•MORE THAN A•

# PRETTY FACE

Diamond shines not only with beauty, but also with its role as a workhorse in the areas of science, industry, and medicine.

BY SHARON ELAINE THOMPSON

Photo © John I. Koivula.

Many of the diamonds made by Sumitomo are used as heat sinks and must be of very high quality. But the devices the diamonds are used to cool are very tiny. Usually the heat sinks need only be about a quarter of a millimeter across.

Kunzite, topaz, rhodolite, rubellite, pearls, and aquamarine — all beautiful stones you see in a jeweler's window. Perhaps the most beautiful among them (at least to many people) is the diamond.

But a diamond is more than a pretty face. Diamond is a tomboy, ready to dig in the mud, stand up under pressure, take the heat, travel to the stars, and survive any hardship. The same properties that give diamond rough and tumble personality make it the workhorse of science, industry, and medicine.

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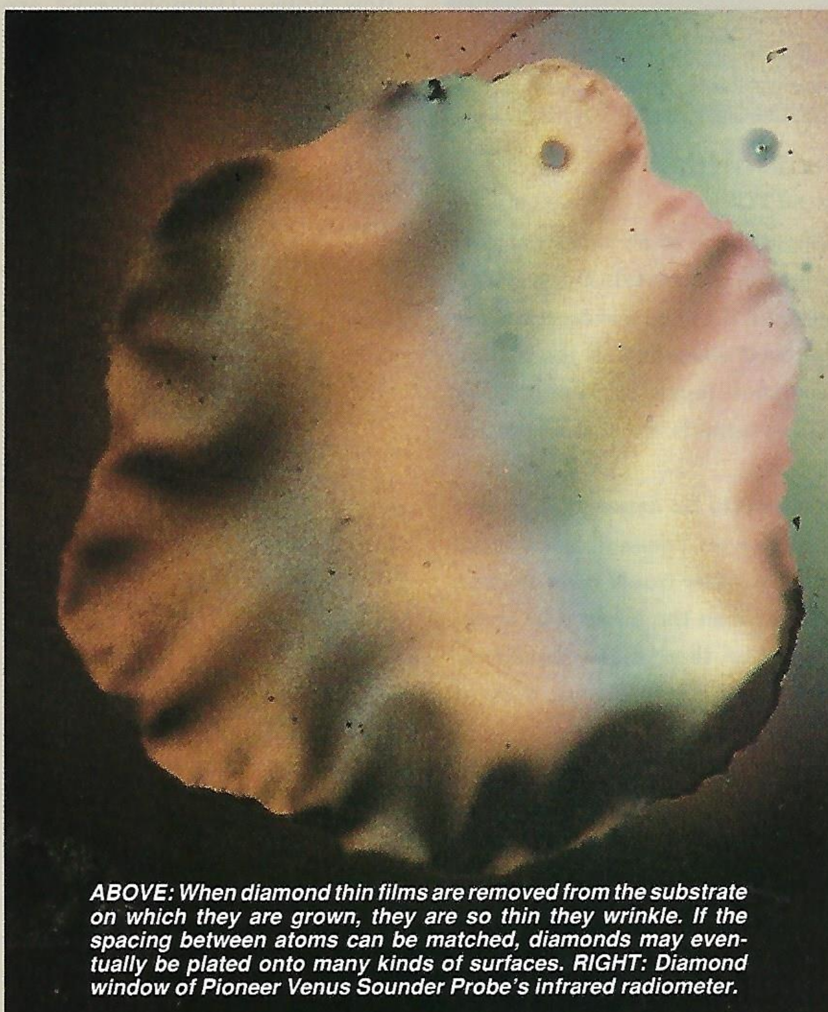

ABOVE: When diamond thin films are removed from the substrate on which they are grown, they are so thin they wrinkle. If the spacing between atoms can be matched, diamonds may eventually be plated onto many kinds of surfaces. RIGHT: Diamond window of Pioneer Venus Sounder Probe's infrared radiometer.

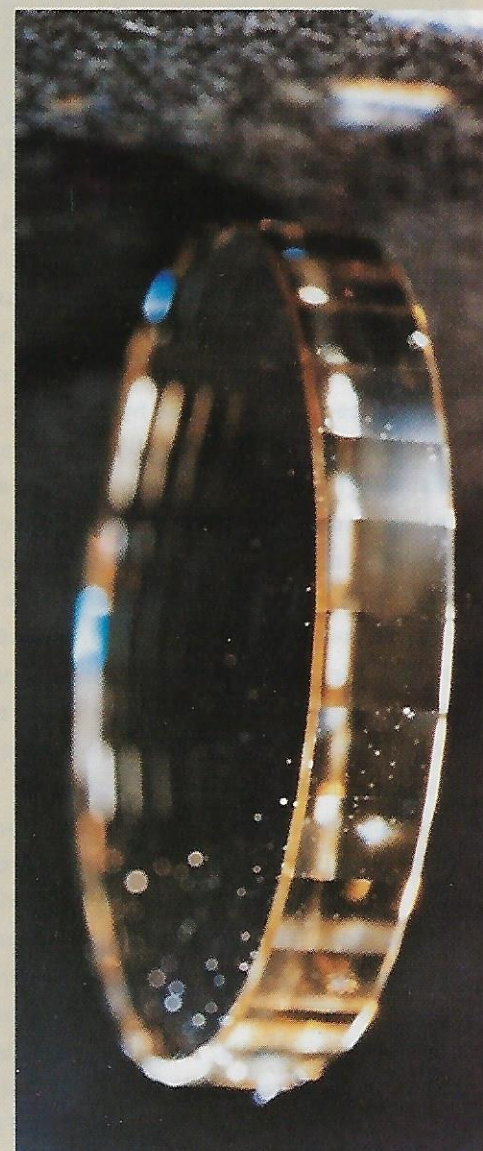

Photo : NASA

**The Unconquerable One.** The Greeks were familiar with diamond's virtual indestructibility and called it *adamas*, or, the unconquerable one, the one who subdues. Today, hardness is still the diamond's most familiar property. Any child will tell you that diamonds cut glass, and they do. Glaziers use diamonds to cut window and mirror glass; artists use it to shape stained glass segments and to engrave patterns on crystal; opticians depend on it to grind and shape lenses for spectacles, and astronomers use telescopes mounted with huge mirrors ground by diamond. In a pinch, though, even quartz, a mere 7 on the Mohs scale compared to diamond's muscular 10, can effectively grind glass. For other kinds of grinding and cutting, however, only the world's hardest mineral will do.

Photo: NASA

Artist's conception shows the Pioneer Venus Multiprobe approaching Venus. The diamond window is part of the largest of the four small probes.

## Window on a New World

BY SHARON ELAINE THOMPSON

**One of the most spectacular and unusual applications of an industrial gem diamond was the stone used in the Pioneer Venus II spacecraft. The purpose of Pioneer's long trip was to collect information about the chemical composition and temperature of Venus by analyzing the infrared emissions of the planet. Hot materials emit characteristic infrared radiation (such as heat), so by analyzing the infrared emissions it is possible to determine the composition of the environment as well as the temperature.**

**But to measure the radiation, the equipment had to be exposed to it, and therein lay a snag. The highly corrosive atmosphere on Venus is made up of carbon dioxide and sulfuric acid. In addition, the window would have to pass from the freezing vacuum of space to temperatures on the surface of about 900°F (480°C) and pressures 100 times greater than those on Earth. Scientists had to find something that would admit the radiation without dissolving or shattering in the process.**

**Diamond was the only material that would meet the requirements. It would resist corrosion, take the tremendous changes in temperature and pressure with ease, and most importantly, it would transmit infrared wavelengths.**

**But there was another snag. The diamond had to be free of internal strain and imperfections and it had to be nitrogen free. Nitrogen in the structure interferes with the transmission of infrared. Nitrogen-free diamonds are those classified as Type IIa. They are usually large and colorless (the yellow in most diamonds being caused by the presence of nitrogen). They are also very rare.**

**The firm of D. Drukker and Zn NV of Amsterdam handles five to 10 million carats of diamond rough a year, yet they only came across two stones in 1976 that met the specifications of Pioneer. Both came from the Premier mine in South Africa, and both were purchased, one as a spare.**

**The Pioneer Venus window was cut from a rough of 205.40 carats. Sawing and polishing were done on traditional equipment. The sides of the stone, each the size of a quarter, had to be perfectly parallel.**

**The finished window was 18.2 millimeters in diameter by 2.8 millimeters thick. It weighed 13.5 carats. After extensive testing, the window was installed in Pioneer Venus II and went off to Venus, contributing a great deal to our knowledge of that mysterious world.**

**And for any enterprising salvage operators, the diamond is probably still there.**

The drill bits used in oil and gas exploration, for example, are commonly made with diamond grit, whole natural diamonds or polycrystalline synthetics, bonded in the edges. Large drills may be studded with up to 1200 diamonds and cost as much as — or more than — a new Volvo. Diamond saws are used to slice the thin, decorative stone panels on many high-rise office buildings. Lapidary hobbyists, too, use diamonds to slab, drill, and polish valuable minerals. And only diamond grit can bring out the beauty of gem-quality diamonds.

Diamonds also make highways and runways safer for the cars and aircraft that other diamonds have built. Banks of diamond blade saws are used to cut the multiple parallel grooves in the road surfaces that prevent hydroplaning. Not only rock and concrete dissolve in the face of diamond. The special, super hard alloys and laminated metals developed for the automotive, aircraft, and space industries often cannot be finished by anything else. Diamonds (usually whole, near gem quality stones) can be cut to the specific shape necessary to machine a particular part. They resist wear, deformation and heat, maintaining the close tolerances necessary for a perfectly functioning engine or tight seal on a spacecraft.

Despite myriad uses, diamonds were rarely used in industry before World War II. Although the production of most diamond mines was up to 80 percent industrial quality diamonds, mining companies were after the gem diamonds where the real value lay before the war.

During the war, however, diamonds became a vital component in the manufacture of military equipment. Afterwards, Sir Ernest Oppenheimer, chairman of the board of De

Beers Consolidated Mines, Ltd., recognizing post-war industries as potential new markets for non-gem material, established the De Beers Research Laboratory to investigate other possible applications for industrials. Development and marketing efforts were so successful that demand soon began to outstrip supply, triggering efforts to produce synthetic diamonds.

**SYNTHETIC SEARCH.** General Electric Company was the first to announce success in 1955. (Although tiny crystals had been produced by the Swedish electric company ASEA two years earlier, no announcement was made at the time.) Thirty-five years later, most of the diamond used in mining and manufacturing is synthetic. In fact, in 1988 the U.S. Bureau of Mines reported that worldwide production of synthetic diamond reached 241,500,000 carats, while that of natural industrials was only 50,393,000 carats.

Manufacturers have not been shy about trying to build a *better* diamond either. Nature's industrial diamonds fall into only three categories — *bort*, massive or badly colored and flawed crystals; *ballas*, round pellets of minute diamond crystals, and *carbonado*, a massive variety and the toughest of the three. However, the synthetic seekers found that by varying the temperature, pressure, time, and metal solvent used, they could alter the size, shape, fracture resistance, and friability of the material. General Electric now manufactures 250 different kinds of industrial diamonds for an almost endless number of uses.

There are advantages to designer diamonds. Diamonds manufactured to a specific size do not have to be crushed, eliminating the weaknesses generated in natural crystals during crushing. Friable diamonds constantly expose new sharp surfaces while they are working. Crystals coated with certain metals bond better to steel tools, slowing down the transfer of heat to the surrounding bonding material. And the properties of the synthetics are always consistent — a feat Mother Nature has often found difficult to pull off.

Industrial diamonds are not all industrial grade, however. Diamonds that might, had fate decreed otherwise, have been cut into unparalleled gemstones are increasingly put to work and treated rather unchivalrously. One such flawless, colorless gem now sits baking on the surface of Venus, carried there by the Pioneer Venus II. (See box.)

Gem-quality diamonds are often the integral part of wire-drawing dies used to make wires for telephone, electronic, and electrical devices. Gem diamonds can take the drilling of the die and resist the wear generated by thousands of feet of wire being pulled through them, when lower quality industrials would shatter.

Single crystal gem diamonds are "softer" in some directions than in others, however, so the holes in the dies tend to wear into ovals. (Even when the diamonds *do* start to wear, though, they can be remachined many times and reused to form the next larger size wire.) Carbonado would resist this kind of wear due to the random orientation of the crystals, but its toughness makes it impossible to machine. Some synthetic diamond manufacturers get around that problem by making a type of synthetic carbonado that can be produced in the specific dimensions needed for the drawing dies.

**SURGICAL SAVIOUR.** The same hardness that makes diamond the tool of choice in the drilling, cutting, and grinding of rock makes it invaluable in the field of surgery. Gem diamonds can be shaped into blades less than a tenth of a millimeter thick, with a cutting edge that makes the proverbial razor's edge look like "the Grand Teton Mountains," according to Dr. George O. Waring III, professor of ophthalmology at Atlanta's Emory University School of Medicine.

There are only a few firms that make these light sabers of medicine and LAB Instruments in Carson City, Nevada, is one of them. Bill Ballard, one of the company's owners, explains that only natural yellow diamonds will hold so fine an edge. He believes that clusters of nitrogen platelets in brown diamonds give him a less perfect, more brittle edge. (LAB grinds and finishes their blades under 500x magnification and guarantees the quality under 400x.) Depending on blade configuration and use, Ballard can get four to 10 blades from a 1.5 to 2 carat rough diamond. In addition to ophthalmologists, LAB makes blades for heart and neurosurgeons.

Because of their sharpness, diamond blades, unlike steel, cut tissue immediately, with virtually no pressure. This gives surgeons more control over the depth of their incisions. Control is vital in operations such as radial keratotomies (surgery to correct near-sightedness) when a too-deep incision could result in blindness. In fact, according to Waring, this is one surgery that cannot be done right with a steel blade.

How does it feel to use such a blade? "Sexy," says Waring. The diamond "floats through tissue . . . it has an elegance that just isn't there with other blade technologies."

Naturally such knives are not inexpensive. While a steel blade may cost $15 to $25, a diamond blade can run $1300 to $2500. However, Waring uses one blade for hundreds of surgeries. The secret to such longevity, though, is care. Waring is adamant about who handles his knives — when a blade is extended, he is the only one who touches it. Whether diamond or not, a blade so thin is fragile, and diamond's cleavage makes it only too easy to chip the point.

**OTHER USES.** Diamond has other properties useful to industry. Its thermal conductivity is up to six times greater than that of copper, making it ideal as a heat sink in electronic devices which generate large amounts of heat. The incomparable smooth surface that can be put onto a diamond increases its effectiveness, because heat is only transferred where the sink is in direct contact with the device it is meant to cool.

Diamond does not normally conduct electricity. To do that, the electrons in a material must be easily knocked from their orbits to create ions. Then when electricity is applied, the electrons can move from one ion to another to create the flow of electricity. But the atoms in diamond are too tightly bonded to form ions.

In the very rare natural blue diamonds, however, atoms of boron have insinuated themselves into the diamond's structure. The electrons in the boron atoms are easier to push around. As a result, natural blue diamonds (among them the Smithsonian's famous Hope) are excellent semi-conductors.

Diamonds also conduct electricity when they are exposed to radiation, such as ultraviolet or X rays. By measuring the change in electrical conductivity, the level of radiation to which the stone is exposed can be measured. Thus, diamonds are used to monitor the doses of radiation given during cancer treatment.

The potential uses for gem diamonds in the medical and electronics fields are almost limitless. But the number of stones available is not. These highly specialized uses demand rare, top-quality diamonds. (Inclusions in a heat sink, for example, could not only interfere with the transfer of heat, they could shatter the diamond, just as a large garnet inclusion in a gem diamond could break or fracture a stone heated with a torch.) Rarer still are the natural blue semi-conductors. Stones like these command top dollar in the jewelry industry.

Natural gems are individuals, too. For example, each stone used as a radiation counter must be calibrated separately to determine how much radiation causes what degree of conductivity. These limitations present too tempting a challenge to man the tinkerer. After all, if he can make a synthetic industrial diamond to his specifications, why not a synthetic gem diamond?

**GEMSTONE CHALLENGE.** Again, General Electric Company was the first to succeed, but determined that the costs and time involved prohibited producing the stones commercially. The De Beers Diamond Research Laboratory, too, has produced synthetic gems, one over 11 carats, but has also decided to wait on commercial production.

Sumitomo Electric Industries in Japan took up the gauntlet, though, and they are now growing gem-quality crystals in one to two carat sizes for use in the electronics industry. The stones are primarily yellow, although colorless and blue stones have been produced by altering the chemical impurities (such as boron). Grown at high temperatures and pressures, the diamonds have consistent physical properties from one crystal to the next.

Sumitomo cuts all its material into small preformed slabs, three to four millimeters square. They do not sell the crystals. (However, in 1987, a half-carat Sumitomo diamond was brought into GIA's Gem Trade Laboratory in New York for certification.)

It would be nice if someone would develop a diamond that could be spread like peanut butter on a surface. That day is coming faster than you might think.

**NEW TECHNOLOGY.** In the 1970s, there were reports that researchers in the Soviet Union had produced diamond-thin films with a process called chemical vapor deposition (CVD). The reports were greeted with skeptcism until the Japanese duplicated the efforts in the early 1980s. Now a consortium of powerful U.S. firms such as Du Pont, AT&T Bell Labs, Bausch and Lomb, and GTE have teamed up with researchers at Pennsylvania State University to share in the new technology.

The CVD process has been used for years to coat lenses, cutting tools, and toys, explains Dr. Russell Messier, professor of engineering science and mechanics at Penn State. To produce coatings of diamond, a hydrocarbon, such as methane (the gas produced in landfills and the intestinal tracts of animals) and hydrogen are exposed to heat or radiation creating a "plasma" of charged particles. Then the carbon is deposited on a substrate. The spacing of atoms in the substrate must be similar to the spacing in the diamond, says Messier, before a diamond coating will grow.

CVD works at low pressures and moderate temperatures and can deposit one to 10 microns of diamond an hour. According to Messier, eventually the technology could allow them to diamond-plate a surface as large as the side of a building. More practically, companies are eyeing the process in order to create sharper tools, abrasion-resistant hard disks, high density computer chips, and window coatings for planes and spacecraft. Sony is already marketing a loudspeaker featuring a diamond-coated "tweeter." But the biggest demand is going to come from the electronics industry in its on-going search for diamond heat sinks and semi-conductors.

The addition of high quality synthetics and thin films to the arsenal of industrial diamonds means the invincible diamond is certain to become an even greater part of our daily lives. But will the day come when we use diamond-coated pans to fry our eggs? Will we live in the diamond-walled cities of science fiction? Will home diamond-platers become as common as the microwave today?

Probably not. But with technology that can make a diamond out of swamp gas, who knows? ◆