The observation of internal scattering of 633 Nm red laser light in Aceh natural gemstones

Kurnia Lahna*, Suhrawardi Ilyas, Setia Rahmati
Department of Physics, Faculty of Science, Syiah Kuala University, Darussalam, Banda Aceh

*Email: kurnilahna@gmail.com

Abstract. One of the methods in assessing the quality of gemstones is by observing the degree of scattering of visible light inside or on the surface of the gemstones. This scattering phenomenon is determined by its optical characteristic and its stoichiometric compounds. In this study we analyze the internal scattering of red 633 nm HeNe laser light in several natural Aceh gemstones. We found that the degree of crystallinity and homogeneity of samples significantly affect scattering process inside the materials. Amorphous samples tend to transmit light and only scatter low amount of light, and samples with high degree of crystallinity tend to scatter light to all directions. Homogeneous samples have low degree of scattering, while nonhomogeneous samples scatter light with high degree of directionality. We also observed strong backscattering of light on some samples with high degree of crystallinity. The utilization of laser on the raw materials of gemstone quality could help gemstone makers in cutting and grinding process in order to get high quality gemstone final products.

1. Introduction

The study of light interaction with gemstone materials has attracted researchers from many part of the world, both natural and synthetic gemstones [1]. Natural gemstones are studied in order to investigate their optical properties, crystalline characteristics, and possible trace of impurities that may increase their aesthetic values. The thorough optical observation on synthetic gemstones reveals their formation process and may tell how they are formed in geological layers. Natural gemstones have for long fascinated human desire for their beauty as well as their economic value. They 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 [2,3]. 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. Despite all effort to retrieve high quality gemstones at mining localities, the low quality materials are recovered at a much larger percentage. The low quality gemstones have poorer color or clarity and lower 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 market place. Precious stones suitable for jewellery are seldom encountered in nature; however, there are great resources of colorless types of these stones which are of little value. Therefore, with respect to the
growing demands for jewellery, it is necessary to study optical properties of natural gemstones especially the light scattering inside the gemstones.

In recent years the natural gemstone business in Aceh has reached its booming time. Suddenly people found their interest in procuring or acquiring the best looking gemstones for rings and bracelets. Amateur stone polishers were popped up almost everywhere to offer their service, however they were equipped only with crude quality-checking apparatuses and minimum understanding on how light interacts with materials. This may causes high quality raw materials loss their beauty and aesthetic value after cutting and polishing processes.

![Figure 1. Agate is a common mineral in Aceh that is cut and polished to be ring ornaments and bracelets](image)

There are almost 4000 known minerals, of which only about 50 are commonly used as gemstones. Those that form crystals of sufficient size and quality to be cut and fashioned as gems are referred to as ‘gem quality’ or ‘cuttable’ pieces; other minerals or rocks with particularly attractive features (color, texture, or pattern) may be called ‘decorative’ pieces. Crystals are usually faceted (cut and polished) to give a gemstone with a number of flat faces, while decorative stones are mainly tumbled or polished to produce pieces for personal adornment [4,5].

Figure 1 shows an example of gemstone that has recently undergone a moderately short period of booming in Aceh. This agate was found in Teunom, a district at the western coast of Aceh. Agate was formed in a water-rich environment and has been deeply buried under multilayer of sediments for several millions of years. Under high pressure at an elevated temperature, the crystalline structure was formed, most of the time with layered structure with different colours appear in the material.

2. Methods

We acquired gemstone materials from some amateur gemstone polishers in Banda Aceh. Some materials had been cut and polished in common form (as for ring and bracelet) and some in raw form that had been cleaved along their natural surface. There were two types of gemstones that we used for this study, agate and amber. They were mined from natural rock formation in Aceh Besar, Aceh Jaya and Aceh Barat districts.

The size of samples that had been cut and polished is about 1 to 1.5 cm in length and 1 cm in width. The raw gemstone materials were irregular in shape, with surfaces that showed its natural fracture patterns. Samples were placed on sample holder and were illuminated with red HeNe laser source. Then the directions of transmitted, reflected, and internally scattered light are observed for each sample. We also rotated samples in such a way that any difference in light scattering due to minute impurities or crystalline defects may be observed.
3. Result and analysis

In gemstones market, the gemstones are usually valued for their beauty and aesthetic value more than its chemical compound or crystalline shapes. They are inspected under illumination with common white light sources such as flashlight. Laser light is rarely used to inspect, mostly because it is inaccessible for the people in gemstone market. Meanwhile common white light came very handy for most people, as match and mobile phones provide LED white light illumination. These light sources may reveal the color of gemstones properly, but unable to reveal the natural lines such as crystal boundaries or layer structures inside the gemstone. The layered structure and natural lines inside gemstones are what really looked for by gemstone enthusiasts. Some of them perceive those lines as divine calligraphy picture of some sort. However, because white light sources are unable to reveal that internal detail, the gemstone were cut in rough way and those “calligraphy” or “pictures” are cut or polished. This caused some losses of valuable part of gemstones in cutting and polishing processes.

We have observed that inspection of gemstones under laser light illumination revealed much more information about the physical characteristics of gemstones. The high intensity beam is scattered easily by impurities or defects inside the materials. Therefore the thinly internal layered structure, which are the result of geological activity for thousands or even millions of years, are revealed easily by laser source. Some impurities may form a “picture”, that would look like a hand or a person praying, can be observed in easier way. Agate samples that have those forms are valued higher in market.

When a laser beam penetrates a block of raw gemstone, as shown in Figure 2, the beam undergoes two process, internal scattering within the rock and transmission out of the rock. If heavy scattering occurs to the beam inside the gemstone, the transmitted intensity will be small. This occurs on material with some degree of translucency, where the granularity of material causes some light to be diffusely scattered within the material. The inside rock is well illuminated and the internal layer structure of the gemstone can be revealed. The block gemstone in Figure 2 shows several layered structure which can be used as guidance by gemstone polishers to get higher price for their final cut.

Currently most gemstone polisher in Aceh use flashlight (white light) as a tool to reveal the internal layered structure. This has proven ineffective. White light from a flashlight is good in some part because it is polychromatic. It could reveal the true color of gemstone if the gemstone is partly transparent. However, is an incoherent light. The internal scattering of an incoherent beam only reveal some distinct layers, but mostly fail to characterize layers that may increase its aesthetic value. We have heard a lot of bad experience among gemstone polishers, where they purchases raw gemstone at a considerably high price but failed to get an excellent cut. The best layer has lost in cutting or polishing process. Therefore we tried using laser beam as a better solution for light source, and Figure 2 shows that laser light could reveal more of internal layered structure than any ordinary white light source.

The layered structure inside agate as formed through metamorphic process deep inside the geological layer of earth’s crust. The heat caused partial melting on the crystal grain within the material, and this increased the degree of crystallinity of the material. When heating process occurred gradually in long period of time, the degree of crystallinity increases and the grain size is larger.
Figure 2. Laser light penetrated into raw samples, scattered uniformly, and revealed internal layered structures. The layered structure is important for gemstone polisher in order to increase the market value of their polished products.

Figure 3. Some of crystalline gemstone have crystal planes at various direction. Each plane reflect light into certain direction. This caused multiple reflections at various direction from single incoming light beam.
We also observed some back reflection from polycrystalline agate samples, as shown in Figure 3. A polished agate sample may allow more light to be penetrated inside, and when the beam hit the polycrystalline grains inside, each grain produces reflection according to their optical orientation. As laser source is highly directional, the reflected light is still maintaining its directionality. Therefore these samples produced several reflected beams according to crystal direction of the regions stroke by laser light. The multiple reflection from a single sample may increase its aesthetic value, and we expect gemstone makers to be able to use this phenomena as this may increase the value of gemstone in the market. This phenomenon is very new for amateur gemstone makers in Banda Aceh.

The degree of transparencies of samples shows the crystalline qualities of materials. Amorphous materials such as ambers are more translucent, where light are scattered strongly inside the materials. When a highly directional laser beam enters the sample, some are reflected by the surface (its reflectivity depend mostly from polishing quality), and most part of it is scattered internally and exit the material from any direction. This makes the sample glowing, as shown in Figure 4 for calcite sample. In this case, the calcite crystal may be hydrated and this increases the light scattering phenomena in the sample. The rhombohedral properties of crystalline calcite causes the strong reflection of light at the surface. Therefore, less light is transmitted and more light is reflected back inside the material. This observed phenomena, as shown in Figure 4, opens a new opportunity of crystalline calcite to be used as light diffuser on the ornamental lamp.

![Figure 4. Homogeneous agate showed translucent properties. An incoming laser source is scattered uniformly inside the bulk material](image)

4. Conclusion

We have investigated the internal scattering of 633 nm HeNe laser beam on several natural gemstone of Aceh origin. The use of laser light reveals more internal structure than the use of common white light from cheap sources. Laser light reveals deep layered structure and localized impurities in agate. The crystalline form in jadeite samples was also revealed by back reflection from crystal boundaries inside the bulk material. This information may increase the aesthetic value and beauty of polished gemstones in gemstone market. Therefore we recommended gemstone makers to use laser light as a way to inspect their raw material before processing in order to gain more value in the market.
References

[1] Baryshev, A. V., Kosobukin, V. A., Samusev, K. B., Usvyat, D. E., and Limonov, M. F. 2006
   *Phys. Rev. B* 73 205118

[2] Germer, T. A., Zwinkels, J. C. Tsai, B. K. 2014 *Spectrophotometry: Accurate Measurement of
   Optical Properties of Materials*, Elsevier

[3] Henderson, B., Frank-Imbusch, G 2006 *Optical Spectroscopy of Inorganic Solids*, Clarendon
   Press

[4] Scumann, W. 2009 *Gemstones of the world*, Sterling Publishing Company, Inc, New York

[5] Sodo, A., Ajo, D., Pozza, G. Bicchieri, M. 2003 *Journal of Cultural Heritage*, 4 317