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Crystalline Signatures: Advanced Photoluminescent Profiling of Multi-Origin CVD Synthetic Diamonds Versus Natural and HPHT Counterparts

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Abstract

This paper delineates the spectroscopic and gemo-logical distinctions between CVD synthetic diamonds sourced from primary global producers—China, India, and the United States—and contrasts them with both natural diamonds and HPHT-grown synthetics. Through advanced diagnostic tools in-cluding DiamondView™ imaging, FTIR spectroscopy, and pho-toluminescence analysis via EXA™ and laser Raman systems, the study identifies origin-specific luminescent behaviors and structural defects, such as the [Si-V] center at 737 nm, exclusive to CVD specimens. Notably, melee-sized diamonds marketed as CVD were frequently misidentified, with over 90% exhibiting HPHT characteristics. The research establishes a refined detec-tion framework that integrates luminescence mapping and defect spectroscopy, enhancing the reliable segregation of CVD synthetics from natural and HPHT diamonds within the gemological pipeline.

Index Terms—CVD diamond, synthetic diamond, photolumi-nescence, gemology, DiamondView, FTIR, Raman spectroscopy, melee diamonds

I. INTRODUCTION

The diamond industry is witnessing a change in paradigm with commercial introduction of laboratory grown diamonds (LGD) especially CVD LGDs. According to a report by Geologist Michael D. B. Atkinson, the mixing of natural diamonds and synthetics is threatening the integrity of the diamond supply chain. According to estimates, in the last few years, CVD production has increased exponentially. The global output of CVD is now more than 8 million carats of gem-quality CVD, mainly from China, India and the US. Due to the advanced technology of CVD synthesis especially the use of the microwave plasma CVD (MPCVD), diamonds are produced with properties that are increasingly similar to natural stones. This challenges the traditional detection methods.

Conventional gemological screening tools like ultraviolet fluorescence testers and magnification-based inclusion anal-ysis often prove ineffective for the differentiation of CVD synthetics, especially at melee sizes (below 0.2 carats). The constraints imposed by these rudimentary instruments arise from their dependence on explicit fluorescence response or visible inclusions that may be missing altogether, or opaque or barely noticeable in the case of high-quality CVD diamonds. As a result, a requirement is there for sufficient analytical methods able to identify the origin of CVD from varieties of source of production. A systematic investigation is carried out on 46 diamond samples, which consist of natural references and CVD samples from the three major producing regions. The present research aims to develop signatures to identify CVD diamonds using a multi-technique approach encompassing basic gemological test, spectroscopic analysis, and photoluminescence mapping. These results can help in establishing a strong identification framework, which is critical for assuring consumer confidence and transparency in the diamond trade. Additionally, the study identifies misleading melee-sized synthetics marketed with many claims regarding the way of growing those reports a distortion in the actual way of growing.

II. RELATED WORK

The rapid expansion of laboratory-grown diamond produc-tion has intensified the need for reliable diagnostic tech-niques capable of distinguishing synthetic diamonds from natural stones. Spectroscopic characterization has emerged as a cornerstone in gemological research because it enables the identification of lattice defects, impurity centers, and growth signatures that reflect formation conditions.

A comprehensive body of work has established the scientific foundation for diamond spectroscopy by detailing the role of defect centers such as nitrogen-vacancy (NV) and silicon-vacancy (Si-V) in determining diamond color, treatment his-tory, and origin [3]. This research highlights the importance of photoluminescence and infrared spectroscopy as primary analytical tools, directly supporting the multi-technique frame-work adopted in this study.

Optical absorption studies have further refined defect-based classification. Prior investigations into diamonds exhibiting the 480 nm absorption band demonstrated how spectroscopic signatures correlate with structural defects [1]. Statistical eval-uations of natural diamonds have additionally confirmed that quantitative spectral analysis significantly improves identifi-cation reliability [5]. Research on rare pink diamonds with yellow zones further emphasizes the complexity of defect distributions in natural specimens [6].

Comparative insights into synthetic diamonds are provided through analyses of optical properties and functional groups in HPHT micro-diamonds, revealing impurity-driven differ-ences between growth techniques [2]. Studies exploring HPHT

single-crystal synthesis offer valuable understanding of high-pressure growth environments that contrast with CVD pro-cesses examined in the present work [11].

Advances in diamond growth engineering have also influ-enced characterization strategies. High-quality diamond film fabrication via ion implantation and epilayer growth has demonstrated the increasing precision of synthetic meth-ods [10]. Investigations into co-doped diamond crystals show how controlled impurity incorporation alters structural be-havior [12]. Similarly, top-down fabrication approaches for diamond nanostructures reinforce the relationship between processing techniques and observable spectroscopic fingerprints [14].

Hydrogen and impurity incorporation remain critical indi-cators of formation history. Multi-analytical approaches com-bining ERDA, FTIR, and NanoSIMS have illustrated the value of integrating multiple analytical platforms for structural interpretation [8]. Complementary spectrometric studies of doped diamond coatings further demonstrate the sensitivity of spectroscopic tools to compositional variation [9].

Beyond gemological applications, diamonds are increas-ingly studied for electronic and advanced material uses. Re-views of diamond materials for electronic devices emphasize the importance of crystalline purity and defect control [7]. Investigations into diamond-like carbon films using classifica-tion and synchrotron spectroscopy broaden the understanding of carbon-based crystalline systems relevant to spectroscopic interpretation [4], [15]. Additional work on polymeric semi-conductors provides comparative insight into luminescent ma-terials [16].

Natural diamond diversity has also been documented in geological contexts, including the identification of fossil di-amond types that underscore the structural variability present in natural formations [13].

Despite substantial progress in diamond spectroscopy and growth characterization, limited research has systematically compared CVD diamonds from multiple geographic origins while simultaneously differentiating them from both natural and HPHT counterparts. Furthermore, the misidentification of melee-sized diamonds remains insufficiently addressed within existing literature.

Therefore, the present study extends prior work by imple-menting an integrated photoluminescence-driven framework supported by FTIR, Raman spectroscopy, and DiamondView imaging to establish origin-specific crystalline signatures. By correlating luminescent behavior with structural defects, this research contributes toward more reliable segregation proto-cols within the gemological supply chain.

III. RESEARCH GAP AND CONTRIBUTION

Existing literature demonstrates substantial progress in un-derstanding diamond defect chemistry, spectroscopic behavior, and synthesis pathways. Foundational studies have established spectroscopy as a reliable tool for identifying impurity centers and structural irregularities in both natural and synthetic diamonds [1], [3], [5]. Investigations into HPHT diamonds and engineered crystals further confirm that growth conditions strongly influence optical and structural properties [2], [11], [12].

Similarly, advancements in fabrication technologies and nano-engineering continue to produce diamonds with increas-ingly controlled characteristics, complicating traditional iden-tification approaches [10], [14]. Multi-instrument analytical strategies have been proposed to improve characterization accuracy, particularly for impurity detection and hydrogen incorporation [8], [9]. Research into electronic-grade dia-monds and carbon-based materials also highlights the growing sophistication of synthetic crystalline systems [4], [7], [15],

[16].

However, three critical gaps remain evident.

First, prior studies largely focus on either natural or syn-thetic diamonds independently, with minimal emphasis on cross-comparative analysis involving geographically distinct CVD sources. Second, while defect centers are well doc-umented, their potential as indicators of production origin has not been sufficiently explored. Third, the reliability of screening methods for melee-sized diamonds remains a major challenge despite increasing market prevalence, particularly given the geological variability reported in natural forma-tions [13].

The present work addresses these limitations by introducing a comprehensive multi-technique diagnostic framework that integrates photoluminescence mapping, FTIR spectroscopy, Raman analysis, and gemological evaluation. Unlike earlier research, this study directly compares CVD diamonds from major global producers with natural and HPHT specimens to identify reproducible luminescent and structural signatures.

A key contribution of this research is the identification of the silicon-vacancy ([Si-V]) center as a robust marker for CVD origin, alongside the recognition of region-dependent fluorescence patterns that may support provenance determi-nation. Additionally, the study exposes significant misrepre-sentation within melee-sized diamonds, reinforcing the need for advanced screening protocols.

Collectively, this work strengthens the scientific basis for diamond origin authentication and supports the development of standardized detection methodologies, thereby enhancing transparency, consumer confidence, and integrity within the modern gemological pipeline.

IV. MATERIALS AND METHODS

A. *Sample Collection and Preparation*

The study included a total of forty-six diamond samples segregated based on two main groups natural reference dia-monds and CVD synthetic diamonds. The natural diamonds we used were certified precious stones that belonged to type Ia and were real (n=3) natural diamonds that certified gemological collections use as benchmarks. CVD synthetic diamonds (n=43) were acquired directly from manufacturers in India (n=26), China (n=8) and the USA (n=10). All samples of CVD were developed by Microwave Plasma Chemical Vapor Deposition method which is the industrial standard for gem-quality single crystal synthesis. The weights of the samples used for analysis were 0.3-0.1 carats.

Furthermore, thirty-seven melee-sized diamonds as an ag-gregate of around 0.01 ct were sourced from commercial CVD origin claim vendor. To tackle the identification issues of very small-size diamonds, the sub-0.2-carat stones were analyzed separately. To remove any surface contaminants that could interfere with spectroscopic measurements, ultrasonic cleaning was done with analytical-grade ethanol prior to analysis of all samples.

B. *Gemological Characterization*

STANDARD INSTRUMENTS AVAILABLE IN GEMO-LOGICAL LABORATORIES HAVE BEEN USED TO EVALUATE BASIC GEMOLOGICAL PROPERTIES The density kit and digital balance hydrostatically determined specific gravity as the values. When measured with a refrac-tometer most diamonds gave OTL readings due to their high refractive indices. However, it was possible to identify some stones. Fluorescence reactions were registered in an appro-priate dark cabinet under short-wave (254 nm) and long-wave (365 nm) ultraviolet lamps. The internal features and inclusion characteristics were documented with a trinocular gemological microscope equipped with darkfield, brightfield and fiber-optic illumination.

Birefringence patterns were observed with cross-polarized filters and oriented for interference contrast.

C. *Spectroscopic and Advanced Analysis*

Advanced and sophisticated tools were used for characteri-zation. The thermometer scientific Nicolet iS50 FTIR micro-scope was used to record the FTIR Spectra of the sample in the absorbance mode ranging from 400 to 300 cm1 with a resolution of 4 cm1. Fluorescent and Phosphorescent pattern studies were done by DiamondView™ imaging employing deep ultraviolet (˜230 nm) excitation. This tool shows growth structures and defect distributions invisible using normal mi-croscopy.

The two complementary systems were analyzed using pho-toluminescence. The EXA diamond detector, optimized for detecting nitrogen-related flaws, was used to take the PL spectra at excitation wavelengths of less than 410 nm. The laser Raman spectrosopy with 532 nm excitation has been used to characterize [Si-V] and [N-V] defect centers in the 535–850 nm higher-resolution PL spectra. Cryogenic Raman measurements were performed with liquid nitrogen to enhance the spectral resolution and mitigate thermal broadening effects. All data received was corrected for the baseline and normal-ized for the analysis for comparison.

V. RESULTS AND DISCUSSION

A. *Gemological Properties*

Table I presents the physical characteristics of the diamond samples. The specific gravity values of all the samples were in the range of 3.49 to 3.55 which is quite similar to the pure diamond. The materials were confirmed as diamond since refractive indices ranged above the measureable limit of a standard refractometer. When exposed to both short-wave and long-wave ultraviolet light, natural diamonds proved to be inert under regular UV light. CVD synthetic diamonds were weak to strong yellowish-green under short-wave UV, and inert under long-wave UV source. This differential fluorescence response may provide initial indication; however, identification is not guaranteed as some treated natural diamonds exhibit the same fluorescence response.

TABLE I: Gemological Properties Summary

Type (Source)	Pieces	Color	Clarity	Fluorescence
Natural	3	E–G	VVS–VS	Inert
CVD (India)	26	G–I	VVS–SI	Weak–Mod. yG
CVD (China)	8	F–K	VS–SI	Mod.–Strong yG
CVD (USA)	10	G–H	VVS2–VS1	Weak–Mod. yG

yG: yellowish-green; All samples: RI OTL, SG 3.49–3.55

Microscopic examination revealed distinct inclusion char-acteristics. Natural diamonds contained mineral inclusions such as crystals, pinpoints, and needle-like features, along with natural indented girdles. CVD diamonds predominantly featured dark, non-carbon inclusions (likely graphite), cloud-like assemblies of dark particles, and feather or blade-like fractures. These internal features, while suggestive, are not universally present and thus insufficient for conclusive identi-fication.

(A) Natural Diamond (B) CVD Diamond

Fig. 1: Schematic representation of birefringence patterns: (A) Patchy strain in natural diamond; (B) Columnar pattern in CVD synthetic diamond.

Birefringence patterns seen through cross-polars show def-inite patterns. Natural diamonds exhibit uneven patchy strain patterns, which appear blue, brown, and grey in interference colors (Figure 1A). This is due to internal stresses that formed during their geological formation. Diamonds with chemical va-por deposition sourced diamonds displayed columnar patterns of parallel black lines with colored stripes (Figure 1B). Certain specimens showed distinctive tatami strain patterns with a cross-hatch banding indicative of stoppages. As a preliminary screening for bigger stones, these birefringence features can be observed but in melee-sized diamonds, it is difficult.

B. *Spectroscopic Characterization*

All natural diamonds samples are classified as type Ia dia-monds. Their infrared spectra showed strong nitrogen-related absorption bands in the range of 482–1500 cm^{1}. In addition, organic molecules are found to be trapped in diamonds as shown by the appearance of absorption bands at 1405 and 3107 cm^{1}. All synthetic diamonds created with CVD generate no nitrogen or boron absorptions, hence classified as Type IIa. There is little difference between CVD synthetics and rare natural diamonds type IIa. This essentially separates most CVD synthetics from nitrogen containing natural diamonds.

DiamondView™ imaging showed different fluorescent pat-terns. Natural diamonds only showed a deep blue fluorescence and no phosphorescence. CVD diamonds that were sourced from India and China predominantly exhibited bluish-green fluorescence with an associated weak to moderate intensity greenish-blue phosphorescence. Conversely, CVD diamonds sourced from the USA tended to exhibit red to reddish-orange fluorescence alongside a weak greenish-blue phosphorescence. Growth structures visible in DiamondView™ images included fine, parallel striations in Indian and Chinese CVD diamonds, while US-origin stones often showed layered growth patterns with blue patches, indicative of interrupted growth cycles.

C. *Photoluminescence Analysis*

Analysis through photoluminescence spectroscopy gave the clearest identification criteria. The EXA™ analysis of natural diamonds indicated a narrow peak at 415 nanometres cor-related with the N3 defect centre. The synthetic diamonds created by CVD exhibited a noticeable peak at a wavelength of 737 nm, which is due to the defect of [Si-V], which is created by the CVD process. The absence of this peak in the HPHT diamonds and all other natural diamonds proved that it was a reliable marker for CVD origin.

With 532 nm excitation, laser ramn spectroscopy further described the defect structures. Besides the diamond Raman peak at 572.6 nm (i.e. 1332 cm^{1} shift) CVD diamonds showed the characteristic doublet at 736.3 and 736.7 nm due to the [Si-V] center. Some CVD samples, especially the red fluorescent ones, were found to have nitrogen-vacancy centres ([N-V] (574.6 nm) and [N-V] (636.6 nm)). The ratio of intensity and combination of these defect peaks of cracked structures vary as a function of geographic origin. This is an indication of differences in growth parameters and/or concentrations of impurities put in by the various producers.

Diamonds CVD of Indian and Chinese origin which usually have green emission show peaks in the 480-550 nm range. This peak was attributed to nickel impurities from HPHT seed crystals use in CVD. Red-fluorescing CVD diamonds of US origin exhibited enhanced peaks for the [N-V] centre and additional emissions at 575–620 nm. The fingerprints can be used to identify whether something has been produced by CVD and potentially where this took place.

D. *Melee-Sized Diamond Analysis*

Analysis of 37 melee-sized diamonds (1.0-1.7 mm diameter) detected major discrepancies between vendors' claims and actual growth techniques. DiamondView imaging indicates that most developed a strong greenish-blue fluorescence, phos-phorescence, and cubo-octahedral growth patterns associated with HPHT. Only a small amount exhibited that which is characteristic of CVD melees: greenish-blue fluorescence with weak phosphorescence.

It was found that defect investigations using laser raman spectroscopy was carried out. Of the 37 melee samples, only 4 showed the characteristic [Si-V] doublet at 737 nm that indicates CVD growth. The rest 33 samples lacked this signature but exhibited known HPHT defect patterns. All of the 1.7 mm stones were HPHT-grown. Out of 11 stones (1.5 mm), only one was CVD. Three of 12 stones (1.0 mm) were CVD. It means over 90% misrepresentation, which shows that most of the melee diamonds in the market are HPHT synthetics. Advanced testing is necessary to differentiate them accurately.

Melee diamond analysis has challenges that are both tech-nical and practical in nature. Due to their small size, the signal quality in spectroscopic measurements is limited and microscopic features are not well-resolved. Moreover, the commercial demand for rapid screening methods, which may miss the subtle differences between the two, ultimately favors high throughput. These findings illustrate the necessity of specialized protocols and methods to identify melee diamonds.

VI. CONCLUSION AND FUTURE WORK

This study presents a multi-technique approach for reliably identifying CVD synthetic diamonds, as well as distinguishing them from natural diamonds and HPHT-grown synthetics. An examination of basic gemological properties will not allow definitive identification, especially for higher quality and melee sizes. Laser light analysis is used to target the [Si-V]-center, at 737 nm, in order to prove CVD origin.

The differences in location between CVD diamonds from various manufacturers present interesting opportunities for tracing origin in the synthetic diamond market. The character-istics of Indian and Chinese CVD diamonds are very similar indicating a similar technology/raw material. In contrast, CVD diamonds made in the USA show different fluorescence and defects, suggesting different growth and post-growth condi-tions. These regional signatures warrant more study using larger sample sets and controlled growth experiments.

The market is seeing a lot of CVD melee-sized diamonds. But more than 90% of them are not what they claim to be as they are HPHT-grown. This exposes vulnerabilities on which authorities can draw further investigations. Due to accidental commingling or intentional labeling to take advantage of market preferences, this may occur. It doesn't matter what the intent. These findings highlight the need for testing protocols specifically for small diamonds (possibly automated screening systems) in line with the diagnostic criteria to be established. Future work should also target several areas. We can include samples from newly discovered diamond mining regions. Further, diamonds coming from top-quality treatment methods can be added. Next, create standardized testing protocols and reference libraries for gemological laboratories. Focus on quickly screening technologies that will implement the diag-nostic criteria established here in high throughput commercial setups. In the end, the ability to detect attributions will require Absorbance

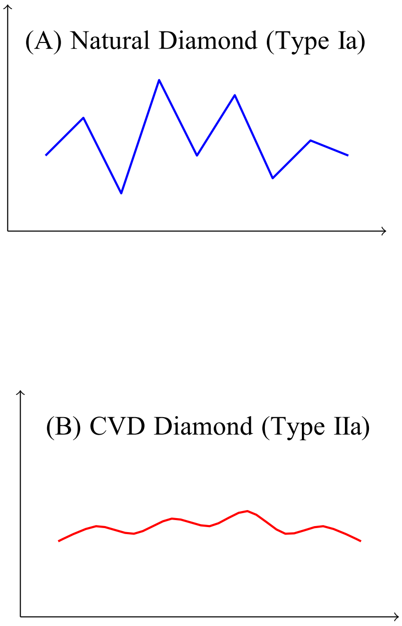

Fig. 2: Schematic FTIR spectra: (A) Natural diamond showing nitrogen and hydrogen absorptions; (B) CVD synthetic diamond lacking nitrogen-related features.

an interdisciplinary scientist approach of gemologists, material scientists, and developers of instrumentations.

REFERENCES

[1] Lai, M. Y., Hardman, M. F., Eaton-Magan˜a, S., Breeding, C. M., Schwartz, V. A., & Collins, A. T. (2024). Spectroscopic characterization of diamonds colored by the 480 nm absorption band. *Diamond and Related Materials*, *142*, 110825.

[2] Caldero´n-Mart´ınez, M. C., Gil-Tolano, M. I., Navarro-Espinoza, S., Mele´ndrez, R., Chernov, V., & Barboza-Flores, M. (2022). Optical properties and functional groups characterization of commercial HPHT micro-diamond samples. *Optical Materials*, *131*, 112592.

[3] Green, B. L., Collins, A. T., & Breeding, C. M. (2022). Diamond spec-troscopy, defect centers, color, and treatments. *Reviews in Mineralogy and Geochemistry*, *88*(1), 637-688.

[4] Ohtake, N., Hiratsuka, M., Kanda, K., Akasaka, H., Tsujioka, M., Hirakuri, K., ... & Saitoh, H. (2021). Properties and classification of diamond-like carbon films. *Materials*, *14*(2), 315.

[5] Hardman, M. F., Lai, M. Y., Breeding, C. M., Eaton-Magan˜a, S. C., & Schwartz, V. A. (2025). A statistical evaluation of the spectroscopic features in natural diamonds with the 480 nm absorption band. *Diamond and Related Materials*, *155*, 112277.

[6] Lai, M. Y., Myagkaya, E., Hardman, M. F., Eaton-Magan˜a, S., Breeding, C. M., Sohrabi, S., & Collins, A. T. (2024). Spectroscopic characteri-zation of rare natural pink diamonds with yellow color zones. *Diamond and Related Materials*, *148*, 111428.

[7] Araujo, D., Suzuki, M., Lloret, F., Alba, G., & Villar, P. (2021). Diamond for electronics: Materials, processing and devices. *Materials*, *14*(22), 7081.

[8] Vangu, D., Bureau, H., Khodja, H., Charrondiere, M., Esteve, I., Be´neut, K., ... & Bouillard, J. C. (2023). Combination of ERDA, FTIR spectroscopy and NanoSIMS for the characterization of hydrogen incorporation in natural diamonds. *Diamond and Related Materials*, *136*, 110007.

[9] Sharma, D. K., Girao, A. V., Chapon, P., Neto, M. A., Oliveira, F. J., & Silva, R. F. (2022). Advances in RF glow discharge optical emission spectrometry characterization of intrinsic and boron-doped diamond coatings. *ACS Applied Materials & Interfaces*, *14*(5), 7405-7416.

[10] Zhang, X., Pieshkov, T. S., Chen, D., Nonis, S., Ngan, K., Oliveira, E. F., ... & Ajayan, P. M. (2025). Ion-Implantation, Epilayer Growth, and Lift-Off of High-Quality Diamond Films. *Advanced Functional Materials*, 2423174. Wang, Z., Ma, H., Fang, S., Yang, Z., Miao, X., Chen, L., & Jia, X. (2020). Synthesis and characterization of gem diamond single crystals in Fe-C system under high temperature and high pressure. *Journal of Crystal Growth*, *531*, 125371.

[11] Chen, J., Li, S., Nie, Y., Hu, Q., Hu, M., Guo, Z., ... & Zhao, C. (2025).

Growth and characterization of diamond with B-Fe3P co-doped grown along the (100) surface. *Ceramics International*, *51*(11), 14021-14027.

[12] Shumilova, T. G., Ulyashev, V. V., Kazakov, V. A., Isaenko, S. I., Svetov, S. A., Chazhengina, S. Y., & Kovalchuk, N. S. (2020). Karite–diamond fossil: A new type of natural diamond. *Geoscience Frontiers*, *11*(4), 1163-1174.

[13] Li, C., Pieshkov, T., Mei, Z., Xu, M., Li, T., Murukeshan, J., ... & Ajayan, P. (2024). Top-down fabrication of diamond nanostructures. *Diamond and Related Materials*, *148*, 111535.

[14] Rittihong, U., Akasaka, H., Euaruksakul, C., Tomidokoro, M., Kamon-suttipaijit, N., Nakajima, H., ... & Tunmee, S. (2020). Synchrotron-based spectroscopic analysis of diamond-like carbon films from different source gases. *Radiation Physics and Chemistry*, *173*, 108944.

[15] Giusto, P., Cruz, D., Heil, T., Arazoe, H., Lova, P., Aida, T., ... & Antonietti, M. (2020). Shine bright like a diamond: new light on an old polymeric semiconductor. *Advanced Materials*, *32*(10), 1908140.