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Gemstones and Technologies of Their Treatment

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Abstract—Criteria of classification of minerals as gemstones are given. Methods of natural stones treatment making it possible to improve the qualitative characteristics of gemstones are described in detail. These methods do not only increase an appeal of the stone, but also its durability by increasing the material strength. Then technologies of stone shaping – tumbling, faceting, carving, and the ultrasonic method of copying cameos are considered. Stages of gemstone faceting are described.

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Gemology (from Latin *gemma* – gem, gemstone and *logos* – science) is a science about gems and gemstones. This comparatively young science is closely connected to mineralogy, petrography, and crystallography. Apart from the methodologies of the abovementioned sciences, it also applies methodological tools of physics, chemistry, petrology, geology, and zoology. The close relation between gemology and mineralogy is determined by the fact that the overwhelming majority of gemstones and decorative stones are minerals. According to G. Smith [1], out of more than 4 000 discovered minerals one third is directly used in the jewelry industry, and the remaining percentage can serve as jewel-decorative, carving, and museum materials. However, not all gemstones and decorative stones are minerals. By definition, a mineral is a natural chemical compound of a crystalline structure, formed in the course of various geological processes. Minerals do not include some natural amorphous formations, such as opals or volcanic glasses, but they are also objects of gemology. Some precious organogenic products, such as amber, pearl, coral, and gagate, do not belong to minerals as well. It is considered that synthetic gems generated in laboratories or at factories are not minerals either.

Often the object of the gemological study is not a mineral in general, but only certain types of the mineral, which have a specific external feature, most commonly a specific color, form of crystals, appearance, and morphological characteristics.

At present there is no generally accepted definition of the gemstone. We will specify the criteria, which make it possible to distinguish gemstones. There are three such criteria: beautiful appearance, durability, and rarity [2, 3]; all the criteria are quite conventional. Thus, gemstones and decorative stones encompass rare decorative minerals and rocks, characterized by a beautiful color or pattern, transparency, and luster, often in a combination. These stones have high durability and chemical stability, which determines their aesthetic properties. In Russia the whole range of precious stones and decorative stones is usually referred to as gemstones (Russian *samotsvety*), the word dating back to the miners of the Urals a long time ago.

Classification of Gemstones by E.Ya. Kievlenko

In the course of gemology development many different classifications of jewelry, decorative, and carving stones have been proposed both in Russia and in other countries. Let us consider one of them: classification of gemstones by E.Ya. Kievlenko [4, 5]. The majority of the Russian gemologists refer to this classification, which is based on the criterion of the gemstone commercial value. According to this classification, gemstones are divided into three groups: jewelry stones, jewelry and industrial stones, and industrial stones. The groups in turn are divided into orders.

Group 1

Order 1: diamond, ruby, emerald, blue sapphire, and alexandrite.

Oder 2: precious jadeite, precious opal, orange, yellow, violet, and green sapphire.

Order 3: demantoid, precious spinel, aquamarine, topaz, and moonstone.

Order 4: tourmaline, zircon, beryl, turquoise, amethyst, peridot, and chrysoprise.

Group 2

Order 1: rock crystal, jadeite, nephrite, lazurite, and malachite.

Order 2: agate, amazonite, rhodonite, labradorite, belomorite, and chalcedony.

Group 3

Jasper, obsidian, selenite, fluorite, quartzite, chert, and marble.

It is necessary to remember that this classification cannot be considered universal. The commercial value of the gemstone is determined by a number of changing factors, for instance by fashion. Therefore, shifts of individual gemstones both to upper and lower orders within this classification are quite possible [6–8].

Improvement of Gemstones

Beautiful appearance, depending on the color, brilliance, and transparency, is the main requirement to any gemstone. As gemstones, included into pieces of jewelry should not only be beautiful but remain so, the properties which are essential for gemstones are those ensuring their durability, such as hardness and resistance to splitting. The color of gemstones is their most prominent feature, which in many respects determines the gemstone beautiful appearance and its commercial value.

It is not always possible to find natural stones of such quality, form, and size, that they could be used in jewelry pieces without a preliminary treatment. While it is possible to change the form and size of the stone through cutting, faceting and polishing, and it is even possible to eliminate some defects (near-surface inclusions and other faults) through proper cutting of the precious material, the color of the gemstone, its transparency, and purity cannot be improved applying "mechanical" means of treatment. In such cases it is efficient to apply a special improvement technique or a combination of them in order to improve the consumer properties of minerals without breaking their natural structure.

Improvement (modification, treatment) of natural gemstones has been known since the ancient times. It is mostly aimed at improving the quality of gemstones. Improvement of the precious material quality can consist in increasing, eliminating or changing the color of the stone, in hiding its defects, in strengthening, and improving the appearance of the stone.

The ways of changing gemstones properties have been always determined by the general level of the scientific and technical development. In the ancient times and in the Middle Ages, identification of methods aimed at improving the quality of gemstones was spontaneous and accidental. One of the most ancient ways to improve various minerals is simple low-temperature burning, enhancing their color and transparency. With the development of chemistry various methods of dyeing gemstones with different chemical substances started to appear; after the discovery of radioactive rays and X-rays, gemstones started to be treated with radiation.

Usually the conditions of gemstones improvement are not disclosed, they are declared to be a commercial secret or intellectual property. Most often the following gemstones undergo this type of treatment: diamonds, sapphires, rubies, emeralds, topazes and a significant number of other less precious jewelry materials. According to the estimates of some experts, the percentage of improved stones on the market at the end of XX reached 2/3. When selecting an improvement method, it is necessary to take into account the characteristics of the specific mineral and its properties, as well as its reaction to various factors of the improvement process.

Most often improvement is connected with changing the color of the mineral. People did this even in the ancient times. To improve the color, people used honey, different ochres and red lead, copper sulphate and acids. With the development of chemistry, impregnation of minerals with chemical reagents became a commonplace. At present, after the discovery of radioactive rays and X-rays, it has been discovered that a lot of gemstones are capable of changing their color as a result of ionizing radiation. By now, gemology has accumulated a significant experience in improving mineral gemstone raw materials. For practical purposes in order to change the color of gemstones, the following three types of influence are applied [9, 10]: impregnation with chemically active substances, thermal influence, and ionizing radiation.

Let us consider each of the types. A good example is a well-known gemstone – turquoise. This complex copper phosphate gets paler when it losses water. Jewelers call this process the aging of turquoise. To

avoid the aging, in the ancient times people impregnated turquoise with wax, paraffin, and fat, and at present colloidal silicon, liquid silica glass, and various organic resins are used for this purpose.

Agate, a microcrystalline, banded variety of quartz, is found in nature mostly in the form of grey-colored sintered aggregates. Agates can be dyed using nonorganic salts of chromium (green), ferrum (yellow), cobalt (blue), nickel, copper, and other metals. Chemical impregnation of agates is often combined with thermal treatment: in former times plain grey agates were first kept in sugar syrup and then burned in furnaces. In this way people obtained extraordinary onyxes with color patterns rich in contrast. Agates dyed by the old masters are almost impossible to distinguish from the best natural samples.

The quality of natural gemstones can be improved through thermal treatment. The miners of the Urals extracted morion crystals (black variety of quartz), baked these stones in dough and as a result obtained excellent yellow citrine crystals, an undoubtedly more valuable variety of quartz.

Thermal treatment is applied to approximately 90% of all rubies and sapphires, minerals of the corundum group, which are used for jewelry purposes. This process makes it possible to significantly improve the stone color and purity [11].

Ionizing radiation of gemstones often results in opposite changes in the gemstone color compared to its thermal treatment [10]. Unfortunately, gemstones subjected to radiation with chemical elements often become radioactive themselves. In gemological practice installations for γ-radiation are usually used. For instance, after radioactive treatment a colorless topaz becomes brown, blue or green, depending on the radiation dose. Diamonds subjected to radiation with radium salts turn green, with neutrons, brown, and with electron flux, blue.

Two methods are applied in order to improve the appearance and strengthen the gemstones [12].

(1) " Healing" of cracks.

Under this technique cracks in the stone are filled with various oils or silica gels. It is usually applied for valuable transparent stones.

(2) Stabilization of loose masses.

This technique involves impregnation of opaque stones, such as turquoise and malachite, with plastic, wax or vitrified materials.

Gemstones Treatment

The majority of organic and nonorganic jewelry materials become more attractive after cutting and polishing. For translucent and opaque stones the main treatment process is tumbling, which makes their surfaces smooth and shiny, at the same time preserving fancy shapes of the initial raw material. Apart from that, stones of this type can be cut in the form of a cabochon, which makes their color or banding more distinct, as in the case of agate and malachite. A cabochon cut makes it possible to show such optical effects as asterism, iridescence, and cat's-eye effect. If the stone is translucent but dark, to reduce the color a low cabochon can be produced. Sometimes for the same purpose cabochons are cut with a concave base.

While tumbling improves the appearance of untreated stones and cabochon cutting is good for opaque stones or stones with optical effects, the majority of transparent gemstones go through faceting, which makes it possible to show their main color, brilliance (surface and internal light reflections), light effects (dispersion), and scintillation brilliance (bursts of light inside the stone due to movements of the light source or the stone itself).

Gemstone brilliance resulting from the reflection of light from the gemstone external surfaces (i.e. luster or reflectivity) is connected with the refractive index of the stone, while gemstone brilliance resulting from the reflection of light from the gemstone internal surfaces depends on the type of faceting, which in turn is partly determined by the value of the critical angle for this jewelry material.

Critical Angle

In order to better demonstrate the internal brilliance of a transparent faceted gemstone it is important that as many light beams, penetrating the stone through its top facets (crown) as possible are reflected back from its rear facets (pavilion) and leave the stone through its crown as a result of the total internal reflection.

To achieve this, cutters of colored gemstones and diamonds should make angles between the crown and pavilion facets in such a way that the majority of light beams, entering the stone through the crown, reach the internal surfaces of the pavilion facets at angles to the normal exceeding the critical angle. If the angles between the facets are chosen incorrectly, the majority of light beams will leave the stone through the pavilion facets, and the gemstone will look dark. It is equally

important that light beams, reflected from the pavilion facets, reach the crown facets at a smaller angle than the critical angle. Otherwise, it will result in a re-reflection and the beams will go backwards inside the stone.

To find the jewelry material critical angle, one is divided by the value of the material refractive index. The resulting figure is the angle sinus, which makes it possible to identify the angle itself using trigonometric tables. The critical angle can be also found directly on the basis of the refractive index with the use of special software, such as GEMDATA [10, 13].

Types of Gemstone Cuts

The main purpose of treatment of colorless gemstones is to obtain faceted gemstones of maximum brilliance and appeal. As it has been described above, gemstone brilliance depends on the stone reflectivity (i.e. luster which can be seen in some gemstones even before they are faceted) and on the total internal reflection of light entering the stone through the crown facets. If dispersion of the gemstone is quite high, the cutter should take this property into account to make the gemstone "play."

Dispersion of white light into its component spectral colors, resulting in the appearance of flashes resembling flashes of fire ("gemstone fire"), at the same time reduces the amount of undispersed white light reflected by the pavilion facets. For this reason, in gemstone faceting it is important to find the balance between the gemstone brilliance and fire. Light beams reaching the crown table at the normal, i.e. perpendicular to its surface, are refracted when reaching the stone and therefore are not dispersed.

If for the sake of simplicity we take into account only the light beams that reach the table at the normal, then the larger the surface of this facet, the more brilliance the stone will posses. In order to obtain a gemstone with more fire, it is necessary to reduce the table so that more light beams could enter the gemstone through the side facets of the crown and disperse. For colored gemstones the type of the cut should be selected in such a manner that will ensure showing the color as much as possible [14].

In case of such expensive gemstones as diamonds, the type of the cut also depends on the form of the rough stone. It results from the necessity to obtain the maximum weight ratio of the faceted diamond to the rough stone. In some colored gemstones, for instance sapphires, color is not distributed uniformly, and the cut type is selected in such a way that will ensure that the stone parts inferior in color will be located in the pavilion. It creates the effect of a more intensive color when looking through the gemstone crown. If a gemstone is characterized by strong pleochroism, the crown should be oriented in relation to the optical axis of the crystal so as to show the best color through the table (or as in case of andalusite, all pleochroic colors).

Technology of Colored Gemstones Treatment

The main method to treat colored gemstones is a combination of cutting and turning, aimed at shaping the stone as required, while the gemstone surface remains mat. Then in order to give maximum luster to the surface and facets of the gemstone, it goes through polishing as the final stage of the treatment [10].

Untreated stones, characterized by strong pleochroism, iridescence or asterism, first of all, should be properly oriented. In gemstones with the cat's-eye effect or star-like fibers, needle-like inclusions or vesicles causing these effects should be located parallel to the cabochon base. The cutter should avoid cleavage planes in the gemstone not to cause an unexpected splitting during the treatment. It is necessary to make sure that any new facet is at an angle of not less than 5° with such a plane. If the cutter tries to make a facet, for instance at the right angle to the topaz prism length (topaz is characterized with perfect cleavage), it will result in a pitted surface due to the gemstone splitting along the cleavage planes.

Afterwards, untreated jewelry material is sawn into pieces of the required size using a disk saw, with the rim charged with diamond dust. Then the required outlines of faceted gemstones are contoured on the stone pieces. In case a cabochon is required, such stone fragment goes to the cutter without contouring, and the cutter produces the gemstone of the required rounded shape, using the vertical water-cooled grinder. Then the stone is adhered to the dop, which makes it easier to hold the stone, and the top of cabochon is shaped with the use of more fine-grain grinding wheels. The final surface polishing is made on the rotating polishing wheel with the corresponding polishing powders. The polishing wheel for cabochons can be made of wood and contain grooves of the required radiuses.

To produce a faceted gemstone, untreated material is sawn into pieces of the required shape and these pieces are sent to the cutter, who performs the faceting

using various wheels made of iron, copper or from a copper alloy with tin and zinc. The polishing wheel can be motor-driven or hand-operated (in case of the latter, it is easier to control the faceting process). Primitive hand-operated polishing wheels are still applied in India and Sri Lanka.

Another traditional element is a bearing peg, a wooden device of a mushroom-like shape with holes for holding the back end of the dop. By placing the back end of the dop into one of the many holes, it is possible to find the required faceting angle. A more advanced device is a mechanical plate for fixing and placing of gemstones.

For many years various types of materials have been applied for faceting and polishing. Traditional polishing powders include emery powder and tripoli powder. Tripoli is a soft polishing silica-based abrasive, varying in color from white to light brown. Emery powder is a more rough abrasive material. At present these materials are almost completely replaced with cerium and tin oxides. Diamond power and corundum powder are also widely used, the former being able to accelerate the treatment process, which partly compensates for its higher costs.

With the exception of diamond powder, which is often mixed with lanolin, the other polishing materials are applied in the form of aqueous suspensions. The surface of the faceting wheel can be made not only from metal or glass, but also from other materials, including wood, rough felt cloth, leather, and even plastic. Cutters usually have a variety of wheels, each one used for a certain gemstone or group of stones (in this case the wheel surface is not damaged by harder jewelry materials). For primary treatment of raw materials diamond powder of 60–90 μm is used. Later powders with a higher degree of fineness are applied: for shaping, powders of 30–60 μm, for preliminary polishing, powders of 6–12 μm, and at the final polishing stage, powders of 1–6 μm. Diamond abrasives are made from industrial or synthetic diamonds, as well as from diamonds obtained from jewelry production waste.

The value of faceted gemstones depends on many factors, including their color, absence of inclusions, and faceting quality. Some organizations have developed standards for gemstones assessment. However, as it is extremely difficult to assess such factors as pleochroism, color, color intensity, and color zoning, none of these standards has become international, like the diamond color and clarity grading systems have.

Gemstone carving is another sphere of gemstones treatment, known for thousands of years. Apparently, the most well-known of all is Chinese jade carving. Historically, the majority of early Chinese carvings used nephrite from the Eastern Turkestan. From XVIII Chinese carvers started to use jadeite, imported from Burma. In 1850 nephrite pebbles were found in the rivers of Siberia, thus providing carvers with a more accessible source of carving materials. Nevertheless, Burmese jadeite with its more intensive color remained the Chinese carvers' preferred material.

Cameos and intaglios (the latter were sometimes used as seals) were carved from shells, corals, and harder jewelry materials, such as carnelian in Italy and other countries. Another centre of gemstone and cameo carving was Idar-Oberstein in Germany [14].

With the appearance of ultrasonic cutting and the possibility to quickly create copies of the cameos carved by famous masters, it has become important to be able to distinguish hand-worked cameos from their copies. As application of the ultrasonic technology causes the effect described as "freshly fallen snow," one of the ways to identify application of this technology is a thorough inspection of the cameo surface. Such "frosty" patterns can be seen in the deep layers of the cameo, even if ultrasonic carving was followed by manual polishing.

Various tools are used for carving, from steel blades and files to rotary cutters and tips made of silicon carbide. For corundum carving diamond tools are applied due to the hardness of the material.

At present the global resources of high-quality gemstones in the existing deposits are significantly depleted, but new deposits of gemstones different in quality are discovered. The methods of treatment and improvement of gemstones described above make it possible to transform even plain low-quality stones into true works of art.

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