EGL USA

LABORATORY CREATED DIAMONDS

Guide to Growth Technology and Identification of HPHT & CVD Diamonds

Sharrie Woodring
Branko Deljanin

Acknowledgements

We are fortunate to have many people to thank for their assistance in the preparation of this booklet.

This booklet would not be possible without the support from **Mark Gershburg** and the staff at EGL USA. Special thanks to **Dusan Simic**, **Elena Semenets**, **Nick DelRe** and **Marina Epelboym** for their instrumental analysis and grading of the numerous samples of laboratory-created diamonds and for their advice and assistance with this project. It is a pleasure working with all of you.

We are grateful to **Lynn Ramsey** and **Shawn Moffitt** for their skillful editing and invaluable feedback.

We appreciate the generosity of **Apollo Diamond Inc**, **Chatham Created Gems** and **Gemesis** for lending EGL USA samples to study. We especially thank the the following individuals and appreciate their valuable insights into the growth processes and their technical assistance in reviewing the text: **Robert Linares** and **Bryant Linares**, *Apollo Diamond Inc*, **Tom Chatham**, *Chatham Created Gems* and **Rob Chodelka, Ph.D.**, *The Gemesis Corp.*

We would also like to thank an international team of researchers for letting us use material that Branko Deljanin presented in a lecture at the **ICNDST-9th Conference on New Diamond Technology** *(March 2004, Tokyo, Japan)*, and presented in a poster at the **55th Annual De Beers Diamond Conference at Warwick University** *(July 2004, England)*. The subject of the presentation and poster was: ***"Identification of CVD gem-quality, single-crystal diamond, as-grown and HPHT-treated."*** We would like to acknowledge:
E. Fritsch, *IMN-CNRS & Nantes University, France*, **J.P.Chalain**, *SSEF Swiss Gemmological Institute, Switzerland*, **T. Hainschwang**, *Gemlab, Lichtenstein*, **H. Kanda**, *National Institute for Material Science, Japan*, **M. Akaishi**, *National Institute for Material Science, Japan*, **J. Ponahlo**, *Museum of Natural History, Austria*, **P. Doering**, *Apollo Diamond Inc, USA*, **Y. Horikawa**, *Central Gem Laboratory, Japan*.

Sharrie Woodring and Branko Deljanin, EGL USA

Cover photos:
Yellow Gemesis Created diamond
Pink and blue Chatham Created diamonds

Cover & layout design:
Jack Hand, *www.jackhand.com*

EGL USA

Contents

Introduction

Diamonds are the most desired of gems as well as a highly significant industrial material. They are renowned for being the hardest natural substance and the best thermal conductor known to man. Industrially they are used in almost every field from drills in oil mining to optical windows in aerospace technology. Man's ability to "create" diamonds in a lab, first accomplished over 50 years ago, will have significant implications for fine jewelry and other industries as this technology is refined. For example, in the near future, laboratory-created diamonds will most likely radically change the computer industry by being an alternative to silicon chips.

What are laboratory-created diamonds? Laboratory-created diamonds are diamonds with essentially the same chemical, physical and optical properties as natural diamonds, but instead of being mined from the Earth, they are grown by man in specially designed equipment.

Industrial quality laboratory-created diamonds have been grown since 1954, and gem-quality laboratory-created diamonds have been grown since the 1970s. However, the number of gem quality laboratory-created diamonds currently in the jewelry industry is very limited -- only a small fraction of 1% of the total diamond jewelry market.

There are currently two known methods for growing gem-quality diamonds: the **High Pressure High Temperature method (HPHT)** and the **Chemical Vapor Deposition method (CVD)**. The way a diamond crystal grows leaves behind characteristics that can often can be detected with careful examination. The purpose of this booklet is to explain the different methods used to grow laboratory-created diamonds, and to teach jewelers and gemologists the characteristics to look for when examining different types of laboratory-created diamonds with standard gemological equipment. In some cases, especially type IIa lab-created diamonds, identification requires advanced testing by gemological laboratories, which is also explained in this booklet.

So why are lab-created diamonds, which have been grown for many years, generating more attention?
There are two reasons: 1. Until 2003, single-crystal diamonds grown by the CVD method were too thin to be faceted into gemstones.

2. Manufacturers of lab-created diamonds have refined the HPHT method and are finally able to produce a large enough supply of gem-quality material, at a reasonable cost, to create a demand.

Laboratory-created diamonds manufactured by Chatham Created Gems. Photo by Julia Kagantsova.

With the evolution of these processes, our industry is entering a new era. This is an challenging time for jewelers and gemologists. It requires more education and vigilance than ever before in order to maintain the distinction between natural and man-made diamonds.

Since 1999, when the first HPHT treated diamonds began appearing in the market, EGL USA's research team has worked closely with scientists from around the world to ensure the detection of diamond treatments and synthetic diamonds. We are pleased to share our findings with the trade.

A Diamond By Any Other Name . . .

The Federal Trade Commission (FTC) accepts the terminology "laboratory-created," "laboratory-grown," "man-made," "(manufacturer-name)-created," and "synthetic" to describe diamonds made in a laboratory. Using the term "diamond" or "created diamond" to describe man-made diamonds is not acceptable. Some members of the trade are using the term "cultured," however, at this time, the Jewelers Vigilance Committee (JVC) does not consider this term sufficient without further disclosure.

There is some controversy over the use of the term "synthetic." In the U.S., the term is sometimes considered confusing to consumers who generally understand it to be synonymous with faux or imitation. However, among gemologists the term is understood to mean laboratory-created, and some organizations, such as CIBJO, actually require their members to use this term.

At EGL USA we use the term "laboratory-created" on our reports to describe man-made diamonds. By laser inscribing and issuing grading reports on laboratory-created diamonds, EGL USA is helping to ensure that their origin is disclosed to the end consumer.

For the purpose of this booklet, the terms laboratory-created, laboratory-grown and synthetic are used.

Part I

Background

The History of Diamond Making: The HPHT Method

When WWII jeopardized the world's supply channels of natural diamonds, which were essential for industrial cutting tools, the race was on to grow diamonds in a laboratory. In the U.S., General Electric (GE) started "Project Super-Pressure" to research growing diamonds. Meanwhile, scientists in Sweden were working on a diamond-making project called "Quintus" at the ASEA Electric Company.

Two members of the team at GE with the belt apparatus for growing diamonds in 1954. Tracy Hall pictured on the right. Courtesy of H.Tracy Hall Foundation © 1998.

Scientists had already discovered that diamonds were made of carbon, so they had to determine at what conditions graphite would turn into single-crystal diamond. They looked to nature for clues. Diamonds are found in extinct volcanic pipes and brought to the surface in lava; they form at depths of around 200 miles within the Earth, where pressures and temperatures are very high. To create diamonds, scientists had to find a

Opposite Page: Blue, pink and yellow laboratory-created diamonds set in rings, courtesy of The Gemesis Corp.

way to sustain very high pressure and very high heat simultaneously. Graphite is extremely stable and resistant to change. Even at very high pressures and temperatures, carbon atoms do not break apart and reform into diamond.

Then scientists found a clue while studying a meteor crater. They discovered tiny diamond crystals, surrounded by metal, which they believed formed upon impact of the meteor. The scientists tried dissolving the graphite in a molten metal so that the carbon atoms from the graphite would be free to crystallize as diamond. They placed a capsule containing metal and graphite in the presses and turned on the pressure to 55,000 atmospheres and the temperature to between 1400-1500 degrees Centigrade for a few minutes. Eureka! They had created diamonds!

On February 15, 1955, GE announced to the world that "Project Super-Pressure" was successful. They were the first to publish and patent the process of making diamonds. However, the team at ASEA had achieved making diamonds by a very similar process a year-and-a-half earlier. They feared competitors would steal their methods, so they kept their diamond-making achievements a secret. By not duplicating and publishing their process first, they lost the privilege of owning the patent.

Man had created diamond, but the diamonds were far from gem quality and the size of grains of sand, less than 1mm in diameter. Since then, scientists from the U.S., Europe, Russia and around the world have been studying and experimenting to have the capability to create a sufficient quantity of laboratory-created diamonds of a marketable size and quality to drive demand in the jewelry industry.

By 1985, researchers had achieved growing large laboratory-created diamonds in a variety of colors, but commercial production was not economically feasible and therefore availability was limited. The equipment was expensive to build, operate and maintain; additionally, the quality of the crystals produced was inconsistent and often plagued by eye-visible metallic inclusions.

Now, twenty years later, techniques have been refined, running costs reduced, and equipment is precisely controlled by computers. Investments have been made in more equipment and marketing. Today HPHT-diamond producers, such as Gemesis, Chatham Created Gems, and a number of companies in Russia, are able to grow enough supply to meet the current and growing demand.

The Chemistry behind Diamond's Strength

If diamonds and graphite are both made of the element carbon, then why are they so different?

It's all in the atomic structure. The atoms in graphite are arranged in layers, and the carbon atoms within each layer are connected by strong covalent bonds. However, only weak forces exist between the layers.

Imagine graphite to be a stack of paper. It is very difficult to go through the stack perpendicularly, but very easy to slice through horizontally.

By contrast, the bonding of carbon atoms in the crystal lattice of diamond has perfect tetrahedral symmetry. Each atom is bonded to four other atoms in an equal 3-dimensional way, rather than only in layers. This creates an incredibly strong structural bond in all directions.

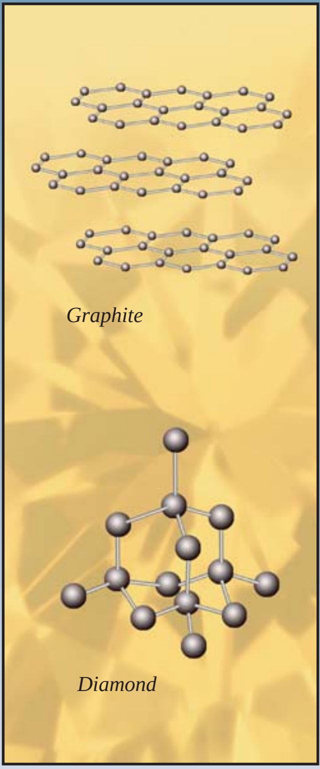


Illustration of the layered structure of graphite and the symmetrical structure of diamond.

Under Pressure……

What is an atmosphere of pressure?
A column of air, 1 square inch in cross section, measured from sea level to the top of the atmosphere would weigh approximately 14.7 lb. In other words, one atmosphere (atm) of pressure is equal to 14.7 pounds per square inch.

Typically 55,000 to 60,000 atmospheres of pressure are used to grow a diamond by the HPHT method. To visualize 55,000 atmospheres, imagine the weight of 400 mid-size cars on a silver dollar, or 600 African elephants resting in the palm of your hand.

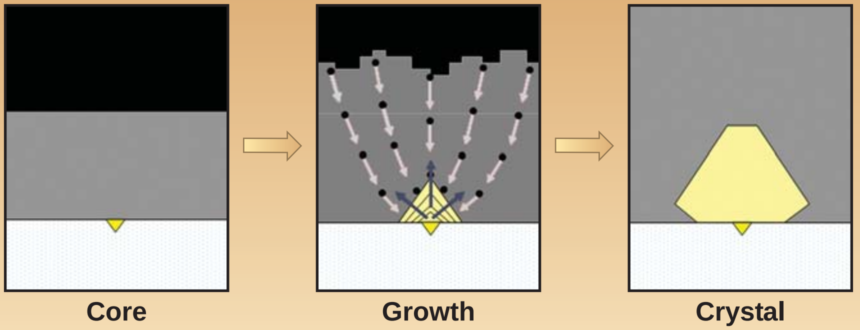
The CVD method of growing diamonds requires low pressure, typically one-tenth of atmospheric pressure.

HPHT Growth Technology

Since its development in the 1970, the **temperature gradient method** has been the standard technology used by manufacturers of HPHT laboratory-created diamonds. The process begins with meticulous assembly of the growth capsule. The capsule contains one or more tiny diamonds that function as "**seeds**" or a foundation for the carbon atoms to precipitate upon. The number of seeds will dictate the number of crystals. The capsule also contains a solid, metal-based material that will become molten when heated and act as both a solvent for the graphite and a catalyst to enable the crystal growth. The solvent/catalyst is a proprietary blend composed of iron, nickel and/or cobalt as well as other additives, such as boron or aluminum, that influence properties, like color. Either graphite or diamond powder is added to the capsule as a source of carbon from which the diamond will grow.

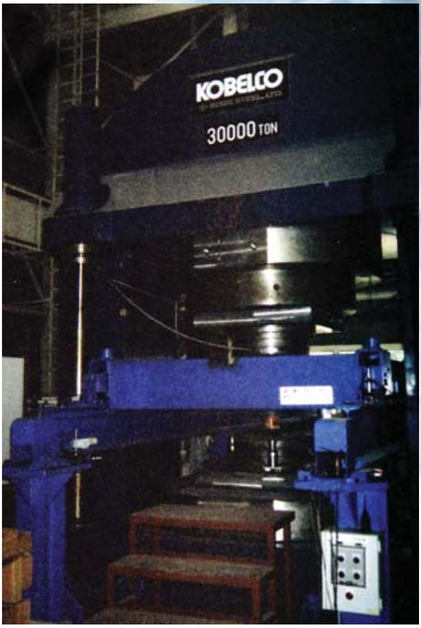
Once the capsule is assembled, it is placed inside the press where pressure will become as high as 55,000 atmospheres (atm). While under pressure, electric resistors heat the capsule to around 1500°C, reproducing the conditions that diamonds form in the Earth. The heat is carefully controlled so that the end containing the carbon source is approximately 30°C hotter than the end containing the diamond seed. The greater the difference in temperature, the faster the diamonds grow, but a balance must be found because faster growth means a potential for more metallic inclusions.

Nitrogen is abundant in our atmosphere. As a consequence, it enters the growth capsule, allowing the nitrogen atoms to become part of the growing diamond crystal lattice. The effect of nitrogen, also a common impurity in natural diamonds, is two-fold: **the nitrogen produces a**



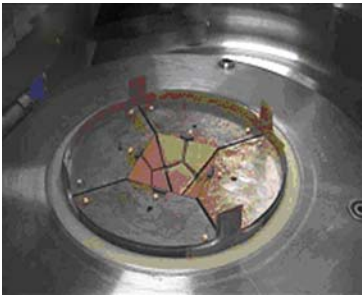
Schematic diagram of the HPHT process used by The Gemesis Corp. The white area represents part of the ceramic capsule with an embedded diamond seed crystal. The gray area represents the metal-based solvent/catalyst and the black area represents the carbon source. Illustration courtesy of The Gemesis Corp.

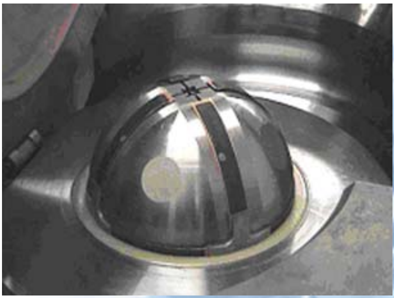
yellow color and seems to assist in the diamond growth.



A belt-type press at National Institute for Material Science (NIMS) in Japan. Photo by Branko Deljanin.

Producing other hues and colorless diamonds was a challenge researchers overcame. By the mid-1980s, several companies, including **De Beers** and **Sumitomo Electric** of Japan, had succeeded in growing large (over 1ct.), colorless synthetic diamonds. They discovered that adding other elements to the metal alloy affects the resulting colors. Aluminum and titanium act as **"nitrogen-getters"** by bonding to the nitrogen atoms, making them inaccessible to the growing crystal. If there is less nitrogen in the crystal, than the result is a less saturated yellow to colorless diamond. Adding boron to the catalyst produces blue diamonds that are type IIb. Both synthetic and natural type IIb diamonds conduct electricity. However,synthetic IIb diamonds have great commercial potential as semiconductors in electronics, whereas, natural type IIb diamonds do not because they are extremely rare and have inconsistent electronic properties. Creation of other colors during the growth process are still being studied. Pink colors are produced by irradiation treatment after the crystals are grown. For more information about color treatments of diamonds, see pages 15-16.





A split-sphere (BARS) press operating in Prague, Czech Republic, for growing synthetic diamonds and for HPHT treatment. A ceramic growth capsule is placed in the center of the four anvils shown in the photo on the left. When all anvils are in place, the split-sphere is complete (right). Photo by Alexey Chepurov.

The History of Diamond Making: The CVD Method

In the early 1950s, when most of the scientific community attempting to grow diamonds was focused on HPHT methods, only a few people studied low-pressure techniques because success seemed improbable. Nevertheless, in the winter of 1952-1953, a scientist at Union Carbide, **William G. Eversole**, recorded the first successful attempt at creating diamonds, preceding the achievement of HPHT scientists at ASEA in 1953. He used a process called **Chemical Vapor Deposition (CVD)**.

Three faceted CVD-grown laboratory-created diamonds manufactured by Apollo Diamond Inc. Apollo announced plans to begin selling limited quantities of faceted CVD material starting in late 2004. Photo courtesy of Apollo Diamond Inc.

Inside a vacuum chamber, Eversole exposed tiny natural diamond seeds to hot carbon-rich gases, such as carbon monoxide and methane (natural gas). In an excruciatingly slow manner, the carbon atoms from the gas would deposit onto the diamond seeds and add new layers to the atomic crystal lattice. The time-consuming and tedious process caused scientists to virtually abandon CVD research and focus on the faster and seemingly more commercially viable HPHT methods. Although not greatly appreciated at the time, Eversole's work laid the foundation for much of the CVD research of the next several decades.

A few scientists in Russia picked up the CVD research and by 1956 had discovered how to grow polycrystalline diamond on non-diamond substrates. This new discovery had great potential for use as coating on cutting tools, windows, etc., however the process was still extremely slow. Several days were needed to grow even a minimal coating. In 1982, scientists at the **National Institute for Research in Inorganic Materials (NIRIM)** in Japan achieved increased growth rates to over 1 micrometer per hour. In the late 1980's, the **Industrial Diamond Division of De Beers (now called Element Six)** started production of CVD polycrystalline industrial products and research into single crystal CVD diamonds. **General Electric** patented the production of transparent polycrystalline diamond films in 1995.

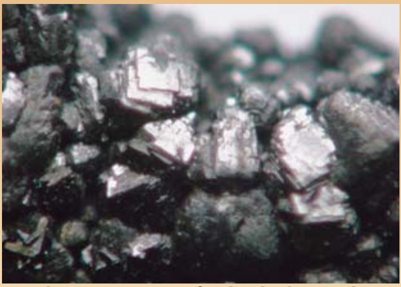
Rapid advances in CVD research continued, and in 1998 **Apollo Diamond Inc**, a Boston-based company, became a major player when they announced the ability to grow single-crystal CVD diamonds over 0.5mm thick. Apollo received a U.S. patent in 2003 for their process of growing high quality single-crystal CVD diamonds. By the spring of 2004, a team of researchers at **Carnegie Institution's Geophysical Laboratory** in Washington, D.C. reported the breakthrough of growing crystals over 3mm thick in only one day.

De Beers' Element Six is also a major player in CVD research with commercial production of industrial-quality polycrystalline CVD material. They also have a separate research program devoted to the experimental production of single-crystal gem-quality CVD diamonds for strictly educational purposes. Their researchers have been able to grow gem-quality CVD diamonds with varied properties by altering the ingredients of the growth process.

In an article written by Element Six researchers, published in *Gems and Gemology* (Spring 2004), three groups of CVD diamonds with distinct properties are described. The groups are: 1. nitrogen-doped material with characteristics similar to the material Apollo is producing: 2. blue boron-doped material; 3. high-purity material, which has a slow growth rate and is technically difficult to produce. The commercial availability of boron-doped and high-purity CVD diamonds, from any manufacturer, is not expected in the near future. This booklet focuses on the identification of nitrogen-doped material that will soon be commercially available.

Polycrystalline Versus Single-Crystal

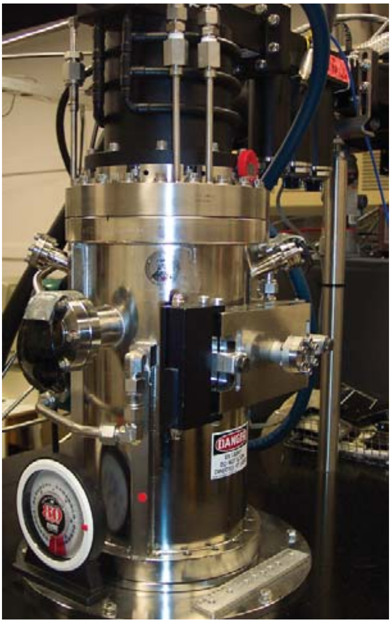
A large percentage of the CVD diamond grown for industrial purposes is polycrystalline. Polycrystalline diamond is composed of many small crystals oriented in different crystallographic directions. Varying directional hardness make polishing and cutting the material into a traditional faceted gemstone nearly impossible, and the individual crystal grains cause the material to be semi-transparent to opaque.



Random orientation of individual crystals in polycrystalline diamond. Courtesy of Carnegie Institution.

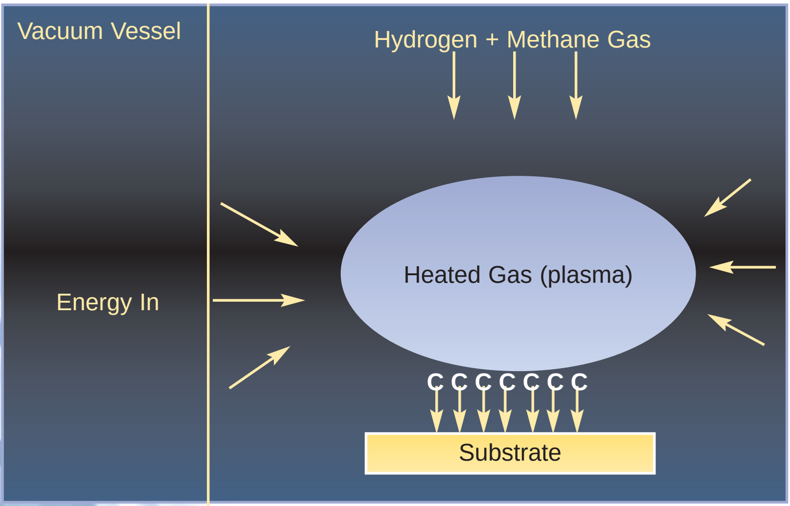
Polycrystalline CVD diamond can be grown on substrates other than diamond, which makes it extremely useful in industrial applications. For example, coating silicon and metal with a layer of diamond makes the materials much more durable. Gem-quality diamonds are composed of a single continuous crystal. Single-crystal diamonds can be grown by using a single-crystal diamond as the substrate or seed in the CVD process.

CVD Growth Technology



Vacuum chamber for growing CVD diamonds at Carnegie Institute, Washington D.C. Photo by Sharrie Woodring.

Growing single-crystal CVD diamonds begins with an atomically flat substrate of diamond, also known as the "seed." The seed, which is generally a HPHT-grown Ib yellow synthetic diamond, is placed in a CVD reactor vessel that is depressurized to one-tenth of an atmosphere to form a vacuum. Then a gas consisting primarily of hydrogen (95% to 99%) and methane gas (1% to 5%) is injected into the chamber and heated by a microwave beam to around 1000°C. The heat causes the molecules in the gas to separate and form plasma of individual atoms. The atoms are attracted to the cooler part of the chamber where the temperature of the seed is carefully controlled to around 800°C. They precipitate out of the gas onto the substrate, slowly forming layers of diamond. The process is similar to the way water molecules condense from the air to form frost on a window.



Schematic diagram of CVD growth technology.
Illustration courtesy of Apollo Diamonds Inc.

Vacuum chamber for growing CVD diamonds and a technician at Apollo Diamond. Photo courtesy of Apollo Diamond.

Will Diamonds Spur the Next Industrial Revolution?

Diamonds are one of the most remarkable materials known to man due to their unique composition and crystal structure of densely packed atoms. They are highly valued for their beauty and durability as gemstones, as well as by industry and scientists for their unique properties. Diamonds are the hardest known substance and have a very high melting point, which make them excellent for cutting tools, wire dyes and as coatings to protect other materials. They have the highest thermal conductivity of any natural substance, yet barely expand when heated, which makes them useful as heat sinks and in other thermal applications. They are also excellent electrical insulators, yet they can be electrically conductive if doped with boron, which could make them the key to faster computers in the future. In addition, diamonds are transparent to UV and infrared light and resistant to acids, which makes them valuable as specialized windows.

The wide range of industrial applications of diamonds affects our daily lives. Diamond cutting and drilling tools make road repairs quicker and oil exploration cheaper. Diamonds make dental work less painful, new eyeglasses ready in one hour, and surgical blades resistant to dulling. Almost every industry from mining to automotive to aerospace is exploring diamond's potential.

Obvious drawbacks of natural diamonds, such as rarity and inconsistent purity, make laboratory-created industrial diamonds the material of choice for most industrial uses. According to the 2003 U.S. Geological Survey, more than 90% of the industrial diamond market used laboratory-created industrial diamond. Each year over 100 tons of synthetic diamonds are produced annually worldwide by manufacturers such as De Beers' Element Six, Diamond Innovations (previously part of General Electric) and U.S. Synthetics.

Imagine how man will be able to put to use laboratory-created diamonds as their quality, purity and size continue to increase in the future. Will diamonds be the key to the super computers of the future, replace sapphire crystals in watches, provide the ultimate in optical windows and be the secret to switches in fusion energy? The possibilities may be virtually limitless.

Diamond Types

Most people think of diamonds as pure carbon, but actually the majority of diamonds contain trace amounts of other elements, called impurities. Diamonds are classified into four basic types based on the relative presence of impurities.

Characterization of different diamond types is established by a diamond's transparency to ultraviolet light, absorption in the 1000 to 1400 cm -1

Ia

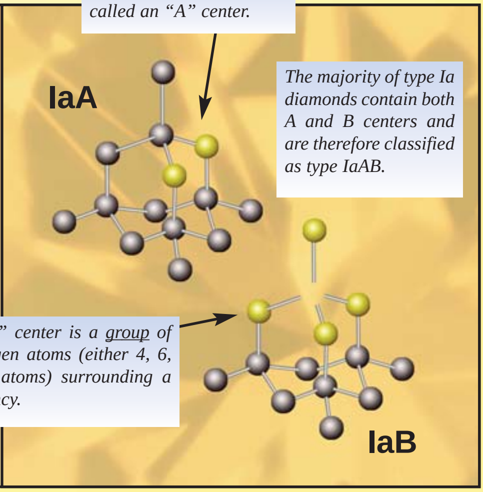
***98%* of all *natural* diamonds**

***Colors*:** *Colorless, near colorless, "Cape" yellow, and brown are the most common colors of Ia. All colors except blue are possible.*

***UV/VIS absorption*:** *Absorb light below 300nm*

***Infrared absorption*:** *Absorption peaks are at 1282 and 1180 cm-1*

Laboratory-created diamonds are never type Ia when they are grown. However, scientists have been able to change type Ib diamonds to type IaA by HPHT treating them.



IIa

***1-2%* of all *natural* diamonds**

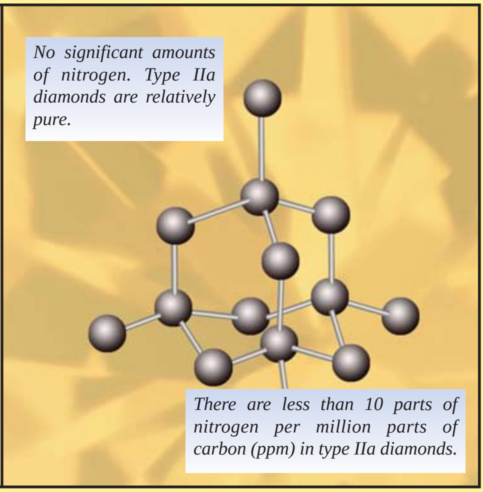
***Colors*:** *Colorless, near colorless, brown, and pink*

***UV/VIS absorption*:** *Transparent to ultraviolet light (opaque below 230nm)*

***Infrared absorption*:** *No detectable absorption from 1000 to 1400 cm-1*

The majority of laboratory-created diamonds grown by the CVD method are type IIa.

It is possible to create type IIa diamonds by the HPHT method, however, the growth rate is much slower and the potential for more metallic inclusions is greater than when nitrogen is present.



range of the mid-infrared spectrum and characteristic birefringence pattern when viewed between crossed polarized filters. These tests are described in more detail in the identification part of this booklet. Determining a diamond's type is a useful first step in identifying the origin (natural versus laboratory-created) because the vast majority of natural diamonds are type Ia. Laboratory-created type Ia diamonds are extremely rare.

Ib

***Less than 1%* of all *natural* diamonds**

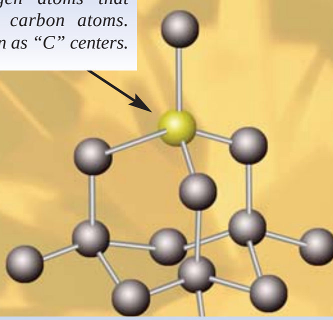
Colors: *"Canary" yellow, orange to brown, and greenish brown*

UV/VIS absorption: *Absorb light below 560nm*

Infrared absorption: *Characteristic absorption peak is at 1130 cm-1*

The majority of HPHT-grown laboratory-created diamonds currently in the jewelry industry are type Ib.

CVD-grown diamonds can contain minor amounts of nitrogen in the form of "C" centers.



IIb

***Less than 0.1%* of all *natural* diamonds:**

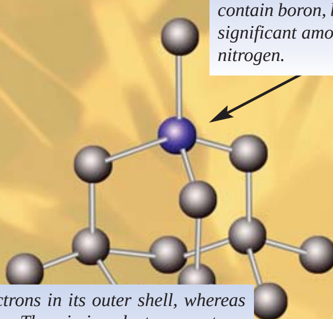
Colors: *Blue and gray*

UV/VIS absorption: *Transparent to ultraviolet light (opaque below 230nm)*

Infrared absorption: *Distinct absorption pattern in the mid-infrared spectrum*

Type IIb diamonds are electrically conductive.

IIb laboratory-created diamonds can be grown by both the HPHT and the CVD method by including boron in the growth chamber



Color Treatments of Diamonds

Laboratory-created diamonds can be further processed, after they are grown, to produce a wider variety of colors. As with natural diamonds, irradiation and high pressure high temperature (HPHT) treatment are the primary color enhancement methods used to change the color of laboratory-created diamonds.

Artificial Irradiation

The artificial irradiation of diamonds uses high-energy particles to create color centers in the atomic crystal lattice. Today, there are a few different types of radiation used to artificially color diamonds. The most common commercial irradiation treatments involve focusing a beam of accelerated particles (electrons or neutrons) at a diamond, which creates green and blue colors. By following irradiation with annealing (heating to around 800°C), the green and blue colors can be changed to warmer hues, such as oranges, pinks and reds. Unlike the earliest experiments with artificially irradiating diamonds, the processes used today do not leave any residual radioactivity in the diamonds.

Ring set with irradiated natural diamonds.
Photo by Dusan Simic.

Irradiation and annealing of natural diamonds can produce a rainbow of colors. However, pink, purple and red colors are exceptional because type Ib diamonds (less than 1% of all natural diamonds) are required to produce these colors.

Type Ib is the most common type of synthetic diamond grown by the HPHT method.

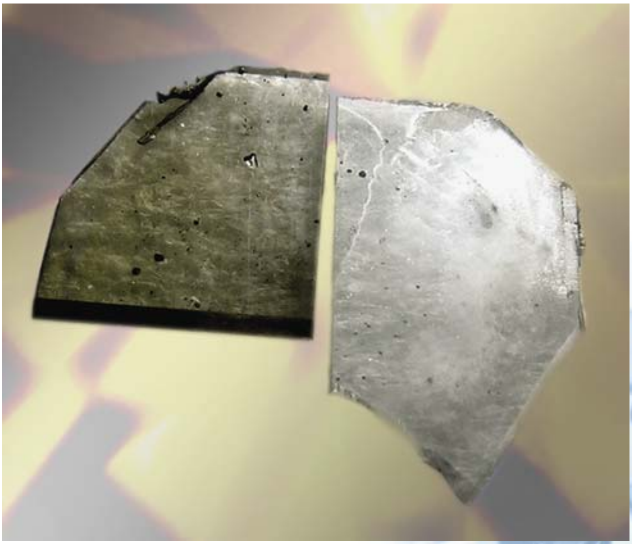
Pink colors are produced by irradiating and annealing type Ib synthetic diamonds after growth.
Gemesis Created diamond.
Photo by Sharrie Woodring.

Manufacturers, like Chatham Created Gems and The Gemesis Corp., are producing a range of pink colors through irradiation and annealing. The purest pink colors result from irradiating and annealing synthetic diamonds with a low concentration of nitrogen (near colorless Ib/IIa), which are more time consuming to grow than type Ib with a high concentration of nitrogen (yellow Ib).

High Pressure High Temperature (HPHT)

The HPHT-treatment process is similar to the process used to grow HPHT-synthetic diamonds. The same equipment is used, but conditions and contents of the capsule are different. HPHT-treatment requires the samples to be heated for only a few minutes at higher pressures and temperatures (1700 to 2400°C at around 70,000 atms) than those required to grow HPHT-synthetic diamonds. The colors resulting from HPHT-treatment primarily depend on the type (i.e. Ia, IIa, etc.) and color of the starting material, but most common enhanced colors are greenish-yellow.

CVD-created diamonds are primarily type IIa. They are very pure and transparent but the majority of "as-grown" CVD-diamonds are brownish. Experiments have shown that treating type IIa brownish CVD-grown diamonds with HPHT can produce lighter to colorless and occasionally pinkish results. The HPHT-treatment of CVD-diamonds is still being studied.



CVD-grown wafers "as-grown" (left) and after HPHT treatment to lighten color (right). Photo courtesy of Apollo Diamond Inc.

Part II

Identification

Introduction

Laboratory-created diamonc have distinct and unique featu because they are grown ir relatively short perio comparison to natural The purpose of this section is to illustrate and describe characteristics of HPHT and CVD-grown diamonds detectable with standard gemological equipment.

*The first impression of this vivid colored diamond is that it may be laboratory-created, but it is a **natural diamond**.*

Ring by Kattan Diamond.

Laboratory-created diamonds are being produced in several colors. Many of the colors are very natural in appearance. It is possible to grow colorless and near colorless diamonds by both the HPHT and CVD methods, but their commercial availability is still extremely limited.

*The optical and physical properties of laboratory-created diamonds are the same as natural diamonds. Therefore **testers designed to distinguish diamonds from simulants will not work**. CZ-type testers measure a sample's thermal conductivity. Moissanite testers measure a sample's electrical conductivity. Photo by Julia Kagantsova.*

Distinguish natural diamonds from synthetic diamonds

How to begin:

1. Verify the sample is a diamond by using a CZ/Moissanite tester.

2. Examine under a gemological microscope. Look for inclusions, color zoning and graining.

3. Observe fluorescence under long wave and short wave ultraviolet light. Look for fluorescence patterns and for phosphorescence.

4. Examine anomalous birefringence strain patterns between crossed polarizing filters.

5. Look for absorption lines with the handheld spectroscope.

6. Analyze the characteristics observed. Determine if the diamond should be sent to a laboratory for additional testing.

Identification techniques are described on pages 19 to 36.

Opposite Page: Metallic inclusions in a HPHT-grown diamond.

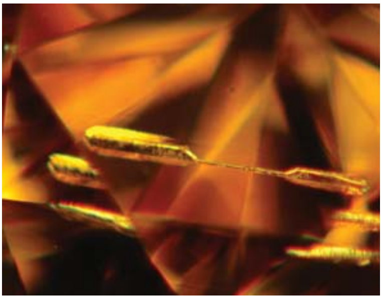
Identification of HPHT-Grown Diamonds: Standard Gemological Equipment

The Microscope

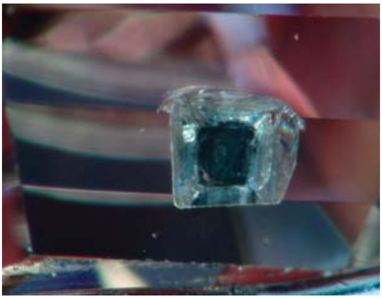
In some cases, careful observation of under magnification can prove a diamond is laboratory-created. HPHT-grown diamonds can have very distinct inclusions attributable to the growth environment and the formation of the crystal. When observing a diamond under the microscope, use a variety of lighting techniques, including darkfield light, fiber optic lighting and diffused transmitted light, to best discern features.

Metallic Inclusions

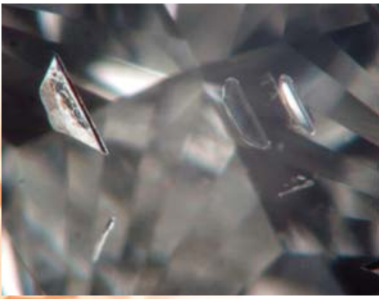
Metallic inclusions occur in HPHT grown diamonds when flux is trapped in the growing crystal. They are **proof of synthetic origin**. Metallic inclusions typically take the form of elongated crystals or flat tabular crystals. Occasionally, metallic inclusions showing crystal faces parallel to the diamond crystal faces are seen.



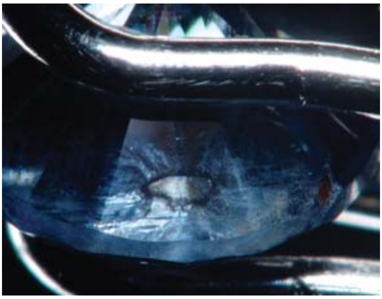
Elongated metallic inclusions in the table of this stone are oriented along growth sector boundaries. Chatham Created diamond.



Occasionally, metallic inclusions showing crystal faces parallel to the diamond crystal faces are seen. Chatham Created diamond.



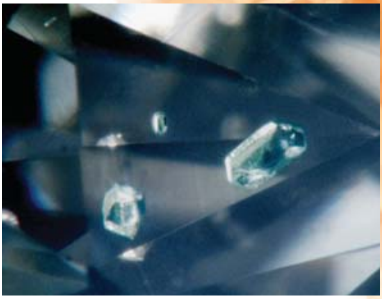
Flat tabular metallic inclusions. In darkfield illumination, metallic inclusions are opaque. Gemesis Created diamond.



A surface reaching inclusion reflects overhead light and has metallic luster. Chatham Created diamond.

Photos by Sharrie Woodring.

Some surface reaching metallic inclusions have more of a granular texture in reflected light. Gemesis Created diamond.



Inclusions in natural diamonds can have a similar elongated, rounded crystal shape, but generally they are not opaque. Test the magnetism of the inclusions by the methods described below. Photos by Sharrie Woodring.

Magnetic Test

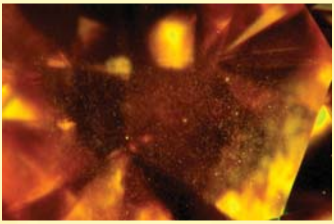
<u>Natural diamonds do not contain metallic inclusions and, therefore, will not be attracted to a magnet.</u>

If the metallic inclusions are large enough, you can suspend the diamond from a strong magnet. If the metallic inclusions are small, magnetism may be difficult to detect. However, by floating a piece of paper in the center of a full glass of water and then placing the diamond on top, even a weak magnetic reaction can be detected. Before starting, make sure the diamond is completely still and there are no air currents to move the diamond. Hold a strong magnet near the diamond without touching it. If the inclusions are magnetic, the diamond will either be repelled away from or move toward the magnet.

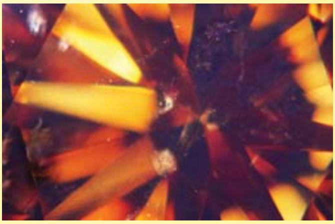
Photos by Julia Kagantsova.

Clouds

Clouds of tiny pinpoints dispersed throughout are common in yellow to orange HPHT-grown synthetic diamonds. However, clouds with a similar appearance can also occur in natural diamonds. Careful examination and experience can sometimes distinguish them.



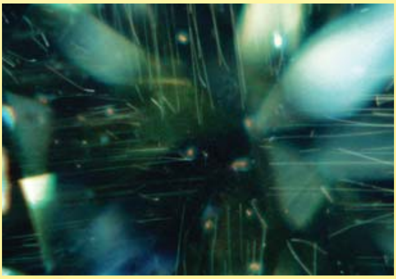
*Clouds can be difficult to find in darkfield illumination, but stand out brightly in **fiber optic illumination**. Gemesis Created diamond.*



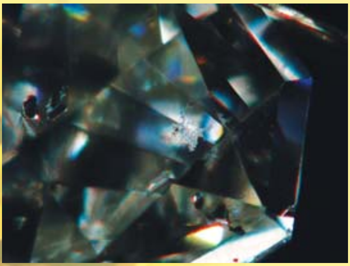
Whitish clouds with denser areas and fairly defined edges, which are typical in natural diamonds.

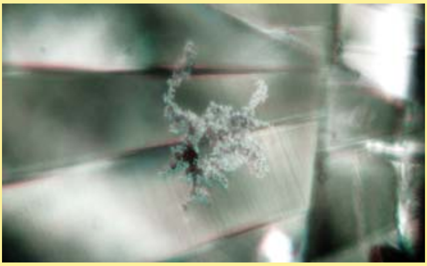
An unusual cloud of geometric shaped, thin platelets, resembling cellophane confetti, was observed around a metallic inclusion in one Gemesis Created diamond.

Other Inclusions



Stringy needles arranged in a cross pattern in a Gemesis Created diamond. EGL USA have never seen documentation on these types of inclusions in synthetic diamonds before.

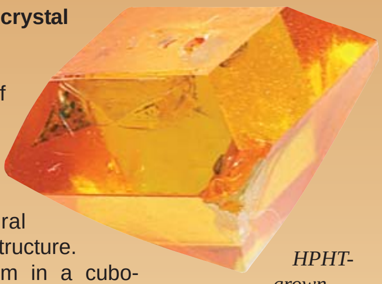




Unusual inclusions, reminiscent of moss-like or dendritic inclusions in agate, were observed in two Gemesis Created diamonds. The nature of these inclusions is not known. Magnification 10x (left and 60x (right).

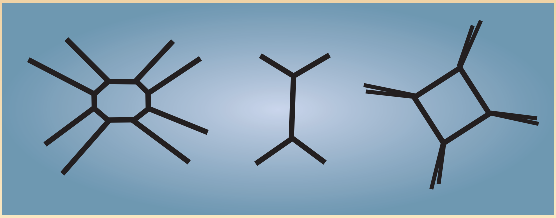
Photos by Sharrie Woodring.

Crystal shape and patterns related to crystal growth



The morphology and growth structure of natural diamond crystals is very different from HPHT laboratory-created diamond crystals. Features correlating to the growth structure are excellent identifying characteristics. Natural diamonds form in an octahedral crystal structure. HPHT laboratory-created diamonds form in a cubo-octahedral structure with possible dodecahedral and trapezohedral faces depending upon the temperature and pressure used during growth and the metal alloys of the solvent/catalyst.

HPHT-grown synthetic diamond crystal with a cubo-octahedral crystal structure. Courtesy of The Gemesis Corp.

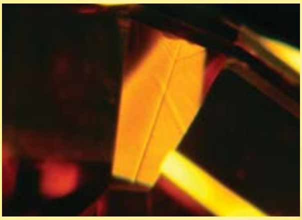


Characteristic patterns related to the growth structure and morphology of HPHT-grown synthetic diamonds. In faceted HPHT laboratory-created diamonds, all or only parts of these patterns may appear as color zoning, graining, and UV fluorescence patterns. Observation of these patterns conclusively identifies a diamond as laboratory-created.

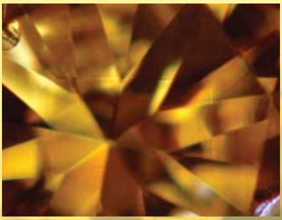
Graining

Graining is caused by boundaries between growth sectors. When graining, oriented in the patterns described in the box above, is detected, it is proof the diamond is a HPHT-grown synthetic. Graining is usually best viewed through the pavilion with darkfield illumination.

Round brilliant cut Chatham Created diamond with crisscrossing graining visible in the pavilion.



Emerald cut from an unknown manufacturer with graining in the pattern commonly known as an "hourglass." Frequently, this graining pattern is found in the corners of emerald and Asscher cuts when observed through the pavilion.



The graining in the table of this Chatham Created diamond is easily overlooked because it is so faint, but detecting it is worth the effort because it conclusively proves synthetic origin.

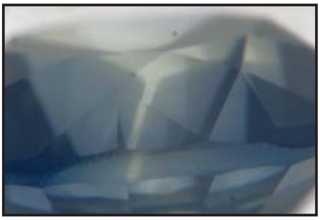
Photos by Sharrie Woodring.

Color Zoning

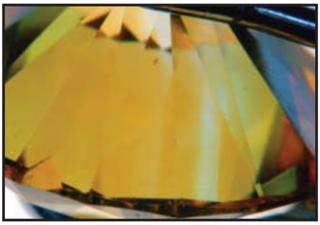
Viewing colored diamonds in diffused transmitted light is the best way to see variations and zones of color that are helpful in identification. If the zones follow the cubo-octahedral internal growth sectors then it is proof of synthetic origin (as pictured on page 22).

Some synthetic diamonds that appear green face-up have distinct zones of blue and yellow causing the green color. To the best of our knowledge, such distinct blue and yellow zoning has never been observed in natural green diamonds. Gemesis Created diamond.

Purplish pink colors are zoned with lighter yellowish pink areas. Color concentrations resulting from irradiation treatment are not visible. Chatham Created diamond.

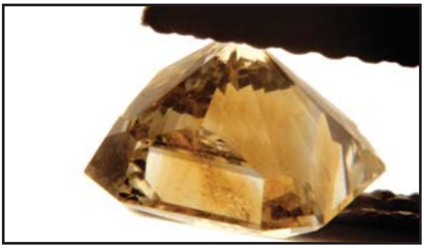


Colorless and blue zoning follow the cubo-octahedral growth sectors, creating a diagnostic pattern in this Chatham Created diamond. The colorless "martini glass" shaped pattern in the crown on the left continues into the pavilion.



In these Gemesis Created diamonds, distinct yellow and colorless zones are visible through the pavilions.

A darker yellow cross-shaped zone is visible against a lighter body color in this laboratory-created diamond. Manufacturer is unknown.



Color zoning is unusual in natural yellow diamonds, however, when it does exist, it tends to be irregularly distributed and have less defined edges. Color zoning in synthetic diamonds is straight and angular.

Photos by Sharrie Woodring.

The Ultraviolet lamp

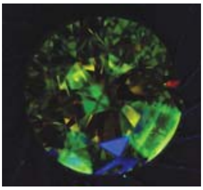
An ultraviolet lamp is one of the most useful pieces of equipment for identifying HPHT-grown diamonds. Many fluorescent colors are subtle so they should be viewed in a dark room after giving your eyes time to adjust. View the diamonds against a black non-fluorescent background and hold the lamp close to the stone. To help discern fluorescence patterns, magnification is helpful. A microscope fixed with an UV lamp positioned overhead is ideal, but a magnifying visor can also serve if necessary. Use caution when working with ultraviolet light, especially with shortwave (SW). Wear protective lens and never look directly at the light

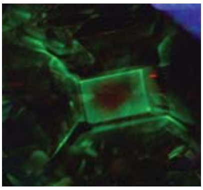
Yellow

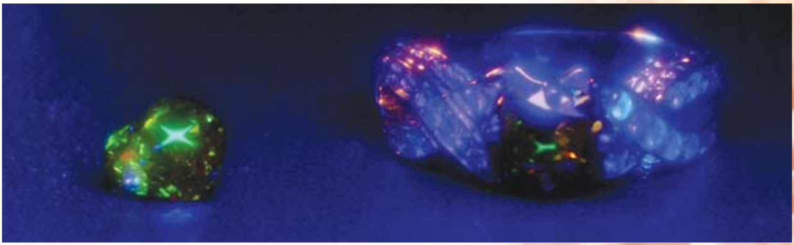
Vivid yellow HPHT laboratory-created diamonds have been produced longer than any other color. Today, a much larger range of the hue is commercially available, from light yellow to intense yellow orange to deep yellow.

When viewed under SW UV light, yellow to orange laboratory-created diamonds usually display a yellowish green pattern with inert areas. Sometimes the pattern is very small and requires magnification to distinguish. When the pattern follows the internal growth sectors, as in the photos below, it is proof of synthetic origin. Under LW UV light, the intensity of the fluorescence is much weaker or inert.

Gemesis Created diamonds. Photos by Julia Kagantsova.







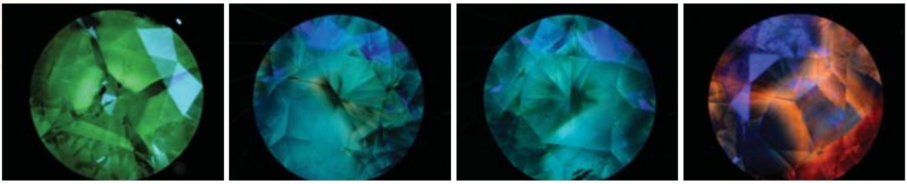
Upper left and center photos: Yellow Chatham Created diamonds.
Upper right and lower photos: Yellow Gemesis Created Diamonds. Photos by Sharrie Woodring.

Blue

Chatham Created diamond. Photo by Julia Kagantsova.

The blue color of HPHT-grown diamonds is produced during the growth of the crystal by the addition of boron to the metal flux.

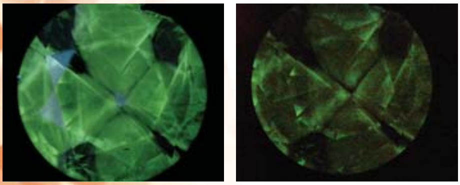
Blue HPHT-laboratory-created diamonds display a stronger reaction under SW UV light than under LW. Fluorescence under SW UV varies from a yellowish green to a chalky greenish blue to a reddish orange. Some samples emit phosphorescence after the lamp is turned off, which is generally the same color as the fluorescence but a weaker intensity. Under LW light, the fluorescence ranges from inert to medium intensity and in many samples is orange. In some samples, the phosphorescence after LW UV is stronger than the fluorescence to LW UV.



Left: blue Gemesis Created diamond. Center and Right: Three blue Chatham Created diamonds. Photos by Sharrie Woodring.

Green

A range of green hues produced by Gemesis for research purposes only. The round and square samples in the top row and the round brilliant in the lower right are type IIb and Ib with zones of blue and yellow producing an overall green color. The center and the lower left samples were irradiated after growth to produce the green color. Photo by: Julia Kagantsova.



SW UV fluorescence (left) and SW phosphorescence (right) of a Gemesis Created diamond. The fluorescent reaction of the as-grown greens is similar to the blues described above. Photos by Sharrie Woodring.

Chatham Created diamond. Photo by Julia Kagantsova.

Pink

A range of pink colors, from peachy pink to purple pink, are produced by irradiating and annealing laboratory-created diamonds after growth is complete. The starting material is light yellow to near colorless. Reddish colors can also be produced by irradiation and annealing.

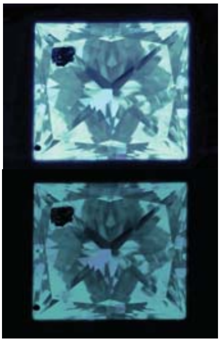
Gemesis Created diamond produced for research purposes only. Photo by Julia Kagantsova.

Pink HPHT-laboratory-created diamonds display a weak to strong reddish orange fluorescence with a similar intensity under both LW and SW UV. Some samples emit a weak orange phosphorescence. Occasionally a greenish pattern is visible, seemingly superimposed on orange body color fluorescence under SW UV, as seen in the photo on the right. Left and center: Pink Chatham Created diamonds. Right: Pink Gemesis Created diamond. Photos by Sharrie Woodring.

Colorless to Near Colorless

Colorless to near colorless HPHT-grown synthetics are able to be produced in higher clarities and colors than ever before. However, their commercial availability is still very limited. Neither Chatham nor Gemesis are currently marketing colorless laboratory-created diamonds.

Gemesis-Created diamond produced for experimental purposes only. Photo by Julia Kagantsova.



SW fluorescence (upper) and LW fluorescence (lower) of a colorless Gemesis Created diamond. The fluorescence of colorless synthetic diamonds is usually stronger under SW than LW UV. Colorless synthetic diamonds fluoresce a range of colors from yellowish green to bluish green to chalky greenish blue. The intensity of the fluorescence is very weak to strong under SW UV and inert to weak under LW UV. In almost all colorless HPHT-grown synthetics, the SW phosphorescence is strong and persists for more than 10 seconds. Photos by Sharrie Woodring.

Identification of HPHT-Grown Diamonds: Advanced Gemological Equipment

Spectroscopy

One of the most important techniques used by gemological laboratories is spectroscopy. Different types of gemstones have characteristic absorption and transmission patterns that aid in identification. Handheld prism and diffraction spectroscopes can only look at the visible region of the electromagnetic spectrum. Spectrophotometers provide a way to analyze a wide range of the spectrum and objectively and quantitatively record the data by plotting a graph of results.

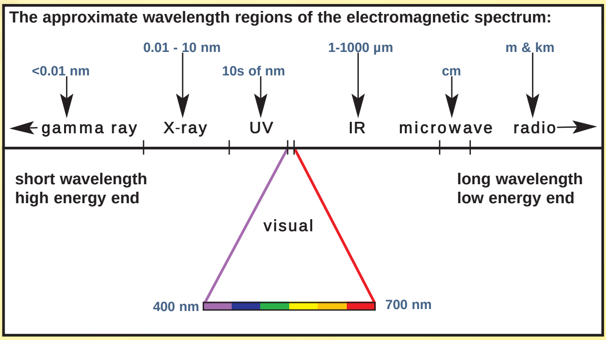


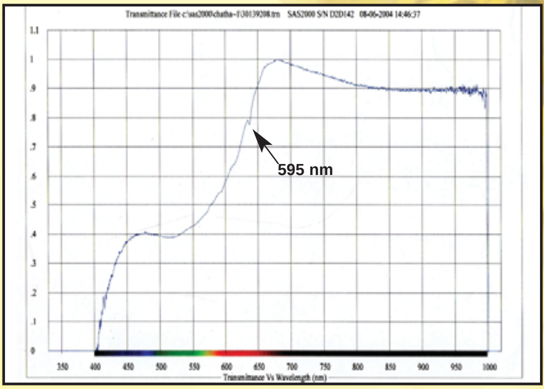
Diagram of the electromagnetic spectrum. The UV, Visible and Infrared regions are examined by gemological laboratories.

VIS/NIR Spectroscopy

VIS/NIR spectroscopy measures how much light a gemstone absorbs or transmits at wavelengths from 400 to 1000 namometers (nm). Many color-causing defects in diamonds can be detected by this technique. EGL USA prints this graph on its Colored Diamond Analysis Report to support the identification and conclusion of origin.

Visible spectra of a HPHT-grown synthetic yellow diamond produced by a Russian manufacturer showing nickel lines between 700 and 800 nm. Graph taken by an SAS2000 spectrophotometer with the sample cooled in liquid nitrogen to approximately -196 C to achieve the best possible resolution.

Nickel is frequently a component of the catalyst/solvent during growth of HPHT-grown synthetic diamonds, and therefore often occurs as an impurity. Nickel is very rarely found in natural diamonds.

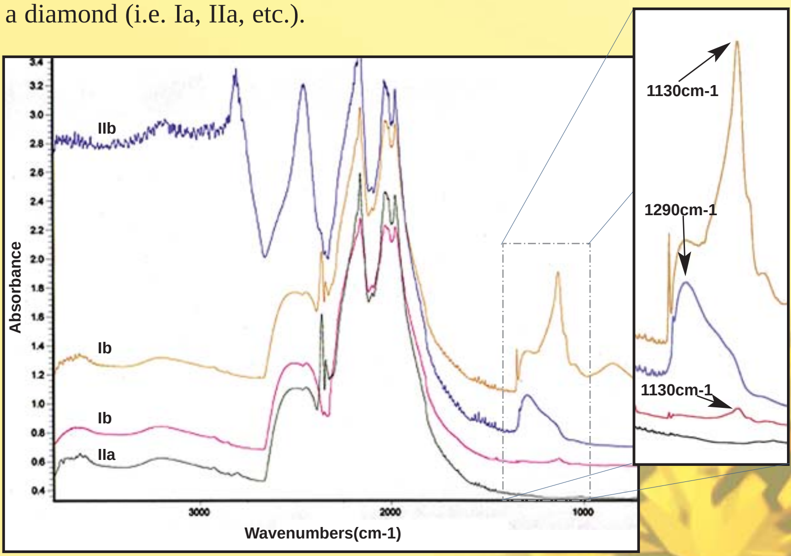


Visible spectra of a HPHT-grown irradiated pink diamond produced by Chatham Created Gems showing peaks at 595 and 637 nm. Graph taken by an SAS2000 spectrophotometer with the sample cooled in liquid nitrogen to approximately -196 C to achieve the best possible resolution.

These peaks are caused by radiation damage and occur in both irradiated laboratory-created diamonds and irradiated natural diamonds. Irradiation of HPHT-grown light yellow to near colorless diamonds can produce reddish, purple and pink colors. For more information, please see *pages 15-16 regarding color treatments.*

Fourier-Transform Infrared Spectroscopy (FTIR)

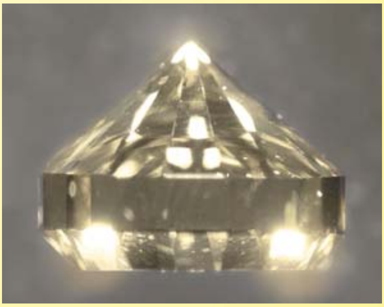
Infrared spectroscopy measures how much light a gemstone absorbs or transmits at wavelengths from approximately 12,000 to 400 cm-1 (1,000 to 25,000 nm). Infrared spectroscopy is usually referred to in wavenumbers (cm-1) rather than nanometers (nm). One of the most common uses of FTIR is for analysis of the single-photon region of the spectra, from 1000 to 1500 cm-1, which can determine the quantity and form of nitrogen a diamond contains and therefore establishes the type of a diamond (i.e. Ia, IIa, etc.).



FTIR graphs typical of laboratory-created diamonds. Blue laboratory-created diamonds are type IIb, yellow to orange are type Ib, and colorless are type IIa. Diamonds containing a small amount of single nitrogen are typically near colorless to light yellow and are the starting material for irradiation to create pink colors. Single nitrogen causes a peak at 1130cm-1. Boron causes a peak around 2457cm-1 and band centered at 1290cm-1.

Identification of CVD-Grown Diamonds: Standard Gemological Equipment

CVD diamonds range in color from near colorless to brown (light to dark) to tool-grade black. After growth is complete, the synthetic diamonds can be HPHT treated to lighten the color. It is also possible to grow pink and blue colors, however these are still extremely rare. EGL USA has not examined any of these diamonds so their properties are not described in this booklet. Faceted CVD-diamonds can be any shape, however, they tend to be shallow due to the shape of the rough material.

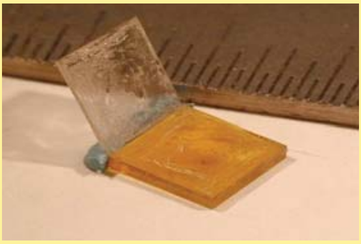


A near colorless as-grown CVD diamond created for research purposes by Carnegie Institution's Geophysical Laboratory. The diamond is 2.5mm deep and was grown in about one day. They are using diamonds as anvils in specially designed presses to analyze materials at ultrahigh pressures. Photo courtesy of Carnegie Institution.

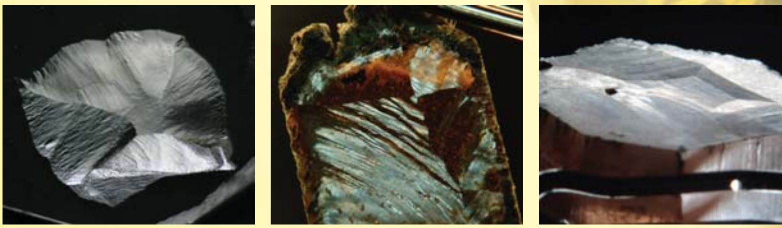
Crystal Shape

Three CVD-grown diamond crystals prepared for faceting (left). The largest is 2.95mm thick. The rough crystals are cut in a variety of shapes, but typically the faceted stones are shallow due to the limited depth of the crystal (right). Apollo Created diamonds. Photos by Julia Kagantsova.

During growth, polycrystalline diamond develops on the edges of CVD diamond crystals. The polycrystalline diamond is extremely hard and difficult to cut with traditional lapidary saws. Before faceting, these areas are removed by lasers. Photo by Sharrie Woodring.



CVD wafer (near colorless) was lifted from the seed (yellow HPHT-grown synthetic diamond) with the use of technology developed by the Navel Research Laboratory. Photo courtesy of Apollo Diamond Inc.



Rectangular depressions, suggesting cubo-octahedral morphology, have been observed on the surfaces of some CVD wafers. Samples courtesy of Apollo Diamond Inc. Photos by: Thomas Hainschwang (left) Sharrie Woodring (center and right).

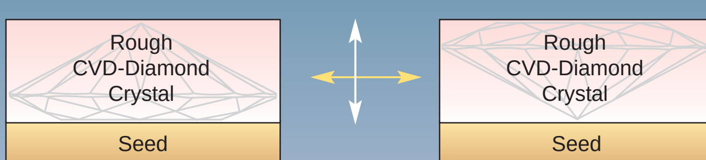
The Microscope

Single-crystal CVD diamonds are generally quite pure and free of inclusions. The faceted samples examined range from slightly to very slightly included. When inclusions are present, they are indications of the origin, but cannot conclusively identify the stone as laboratory-created.

Black, opaque inclusions, assumed to be non-diamond carbon are found in some CVD-diamonds. The inclusions can occur as individual crystals (left: faceted CVD magnified 50x) or around cavities that are oriented parallel to the direction of growth (see box below). In some samples (right: CVD magnified 20x), inclusions are found near the girdle where the polycrystalline diamond was not completely removed.
Apollo Created diamonds. Photos by Sharrie Woodring.

White to brown inclusions, reminiscent of "breadcrumb" inclusions in synthetic amethyst, can be found lying in one plane perpendicular to the direction of growth (see box below). Higher magnification will reveal some of the inclusions to be micro-fractures, unlike pinpoints found in natural diamonds. Apollo Created diamond. Photo by Thomas Hainschwang.

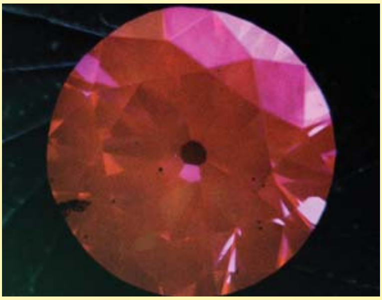
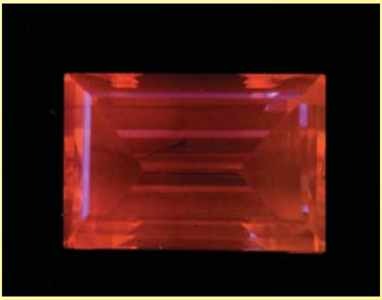
Orientation of inclusions due to crystal-growth



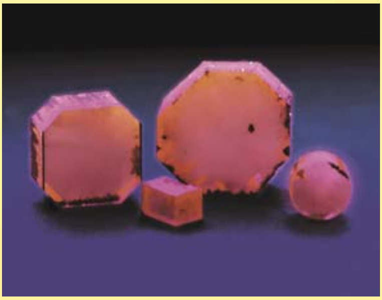
When rough CVD diamonds are cut and faceted, they are normally oriented as illustrated above. Occasionally during faceting, not all of the seed is removed. The remnant of the seed is a thin layer which may be found on the table or on the culet.
The white arrow indicates the direction of CVD growth. In faceted CVD diamonds, cavities and inclusions may by found oriented in this direction.
The yellow arrow indicates the direction perpendicular to CVD growth. Some CVD diamonds have clouds lying in one plane oriented in this direction.

The Ultraviolet Lamp

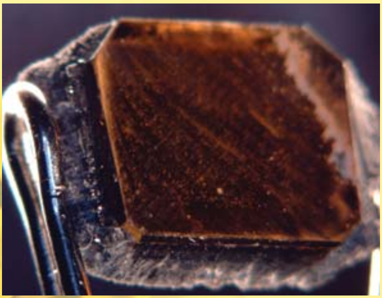
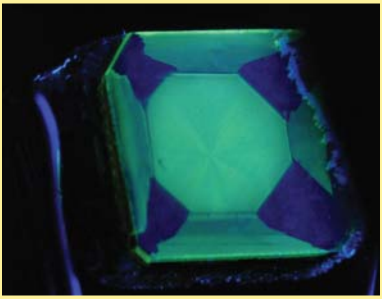
CVD-grown synthetic diamonds show a weak but characteristic orange, with sometimes one surface of yellow-green (due to HPHT synthetic seed) luminescence under 254 nm ultraviolet radiation (SW UV). Unlike most natural diamonds, the SW UV reaction of CVD-diamonds is slightly stronger than the LW UV reaction.

Two typical faceted as-grown CVD diamonds under SW UV light emitting a weak reddish orange fluorescence and medium yellowish orange fluorescence. Apollo Created diamonds. Photo by Sharrie Woodring.

Four as-grown CVD crystals ranging from 0.21 to 2.54 carats under daylight (left) and under SW UV light. Apollo Created diamonds. Photos by Julia Kagantsova..

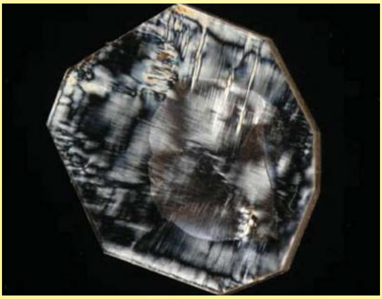



CVD-diamond wafer with seed in daylight (left) and under SW UV light. The CVD part has only a very weak reddish fluorescence but the seed fluoresces a strong yellowish green with a pattern characteristic of HPHT-grown synthetics.
Apollo Created diamond. Photo by Sharrie Woodring.

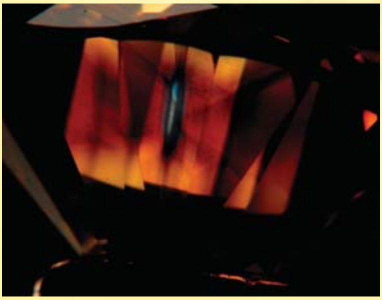
Crossed Polarizing Filters

All diamonds show anomalous birefringence strain patterns to some extent when examined between crossed polarizing filters. The patterns are significant to diamond cutters because they reveal areas of stress in diamonds. Anomalous birefringence appears as light and dark bands alternating with bright rainbows of color centered around areas of strain. While the patterns of natural diamonds vary widely, distinct characteristic patterns exist that can aid in the identification of different diamond types and in the identification of laboratory-created diamonds.

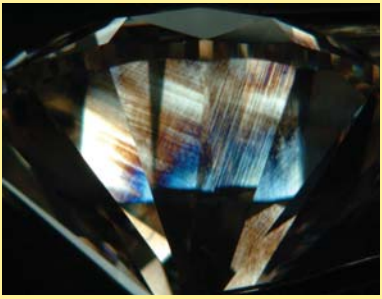
Observe anomalous birefringence strain patterns by attaching polarizing filters to a gemological microscope with darkfield illumination. Orient the filters in the crossed (dark) position and examine the diamond from table to culet.



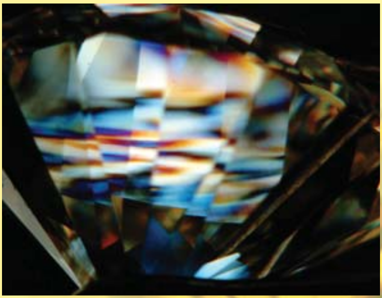
***CVD wafer** between crossed polarizing filters, a strong striped anomalous birefringence pattern suggests that the diamond grew from only 4 growth sectors. Photo by Thomas Hainschwang.*



***HPHT-grown synthetic diamond** with anomalous birefringence pattern following the cubo-octahedral growth structure. In many HPHT-grown diamonds, the strain patterns are weaker than the example shown here. Photo by Sharrie Woodring.*



*Cross-hatched strain known as the "Tatami" pattern is typical of **natural type IIa diamonds** and is caused by plastic deformation (misalignment of the crystal lattice). Photo by Sharrie Woodring.*



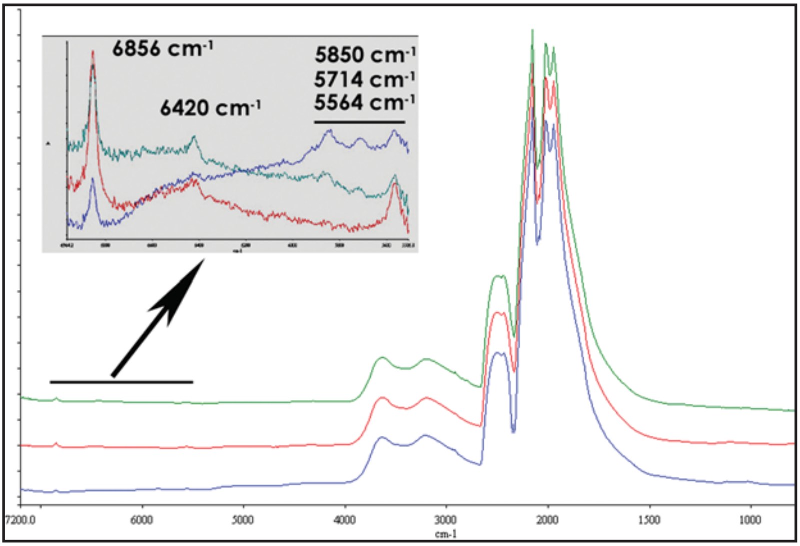
*One of many anomalous birefringence patterns, with typical bright colors, found in **natural type Ia diamonds.** This pattern is due to non-uniform impurity distribution. Photo by Sharrie Woodring.*

Handheld Spectroscope

CVD-grown synthetic diamonds **do not** have any significant absorption in the visible spectra, however, examining the spectra is a helpful step in identification because the majority of **natural diamonds** do have characteristic absorption lines. Natural colorless to yellow diamonds absorb light at 415, 450, and 478nm; these are known as **"Cape lines."** Many brown and pink natural diamonds also have a distinct absorption line at 415nm. Thus far, these lines have only very rarely been observed in laboratory-created diamonds. Therefore, **detection of the 415nm line indicates a diamond is natural.**

Identification of CVD-Grown Diamonds: Advanced Gemological Equipment

Fourier-Transform Infrared Spectroscopy (FTIR)



Weak, sharp absorption peaks at about 6856 and 6420 cm-1 are hydrogen-related centers that have never been observed in natural diamonds at these positions.CVD-grown synthetic diamonds are usually type IIa, although some may also have a very minor Ib component. A very low nitrogen content in the form of single nitrogen (Ib) is rarely found in natural diamonds. Graph by Thomas Hainschwang.

De Beers Detection Instruments

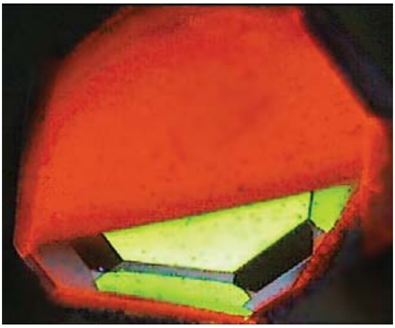
DiamondSure©

The DiamondSure is a preliminary screening instrument that analyzes the region below 500nm in the UV/VIS spectra. The instrument will "PASS" a sample or refer it for "FURTHER TESTS" depending primarily on the detection of the 415nm peak, which is found in an estimated 98 % of all natural diamonds.

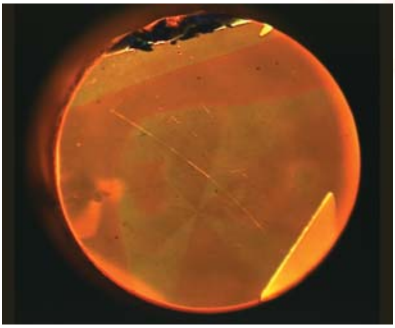
DiamondView©

The DiamondView enables the user to examine the fluorescence and phosphorescence emitted by a sample when exposed to intense far-ultraviolet light (SW UV). Fluorescence patterns are visible due to the varying impurity concentrations in the growth sectors that are unique to natural diamonds, HPHT-grown and CVD-grown synthetic diamonds. The patterns and colors of fluorescence emitted are similar to those sometimes observed under shortwave light from a standard gemological UV lamp. However, the energy of the light in the DiamondView produces results in nearly all diamonds, even those that do not fluoresce under standard UV lamps.

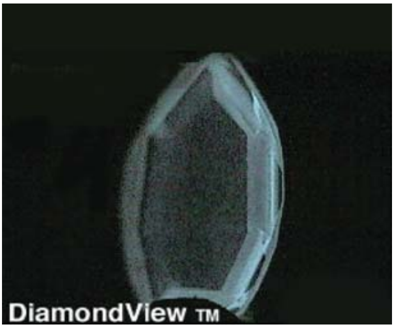
The majority of CVD-grown diamonds emit strong orangy-red fluorescence when observed with the DiamondView. Frequently, striations following the growth structure are visible.



A DiamondView image of an HPHT-treated faceted CVD diamond emitting an reddish orange fluorescence. The yellowish green fluorescence is part of the seed (an HPHT-grown synthetic diamond) used to initiate CVD growth, which was not completely removed by cutting. Image by SSEF Swiss Gemmological Institute, Switzerland.



A DiamondView image of an as-grown CVD wafer showing a cubo-octahedral growth pattern probably initiated by the seed crystal. Image by The Central Gem Lab, Japan.



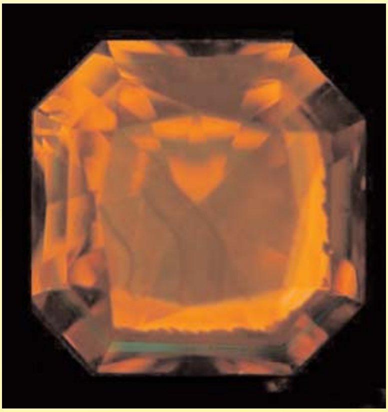
Strong bluish-white phosphorescence of a 0.16ct faceted pear shape as-grown CVD diamond manufactured by Apollo Diamond. Phosphorescence is the glow emitted by a sample after the light source has been turned off.

The majority of colorless HPHT-grown synthetic diamonds have a similar color phosphorescence.

DiamondView image courtesy of SSEF Swiss Gemmological Institute.

Cathodoluminescence

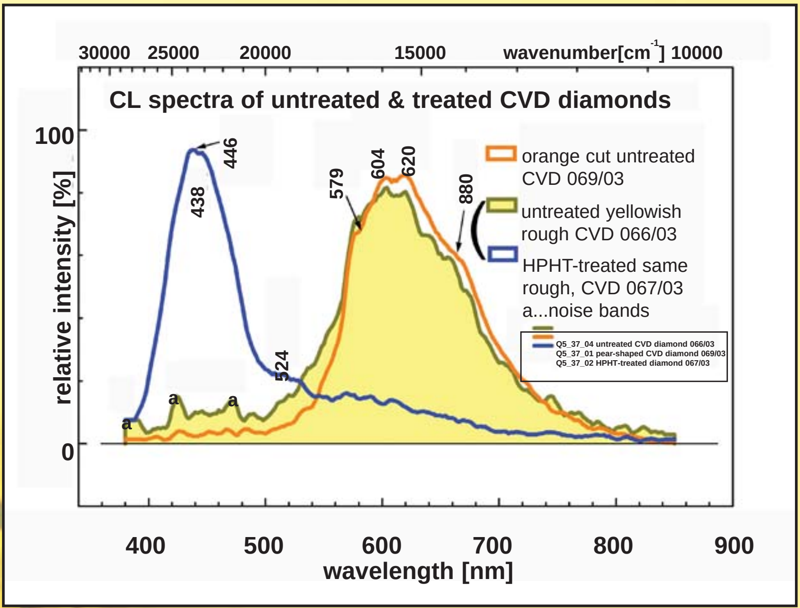
Cathodoluminescence (CL) occurs when a diamond is exposed to a strong beam of electrons. The energy of the electrons excite the molecules and cause the sample to luminesce. The color and intensity of the luminescence can be observed or recorded by spectroscopy.



CL Luminescence of a 0.28-carat faint brown CVD diamond manufactured by Apollo Diamond.

As-grown CVD diamonds usually emit a strong brownish orange luminescence when exposed to a strong beam of electrons (CL). In some cases, patterns revealing the growth history are visible. After the HPHT treatment of CVD diamonds, the CL color typically changes to bluish.

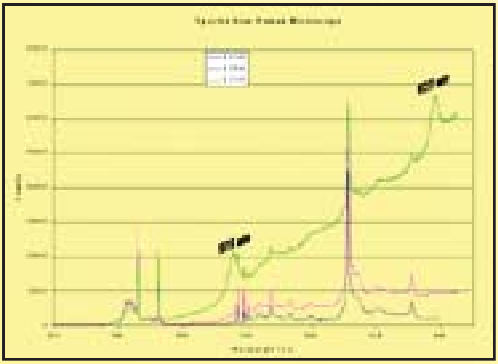
Image by Pat Heyman, University of British Columbia.



CL spectra graph of CVD diamond samples before and after HPHT treatment to lighten the color. The band at 575nm is causing the orange luminescence and shifts to 430nm after HPHT treatment causing blue luminescence. CL spectroscopy provides a way to objectively and quantitatively record the color and intensity of luminescence. Graph by Johann Ponahlo.

Raman Spectroscopy

Raman spectroscopy involves illuminating a sample with a laser of a specific wavelength (monochromatic light) and using a spectrophotometer to analyze the light scattered by the sample. The decrease of the intensity and energy of the light before entering the sample and after scattered by the sample is known as the Raman shift. A spectrophotometer plots the changes to the light as a graph. Raman spectroscopy is done with the sample at low temperature (usually immersed in liquid nitrogen) and is often used to analyze a specific area or an inclusion in a gemstone by focusing through a microscope.

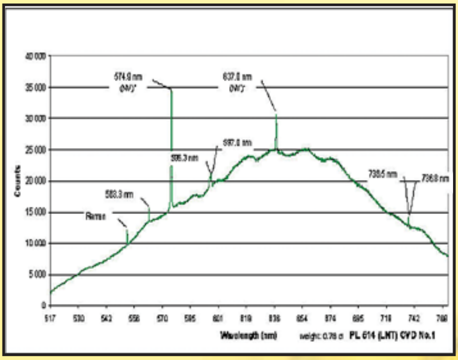


Raman spectroscopy on three CVD samples points out the correlation between the intensity of peaks at 575nm and 637nm (N-V centers) and the intensity of brown colour. The darkest brown material has the strongest N-V centers (plotted in green).

Graph by University of British Columbia.

Raman Photoluminescence

Raman photoluminescence is the analysis of the light emitted by a sample (luminescence) when exposed to a laser of a specific wavelength. A spectrophotometer plots the luminescence as a graph. Raman photo-luminescence is used to examine a gemstone as a whole, not a specific area of the gemstone.



Raman photoluminescence spectra at low temperature (about -120°C.) using the green laser (514.5 nm) with a peaks at 737.5 nm due to silicon. This peak is typical for CVD as-grown synthetic diamonds and has never been found in natural or HPHT-grown synthetic diamonds. Emission peaks at 575 and 637nm (N-V center) also occur in natural diamonds and the intensity ratio of these peaks can be an indication of HPHT treatment. Other noticeable peaks of all as-grown CVD are at 563, 596 and 597 nm.

Graph by SSEF Gemmological Institute.

Identification Summary

When attempting to determine if a diamond is of natural or laboratory-created origin, careful examination with standard gemological equipment will sometimes provide conclusive evidence. Other times, it will only provide hints that indicate the sample should be sent to a gemological laboratory equipped with advanced instruments and experience for additional testing.

Characteristics that are evidence of <u>synthetic origin</u>:

- Metallic inclusion (confirmed by testing for magnetism)
- Graining, color zones and fluorescence in the patterns following cubo-octahedral growth sectors

Characteristics that are evidence of <u>natural origin</u>:

- Cape lines" (415, 450, 478 nm) observed with a handheld spectroscope
- Inclusions of natural origin, such as garnet, peridot and diamond crystals
- Evidence of the rough crystal surface appearing as “naturals” with trigon depressions
- Strong blue reaction to LW UV light

Characteristics indicating the <u>sample should be sent to a laboratory</u> for additional testing:

- Stronger SW fluorescence than LW fluorescence
- Persistent phosphorescence
- Yellowish to reddish orange fluorescence
- Birefringence strain patterns in crossed shaped or columnar configurations

Remember - if in doubt, send it to a laboratory for further testing!

Additional tests used by laboratories:

- UV/VIS/NIR spectroscopy
- FTIR spectroscopy
- De Beers' detection instruments
- Cathodoluminescence observation and spectroscopy
- Raman and photoluminescence spectroscopy

References

Bachmann, P. K. (1995), ***Thermal properties of C/H-, C/H/O-, C/H/N-, and C/H/X-grown polycrystalline CVD diamond.*** *Diamonds and Related Materials, Vol. 4, pp 820-826.*

Barnard A. S., ***The Diamond Formula Diamond Synthesis: A gemmological perspective****. Butterworth Heinemann Press: 2000.*

Chrenko R. M., Tuft R. E., Strong H. M., (1977) ***Transformation of the state of nitrogen in diamond****. Nature, Vol. 270, pp. 141-144.*

Collins A.T. (1982) ***Colour centers in diamond****. Journal of Gemmology, Vol. 18, No. 1, pp. 37-75.*

Collins A.T. (2001) ***The colour of diamond and how it may be changed****. Journal of Gemmology, Vol. 27, No. 6, pp. 341-359.*

Deljanin B., Hainschwang T., Fritsch E. (2003) ***Update of study of CVD diamonds****. Jewellry News Asia, No. 231, November 2003, pp. 134-139.*

Fritsch E., Conner L., Koivula J.I. (1989) ***A preliminary gemological study of synthetic diamond thin films****. Gems & Gemology, Vol. 25, No 2, pp. 84-90.*

Fritsch E., Scarratt K., (1992) ***Natural-Color Nonconductive Gray-to-Blue Diamonds****. Gems & Gemology, Vol. 28, No. 1, pp. 38-39.*

Hainschwang T. (2003) ***Classification and color origin of brown diamonds****. Diplôme d'Université de Gemmologie (DUG), presented at the University of Nantes/France.*

Hazen, R.M. ***The Diamond Makers.*** *Cambridge University Press: New York 1999.*

Lerner, E.J. (2002) ***Industrial diamonds gather strength****. The Industrial Physicist, August/September 2002, pp. 8-11.*

Linares R.C., Doering P.J. (2003) ***System and method for producing synthetic diamond****. US Patent 6,582,513, filed May 14, 1999.*

Martineau M.P., Lawson C. S., Taylor J. A., Quinn J. S., Evans F. J.. D., Crowder J. M. (2004) ***Identification of synthetic diamond grown using chemical vapor deposition (CVD)****. Gems & Gemology, Vol. 40, No. 1, pp. 2-25.*

Nebel C. E., (2003) ***From gemstone to semiconductor****. Nature Materials, Vol. 2, pp. 431-432.*

Olson D. W. (2004) ***Mineral commodity summaries - diamond (industrial)****. U.S. Geological Survey.*

Rooney M-L. T., Welbourn C.M., Shigley J. E., Fritsch E., Reinitz I., (1993) ***De Beers near colorless-to-blue experimental gem-quality synthetic diamond.****, Gems & Gemology, Vol. 29, No. 1, pp. 38-45.*

Shigley J. E., Fritsch E., Reinitz I., Moses T. M. (1995) ***A chart for the separation of natural and synthetic diamond.****, Gems & Gemology, Vol. 31, No. 4, pp. 256-264.*

Wang W., Moses T., Linares R., Shigley J., Hall M., Butler J (2003) ***Gem-quality synthetic diamonds grown by a chemical vapor deposition (CVD) method****. Gems & Gemology, Vol. 39, No. 4, pp. 268-283.*

Welbourn C.M., Cooper M., Spear P. M., (1996) ***De Beers natural versus synthetic diamond verification instruments****. Gems & Gemology, Vol. 32, No. 3, pp. 159-169.*

Yarnell, A. (2004) ***The many facets of man-made diamonds****. C&EN, February 2004, Vol. 82, No. 5, pp. 26-31.*

Zaitsev A.M. (2001) ***Optical properties of diamond****. Springer-Vrlag, Berlin, pp. 502.*

About the Authors

Sharrie Woodring is a Senior Gemologist at EGL USA, one of the world's oldest and largest gemological laboratories. Woodring received her FGA diploma from the Gemmological Association of Great Britain and her Graduate Gemologist diploma in residence from the GIA. She began in the industry in retail and then studied jewelry design at the Fashion Institute of Technology. In 1998, Woodring joined EGL USA, where she has worked as a diamond grader and manager of jewelry services. Currently she is involved with identification, research and education and serves as the company's spokesperson. Woodring has lectured nationally and international about gemology at jewelry trade shows and to gemological associations. She has appeared on NBC News, and in NYC on WCBS-TV, WABC-TV and WNBC-TV. Most recently Woodring was a special guest on the nationally syndicated CBS TV show "Living It Up with Ali & Jack," where she discussed how to buy a diamond and diamond trends.

Branko Deljanin, Director EGL USA's Canadian Operations, is a professional gemologist with extensive background in scientific analysis of gemstones. In 1998, he became Director of Gem Identification and Research for the EGL USA Group. In 2002, he was put in charge of its Canadian Operations, which includes an office in Vancouver and Toronto.

A graduate of the University of Belgrade in geology, Deljanin earned his Graduate Gemologist diploma and worked under the guidance of Bob Crowningshield of GIA in the Gem Identification department in New York. He is a Fellow of the Gemmological Association of Great Britain and an instructor of the FGA Program. Deljanin has conducted on-site research on colored stones and diamonds in Sri Lanka, Russia, Brazil, Australia, and South Africa, and has directed many gemological research projects at EGL USA. Since 1999, he has focused extensively on the High Pressure High Temperature process for changing the color of diamonds and is considered an expert on the subject. Deljanin lectures on diamond and gem issues at jewelry trade shows and scientific conferences around the world. In December 2003, gave a talk at the Material Research Society Conference (MRS) on "New challenge for jewelry industry: Laboratory grown CVD gem quality diamonds."

$19.95 US
$27.95 CAN

EGL USA

Industry Leaders since 1974