Treated and synthetic gem materials

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Both treated and synthetic gem materials are encountered today in the jewellery marketplace. In some cases, they can exhibit appearances that correspond closely to those of valuable natural gemstones. Although often displaying distinctive gemological characteristics, some treated and synthetic gem materials can be difficult for jewellers to identify, especially if they lack gemological training or access to standard gem-testing methods and equipment. In such instances, testing at a gemological laboratory is necessary, and may require the use of advanced analytical equipment. The goal of most current gemological research is to provide practical means of gem identification for jewellers and gemologists to help insure the integrity of the international gemstone market.

GEMS have been objects of desire and admiration in almost all cultures throughout human history. They are often associated with the concept of a gift of love or respect from one person to another. They are also connected to royalty and privilege. Unfortunately, gemstones are sometimes associated with more negative aspects of human nature as well.

Natural gemstones such as diamond, ruby, emerald, sapphire and pearl have for long had significant monetary value. They and other gemstones have achieved this status by possessing the desirable attributes of beauty, rarity, durability, portability, as well as the transient appeal of fashion at certain times and places. These attributes have contributed to the popularity of gemstones that has continued since ancient times.

Although new occurrences of natural gemstones are found from time to time in various parts of the world, the availability of the best quality gemstones does not always meet the current growing demand among jewellery-buying consumers. Besides the small percentage of high-quality gem material produced at a given mining locality, there is recovered a much larger percentage of lower-quality material (with poorer colour and/or clarity) that has little market value. Therefore, researchers strive to develop methods to treat lower-quality gem materials to enhance their appearance and hence their saleability in the jewellery marketplace.

The limited availability and significant cost of high-quality natural gemstones means that their potential use for other applications, such as in advanced technology, is also restricted. Thus, by taking advantage of current knowledge of crystal growth methods, efforts have been made by materials scientists to produce a number of synthetic gem materials in the laboratory for industrial and jewellery uses. Except for gems with a complex chemical composition (good examples are tanzanite and tourmaline), most important gemstones, including synthetic diamond, ruby, sapphire, emerald, spinel, opal, alexandrite and amethyst have been synthesized by various techniques, beginning with the synthesis of ruby a century ago.

In the cases of both treated and synthetic gem materials, information on the treatment and synthesis methods used may not be widely disseminated in the jewellery trade. This ignorance is often compounded by a lack of knowledge, among both jewellers and consumers, of developments in modern science and technology that could impact the jewellery industry. Even trained gemological researchers sometimes find themselves unable to identify a new treated or synthetic gem material.

The purpose of this article is to briefly review the kinds of treated and synthetic gem materials available today in the jewellery trade. This review is based upon examination of thousands of gems of all kinds that are submitted to the GIA Gem Trade Laboratory for identification reports, as well as our knowledge at GIA of the gem treatment and synthesis methods in use. Both standard and advanced techniques available for identifying gems are discussed. Also mentioned are some of the legal and ethical requirements for jewellers to disclose accurate information on the gemstones that they sell to consumers. Finally, some thoughts are presented on the ongoing challenge of gem identification, and on current important areas of gemological research.

The information of gem treatment and synthesis can only be briefly summarized here, and except for a few examples, the identification of particular kinds of treated and synthetic gem materials is not discussed because of the wide variety of materials involved. Standard gemological references and journals provide detailed information on the distinctive characteristics that distinguish various treated and synthetic gem materials from natural gemstones. Although it is not possible to cite specific references in this review article, a list of several useful textbooks and of some important gemological journals is provided at the end of the article for the interested reader.

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Gem treatment

The treatment of gemstones by various means to improve their appearance extends in some cases back to thousands of years. Prior to modern times, the availability of treated gem materials was restricted, and knowledge of them was not widely known. Correct information on all gemstones was quite limited, and that which was available was in part folklore. Accurate knowledge about gemology and natural gemstones accompanied the development of the science of mineralogy beginning in the 1800s. The past century witnessed growth of gem treatment in terms of new and sophisticated techniques utilized on a widening range of gem materials.

As shown in Table 1, the various gem treatment methods currently in use can be grouped into two general categories – methods to change colour, and methods to change clarity. Not all treatment methods are obviously appropriate for every gemstone. The costs of the starting material and the treatment method itself, versus the value of the resulting treated materials, are also significant factors in determining if a particular treatment method will be used. An assessment of the relative abundance in the jewellery trade of treated diamonds, coloured stones and pearls is included in Table 1 (i.e. relatively common or rare occurrence). This assessment is based on published information in the gemological and jewellery trade literature, conversations with individuals involved with treating gems and upon our experience with what is seen in the marketplace.

In general, the most widespread treatment methods, especially for coloured gemstones, involve a change in colour (to either darken or lighten a colour hue, or a change in colour hue; see Figure 1). Two methods in this category, exposure to heat and/or radiation, are similar to processes that can affect natural gemstones in the earth, and as a result, these methods can sometimes produce similar colour-change effects as one could encounter in natural gemstones. The correspondence between natural processes and some laboratory treatments greatly complicates the problem for the gemologist to distinguish certain natural-colour from treated-colour gemstones. For example, both heat-treated corundum (blue sapphire treated from pale-coloured 'geuda' corundum, and red ruby from lower quality ruby) and heat-treated beryl (blue aquamarine from blue-green beryl) are routinely seen in the jewellery trade. Radiation exposure is used to produce treated green-to-blue diamond (further changed to yellow-to-orange colours by heating), blue topaz (from brown topaz) and to a lesser extent, pink or red tourmaline (from pale-pink tourmaline). In the case of treated blue sapphire,

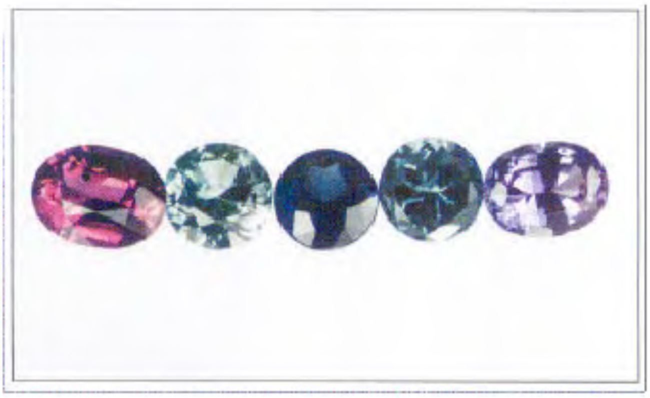

Figure 1. Examples of five treated coloured stones (the colours of these items before treatment are listed in parentheses after each one). From left to right, these include irradiated red tourmaline (pink), heated light blue zircon (reddish brown), heated blue sapphire (colorless to light blue), irradiated blue topaz (colorless to brown), and heated bluish-violet tanzanite (brown). These items range in weight from 1.02 to 1.29 carats. Photograph by Maha Tannous, copyright GIA.

Table 1. Treated gem materials*

	Gem material (gem varieties)									
	Diamond	Beryl (emerald, aquamarine)	Chrysoberyl (alexandrite)	Corundum (sapphire, ruby)	Jade (jadeite, nephrite)	Opal	Quartz (rock crystal, amethys, citrine)	Topaz	Tourmaline	Pearl
Methods to change colour										
Radiation exposure	R	R		R			C	C	R	R
Heat exposure	R	C		C			C	C	R	
Chemical bleaching					C					C
Surface coating	R	R		R	C			R		C
Dyeing		R		R	R	R	R	R		C
Surface colour diffusion				R			R	R		
Heating at high pressure	R									
Methods to change clarity										
Filling cracks/cavities	C	C	R	R					R	
Remove inclusions	R			R						
Laser drill inclusions	C									
Quench crackling				R			R			
Impregnation					C	R				

*This table lists the major kinds of treated gem materials seen in the jewellery trade. For each gem material, the extent of occurrence relative to other treated gem materials is shown by C (common occurrence) or R (rare occurrence).

topaz, and aquamarine, the widespread extent of treatment and the frequent absence of distinctive identifying features, mean that gemologists often just assume that these gem materials are laboratory-treated unless they have specific information that the gems are natural-colour.

Gems treated by the remaining methods to change their colour, (i.e. surface coating, dyeing and surface diffusion) are less frequently encountered in the marketplace. An important exception is treated jade (either jadeite or actinolite variety nephrite). When manufactured, jade is often chemically bleached to remove unattractive brownish staining or other surface contaminants, and then it is surface-coated with wax or other materials to fill cavities and to improve its appearance (some treated jade is also dyed to improve its colour). Pearls can also be bleached with chemicals to remove unwanted staining, and then coated or dyed to improve their luster or colour. Irradiated cultured pearls are also available. Faceted, light-coloured sapphires and rubies are sometimes treated with colouring agents diffused into their surfaces to darken their blue or red colours; this is referred to as diffusion treatment.

Some gemstones must be treated to improve clarity to increase the possibility of their sale. Lower-clarity polished diamonds can be treated with special, high-refractive index glasses to fill surface-reaching cracks, making these filled fractures much less visible, and thus improving the apparent clarity of the diamond. A percentage of diamonds also contain dark-coloured mineral inclusions; lasers are used to create a channel from the surface of the diamond to the inclusion, so that acids can be introduced through the channel to dissolve or lighten the inclusion, thereby lessening its negative effect on the clarity.

Due to their conditions of formation, many natural emeralds also contain surface-reaching cracks that make them look less attractive when they are faceted. These open fractures can be filled with a wide variety of liquids or melted solids (i.e. oils, resins, and on occasion green dyes), again to minimize the visibility of the fractures. Unfortunately, the filling materials used for diamonds and emeralds are not always stable or durable to jewellery manufacture or repair conditions, which can damage gem materials treated in this way. In the case of treated emeralds, laboratories that test gemstones are increasingly called upon to not only identify whether a particular emerald has been treated, but to try to identify the filling material itself because of concerns about durability.

Gem synthesis

Although there were a few early efforts, successful gem synthesis began in the late 1800s with the growth of synthetic ruby by the flame-fusion (or Verneuil) method. The need for various high-quality crystals for a range of industrial applications (i.e. optics components, laser crystals and other uses), and the increased knowledge of crystal growth mechanisms, have since combined to yield the production of a wide variety of crystals, some of which are synthetic counterparts of natural gemstones. A synthetic gem material has the same chemical composition and crystal structure as a natural gem mineral. In contrast, a gem simulant or imitation has the appearance of a natural gemstone, but has a different chemical composition, physical properties, and crystal structure. Both synthetic and simulant gem materials almost always possess gemological properties that allow them to be distinguished from the corresponding natural gemstones.

As shown in Table 2, current methods used for gem synthesis fall into two general categories: crystallization from a fluid of different composition (such as a flux or

Table 2. Synthetic gem materials*

	Gem material (gem varieties)						
	Diamond	Beryl (emerald, aquamarine, red beryl)	Chrysoberyl (alexandrite)	Corundum (sapphire, ruby)	Opal	Quartz (rock crystal, amethyst, citrine)	Spinel
Solution methods							
Low-temperature aqueous					C		
High-temperature hydrothermal		C	R	C		C	
High-temperature flux		C	R	R			C
High-temperature/pressure flux	R						
Melt methods							
Solidification in a container				R			
Crystal pulling from a melt			R	C			
Flame fusion				C			
Zone growth			R	R			C

*This table lists the major kinds of treated gem materials seen in the jewellery trade. Other synthetic gem materials have been produced on an experimental basis, but are not available commercially. For each synthetic gem material, the extent of occurrence relative to other types of synthetics is shown by C (common occurrence) or R (rare occurrence).
Although garnet, jadeite jade, topaz and tourmaline have been synthesized in the laboratory, the material produced is not suitable for jewellery purposes.

aqueous hydrothermal solution), and crystallization from a melt with roughly the same chemical composition as the crystal being grown.

Synthetic diamonds, grown from a metallic flux at high temperatures and pressures, have evoked concern in the jewellery trade ever since the first production of gem-quality crystals in the early 1970s. However, due to the growth conditions involved, as well as the great expense and restricted availability of the growth equipment used, the actual number of gem-quality synthetic diamonds continues to be limited. Those that are encountered in the jewellery trade are mainly brownish-yellow crystals, weighing 1 carat or less (1 carat = 0.2 g), which can yield faceted pieces of 0.5 carat or smaller in size.

In contrast to synthetic diamonds, colourless or near-colourless imitation materials are much more abundant. Over the years, a number of natural gem minerals and synthetic materials have been used to imitate colourless diamond. Cubic zirconium oxide (cubic zirconia, or CZ) is the most widespread simulant because of its low cost and similar appearance to a polished diamond. It (and most other simulants) can be readily distinguished from diamond on the basis of a difference in heat conduction, which can be detected with a simple gemological test instrument. Within the past two years, a new material, synthetic moissanite (silicon carbide), has been marketed for jewellery purposes. It has caused some serious identification problems among jewellers, because it cannot be distinguished from diamond by the heat conduction test mentioned earlier. However, synthetic moissanite displays optical features due to its anisotropic optical character (seen as an optical doubling when viewed with magnification) which allow it to be easily recognized by trained gemologists.

Among coloured stones, the most important synthetics are synthetic corundum (sapphire and ruby), emerald, spinel and amethyst (Figure 2). As indicated in Table 2, they are produced by both solution and melt crystallization techniques. In the marketplace, flame-fusion and crystal-pulled synthetics (corundum and spinel) are relatively less expensive and therefore are more abundant than the flux and hydrothermal synthetics. Solution-grown synthetic amethyst falls into the same less-expensive category because of the existing large-scale production facilities for synthetic quartz for use in the electronics industry. In contrast, hydrothermal- and flux-grown ruby, sapphire and emerald are considered as 'luxury' synthetics that command higher prices.

Figure 2. Five synthetic coloured stones representative of what is seen today in the jewellery trade. From left to right, these include synthetic green beryl (synthetic emerald), synthetic red corundum (synthetic ruby), synthetic blue corundum (synthetic sapphire), synthetic yellow quartz (synthetic citrine), and synthetic purple quartz (synthetic amethyst). These items range in weight from 1.01 to 2.38 carats. Photograph by Maha Tannous, copyright GIA.

Gem identification

Jewellers with gemological training are taught to utilize a variety of standard testing instruments to identify diamonds, coloured stones and pearls. These instruments are listed in Table 3, along with the kind of data that each instrument provides. Diagnostic properties of all natural, treated and synthetic gem materials are published in several standard textbooks; this information is supplemented

Table 3. Equipment used for gem identification

Instrument	Data obtained
Standard equipment	
Hand lens (or loupe)	10 × magnification of visual features
Binocular microscope	10 ×–60 × magnification of visual features (often used with various illumination, immersion, polarization, photographic and other imaging techniques)
Refractometer	Refractive indices, optic character, birefringence
Spectroscope	Visible spectra (both prism and diffraction grating designs)
Polariscope	Optic character, birefringence
Ultraviolet lamp	Fluorescence, UV transparency
Balance	Weight, specific gravity
Calcite dichroscope	Pleochroic colours
Colour filters	Diagnostic colour appearance
Reflectometer	Surface luster (reflectivity)
Thermal conductometer	Thermal conductivity (thermal inertia)
Electrical conductometer	Electrical conductivity
Advanced equipment	
Spectrophotometer	Ultraviolet, visible and near-infrared spectra (can also be used for colour measurement)
FTIR spectrometer	Infrared spectra
Raman microspectrometer	Raman spectra of gems or inclusions
Luminoscope	Cathodoluminescence
X-ray fluorescence	Non-destructive chemical analysis of an area of sample
Electron microprobe	Non-destructive chemical analysis of a small area of a sample
Scanning electron microscope	High magnification images, element distribution mapping, non-destructive chemical analysis of a small area of a sample
Radiograph	X-ray transparency images
Diffractometer	X-ray diffraction patterns (or recorded photographically with a powder camera)

by regular reports on new gem materials in several gemological journals and jewellery trade magazines (see the reference list). With these tools and references, jewellers and gemologists are in a good position to identify many of the gem materials they encounter.

The most important of these basic gemological instruments is the binocular microscope. Used in combination with various lighting techniques, the microscope allows the gemologist to examine inclusions, growth features, colour zoning and other aspects of appearance that provide important clues regarding a gemstone's identity. Measurement of the refractive index (RI) by means of a refractometer is also very important, since RI values are distinctive of many gemstones. Use of a prism or diffraction-grating spectroscope allows the observer to relate a gemstone's colour to its absorption spectra, and indirectly to its chemical composition; these absorption spectra can also be diagnostic for identification purposes. Thermal and electrical conductometers, as well as reflectometers, are mostly widely used for distinguishing diamond from imitation materials such as cubic zirconia.

When basic gem testing does not yield a conclusive answer, or further information is desired to support a preliminary conclusion, jewellers often turn to one of several gem-testing laboratories for assistance with gem identification problems. These laboratories offer more advanced analytical instrumentation, along with experienced gemologists who deal with gem identification problems on a daily basis. In addition to the standard gem-testing equipment, the advanced analytical instrumentation that may be accessible to well-equipped gemological laboratories is listed in Table 3. These analytical techniques must normally involve little or no damage to the gem sample; seldom is rough gem material available for destructive analysis.

In general, this advanced equipment falls into two main categories. Spectroscopy instruments allow the visible, infrared, luminescence or Raman spectra of a gemstone to be recorded (and in the case of the latter technique, spectra can be recorded to identify inclusions within gemstones). Faceted gemstones are cut in styles to control the transmission of light (i.e. to optimize the amount of incident light that exits the gemstone through the upper facets). Therefore, it is sometimes difficult to mount a gemstone (or a gemstone set in a piece of jewellery) in a spectroscopy instrument in such a way that sufficient light can pass from the light source through the gemstone to the detector. Similar light sensitivity problems can exist for recording spectra of highly coloured or highly included gemstones. The path-length of light travelling through the gemstone cannot be measured with accuracy, so the recorded absorption intensities for spectral features are not directly related to this path-length. Visible spectra provide information on causes of colour and evidences of treatment. For determining causes of colour, it may be important to record oriented spectra using polarizing filters for optically anisotropic gem materials. These spectra can also be used to calculate the face-up colour appearance of a gemstone. Infrared spectra are often used to check for the presence of a foreign material in a treated gemstone, such as oil or resins in the open fractures of treated emeralds, or plastic in treated opals.

The second group of analytical instruments includes those used for chemical analysis. Most gemological laboratories utilize an energy-dispersive X-ray fluorescence (EDXRF) system for analysing polished gemstones for the presence of elements between magnesium and uranium on the periodic chart. The X-rays given off by the gemstone are characteristic of the chemical elements in the sample. If suitable standards of known chemical composition are available, comparison of analyses of the standards and the unknown sample can provide semiquantitative chemical composition data on the unknown. The EDXRF method is rapid, and requires no sample preparation other than the requirement for a flat polished surface for analysis. The electron microprobe is a more expensive analytical instrument that offers ability to quantitatively analyse small areas on a sample; the sample itself must possess a polished flat surface, and must usually be carbon coated for the analysis. Although not listed in Table 3, laser ablation combined with a mass spectrometer is a new tool for obtaining more complete chemical analyses of gemstone samples, in which microscopic amounts of material are vaporized by the laser beam for analysis in an inductively coupled plasma (ICP) mass spectrometer.

The remaining kinds of equipment listed under advanced equipment in Table 3 have miscellaneous uses. Radiography is an important tool for obtaining images of the internal structure of pearls, and is used for distinguishing natural from cultured pearls. This method has also been used to test for fracture-filled diamonds, since the filler glass is relatively opaque to X-rays in comparison to the diamond. If sufficient material is available for destructive analysis to prepare a powder sample, a diffractometer or powder camera can provide an X-ray diffraction pattern for the identification of coloured stones or mineral inclusions. One can also check for any cathodo-luminescence when a gemstone is exposed to a beam of electrons in a vacuum chamber.

In contrast to the publication of basic gemological properties in standard reference books, gemological information derived from advanced instrumentation (such as on the absorption spectra or chemical composition data on gemstones) is usually scattered in the scientific and gemological literature. The staff of gem-testing laboratories must compile a database of such information on the gemstones they test in order to help identify them.

Disclosure requirements and ongoing challenges for identification

Customers considering the purchase of a gemstone may have little knowledge about gemstones and their values, and they rely on trained jewellers for this product knowledge. Even then, they may be skeptical of the information they receive from jewellers. In many countries, jewellers are required to disclose accurate information on the gemstones that they sell to consumers. However, this assumes that the jeweller knows if the item is a treated or synthetic gem material. If they are gemologically trained and possess the necessary testing equipment, jewellers can identify many of the gem materials they encounter, or if uncertainty exists, they can get help from a gem-testing laboratory. Often, jewellers rely on some type of certification on the identity of a gemstone from the source whom the item was purchased, or from the gem-testing laboratory. However, given the variety and sophistication of the treatment and synthesis methods mentioned earlier, possessing accurate identity information on gemstones to disclose to consumers can be a problem for jewellers.

Individual important gemstones usually possess sufficient potential value to warrant their careful examination by the trained staff of a gemological laboratory. Most current gemological research is directed at the identification of these important gemstones. However, extensive laboratory testing may not be possible for other gems which are bought and sold in large quantity (i.e. blue topaz, amethyst and other colours of quartz, smaller-size cultured pearls), and whose individual value may be less significant. In such instances, testing for treated and synthetic samples may be carried out only on representative samples in a group.

As mentioned earlier, the use of some gem treatment methods extends back to several centuries. These methods are sometimes considered as accepted trade practices. When such methods are widely used (a good example is the heat treatment of greenish-blue beryl into blue aquamarine), as mentioned above it is assumed by jewellers that all samples of that particular kind of gemstone are treated. Even in such instances, correct identity information should be disclosed to customers.

Conclusions

Besides natural gemstones, an extensive variety of treated and synthetic gem materials are available today in the marketplace, and this trend will continue. The latter offer consumers a wider choice of gem materials, colours, qualities and prices. These materials are the products of conventional and more recently developed treatment and synthesis methods. While trained gemologists can frequently recognize many of the gem materials they encounter, continual efforts are needed to keep them updated on new materials coming into the marketplace. Even with the use of advanced testing methods, the accurate identity of some treated and synthetic materials can be difficult to establish. Advances in modern technology are expected to produce new gem treatment and synthesis methods. These in turn will require the ongoing development of new gem-testing methods and improved gem identification criteria.

Suggested references for further reading

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