MD Technical Review Letter -

Sciences behind Diamond Cutting and Polishing

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Diamond has very high value comparing with various gemstones in both economical and appreciative aspects. Diamond is unique among different gemstones because of its unique material properties, which play important roles in the process of cutting and polishing. The sciences of diamond cutting and polishing have been discussed in the terms of surface roughness and crystal plane orientation. Measurements have been done by atomic force microscope and single-crystal X-ray diffractometer.

Introduction

The optical property of Diamond is very special, like high Refractive Index in visible light range and white light is easily dispersed into discrete colors when passing through each Diamond-Air interface. With proper facet angles and polish quality, these make the appearance of diamond attractive. Certain industrial standards have been made on the cutting and polishing of diamonds [1], the higher grade, the higher value of a diamond. Therefore, it is worth to know some basic sciences behind the cutting and polishing of diamond.

Polishing

Diamond can be polished to have the smoothest surface among different gemstones. It is because diamond is the hardest natural material on the Earth. When compared to other hard natural gemstones such as sapphires and rubies, the hardness can be compared in term of Mohs scale, the higher the value in the Mohs Hardness scale, the harder the material.

Mohs Hardness	Mineral	Absolute Hardness **kg_f/mm^2**
1	**Talc** $Mg_3Si_4O_{10}(OH)_2$	1
2	**Gypsum** $CaSO_4.2H_2O$	2
3	**Calcite** $CaCO_3$	9
4	**Fluorite** CaF_2	21
5	**Apatite** $Ca_5(PO_4)_3(OH-,Cl-,F-)$	48
6	**Orthoclase** $KAlSi_3O_8$	72
7	**Quartz** SiO_2	100
8	**Topaz** $Al_2SiO_4(OH-,F-)_2$	200
9	**Corundum (e.g. Rubies, Sapphires)** Al_2O_3	400
10	**Diamond** C	1600

Table 1 Mohs Hardness Comparison among different gemstones. *[2]*

A study on comparing the surface smoothness of diamond and sapphire has been conducted. Natural diamond and sapphire have been ground and polished in the same conditions such that they both have the smoothest surface on their table facets. Then the surface of each sample was measured by a PARK SYSTEM NX10 Atomic Force Microscope with the non-contact mode at a resolution 0.03nm.Atomic force microscopy (AFM) provides a high-resolution method for surface profilometry measurement of a sample at the nanoscale or an atomic level. Therefore, this technique can be used to study the average surface roughness R_a of both diamond and sapphire. The surface roughness of diamond and that of sapphire are summarized in Table 2.

Sample	Average surface roughness R_a
Diamond	0.526 nm
Sapphire	2.438 nm

Table 2 Summary of the results on different samples using AFM.

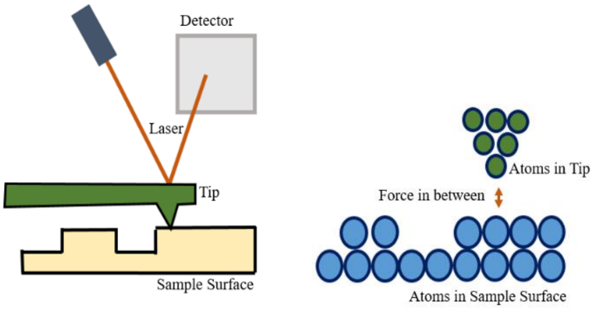

Figure 1 Diagram showing the principle how AFM measures the surface morphology of the specimen.

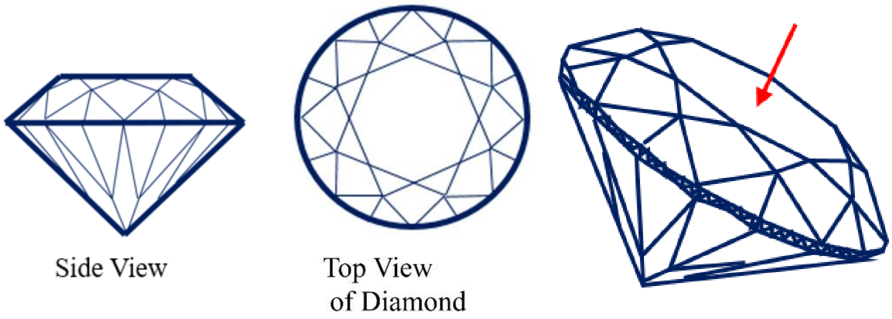

Figure 2 The measurement position of the sample in both SC-XRD and AFM measurements is indicated by the red arrow.

It was revealed that the diamond sample has a relatively low average surface roughness R_a much less than 1 nm, while for the sapphire the value is much higher than that of the diamond sample with the value in above 2 nm. The results are shown in Fig. 3 and Fig. 4.

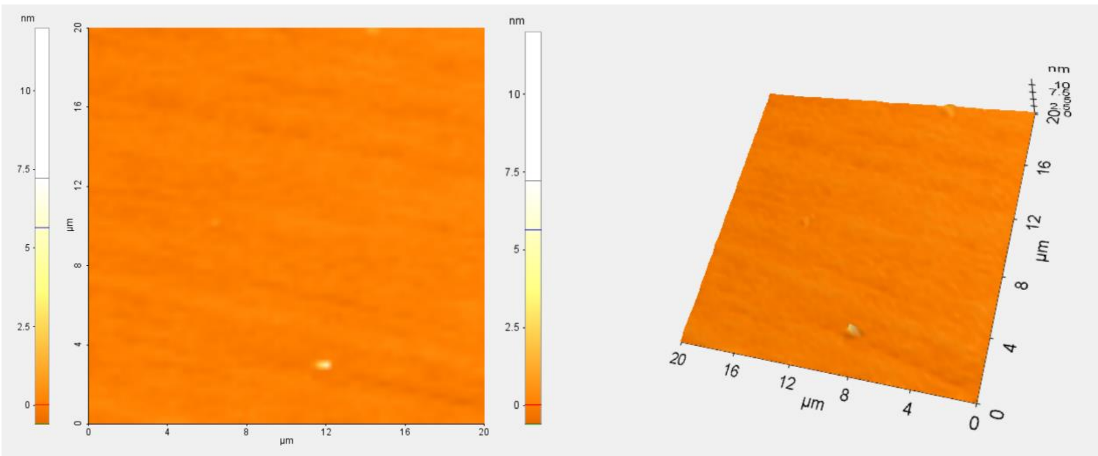

Figure 3 Surface roughness measurement on the polished natural diamond in 2D (left) and 3D images (right).

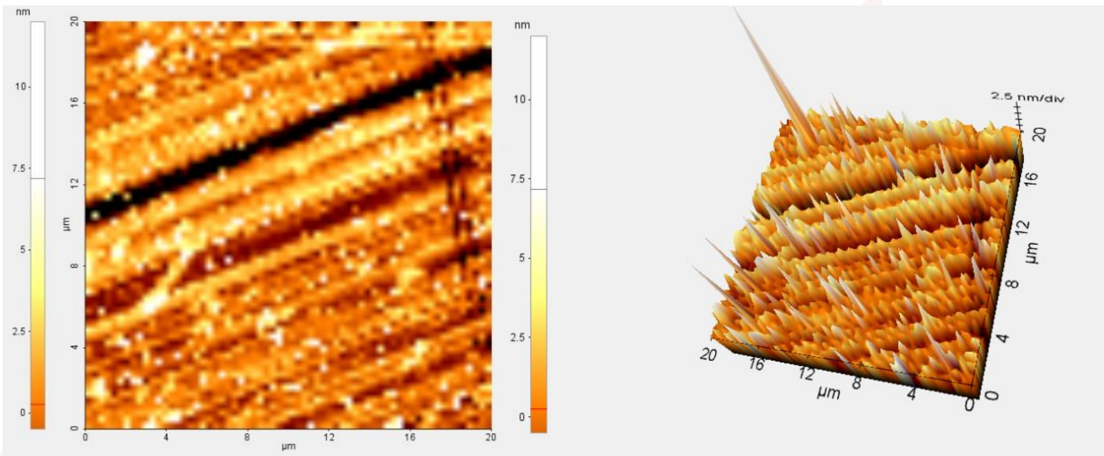

Figure 4 Surface roughness measurement on polished sapphire in 2D (left) and 3D images (right).

Cutting

In minerals, cleavage means that minerals break along the preferential direction or the weakness in the structure. Diamond can be found in many forms in nature and the most common form is in the octahedron form (Fig. 5). The family of the {111} crystal planes is found on the surfaces of this type of raw diamond as the cleavage energy required per unit area is the lowest along {111} planes together with the highest atomic density in the {111} planes [3-7]. In the process of diamond cutting, the raw diamond is cut into two as indicated by the red arrow in Fig. 5. The cutting creates {100} crystal plane surfaces on the two parts of the raw diamond and the surfaces will become the table facets of the resulting diamonds.

The crystallographic information of a natural diamond was investigated quantitatively to reveal the cutting by the single crystal X-ray diffraction (SC-XRD) technique. This technique is a non-destructive method that is able to determine crystallographic information of the lattice in a single crystal on the atomic level, including the crystal structure, the lattice parameters and the crystal orientation [8, 9]

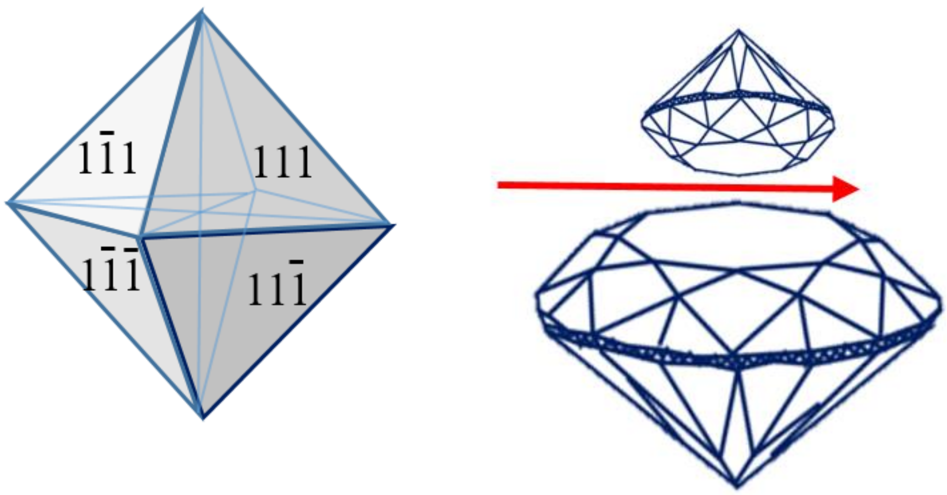

Figure 5 Diagram showing the octahedron form of raw diamond. The red arrow shows the cutting direction *[3]*.

The single crystal sample is mounted on the holder on the sample stage. When, X-rays pass through the single crystal and is diffracted by the atoms, producing the diffraction pattern which gets recorded by the detector. With the intensity information in the diffraction pattern, the electron density map can be deduced, from which the atomic model of the single crystal can be reconstructed. [8, 9]

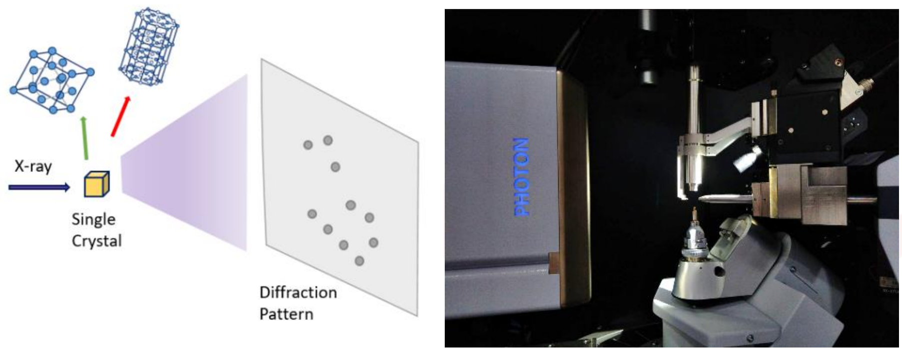

Figure 6 (Left) Schematic diagram showing the SC-XRD experiment. (Right) The BRUKER D8 VENTURE single crystal X-ray diffractometer used in the study.

The single-crystal XRD measurement results are summarized in the Table 3. The investigated diamond crystallizes in a cubic face-centered lattice with a lattice constant of 3.568(4) Å. The crystallographic plane orientation of the diamond table face was also determined. The crystallographic information shows that the diamond was cut at an angle of 10.83° with respect to the (001) plane. The results are rounded to 4 significant figures.

Sample	Lattice parameter and structure	Crystal plane orientation and off-angle between the table facet normal and Phi
Diamond	a = 3.568 Å Cubic face-centered	(0 0 1) 10.83°

Table 3 SC-XRD measurement of a natural diamond.

Conclusion

Diamond has a superior hardness compared to other gemstones such as sapphire. We discussed the difference between polished diamond and sapphire in terms of the surface roughness. In addition, we studied the cutting of a diamond in respect to a principal crystal plane.

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