photographed in polarized light with a first-order red compensator (right), the extinction crosses are again present in all the hematite concretions, but the background of the quartz host has become brighter and more colorful. This was achieved with an exposure time of only 5.72 seconds. Magnified 12×.

called the *polarizer,* should be placed over the light port and under the gem subject. The other plate, called the *analyzer,* should be placed above the gem subject just below the microscope's objectives. Unlike a polariscope, where the analyzer is rotated and the polarizer remains fixed, in this set-up both plates can be rotated. In addition, if the polarizer is removed and the analyzer is rotated, images of inclusions in such strongly birefringent gems as peridot or zircon can be captured easily by clearing the otherwise strongly doubled image.

However, because the polarizing plates filter out much of the light passing through them, exposure times can be exceedingly long. This can be dealt with by using fiber-optic illumination as a supplemental source of light, or by the addition of a first-order red compensator in the light path.

First-Order Red Compensator. In most cases where low levels of light might require extremely long exposure times (e.g., due to the use of polarizers), a filter known as a *first-order red compensator* will dramatically reduce the time required, thereby diminishing the effects of vibrations on photomicrographs (Koivula, 1984). In addition, this filter will intensify low-order, dull, interference, or strain colors, making them much more vibrant.

Unlike what its name might imply, the first-order red compensator is not a red-colored filter. Instead, it is a virtually colorless laminated plastic plate that is inserted in the light path between the polarizer and the subject. When used in this fashion, it imparts a bright magenta color to the blackness, hence the name.

The use of a first-order red compensator in gemological photomicrography not only reduces exposure times dramatically, but it also creates some very pleasing images, as evident in these photomicrographs of epigenetic hematite concretions lining a fracture in quartz taken in direct transmitted light, in polarized light, and with a first-order red compensator in position (figure 23). In addition, this filter is particularly useful in revealing specific features for both gem identification and subsequent photomicrography. For example, it can be used to enhance strain colors and patterns, which is helpful in the separation of diamond from substitutes such as synthetic cubic zirconia and yttrium aluminum garnet.

Shadowing. If you have ever seen curved striae in a flame-fusion synthetic ruby, then you have used shadowing. Your microscope was probably set in darkfield mode, but it was not darkfield that made the striae visible. The basic principle behind the shadowing technique involves direct interference with the passage of light from the microscope light well, up through the subject, and into the microscope lenses. This interference causes the light to be diffracted and scattered at the edge of an opaque light shield inserted into the light path below the subject. As a result, light is transmitted into certain portions of the subject, while other areas appear to be darkened or shadowed (Koivula, 1982b). The desired effect is to increase contrast between the host and any inclusions or growth characteristics that might be present. If properly done, the invisible may become visible, and the results can be quite dramatic.

This light interference can be accomplished in a number of ways. The easiest method of shadowing is simply to "stop down" the iris diaphragm over the microscope's light well. Such a diaphragm is built into most gemological microscopes, so it is easily adapted to shadowing. While looking through the microscope, as the shadow edge approaches and the subject descends into darkness, you will see greater contrast in the image at the edge of the shadow (figure 24). Since shadowing is somewhat directionally dependent, more dramatic results can be obtained through experimentation with a variety of opaque light shields that can be inserted into the light path below the subject at various angles.

Shadowing is also useful to achieve greater contrast when examining surfaces with a fiber-optic illuminator. Contrasting color filters can be inserted or partially inserted into the light path to highlight specific features. This is relatively easy to do.

First, set up the illuminator so that the surface being examined is reflecting brightly through the microscope. Then either slowly move the illuminator so that a shadow begins to appear on the surface, or insert an opaque light shield in front of the illuminator to partially block the light. At the edge of the shadow caused by either of these two methods, the contrast of any surface irregularities—such as polishing draglines extending from surface-reaching cracks, or surface etch or growth features—will be visibly increased. It is amazing how much detail can be revealed by this simple technique. It is also distressing to realize how much visual information can be missed if the technique is never used.

Ultraviolet Illumination. I am going to start this section by pointing out that ultraviolet light is **dangerous** to your vision! If you are going to attempt ultraviolet photomicrography you **must** wear eye protection at all times. While I have taken photomicrographs using short-wave UV, I generally try to avoid this, since the potential risk increases as wavelength decreases. In my opinion, while long-wave UV also is questionable, it is preferable to short-wave UV.

With that said, ultraviolet light does have a small role in photomicrography and inclusion research (Koivula, 1981). For example, certain gem materials, such as quartz or fluorite, are transparent to ultraviolet wavelengths, but inclusions of organic fluids and fluorescent solids will be seen to glow under the influence of the ultraviolet radiation (figure 25). Structural features in some materials, such as the highly diagnostic isometric patterns in synthetic diamonds (see, e.g., Shigley et al., 1995), also can be viewed and photographed using an ultraviolet lamp. Other UV effects on specific minerals are described by Robbins (1994).

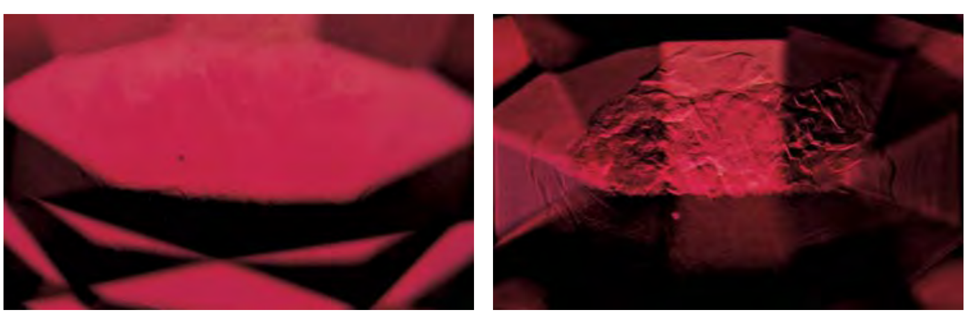


Figure 24. In darkfield illumination (left), the interior of this Seiko floating-zone refined synthetic ruby shows only a hint of its internal structure. With the shadowing technique (right), there is a dramatic change in the visibility of its roiled internal structure. Magnified 15×.

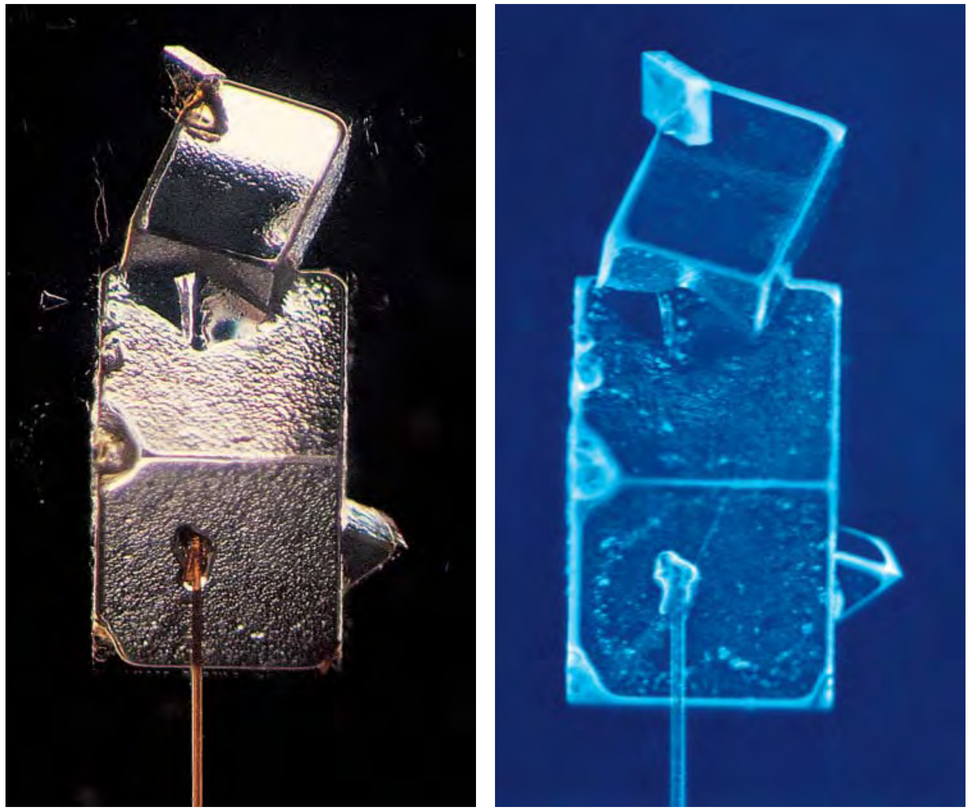


Figure 25. A combination of darkfield and fiber-optic illumination (left) reveals great detail in these calcite crystals "impaled" on a rutile needle in Brazilian quartz. With long-wave UV radiation (right), a distinctive blue luminescence is now evident, which indicates that natural petroleum is lining the surfaces of the calcite crystals and rutile needle. Magnified 20×.

Because of the low light generated by the UV lamp, ultraviolet photomicrography often requires excessively long exposure times. As with polarized light, supplemental fiber-optic illumination also can be used here to shorten the exposure time as long as it does not overpower the desired effects of the ultraviolet radiation in the photomicrograph.

To make double-sure that the message of danger is clear, let me state—once again—that when using ultraviolet illumination in gem testing you should **take extreme care to protect your eyes** from either direct or reflected exposure to the ultraviolet radiation. This is particularly true of short-wave UV. There are filters, glasses, and goggles made specifically for the purpose of UV eye protection. If you have a situation that requires such photomicrography, be sure to use at least one of these protective devices at all times.

Immersion. Total immersion in a liquid such as methylene iodide is useful for certain gem identification purposes (see, e.g., "Immersion…," 1988–89). Indeed, many gemologists have published effective photomicrographs of features seen with total immersion that are important in the identification of treatments, synthetics, and locality of origin in particular (see, e.g., Kane et al., 1990; McClure et al., 1993; Schmetzer, 1996; Smith, 1996). Nevertheless, I continue to believe, as I stated in 1981, that total immersion in a dense, heavy liquid has no place in photomicrography; the results achieved by the authors listed above using total immersion could also have been obtained using much less liquid through the technique of partial immersion. In keeping with this belief, none of the photomicrographs shown in this article were taken using total immersion.

In photomicrography, the quality of the image is lowered with every lens or other optically dense medium that is placed between the film plane and the subject (Koivula, 1981). Even today, the most commonly used immersion liquids are malodorous, toxic organic compounds that typically are colored and very dense. The most popular among these is the specific gravity liquid methylene iodide.

Not only are such liquids difficult (and potentially dangerous) to work with, but they often are light-sensitive; as a result, they may darken after brief exposure to strong lighting. In addition, filters must be used to remove microscopic dust particles that commonly contaminate the liquids, or they will appear through the microscope as "floaters" that constantly move in and out of focus. Another problem for the photomicrographer is that these

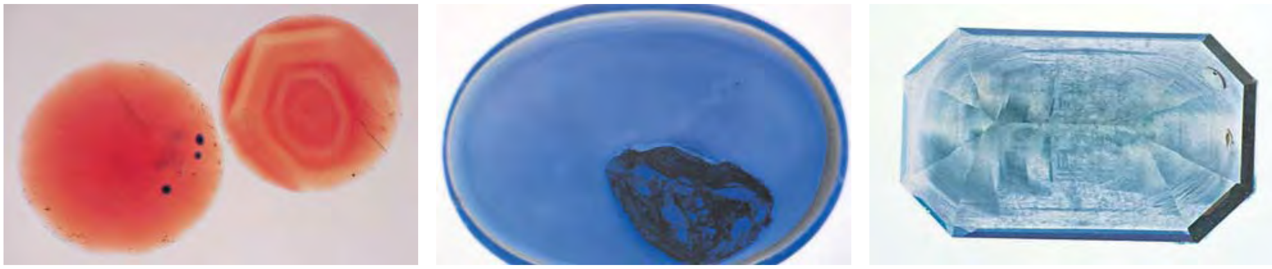


Figure 26. These three photos were all taken in an evaporating dish using partial immersion with methylene iodide and diffused transmitted light. On the left, one of the 4.2 mm bulk-diffused Madagascar sapphires shows the yellow rim indicative of beryllium treatment, whereas the other reveals alteration of the originally pink hexagonal zoning to orange and yellow. The center image details irregular spotty coloration on the surface of a 7.1-mm-long bulk-diffused blue sapphire cabochon. And the image on the right shows structurally aligned, internally diffused blue "ink spots" in an 8.6-mm-long heat-treated sapphire from Rock Creek, Montana.

dense liquids tend to have convection currents that may appear as heat wave–like swirls in the microscope and thus distort the photographed image.

Moreover, the color of the liquid usually interferes with the color of the subject matter; brown emeralds and rubies come to mind. The use of immersion to reduce facet reflections is particularly disturbing, as not only can such reflections add to the effectiveness of the photomicrograph, but the benefits to the image are usually outweighed by the reduction in quality that inevitably results from the use of an optically dense colored liquid and total immersion.

When immersion seems necessary or advantageous—and there are times when it is, such as in the detection of bulk "surface" diffusion in faceted sapphires (figure 26, left) or cabochons (figure 26, center), or in the examination of some sapphires for evidence of heat treatment (figure 26, right)—a modified immersion technique, in place of total immersion, can be very effective. This technique employs only a few drops of a refractive index liquid, such as a Cargille liquid, or a specific gravity liquid such as methylene iodide. The small amount of liquid is placed at the center of a small glass evaporating dish (again, see figure 6), which is positioned over the well of the microscope. The gem is dipped into the liquid, and, as the liquid wets the back facets of the stone, the distracting reflections from them seem to almost disappear, allowing a much clearer view of the gem's interior. The top of the stone also can be wetted simultaneously with the same liquid, as described below in the "Quick Polish" technique.

Partial immersion has several advantages over total immersion. Only a very small amount of liquid is needed, so the effects of the liquid's color and density currents on image quality are minimized. In addition, clean up is very easy, and the strong odors that are so prevalent during total immersion are greatly reduced.

QUICK POLISH

Sometimes, whether one is dealing with a rough crystal, a water-worn stone, a soft gem, or just a badly worn gemstone, the surface of the subject may be too scratched or poorly polished to allow a clear image of the interior (figure 27, left). Rather than taking the drastic—and destructive—step of (re)polishing the material, a modified immersion technique known as a "quick polish" can work very effectively. Simply by spreading on the stone a small drop of refractive index fluid with an R.I. close to that of the gem material, the scratches and other interfering surface characteristics can be made effectively transparent, allowing a clear view of the gem's interior (figure 27, right).

Unlike total (or even partial) immersion, this method uses so little R.I. fluid that any effects on image quality (such as fluid color and density currents) are negligible, and clean up and the unpleasant odors of R.I. fluid are minimized. In addition, it allows back-facet reflection where necessary to highlight inclusions. Finally, regardless of the stone's surface condition, this method can aid in locating (and photographing) optic figures in anisotropic gemstones, without having to resort to total immersion.

CONTROLLING HOT SPOTS

"Hot spots" are areas of such intense brightness that it is impossible to balance the lighting for photography. When hot spots are present, the image produced of the desired area will either be too dark or "burned out" (i.e., over-exposed) from the brightness. Neither is desirable. In such situations, it is important to eliminate the effect of hot spots by learning to control them.

There are basically two methods for controlling hot spots. The first is illustrated in figure 28. In the image on the left in figure 28, a hot spot is visible in the form of a bright, distracting facet reflection. In the image on the right, the hot spot is gone. To eliminate the hot spot, the stone was rotated or tilted slightly, causing the reflection to disappear. This method is not always successful, though, as the movement of the stone often causes other hot spots to appear.

The second and more effective method of controlling hot spots is based on the recognition that if you see a hot spot in your field of view, it has to be caused by one of your light sources. If the 360° darkfield light ring is causing the problem, you know that the hot spot has to be produced somewhere around that ring of light. To block the hot spot, simply take a thin strip of opaque black paper (about half an inch [1.25 cm] wide) and bend it so a section can hang over the edge of the light well to block a portion of the light from the microscope's darkfield light ring. Then, while looking through the microscope, just move the opaque paper strip around the ring until the hot spot disappears (figure 29). Using this method, you do not have to move the stone at all. Compare figure 28 (left) to figure 29 and you will see that, with the exception of the hot spot reflection from the facet in figure 28, the position of the inclusions is identical.

The same means of hot spot control can be used on a fiber-optic illuminator, if that is the cause of the hot spot in the field of view. This can be done by sliding an opaque light shield in front of the fiber-optic light source so it blocks half of the light coming from the light pipe. Then, while looking through the microscope, slowly rotate the light shield. At some point in the 360° degree rotation of the light shield in front of the light pipe, the hot spot will disappear, or at least be greatly reduced in intensity. A simple fiber-optic light shield for blocking hot spots can be manufactured from a film canister. There are two types you can construct (figure 30). The translucent white light shield provides diffused fiber-optic illumination, while the one constructed from an opaque black film canister provides intense direct fiber-optic illumination.

Angle of Illumination. Just because you see something when a gemological subject is illuminated from one direction does not mean that you won't see an entirely different scene if you illuminate it from another direction. This is dramatically illustrated by the fern-like pattern in an opal from Virgin Valley, Nevada, that is shown in figure 31. In one orientation of the fiber-optic light, the main body of the opal is a pale blue-green while the fern pattern is dark gray to black. By simply moving the light to the opposite side of the opal, the fern pattern now appears vivid green while the surrounding opal has darkened considerably.

A slightly less dramatic but equally important illustration of proper illumination angle in gemology and

Figure 27. Holding a soldier and a worker termite captive, this copal from Madagascar is badly scratched, which drastically affects the quality of the image (left). However, spreading a droplet of sesame oil (R.I. 1.47) over the surface creates a "quick polish" on the copal, so the termites can be photographed clearly (right). Magnified 5×.

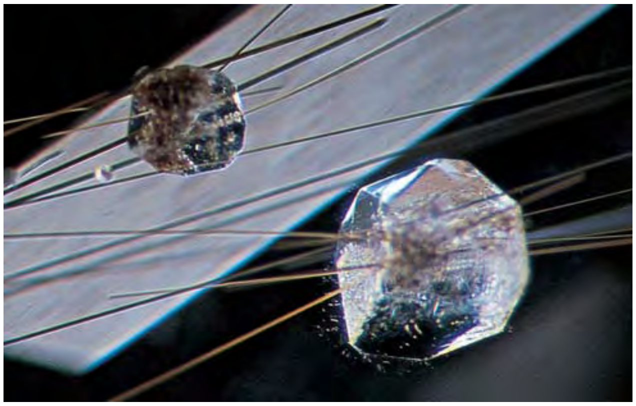


Figure 28. A facet-reflection "hot spot" distracts from the calcite and rutile inclusions in quartz visible in the photo on the left. By slightly tilting the quartz, the hot spot is eliminated (right). This does not always work, however, as the movement often causes new hot spots to appear in other areas of the stone. Notice also that the two images are no longer an exact match in the positioning of the inclusions. Magnified 15×.

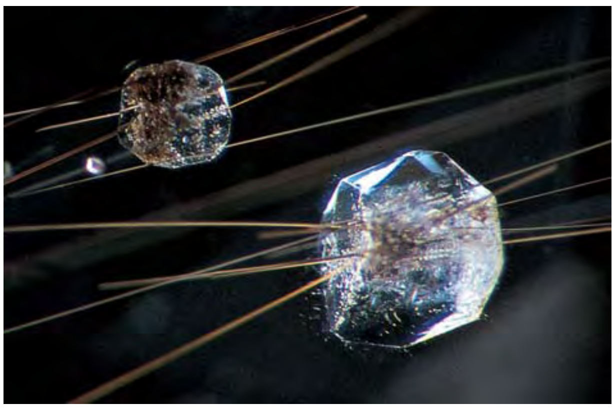


Figure 29. An even more effective method of controlling hot spots is to block the light source rather than moving the subject. This is done by placing a thin strip of opaque black paper in front of the area of the light that is producing the hot spot. Compare this image to the one on the left in figure 28 (with the hot spot): The position of the inclusions in this photo is an exact match. Magnified 15×.

Figure 30. Simple light shields for blocking hot spots produced by fiber-optic illuminators can be manufactured from plastic film canisters. The translucent white light shield provides diffused fiber-optic illumination, while the one constructed from an opaque black film canister provides intense direct fiber-optic lighting. Photo by Maha Tannous.

photomicrography is found in the sequence shown in figure 32. In this sequence, the angle of illumination is changed by moving the stone, rather than the light source. In the image on the left, a filled crack in an emerald is virtually invisible in darkfield illumination when viewed parallel to its plane. As the stone is tilted slightly, the air trapped inside the filler becomes visible (center image). Tilting the stone only a little further causes the reflection from the trapped air in the filled crack to virtually disappear again (image on the right). There is only a shallow angle of clear visibility in the detection of this filled crack, which shows that angle of illumination is very important.

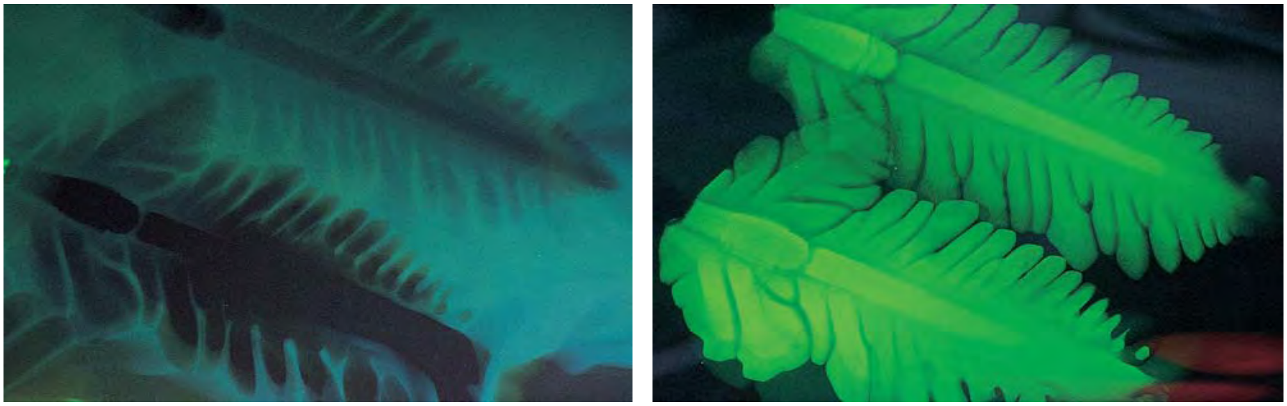


Figure 31. This pair of photomicrographs dramatically illustrates how important angle of illumination can be. In the fiber-optic image on the left, the fern-like pattern in an opal from Virgin Valley, Nevada, is dark while the main body of the opal is a pale blue-green. By simply moving the fiber-optic light to the opposite side of the opal (right), the fern pattern now appears as a vivid green while the surrounding opal is dark. Magnified 4×.

Focus and Problem Detection. If illumination is handled properly, then the best possible focus, coupled with the maximum depth of field, will usually give the best photomicrograph. An example of a photomicrograph with the main subjects clearly in focus is shown in figure 33 (left), a group of blue apatite inclusions in quartz.

If an image appears to be poorly focused, and is not as sharp as you expected it to be, it is important to identify whether the problem is a question of focus or vibration. If it is a focus problem, then some areas within the photograph will be in sharp focus, even if your desired subject is not (see, e.g., figure 33, center). If it is a vibration problem, then there will be no sharply focused areas in the image and all edges and details will appear blurred (figure 33, right).

CONCLUSION

Just because you don't see it, doesn't mean it isn't there.

This short sentence is an excellent summation of why proper illumination is so important to gemology in general and photomicrography in particular. For the photomicrographer interested in producing high-quality gemological images, there are no short cuts where illumination is concerned. Properly identified and catalogued (recording, for example, the magnification, lighting techniques employed, type of gem, origin locality if known, the identity of the inclusion, and how the identity was established), photomicrographs can help the gemologist in the routine identification of gems and whether they are natural, treated, synthetic, or imitation. They can even help "fingerprint" a specific

Figure 32. Another illustration of the importance of illumination angle is found in this darkfield sequence of three photomicrographs, each of which represents a slight tilting of the emerald relative to the light. In the image on the left, a filled crack is virtually invisible when viewed parallel to its plane. In the center view, as the stone is slightly tilted the air trapped inside the filler becomes visible, revealing the presence of the filling itself. Tilting the emerald only a little further causes the reflection from the trapped air in the filled crack to virtually disappear again. Magnified 15×.

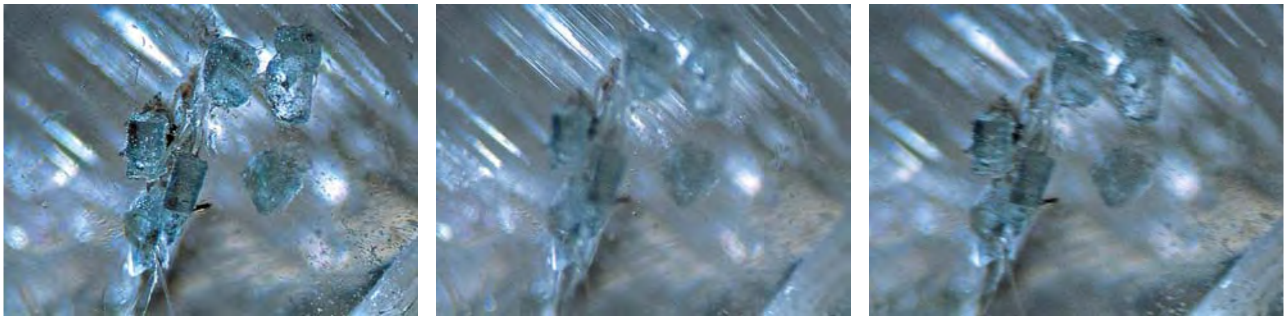


Figure 33. This well-focused photomicrograph (left) shows a cluster of light blue apatite inclusions clearly in focus in their host quartz. In the center image, the apatite inclusions are not in focus, but some of the background clearly is. This must, therefore, be a focus problem. In the view of the same scene on the far right, nothing is in focus. Therefore, this is probably a vibration problem. Magnified 25×.

stone, providing extremely valuable proof of provenance should legal problems arise.

That the photomicrograph may also be beautiful is an added benefit.

The three most important factors to remember are knowledge of your subject, quality of your equipment, and proper illumination. The two most valuable commodities in your possession as a gemological photomicrographer are time and imagination. Use them wisely.

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Mr. Koivula is chief research gemologist at the GIA Gem Trade Laboratory in Carlsbad, California.

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and a pavilion of chalcedony to simulate cat's-eye aquamarine; and doublets manufactured by cementing a rock crystal crown to an orthoclase feldspar pavilion to imitate the adularescence of moonstone. *MT*

Research on the growth habit of hydrothermal emerald crystal. Z. Chen, J. Zheg, W. Zhong, and H. Shen, *Journal of Synthetic Crystals*, Vol. 31, No. 2, 2002, pp. 94–98 [in Chinese with English abstract].

The results of a study on the variables (e.g., growth rate, shape, and orientation of seed crystals) that determine the morphology of hydrothermal synthetic emerald crystals grown by a major producer in Guilin, China, are reported. Spherical (6 mm diameter) and platy seed crystals cut from natural beryl crystals were used, and the syntheses were conducted at 500–600°C and 1.5–2.0 kbar in an autoclave for periods of 3, 6, and 9 days. The hydrothermal solutions contained $Al(OH)_3$ (16%–19%), SiO_2 (63%–67%), Cr_2O_3 (1%–3%), and BeO (13%–15%). Spherical seed crystals were used to determine the development sequence of the various crystal faces during crystal growth, while platy seed crystals with various orientations were used to obtain synthetic emerald crystals that gave the highest yield of gem-quality material.

All the crystal faces that occur on natural emerald crystals were observed on the hydrothermal synthetic emerald crystals (e.g., prisms m $\{10\bar{1}0\}$ and a $\{11\bar{2}0\}$, and basal faces c $\{0001\}$). Also observed were t $\{50\bar{5}1\}$ dipyramidal faces, which are not found on natural emerald crystals. The growth rates of the m and a prism faces were very similar. The growth rates of three dipyramidal faces decreased in a sequence of $u\ \{20\bar{2}1\} \rightarrow s\ \{11\bar{2}1\} \rightarrow p\ \{10\bar{1}1\}$. The basal faces c were always present during the growth process. The growth rates of the main faces increased in the sequence $m \rightarrow c \rightarrow p \rightarrow a \rightarrow s \rightarrow u$. The highest yield (23%–26%) of gem-quality material was obtained when platy seed plates were inclined 20°–25° to the c-axis of the synthetic crystals. Both platy and columnar synthetic emerald crystals were grown. *TL*

A review of developments in shaped crystal growth of sapphire by the Stepanov and related techniques. P. I. Antonov and V. N. Kurlov, *Progress in Crystal Growth and Characterization of Materials*, Vol. 44, No. 2, 2002, pp. 63–122.

The Stepanov method is a specialized technique for growing crystals from a melt. Compared to other melt processes, such as the Czochralski or "pulling" method, its major advantage is that the shape (cross-section) of a crystal can be gradually changed during growth. The basic requirement is that a melt column with a defined shape be formed, which is accomplished with the aid of a special "shaper." Liquid melt columns with various shapes can be made by properly applying a high-frequency electromagnetic field.

Since the initial work by Stepanov in 1938, progress in developing the method has proceeded along two lines: (1) development of technology for producing single crystals of a desired shape, and (2) understanding the physical phenomena involved in the formation of the shaped crystals. Synthetic sapphire crystals with various defined shapes, primarily for industrial use, have been successfully grown using this technique. For example, synthetic sapphire tubes up to 85 mm in diameter and ribbons 120 mm wide have been grown and used for their optical properties. Sapphire rods with various shapes have also been grown. Microvoids and gas bubbles are the main defects found in such crystals. *TL*

Solubility of emerald in H_2SO_4 aqueous solution under hydrothermal conditions. Z. Chen, G. Zhang, H. Shen, and C. Huang, *Journal of Crystal Growth*, Vol. 244, No. 3–4, 2002, pp. 339–341.

Hydrothermal synthetic emeralds have been grown traditionally from NH_4F, NH_4OH, NH_4Cl, and HCl solutions. This article reports the growth of good-quality synthetic emerald crystals from 1.1 mol H_2SO_4 solutions, using synthetic emerald seed crystals. Experimental conditions are: T=500–600°C; P=1.5–2.0 kbar; autoclaves ~60% full. These temperatures and pressures are relatively low compared to those used in growing synthetic emeralds from an HCl solution. *CT*

Some aspects of precious opal synthesis. S. V. Filin, A. I. Puzynin, and V. N. Samoilov, *Australian Gemmologist*, Vol. 21, No. 7, 2002, pp. 278–282.

The development of the method and the basic steps involved in synthesizing pure silica opal at the Center for Applied Research in Dubna, Russia, are outlined. This process involves four stages: (1) synthesis of monodisperse particles of silica in alcohol-based sols; (2) precipitation of a "raw" opal precursor by spontaneous sedimentation or centrifuging; (3) drying of the precursor opal to remove liquid from its pores; and (4) filling these pores with silica gel, and then sintering the samples at 825°C. The physical, chemical, and gemological properties of synthetic opal produced by this method are reported as identical to those of natural opal. The total time involved in the synthesis is around 10 months, which the authors compare to that of Gilson (12+ months) and Chatham (about 18 months). *RAH*

TREATMENTS

Black diamond treatment by "internal" graphitization. F. Notari, *Revue de Gemmologie*, No. 145/146, 2002, pp. 42–60 [in French with English abstract].

In the last three years, large quantities of treated black diamonds (with their color resulting from internal graphitization) have appeared on the market. The graphitization is induced in four ways, all of which require the application of heat to low-quality diamonds that have a large number of fractures and cavities, so the heat-induced graphites can be isolated from oxygen. Two of the methods apply heat to rough and cut diamonds under various conditions of pressure and environment. In the third method, small cut stones develop graphitic products as a result of the high temperatures induced during fashioning. The fourth method subjects larger diamonds to ion beam techniques, usually accompanied by heating. All these processes may produce glassy deposits in fractures and cavities on the diamonds, as well as synthetic carbons, frequently as films, on the surface.

These treatments can be identified by conventional microscopy combined with strong lighting or luminescence. Raman spectrometry is helpful in identifying the different types of carbon in these diamonds. Diamonds with graphite on the surface can be recognized with the aid of a thermal-type diamond tester. *MT*

Change of colour produced in natural brown diamonds by HPHT-processing. V. G. Vins, *Proceedings of the Russian Mineralogical Society*, Vol. 131, No. 4, 2002, pp. 111–117 [in Russian with English abstract].

The change in color produced by high pressure–high temperature (HPHT) processing of natural brown diamonds at 5.0–6.0 GPa and 2,100–2,300 K has been investigated by absorption spectroscopy in the UV, visible, and IR ranges. Such treatment of type IIa brown diamonds makes them colorless, but occasionally they acquire a light pink color. Type Ia brown diamonds change to bright yellow-green of various tints. The depth of color, as well as the relative strength of the yellow and green hues, depends on the absorption intensity of N3, H4, H3, and H2 nitrogen-vacancy centers formed during the HPHT treatment. It is concluded that annealing of plastic deformation takes place during the HPHT treatment and thus the density of dislocations decreases. The energy activating the dislocation movement via plastic deformation is 6.4 eV. Models of the color-center transformations are discussed, and color photos of diamonds faceted after HPHT processing are presented. *RAH*

Change of colour produced in synthetic diamonds by bHT-processing. V. Vins, *Gemological Bulletin (Gemological Society of Russia)*, No. 5, 2002, pp. 26–32.

Changes in types IIa and Ib, and subtypes IaB and IbA, synthetic diamonds on bHT-processing (exposure to fast-electron irradiation and subsequent high-temperature annealing) are described. Some observations about synthetic diamonds subjected to this treatment include: A lower growth rate results in fewer impurity defects; synthetic diamonds grown at various temperatures display different optically active defects, including color centers; an increase in growth temperature results in a gradual change of the synthetic diamond type (Ib → IaB → IbA → IaA) and sharp color zoning in the synthetic diamond crystal; nitrogen–nickel–vacancy defect formation (and sometimes resultant photoluminescence) may be induced in synthetic diamonds by HPHT processing.

[*Editor's note:* An earlier paper on βHT-processing of natural diamonds by the same author, including details of the process, was abstracted in Fall 2002 *Gems & Gemology*, p. 288.] *CT*

Investigation of radiation-induced yellow color in tourmaline by magnetic resonance. K. Krambrock, M. V. B. Pinheiro, S. M. Medeiros, K. J. Guedes, S. Schweizer, and J.-M. Spaeth, *Nuclear Instruments and Methods in Physics Research B*, Vol. 191, No. 1–4, 2002, pp. 241–245.

The cause of the yellow color produced by γ-irradiation of colorless Li-bearing tourmaline (elbaite) from Minas Gerais, Brazil, was determined by electron paramagnetic resonance (EPR) and electron nuclear double resonance (ENDOR) techniques.

Two paramagnetic centers (I and II) are present. Center II is identified as an H^0 electron trap. The identification of center I is not as direct and is proposed to be an Al–O^-–Al hole trap. Both centers are stable up to 250°C. It is suggested that the O^- hole trap is responsible for the yellow color, with an optical absorption band centered around 3.4 eV and a tail extending into the visible range of the spectrum. *AI*

MISCELLANEOUS

Closing the gender gap. R. Bates, *JCK*, Vol. 173, No. 8, 2002, pp. 65–66.

It is ironic that even though most of the products of the jewelry trade are bought and worn by women, the industry is dominated by men. However, this is changing. Women have a large and growing presence in certain sectors of the industry, namely retail, design and fashion, and public relations. Conversely, men dominate the watch, gemstone, and manufacturing sectors, and there is relatively little female involvement in the diamond trade, which is the most tradition-bound branch of the industry.

Much of the credit for the increased visibility and advancement of women in the jewelry trade deservedly goes to the Women's Jewelry Association (WJA). It was organized in the early 1980s mainly to give women a place to network but also as a response, in part, to the fact that other organizations in the industry were male dominated. WJA has since grown to more than 1,000 members and now welcomes men as full-fledged members.

Even with recent advances, some feel that the trade is still significantly behind the times when it comes to gender equality. But the once-homogenous (i.e., overwhelmingly male) industry is moving inexorably forward with respect to gender issues. Recent demographics show that more women are interested in entering the trade than men; for example, 60% of the resident students at GIA are women. Eventually this will result in a closing of the gender gap, as it has in many other industries and professions where ability and performance are the main criteria for success.

AAL