Real World Connections
Matter (Part 2)
Hannah

THE MANY FACETS OF MAN-MADE DIAMONDS

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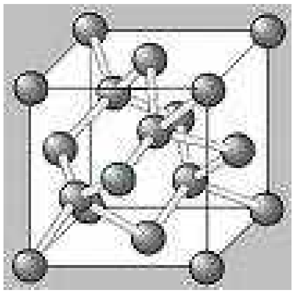
and HOW STUFF WORKS

Diamonds are just **carbon** in its most concentrated form. That's it -- carbon, the element that makes up 18 percent of the weight of your body. When occurring in nature, carbon exists in three basic forms:

- **Diamond** - an extremely hard, clear crystal
- **Graphite** - A soft, black mineral made of pure carbon. The molecular structure is not as compact as diamond's, which makes it weaker than diamond.
- **Fullerite** - A mineral made of perfectly spherical molecules consisting of exactly 60 carbon atoms. This allotrope was discovered in 1990.

Diamonds form about 100 miles (161 km) below the Earth's surface, in the molten rock of the Earth's mantle, which provides the right amounts of pressure and heat to transform carbon into a diamond. In order for a diamond to be created, carbon must be placed under at least 435,113 pounds per square inch (psi or 3,000,000 kilopascals) of pressure at a temperature of at least 752 degrees Fahrenheit (400 Celsius). If conditions drop below either of these two points, graphite will be created. At depths of 93 miles (150 km) or more, pressure builds to about 725,189 psi (50 kilobars) and heat can exceed 2,192 F (1,200 C). Most diamonds that we see today were formed millions (if not billions) of years ago. Powerful magma eruptions brought the diamonds to the surface.



It is the **molecular structure** of diamonds that gives them their properties. Diamonds are made of carbon atoms linked together in a lattice structure. Each carbon atom shares electrons with four other carbon atoms, forming a **tetrahedral** unit. This tetrahedral bonding of five carbons forms an incredibly strong molecule. Graphite, found in pencil lead, isn't as strong as diamond because the carbon atoms in graphite link together in rings, where each atom is only linked to one other atom.

Before the 1930s, the gems of choice for engagement rings included opals, rubies, and sapphires. But in the 1940s, De Beers--the South African mining firm that controls the majority of the world's diamond supply--introduced "A Diamond Is Forever." The success of this campaign turned diamond into the symbol of eternal love and dramatically increased demand for the gems.

Today, two start-up companies are staking their futures on the lure of more affordable, laboratory-grown diamond gemstones. But because of diamond's remarkable optical, thermal, chemical, and electronic properties, synthetic diamond promises to offer a lot more than just beautiful jewelry.

In a warehouse in Sarasota, Fla., a company called Gemesis is growing diamonds in two dozen or so high-pressure, high-temperature crystal growth chambers, each the size of a washing machine. Within each chamber, a tiny sliver of natural diamond is bathed in a molten solution of graphite and a proprietary metal-based catalyst at approximately 1,500 °C and 58,000 atm of pressure. Slowly, carbon precipitates onto the diamond seed crystal. A gem-quality, 2.8-carat rough yellow diamond grows in just under three-and-a-half days.

A rough diamond of this size can be cut and polished to give a diamond gem larger than 1.5 carats. (One-half carat is equal to 100 mg of diamond and is roughly the size of a kernel of corn.) Just like naturally occurring yellow diamonds, the yellow lab-grown stones get their color from trace amounts of nitrogen impurities: Replacing fewer than five out of each 100,000 carbon atoms in the diamond crystal lattice with nitrogen atoms gives a yellow diamond.

Naturally occurring fancy-colored diamonds--yellows, blues, pinks, and reds--are very rare and thus very valuable. A Gemesis-created yellow fancy-colored diamond--visibly indistinguishable from a natural one, even to a trained gemologist--can be purchased for about $4,000 per carat. That's about 30% less than the price of a natural diamond of similar color and quality, according to Robert Chodelka, Gemesis' vice president for technology.

IN THE ROUGH To grow its gem-quality yellow diamonds (a rough one is shown above), Gemesis uses washing-machine-sized crystal-growing chambers to reproduce the high pressures and high temperatures that nature relies on.

Gemesis is growing diamonds for jewelry. And because Gemesis' yellow lab-grown diamonds are visually indistinguishable from their mined counterparts, some in the gem industry have expressed concern that the lab-grown diamonds could be passed off as naturals.

SYNTHETIC DIAMONDS are nothing new. Producing them has been a stable business for the past half century. Today, more than 100 tons of the stones is produced annually worldwide by firms like Diamond Innovations (previously part of General Electric), Sumitomo Electric, and De Beers. Tiny synthetic diamonds are used in saw blades for cutting asphalt and marble, in drill bits for oil and gas drilling, and even as an exfoliant in cosmetics.

The first synthetic diamonds (diamond grit) were produced in the early 1950s by researchers at the Allmanna Svenska Elektriska Aktiebolaget Laboratory in Stockholm, Sweden. They did not immediately publish their work. Soon thereafter, GE researchers reported their own successful diamond synthesis in *Nature*. Like Gemesis, both teams used conditions that mimic the pressures and temperatures under which diamonds are thought to form naturally.

Diamond has an extraordinary range of materials properties: It is the hardest and stiffest material known; is an excellent electrical insulator; has the highest thermal conductivity of any material yet barely expands when heated; is transparent to UV, visible, and infrared light; and is chemically inert to nearly all acids and bases.

Diamond's superlative properties are fine-tuned by impurities found in the carbon lattice--the same impurities that produce colors in naturally occurring diamond. Diamonds having a perfect carbon crystal lattice without defects or substitutions are colorless. Such diamond has a large band gap--meaning that the energy required to free an electron so it can move through the diamond lattice is high--and therefore is an excellent electrical insulator. But replacing some of the carbon atoms in the diamond lattice with boron--an impurity that produces the pretty blue color in some rare diamonds, including the famed Hope Diamond--transforms diamond into a p-type semiconductor. That's because boron has only three outer-shell electrons and can make only three of four bonds that carbon normally does in the diamond lattice. The result is a missing electron or "hole" that can move freely through the crystal, allowing the diamond to conduct positive charge.

DIAMOND RING Because of its op cal transparency, high thermal conductivity, and resistance to chemic attack, synthetic diamond is an attr tive material for making optical v dows for instruments used in extreme environments.

For materials applications that take advantage of these remarkable properties, natural diamonds have obvious flaws: They are prohibitively expensive and limited in size. Gemesis and many others are eager to create large synthetic diamonds with carefully selected impurities--for instance, boron-doped semiconducting diamonds that could be used to fabricate diamond-based electronic devices that could stand up to heat and chemical attack.

But high-pressure, high-temperature methods of synthesizing diamond like Gemesis' offer limited control of impurities and produce diamonds of limited size.

Apollo Diamond, a start-up company in Boston, thinks that a low-pressure technique called chemical vapor deposition (CVD) could be the answer.

Apollo is using CVD to grow single-crystal diamond wafers big enough to be cut into diamond gemstones of a carat of more. Apollo's method can grow larger diamonds and is less expensive than high-pressure, high-temperature methods, notes Robert C. Linares, Apollo's founder and chairman.

CVD allows finer control of impurities than do high-pressure, high-temperature methods, Linares says. This enables Apollo to produce a wider variety of colored diamonds--including colorless, pink, blue, honey brown, and even black.

A CUT ABOVE Apollo uses chemical vapor deposition to grow plates of very pure diamond (left) t can be cut and polished into beautiful gems (rig

In Apollo's CVD reactor, hydrogen gas and methane are flowed through a chamber containing a diamond seed crystal (often a highly polished synthetic one produced by high-pressure, high-temperature methods). Carbon from the methane eventually deposit onto the diamond seed, forming new diamond carbon-carbon bonds.