

Memorial Diamond Manufacturing — Physics, Equipment, and Operational Parameters

Version 1.1 · July 2026

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Business Registration: 91410300MA9KJT0M47

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1. Executive Summary

High-Pressure High-Temperature (HPHT) synthesis is the industrial process that reproduces the thermodynamic conditions under which natural diamonds form in Earth’s mantle. At BioGem Lab, we use HPHT to convert purified biological carbon — derived from pet hair, human hair, plant fibers, and other organic sources — into genuine diamonds with the same optical, physical, and chemical properties as natural stones.

Our standard production cycle runs 60 days from receipt of biological sample to finished gemstone. The process breaks down as follows: carbon extraction (3–5 days), purification (5–7 days), graphitization (2–3 days), HPHT crystal growth (18–25 days), cutting and polishing (7–10 days), and grading with certificate issuance (2–3 days). HPHT growth itself accounts for the longest single phase and determines the final yield, color, and clarity of the diamond.

BioGem Lab operates at 5.5 GPa (approximately 54,000 atmospheres) and 1,450°C, placing the growth chamber well within the diamond stability field above the Berman-Simon equilibrium line. We use Ni-Mn-Co alloy as the catalyst solvent and tungsten carbide anvil systems in a cubic press configuration. Our carbon purification process achieves 99.95% purity before the sample ever enters the press.

This whitepaper documents the physics, equipment, chemistry, and operational parameters that define industrial HPHT memorial diamond production. It is written for B2B partners, materials engineers, and procurement teams who need technical depth beyond marketing copy.

Key Specifications at a Glance

Parameter	Value
Operating Pressure	5.5 GPa
Operating Temperature	1,450°C
Growth Duration	18–25 days
Total Production Cycle	60 days
Carbon Purity (pre-press)	99.95%
Catalyst Alloy	Ni-Mn-Co
Standard Output	0.5 ct – 2.0 ct

Parameter	Value
Color Grade	E-H
Clarity Grade	VS
Cut Grade	Ideal
Patent	ZL 201010565778.9

2. What is HPHT? — Physics Fundamentals

2.1 The Carbon Phase Diagram

Carbon exists in multiple allotropes. At ambient pressure and temperature, graphite is the thermodynamically stable form. Diamond becomes stable only under high pressure. The boundary between these two stability fields is defined by the Berman-Simon line, established in 1955 by Robert Berman and Francis Simon through thermodynamic measurements.

The Berman-Simon line is expressed as:

$$P \text{ (GPa)} = 0.6865 + 0.00266 \times T \text{ (K)}$$

At 1,450°C (1,723 K), the equilibrium pressure is approximately 5.27 GPa. BioGem Lab operates at 5.5 GPa — roughly 0.23 GPa above the equilibrium line. This margin provides the thermodynamic driving force for graphite-to-diamond conversion while avoiding excessive internal stress that would crack the growing crystal.

Operating too far above the line accelerates nucleation but increases defect density. Operating too close to the line slows growth and reduces yield. Industrial optimization finds the midpoint.

2.2 Mantle Conditions

Natural diamonds form 150–200 kilometers below Earth's surface, where the lithospheric mantle experiences pressures of 4.5–6.5 GPa and temperatures of 900–1,300°C. These conditions correspond to the diamond stability field on the carbon phase diagram.

HPHT synthesis does not merely reach mantle conditions — it engineers them. The industrial press compresses a growth cell containing graphite powder, a metal catalyst, and a diamond seed crystal. Resistive heating brings the cell to target temperature. The combination of pressure and temperature melts the catalyst, dissolves the graphite, and drives carbon atoms to precipitate onto the seed crystal in the sp^3 tetrahedral lattice structure of diamond.

2.3 The Diamond Stability Field

The diamond stability field is the region of the carbon phase diagram where diamond has lower Gibbs free energy than graphite. In this field:

- Carbon atoms spontaneously arrange in sp^3 bonding (tetrahedral).
- The density increases from 2.27 g/cm³ (graphite) to 3.52 g/cm³ (diamond).

- The phase transformation is irreversible under ambient conditions — diamond is metastable at room temperature because the kinetic barrier for reversion to graphite is prohibitively high.

The phase diagram also contains a region labeled “Region B” (Bundy et al., 1996) where very fast solid-solid transformation of graphite to diamond occurs. This region sits at higher pressures (7+ GPa) and is not used for commercial gem-quality synthesis because the rapid transformation produces polycrystalline material with poor optical quality.

Commercial catalytic HPHT synthesis (Region A) operates at lower pressures where the metal catalyst mediates the phase transition, enabling controlled single-crystal growth over days rather than instantaneous polycrystalline conversion.

2.4 Why Pressure Matters

Pressure serves two functions in HPHT synthesis:

Thermodynamic function: Pressure shifts the equilibrium toward diamond. Without sufficient pressure, the carbon would remain as graphite or convert back to graphite during cooling.

Kinetic function: Pressure reduces the activation energy for the graphite-to-diamond transition. The metal catalyst further lowers this barrier by providing a liquid medium through which carbon atoms diffuse.

At 5.5 GPa and 1,450°C, the metal catalyst (Ni-Mn-Co) is fully molten. Carbon solubility in the molten alloy is approximately 5–8 atomic percent. This dissolved carbon diffuses toward the cooler diamond seed, where the lower temperature reduces solubility and drives precipitation onto the existing crystal lattice.

3. HPHT vs CVD — Why HPHT for Memorial Diamonds

3.1 Two Growth Methods

Two industrial methods produce laboratory-grown diamonds: HPHT and Chemical Vapor Deposition (CVD).

HPHT replicates Earth's mantle conditions. A press generates extreme pressure and temperature. A metal catalyst mediates the conversion of solid graphite into diamond crystal.

CVD operates at low pressure (typically 0.01–0.1 atm) and moderate temperature (700–1,000°C). A hydrocarbon gas (usually methane diluted in hydrogen) is ionized into a plasma. Carbon atoms deposit onto a substrate, building up diamond layer by layer.

3.2 Why BioGem Lab Uses HPHT

For memorial diamonds — diamonds grown from the carbon of a specific biological source — HPHT is the only viable method. The reasons are structural:

Carbon source compatibility: CVD requires a gaseous carbon feedstock. Converting biological carbon (hair, fur, plant matter) into a suitable hydrocarbon gas would require pyrolysis, extensive purification, and reforming — a process that introduces contamination risk and loses the provenance chain. HPHT accepts solid graphite derived directly from the biological source.

Growth from a seed: HPHT grows a single crystal outward from a diamond seed. The seed provides a crystallographic template, ensuring the final stone is a single continuous crystal. CVD produces a plate-like crystal that often requires post-growth HPHT annealing to improve color.

Color control: HPHT with Ni-Mn-Co catalyst produces near-colorless to faint yellow diamonds (E–H color range). CVD diamonds frequently grow with brown coloration due to nitrogen-vacancy complexes and require post-growth treatment.

Provenance integrity: The HPHT process keeps the biological carbon in solid form throughout extraction, purification, graphitization, and growth. Each batch is traceable to a specific sample. CVD's gas-phase chemistry would make this tracing far more complex.

3.3 Limitations of HPHT

HPHT is not without constraints:

- Chamber size limits crystal size: The growth cell volume is restricted by press geometry. Producing stones larger than 3 carats requires proportionally larger presses and longer growth times.
- Catalyst inclusions: Metal catalyst can become trapped inside the growing crystal, appearing as dark inclusions under magnification.
- Energy intensity: Maintaining 5.5 GPa and 1,450°C for 18–25 days consumes significant electrical power.
- Equipment cost: Industrial HPHT presses range from \$70,000 to \$150,000 per unit (source: industry manufacturer quotes, 2024–2025), with tungsten carbide anvils requiring periodic replacement.

For BioGem Lab's product range (0.5 ct to 2.0 ct), these limitations are manageable. The HPHT method delivers the provenance integrity, color consistency, and single-crystal structure that memorial diamonds require.

4. Equipment — Belt-Type Presses, Cubic Presses, Tungsten Carbide Anvils

4.1 The Four Main Press Types

Industrial HPHT equipment falls into four categories: belt presses, toroid presses, cubic presses, and BARS (split-sphere) presses.

Belt Press: Invented by H.T. Hall at General Electric in 1958 (US Patent 2,947,610). Two opposing tungsten carbide anvils compress a cylindrical growth cell. Binding rings form a “belt” around the structure to contain lateral deformation. Belt presses offer the largest reaction volumes (up to 300 cm³) and are favored for industrial diamond grit production. They are mechanically complex, expensive to maintain, and require massive hydraulic systems.

Toroid Press: A variation of the belt press where toroidal sub-cavities hold pressure inside a semi-spherical cavity. Developed in the USSR by Kolchin and Khvostantsev. Offers good pressure distribution but smaller volumes than belt presses.

Cubic Press: Six perpendicular anvils, each driven by an independent hydraulic cylinder, compress a cubic chamber. Invented by Zeitlin in 1961; first cubic press patented in 1969 (US Patent 3,440,687). Cubic presses provide isotropic pressure distribution from all six faces of the cube. They are more compact than belt presses, achieve target pressure faster, and have lower operating costs. Chamber sizes range from 650 mm to 1,000 mm anvil diameter.

BARS Press: Russian-designed split-sphere system using eight outer steel anvils and six inner tungsten carbide anvils. A rubber membrane transmits hydraulic oil pressure to the central cell. The most compact and economical design, but with smaller reaction volumes (typically 2–5 cm³). Popular in Russian and Eastern European laboratories.

4.2 BioGem Lab Configuration: Cubic Press

BioGem Lab operates cubic presses. The choice is deliberate:

- **Isotropic pressure:** Six anvils applying pressure along three perpendicular axes produce uniform pressure distribution within the growth cell. This reduces stress gradients that cause crystal deformation.
- **Faster cycle times:** Cubic presses reach target pressure more rapidly than belt presses, reducing the non-growth portion of each cycle.
- **Lower operating cost:** Maintenance, anvil replacement, and energy consumption are lower per carat produced compared to belt presses.

- Scalability: Multiple cubic presses can be operated in parallel, matching the output of a single large belt press at lower capital investment.

4.3 Tungsten Carbide Anvils

The anvils are the critical wear component. They are made from cemented tungsten carbide (WC-Co), typically with 6–10% cobalt binder. Tungsten carbide has:

- Bulk modulus: 590 GPa
- Compressive strength: 2,500–3,000 MPa
- Hardness: 1,600–1,800 HV
- Maximum operating temperature: 600°C (above this, cobalt binder softens and strength deteriorates rapidly)

The 600°C limit is why the growth cell must be thermally insulated from the anvils. Ceramic sleeves (typically pyrophyllite or boron nitride) surround the cell, maintaining the anvil face below 600°C even when the cell interior reaches 1,450°C.

Anvil lifespan depends on operating pressure, cycle frequency, and maintenance protocol. Under BioGem Lab's parameters (5.5 GPa, 1,450°C), anvils typically last 5,000–8,000 cycles before requiring replacement or reconditioning. A single anvil set for a 750 mm cubic press costs approximately \$8,000–\$12,000 (source: tungsten carbide tooling suppliers, 2024 pricing).

4.4 Growth Cell Assembly

The growth cell is the container that holds the sample, catalyst, and seed during synthesis. A typical cell assembly includes:

1. Outer ceramic sleeve: Pyrophyllite or boron nitride. Provides thermal insulation and electrical isolation.
2. Graphite heater: A tubular graphite element that carries electrical current to heat the cell. Resistance heating at 10–20 V, 1,000–2,000 A.
3. Inner ceramic capsule: Contains the actual reactants. Made from refractory ceramic to prevent contamination.
4. Graphite powder: The carbon source, derived from purified biological material. Particle size 1–10 µm.
5. Catalyst disk: Ni-Mn-Co alloy, typically 0.5–1.0 mm thick, positioned between the carbon source and the seed.
6. Diamond seed: A small high-quality diamond crystal (0.5–1.0 mm) that serves as the crystallographic template. Seed orientation matters: (100) faces grow faster than

(111) faces.

7. Temperature gradient: The seed is positioned at the cooler end of the cell. The temperature difference between carbon source and seed is typically 20–50°C.

Cell assembly is performed in a cleanroom environment. Contamination at this stage — dust, organic residue, or metal particles — will appear as inclusions in the final diamond.

5. Catalyst Systems — Ni-Mn-Co Alloy

5.1 Role of the Catalyst

Pure graphite does not convert to diamond at 5.5 GPa and 1,450°C on a commercially relevant timescale. The kinetic barrier is too high. A metal catalyst is required to mediate the phase transition.

The catalyst performs three functions:

1. Dissolves graphite: At HPHT conditions, the metal is molten and dissolves carbon from the graphite powder.
2. Transports carbon: Carbon atoms diffuse through the molten metal toward the cooler diamond seed.
3. Precipitates diamond: At the seed surface, the lower temperature reduces carbon solubility, causing carbon to crystallize onto the existing diamond lattice.

Without a catalyst, graphite-to-diamond conversion would require pressures above 12 GPa (direct solid-solid transformation, Region B on the phase diagram). The catalyst lowers this threshold to approximately 5 GPa, making commercial production feasible.

5.2 Ni-Mn-Co Alloy

BioGem Lab uses a nickel-manganese-cobalt (Ni-Mn-Co) alloy as the catalyst solvent. The composition is proprietary but typically falls in the range:

- Nickel (Ni): 60–70%
- Manganese (Mn): 15–25%
- Cobalt (Co): 10–20%

This ternary alloy was selected after extensive experimentation by BioGem Lab's engineering team. The rationale:

Nickel: Primary solvent. Has high carbon solubility at HPHT conditions (5–8 at.% at 1,450°C, 5.5 GPa). Forms a eutectic with carbon at approximately 1,320°C under pressure.

Manganese: Lowers the melting point of the alloy and increases carbon solubility. Mn also modifies the nucleation kinetics, reducing spontaneous nucleation away from the seed crystal.

Cobalt: Improves crystal quality by reducing stacking faults and dislocations. Co-C systems produce diamonds with fewer nitrogen-related defects compared to pure Ni catalysts.

5.3 The Dissolution-Precipitation Mechanism

The growth process follows these steps:

Step 1: Melting — At 5.5 GPa, the Ni-Mn-Co alloy melts at approximately 1,250–1,300°C. As temperature increases to 1,450°C, the metal is fully liquid.

Step 2: Dissolution — Carbon from the graphite powder dissolves into the molten alloy. The dissolution rate depends on temperature (higher = faster), graphite surface area (finer powder = faster), and metal-carbon interface area (larger catalyst disk = faster).

Step 3: Diffusion — Dissolved carbon atoms diffuse through the molten metal toward the cooler seed crystal. Diffusion follows Fick's law:

$$J = -D \times (dC/dx)$$

Where J is the flux, D is the diffusion coefficient (typically 10^{-9} to 10^{-10} m²/s for carbon in Ni at 1,450°C), and dC/dx is the concentration gradient.

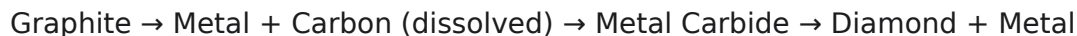
Step 4: Precipitation — At the seed surface, the temperature is 20–50°C lower than at the carbon source. Carbon solubility in the metal decreases with temperature. The excess carbon precipitates onto the diamond seed, extending the crystal lattice.

Step 5: Growth — The process continues for 18–25 days. The diamond crystal grows at a rate of 0.5–2.0 mg/hour, depending on temperature, pressure, and catalyst composition. A 1.0 ct diamond (200 mg) requires approximately 100–400 hours of growth.

5.4 Thermodynamic Analysis

From a thermodynamic perspective, the catalyst does not change the equilibrium between graphite and diamond. The Berman-Simon line remains the boundary. What the catalyst changes is the path between the two phases.

Thermodynamic calculations for Fe-based catalysts (analogous to Ni-Mn-Co) show that metal carbide phases (such as Fe₃C) form before diamond nucleation. The carbide decomposes to release carbon, which then crystallizes as diamond. The reaction pathway:



The formation of the metal carbide intermediate reduces the potential energy barrier for the graphite-to-diamond transition. From the perspective of the overall system, the catalyst provides a lower-energy reaction pathway without altering the final equilibrium state.

6. Growth Parameters — 5.5 GPa, 1,450°C, 18-25 Days

6.1 Pressure: 5.5 GPa

BioGem Lab operates at 5.5 GPa, equivalent to approximately 54,000 atmospheres or the pressure at 180 km depth in Earth's mantle.

This pressure was selected for three reasons:

1. Adequate margin above Berman-Simon line: At 1,450°C (1,723 K), the equilibrium pressure is 5.27 GPa. Operating at 5.5 GPa provides a 0.23 GPa (4.4%) margin. This is sufficient to drive the phase transition without creating excessive internal stress.
2. Catalyst effectiveness: The Ni-Mn-Co catalyst requires minimum 5.0 GPa to remain effective. At 5.5 GPa, carbon solubility in the molten catalyst is high enough to sustain growth rates of 0.5–2.0 mg/hour.
3. Equipment safety: Tungsten carbide anvils have a safety margin up to approximately 8 GPa. Operating at 5.5 GPa (69% of rated capacity) extends anvil life and reduces catastrophic failure risk.

Pressure stability during growth is maintained within ± 0.1 GPa. Fluctuations larger than this alter carbon solubility in the catalyst, causing growth rate variations that manifest as growth bands (visible under magnification as parallel lines).

6.2 Temperature: 1,450°C

The growth temperature of 1,450°C was determined through iterative optimization:

- Below 1,350°C: Growth rate drops below 0.3 mg/hour. A 1.0 ct stone would require 30+ days, increasing cycle cost without proportional quality improvement.
- Above 1,550°C: Risk of catalyst over-dissolution, increased nitrogen incorporation (yellow color), and thermal stress cracking during cooldown.
- 1,450°C: Balances growth rate (~1.0 mg/hour typical) against crystal quality and color control.

Temperature uniformity across the growth zone is maintained within $\pm 25^\circ\text{C}$. Hot spots cause localized rapid growth and defect formation. Cold spots slow growth and produce uneven crystal faces.

The temperature gradient between the carbon source (hotter) and the seed (cooler) is 20–50°C. This gradient is the primary driving force for carbon diffusion. A steeper gradient increases growth rate but also increases thermal stress. BioGem Lab uses a

gradient of approximately 30°C for standard production.

6.3 Duration: 18-25 Days

Growth duration is determined by target carat weight and growth rate.

Target Weight	Typical Growth Time	Growth Rate Assumption
0.5 ct (100 mg)	10–14 days	0.6 mg/hour
1.0 ct (200 mg)	14–18 days	0.9 mg/hour
1.5 ct (300 mg)	18–22 days	1.0 mg/hour
2.0 ct (400 mg)	20–25 days	1.1 mg/hour

Growth rate is not constant. It typically follows a curve:

- Days 1–3: Slow start as the system equilibrates. Growth rate 0.3–0.5 mg/hour.
- Days 4–15: Steady-state growth. Rate 0.8–1.2 mg/hour.
- Days 16+: Rate may decline slightly as carbon source depletes or as the growing crystal alters the thermal profile.

The 18–25 day range accounts for normal variation in: batch-specific graphite quality, catalyst batch composition tolerances, ambient temperature fluctuations (affecting cooling water temperature), and press-specific thermal characteristics.

6.4 The Complete Cycle

While HPHT growth is the longest single phase, it is one part of a 60-day total cycle:

Phase	Duration	Description
Carbon extraction	3–5 days	Biological sample is processed to extract carbon. Involves cleaning, drying, and pyrolysis.
Purification	5–7 days	Extracted carbon is purified to 99.95%+. Removes nitrogen, sulfur, and metal contaminants.
Graphitization	2–3 days	Purified carbon is converted to graphite. Requires 2,600–3,000°C in inert atmosphere.
HPHT growth	18–25 days	Graphite is converted to diamond single crystal in the press.
Cutting & polishing	7–10 days	Rough diamond is cut to specified shape and polished.

Phase	Duration	Description
Grading & certificate	2-3 days	Final diamond is measured, graded for color/clarity/cut, and documented.

Total: 60 days (with ± 5 days normal variation).

7. Quality Control — In-Process Spectroscopy, Crystal Monitoring

7.1 Pre-Press Quality Control

Quality control begins before the sample enters the press.

Carbon purity verification: After purification, carbon is tested by combustion analysis. Target: 99.95% carbon. Residual nitrogen must be below 500 ppm — higher nitrogen levels cause yellow coloration in the final diamond. Residual sulfur must be below 100 ppm — sulfur can cause inclusions and crystal defects.

Graphite crystallinity: X-ray diffraction (XRD) confirms the carbon has fully converted to graphite with an interlayer spacing of 3.35 Å (characteristic of well-ordered graphite). Amorphous carbon or incomplete graphitization produces irregular growth and low yield.

Seed crystal inspection: Each diamond seed is inspected under 40× magnification. Seeds with cracks, inclusions, or surface damage are rejected. A flawed seed propagates defects into the grown crystal.

7.2 In-Process Monitoring

Once the press cycle begins, direct observation of the growth cell is impossible. Monitoring relies on indirect measurements:

Pressure telemetry: Strain gauges on the hydraulic system report chamber pressure in real time. Drift >0.05 GPa triggers automatic correction. Drift >0.15 GPa aborts the cycle.

Power consumption monitoring: The graphite heater's electrical resistance changes with temperature. Power draw is correlated to cell temperature through calibrated curves. An unexpected drop in power draw indicates heater failure. An unexpected rise suggests thermal runaway.

Thermal profile modeling: Finite element models predict the temperature distribution within the cell based on heater power, cooling water flow, and press geometry. These models are validated against thermocouple measurements during setup runs.

7.3 Post-Growth Analysis

When the press is opened, the rough diamond is immediately inspected:

Visual inspection: The rough crystal is examined for cracks or fractures (thermal stress during cooldown), unusual coloration (indicates contamination or nitrogen incorporation), and surface defects (pits, cavities, or growth irregularities).

Raman spectroscopy: A confocal Raman microscope confirms the material is diamond (sp^3 carbon, Raman peak at $1,332\text{ cm}^{-1}$) rather than graphite (sp^2 carbon, peak at $1,580\text{ cm}^{-1}$). The full width at half maximum (FWHM) of the diamond peak indicates crystal quality — narrower peaks mean lower defect density.

Weight measurement: The rough is weighed to determine yield. $\text{Yield} = (\text{rough weight} / \text{initial graphite weight}) \times 100\%$. Typical yields are 15–25%. Low yield indicates incomplete conversion or poor growth conditions.

Infrared spectroscopy: FTIR (Fourier Transform Infrared) spectroscopy measures nitrogen content and aggregation state. Type Ia diamonds have nitrogen in aggregated form (A-centers and B-centers). Type IIa diamonds have negligible nitrogen. BioGem Lab targets Type IIa or weak Type Ia, corresponding to E–H color.

7.4 Cutting and Polishing QC

After growth, the diamond rough goes to the cutting workshop:

Planning: A 3D scanner maps the rough crystal. Software determines the optimal cut to maximize yield and achieve target proportions. For a round brilliant cut, the software calculates pavilion angle, crown angle, table percentage, and girdle thickness.

Sawing/laser cutting: The rough is divided (if necessary) and the table facet is oriented. Laser cutting is preferred for memorial diamonds because it minimizes weight loss compared to mechanical sawing.

Bruting: The diamond is shaped into a round outline by grinding two diamonds against each other.

Faceting: 57 or 58 facets are cut and polished. Each facet angle is controlled to within $\pm 0.1^\circ$. Polish quality is inspected at $10\times$ magnification — surface scratches or polish lines downgrade the final grade.

Final grading: The cut diamond is graded for color (compared against master stones under controlled lighting; BioGem Lab targets E–H), clarity (inspected at $10\times$ magnification; targets VS), cut (measured for proportions, symmetry, and polish; targets Ideal), and carat weight (measured to 0.001 ct precision).

8. BioGem Lab Implementation — Specific Setup, Capacity, Batch Processing

8.1 Laboratory Infrastructure

BioGem Lab operates from a dedicated facility in Luoyang, China (Luoyang BioGem Technology Co., Ltd., Tax ID: 91410300MA9KJT0M47). The facility includes:

- Carbon extraction laboratory: Fume hoods, pyrolysis ovens, acid digestion stations.
- Purification cleanroom: ISO 7 cleanroom for carbon purification and graphitization. Positive pressure, HEPA filtration, temperature $22\pm2^{\circ}\text{C}$, humidity $45\pm5\%$.
- HPHT press hall: Climate-controlled to $18\text{--}25^{\circ}\text{C}$, humidity $<60\%$. Vibration-isolated concrete foundations. Three-phase power with UPS backup.
- Cutting and polishing workshop: Diamond cutting equipment, laser saws, bruting machines, polishing scaives.
- Grading room: Darkened room with D65 standard illuminant, $10\times$ microscopes, diamond proportion scopes.

8.2 Press Fleet

BioGem Lab operates multiple cubic presses in parallel. Each press has:

- Anvil diameter: 750 mm
- Nominal thrust: 50 MN
- Pressure range: 4.0–6.0 GPa
- Temperature range: $1,200\text{--}1,600^{\circ}\text{C}$
- Cycle capacity: 12–15 runs per press per year (accounting for 18–25 day growth + setup/cooldown)

With multiple presses operating in overlapping cycles, the facility maintains continuous output rather than batch-batch-batch production. This is how BioGem Lab achieves its 60-day standard delivery timeline.

8.3 Batch Processing Protocol

Each batch corresponds to one biological sample. The batch protocol:

1. Sample intake: Hair/fur/plant sample is logged, photographed, and assigned a unique batch ID.

2. Carbon extraction: Sample is cleaned, dried, and pyrolyzed. Yield: 30–40% carbon by weight for hair/fur.
3. Purification: Extracted carbon is purified to 99.95%+. A small sample is retained for archival purposes.
4. Graphitization: Purified carbon is converted to graphite at 2,500°C in argon atmosphere.
5. Cell assembly: Graphite powder, Ni-Mn-Co catalyst, and diamond seed are loaded into a ceramic capsule in the cleanroom.
6. Press loading: Cell is centered between anvils. Alignment is verified with laser positioning.
7. Growth cycle: 18–25 days at 5.5 GPa, 1,450°C.
8. Recovery: Press is decompressed and cooled. Rough diamond is extracted.
9. Cutting/polishing: 7–10 days.
10. Grading/certification: 2–3 days. CCIC or IGI/GIA certificate issued.
11. Packaging: Diamond is sealed in tamper-evident packaging with certificate and batch documentation.

8.4 Carbon Purity Achievement

BioGem Lab’s purification process achieves 99.95% carbon purity. This is higher than typical industrial diamond production because memorial diamonds require:

- Lower nitrogen (prevents yellow color)
- Lower boron (prevents blue color)
- Lower metallic contaminants (prevent inclusions)
- Complete removal of organic residues (prevent structural defects)

The purification protocol, covered by Chinese Invention Patent ZL 201010565778.9 (Certificate No. 1058820, granted October 10, 2012), was developed by Li Lihua and Wang Hongtao beginning in 2003. The patent specifically addresses carbon extraction from biological raw materials — hair, fur, plant matter — and the purification steps required to render this carbon suitable for diamond synthesis.

8.5 Capacity and Scaling

Current capacity supports production for partners across 14+ countries. The modular press configuration allows capacity expansion by adding presses without redesigning the facility. Each additional press adds approximately 12–15 stones per year (at 1.0 ct

average) to total output.

Batch processing ensures that each diamond is traceable to its source sample. Batch records include: sample photographs and weight, carbon extraction yield, purification test results, graphitization parameters, press run log (pressure, temperature, duration), rough weight and yield, cut parameters, final grading report, and certificate number.

9. Common Defects & Mitigation

9.1 Inclusions

Metal inclusions: Small pockets of Ni-Mn-Co catalyst trapped inside the growing crystal. Appear as dark spots under magnification. Mitigation: Controlled cooling rate (50°C/hour) allows molten metal to migrate out of the crystal before solidification. Post-growth acid cleaning dissolves surface-accessible metal residues.

Graphite inclusions: Unconverted graphite trapped in the crystal. Appear as black platelets. Mitigation: Ensuring complete dissolution of graphite before growth begins. Using fine graphite powder (1–10 µm) maximizes surface area for dissolution.

Nitrogen aggregates: Nitrogen atoms trapped in the diamond lattice cause yellow coloration. Mitigation: Pre-press carbon purification targets <500 ppm nitrogen. Growth parameters are optimized to minimize nitrogen incorporation from residual sources.

9.2 Color Control

Memorial diamonds target E–H color (colorless to near-colorless). Color deviations occur when:

- Nitrogen contamination → Yellow tint. Mitigation: Ultra-high purity carbon, controlled atmosphere during graphitization.
- Boron contamination → Blue tint. Mitigation: Boron is rare in biological samples but can enter from impure chemicals during purification. Reagent-grade chemicals are mandatory.
- Plastic deformation → Brown or gray tint. Mitigation: Stress-free growth geometry, isotropic pressure distribution, controlled cooldown.

Color is measured after cutting. If a stone falls outside the E–H range, BioGem Lab's policy is to remake the diamond at no charge.

9.3 Crack Prevention

Cracks form from thermal or mechanical stress:

- Thermal stress: Rapid temperature changes cause differential expansion between the diamond and surrounding material. Mitigation: Controlled cooldown at 50°C/hour. Press is not opened until the cell cools below 400°C.
- Mechanical stress: Pressure gradients across the growth cell cause asymmetric stress on the crystal. Mitigation: Precise cell centering, uniform anvil contact, isotropic press geometry (cubic press advantage).

- Internal stress: Growth too fast produces internal strain. Mitigation: Temperature gradient kept at 30°C (not 50°C). Growth rate limited to <1.5 mg/hour for gem-quality production.

9.4 Growth Irregularities

Adjunct crystals: Small secondary diamonds nucleate away from the seed, usually due to temperature fluctuations during growth. These reduce yield because they consume carbon without contributing to the main crystal. Mitigation: Ambient temperature control in the press hall ($\pm 2^\circ\text{C}$). Thermal insulation of hydraulic lines.

Growth bands: Visible parallel lines in the crystal, caused by pressure or temperature fluctuations. Mitigation: Pressure control within ± 0.1 GPa. Power supply stability (UPS backup prevents heater interruption).

Seed-related defects: The seed crystal's own defects propagate into the grown material. Mitigation: Rigorous seed inspection. Using high-quality Type Ia or Type IIa seeds with low defect density.

10. References & Further Reading

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13. IGI Diamond Grading Reports — International Gemological Institute, Antwerp, Belgium.
14. CCIC Gemstone Certificates — China Certification & Inspection Group.

Document Information

Property	Value
Author	BioGem Lab Engineering Team
Version	1.1 (optimized, July 2026)
Category	Technical Whitepaper

Property	Value
Language	English
Last Updated	July 26, 2026
Patent	ZL 201010565778.9 Certificate No. 1058820