Diamond Growth on An Array of Seeds: The Revolution of Diamond Production

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ABSTRACT

Industrial diamond production was pioneered by General Electric Company of U. S. in 1957 and followed by De Beers of S. Africa in 1961. The two companies optimized the production of diamond grits by heating alternative layers of graphite disks and metal catalyst (Fe, Ni, Co) under high pressure. Although there have been 20 countries attempting to duplicate the success of GE and DB, only Iljin Diamond of S. Korea is able to join the lucrative business starting with a technology provided by the author in 1989. In 1970s Winter of Germany developed a powdered mixture of graphite and metal and demonstrated that this assembly can greatly improve the diamond yield and quality. This technology has since been applied to make high grade saw diamond by the above "big three."

China start commercial production of diamond grits in 1966, since then, their diamond output has been growing at a much faster pace than that of the "big three." Today, Chinese makes 2/3 of diamond grits of the world consumption of about 600 tons. However, Chinese cannot make saw diamond larger than about 45 mesh (0.36 mm). Even so, the "big three" has felt the pressure of "yellow fever." As a consequence, De Beers reorganized their industrial diamond group in 2000 and renamed it Element Six, GE Superabrasives was sold to Little John in 2003, and Iljin Diamond suffered the first loss in 2003.

The world high pressure diamond synthesis is due for another technology advancement, this time, the random nucleation of diamond in the reaction cell is planted with a matrix of diamond seeds that will do away with the erratic growth of diamond. The result would be doubling of the diamond yield and quadrupling of the sales value.

Keywords: diamond synthesis, high pressure, diamond seed, diamond grit, De Beers

POSITIVE NUCLEATION CONTROL BY SEEDING

More than 700 tons of diamond were produced as superabrasives by subjecting graphite and a metal catalyst (Fe, Ni, Co or its alloy) under pressure of >5 GPa and heated to melt the catalyst. Graphite will transform into diamond by the catalytic action of the molten metal. Graphite and metal may form alternative layers in a high pressure cell, or they can be mixed as powder.

The layered structure of the cell design has many intrinsic advantages, such as it is simple to handle and easy to control. Moreover, a layered structure is particularly suited for high pressure belt apparatus of uniaxial design. In this case, the pressure is compressed and the current is transmitted in perpendicular to stacked layers. This uniaxial symmetry of cell design can allow a more uniform field of pressure and temperature, two critical factors for diamond growth. The problem of layered structure is the nucleation control and the interface uniformity. As the result of random nucleation and erratic growth, diamond yield and quality suffer.

The nucleation can be controlled by seeding of smaller diamond particles (e.g., 50 microns in size), for example, by fitting these diamond particles in holes drilled on catalyst (Showa-Denko 1984). A better way of controlled seeding is to guide diamond particles by a template. The seeded crystals can then be pressed directly into either catalyst or graphite (Sung, 2000). The diamond seed can be buried half way to allow for the protrusion into graphite volume when the stack of graphite and catalyst layers is assembled (Figure 1). In such a configuration, the molten catalyst can easily follow the diamond profile to form the metal envelope. This metal strait can facilitate the transport of graphite flakes across so the diamond can grow.

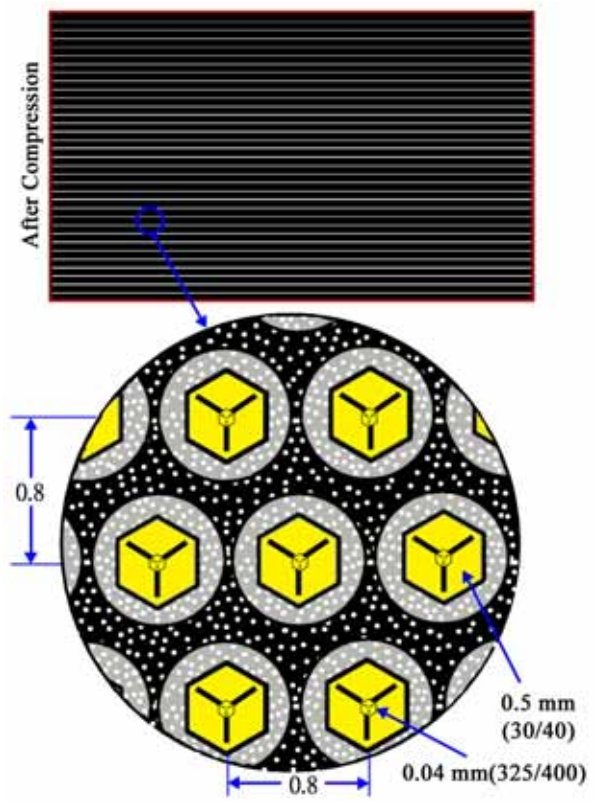

Figure 1: The design of a high pressure cell that shows the growth of diamond seeds to about 2000 times in volume. The typical growth conditions are about 5.2 GPa in pressure, about 1300 ℃ in temperature, and about 50 minutes in time. The diagram shows diamond is separated by the molten alloy (e.g. Invar or $Fe_{65}Ni_{35}$) during its growth. Graphite from the matrix will disperse into the molten alloy and rearrange to form diamond. The matrix contains the mixture of graphite and catalyst powder.

The seeded diamond may be overcoated with a thin layer of catalyst metal e.g., by electroplating Ni. This catalyst envelope can draw other catalyst particles to grow with the diamond. The catalyst envelope in the molten state is impregnated with suspended graphite flakes that feed to the growing diamond.

Assuming the saw grits to be grown are in 40 to 50 mesh (0.3 mm to 0. 4 mm), the most popular size for commercial applications, then the largest crystals (40 mesh) has a size of 0.4 mm and a surface area of about 0.5 mm2. The thickness of a catalyst envelope is less than 0.1 mm, hence after the synthesis, the volume of the catalyst covered each crystal is 0.05 mm3, or less than 0.5 mg. Such an amount of catalyst can form a sphere of about 0.4 mm in diameter

Assuming the diamond-to-diamond distance is two times of the largest diamond size, hence the growing area is 4 times of that covered by the diamond, or 0.7 mm^2. The thickness of the catalyst can be 0.15 mm, more than twice needed to envelop the crystal.

The graphite thickness can be 0.3 mm, twice of that for the catalyst. However, the mass of the former is only about 40% of the latter.

In the above example of cell design, the diamond grown will span the total thickness of graphite and catalyst. Each crystal will have a growing space of about 0.3 mm3. Hence, each cubic centimeter of the reaction cell will produce more than 3000 crystals that are more than 4 carats for 40-mesh diamond (770 pieces per carat). In this case, the graphite to diamond conversion rate is nearly 50%, a very high value for growing good quality diamond. However, because the distribution of diamond crystals is regular, each diamond occupies less than 15% of the reaction volume, so there are ample rooms for uninterrupted growth that are critical for the development of euhedral crystal shape with a minimized amount of inclusions.

The above cell design assumes that the graphite layer and catalyst layer is uniform in structure and composition. However, the reality is that these materials are quite heterogeneous. Hence, a better design is to use powdered graphite and catalyst with more uniform properties. But instead of mixing them and load into the cell, the mixture is first pressed to form disks, and then these disks planted with diamond seeds that are coated with catalyst metal. The powder layers with uniformly distributed diamond seeds are then loaded into the reaction cell for the diamond synthesis. Such a design has the advantages of both layered and powdered cell. Moreover, the diamond seeds would guarantee that the grown diamond crystals are in the same size and quality. Furthermore, because the elimination of the catalyst layer, the efficient of cell volume utilization is further improved. In such a cell, it is possible to achieve a yield of 5 carats per cubic centimeter with at least 4 carats in the desirable size and quality.

The diamond yield for this optimized cell design is compared with that for current arts of diamond synthesis as shown in Table 1.

Cell Size	Charge Type	Nucleation Uniformity	Seeding		Yield Good
			Used	Gross	
Small	Layer	Random	No	1	0.3
Large	Layer	Random	No	2	1
Large	Powder	Random	No	3	2
Large	Layer	Regular	Yes	4	3
Large	Powder	Regular	Yes	5	4

Table 1: Comparison of Diamond Yields.

The positive control of diamond nuclei was demonstrated in growing 30/40 mesh diamond with high grade with a cubic press (Fig. 2). The result indicates that Chinese cubic presses are capable to grow such high valued diamond crystals in competing with that produced in expensive belt apparatus.

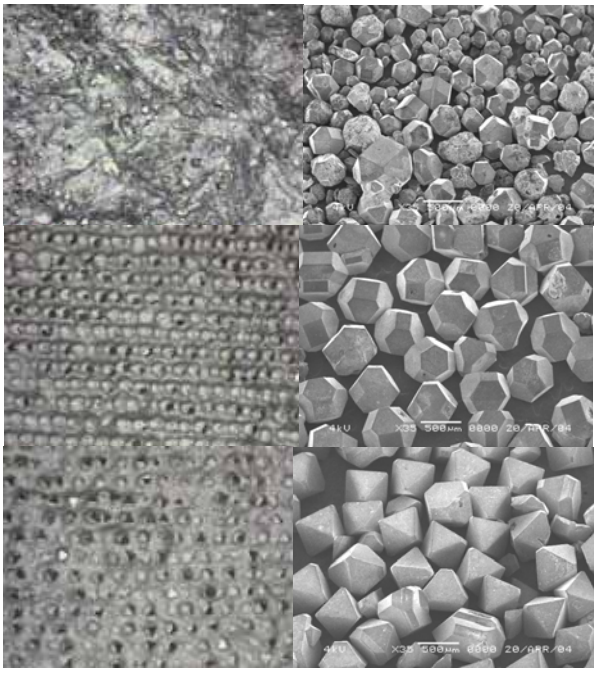

Fig. 2: High pressure cells at diamond synthesis conditions heated for the same period of time. The left diagrams show diamond distributions in the original cell. The right diagrams show recovered diamond WITHOUT SIZING & SORTING. Note that Sung's cells produced larger diamond. Moreover, Sung's cells could be "dialed" for a tight range of size, shape, and quality. The above numbers in parenthesis are diamond yields in carats per cubic centimeter.