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Hot filament chemical vapour deposition on tung sten carbide milling tools with magnetic field as sistance

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Microcrystalline diamond (MCD) is the common diamond coatings applied to manufacturing tools that are used to machine difficult-to-cut materials. The coating layer is typically produced through hot filament chemical vapor deposition (HFCVD). In order to improve the growth rate as well as control the grain size of diamond particles which form coating layers on tungsten carbide milling tools, this study investigated deposition of the diamond film layers using conventional HFCVD machine design with the novel magnetic field assisted system. It was found that a magnetic field favoured the fabrication of smaller diamond grain of MCD and increased the growth rate of the diamond film. The characteristics of the diamond film on the milling tools were evaluated using SEM. The results showed that the cross-section of the diamond film reached to 3.25 µm with magnetic flux density of 100 mT, and 2.00 µm without magnetic flux density. The results show that the growth rate of the diamond film on the milling tools has been improved nearly 50% faster with magnetic field assistance. With the magnetic field assistance applied on the HFCVD machine, the grain size and the growth rate of diamond film can be controlled.

1. Introduction

Current research theory and industrial practice agree that there are two main types of diamond films, MCD and NCD. MCD films are composed of diamond grains ranging in size from 1 to 100 µm. I Comparatively, NCD films are composed of diamond grains with ballas or cauliflower-like shapes and a size of less than 500 µm. The grains of MCD films are comprised of numerous misaligned and dislocated characteristic planes as well as surface defects that promote anisotropy. Therefore, MCD grains do not consist weak planes or directions that MCD films exhibit superior hardness or strength. In addition, MCD films has higher phase purity and crystallinity than NCD films [1]. Thus, MCD coating has been widely used in precision and ultra-precision machining to machine hard and difficult-to-cut materials, especially brittle materials such as graphite and engineering ceramics [2]. As for NCD films, the presence of non-diamond composition at crystal boundaries reduces adhesion between the film and the substrate as a result of smaller grain size and sp^2 bonding. Despite this, the coefficient of friction in the NCD film is still considerably less than that of the MCD film. The weak adhesion can be strengthened by employing a multilayer approach. NCD coating is utilized in applications involving high-speed machining and micromachining, such as the fabrication of printed circuit boards (PCB) [3].

There consist various processing parameters for growing MCD and NCD diamond films via HFCVD, e.g., selection of precursor gas as the carbon source (i.e., methane, ethene and acetone [4]), filament material (i.e., tungsten [5], tantalum [6]), filament temperature, pre-treatment, seeding method of substrate, and functional enhancement of the HFCVD machine.

In order to control the crystal orientation and grain size during growth of diamond film, researchers have suggested a number of approaches, including an application of magnetic field in the HFCVD machine. While there are researchers who have studied the influence of periodic magnetic field towards the grain growth rate [7] and crystal orientation [8], the mechanism and outcome of HFCVD with static magnetic field assisted has yet been discussed as thoroughly. Little et al. [9] set the foundation by demonstrating that under low pressure high temperature (specifically at atmospheric pressure), strong static magnetic field can promote nucleation and growth of smaller diamond grains. Several researchers [7–13] stated that magnetic field has important effect on motion of electrons. Due to law of the Lorentz force, ions move in spiral pathway in magnetic field and are constrained in the helical region, reducing the probability of annihilation at the substrate or wall, and thus reducing energy losses.

This paper further deep dived into the production of diamond films on using HFCVD with static magnetic field assisted, investigating on factors influencing grain growth rate, grain size, film thickness and crystal orientation for various applications. With magnetic field assisted in the system, growth rate of diamond film on the tungsten carbide milling tools can increase with controllable grain size.

2. Experimental procedures and set up

2.1 HFCVD machine with magnetic field system

Schematic diagram of the HFCVD with magnetic field system is shown in Figure 1. The magnetic field system is placed below the tantalum filament at the centre of the working table. Permanent Sm2Co17 magnet (samarium and cobalt) was selected due its superior operating temperature compared to other magnets such as NdFeB. The magnet has the strength of 100mT on the surface, as measured by Tesla metre. Detailed information of the magnetic field system is shown in Figure 2. The Sm2Co17 circular magnets with outer diameter of 30mm are installed in the graphite holder, with the tungsten carbide milling tool placed into the center of the circular magnets. Three different sizes of quartz surround the carbide tool, the magnets and the top of the graphite holder surface to prevent heat transfer from the circular magnets.

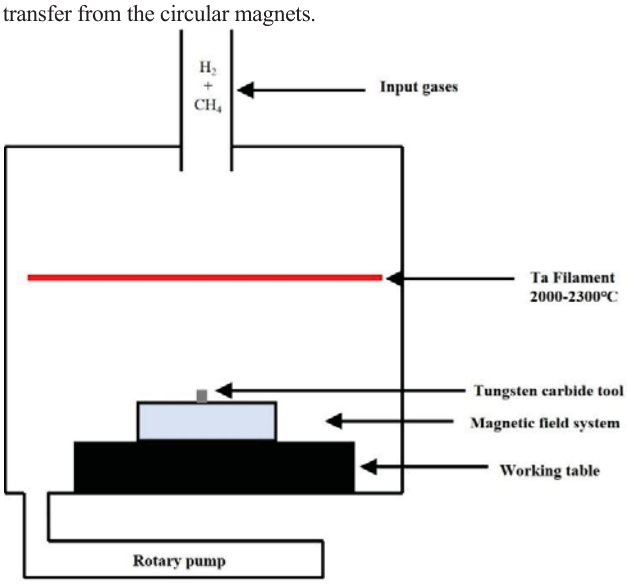


Fig. 1 Schematic diagram of HFCVD with magnetic field assisted

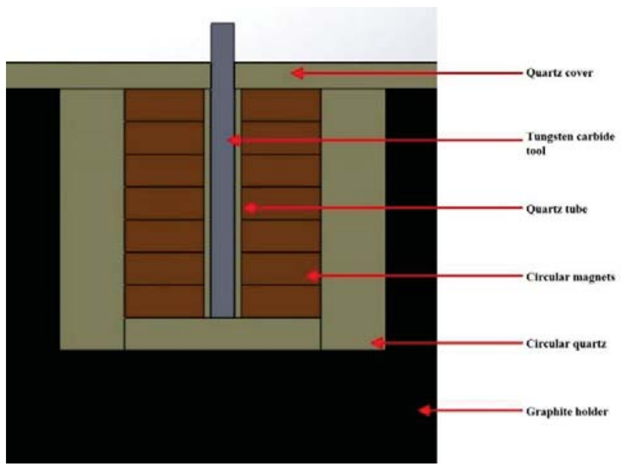


Fig. 2 Magnetic field system for HFCVD

2.2 Fabrication of diamond films on milling tools

In this study, ball end mill (R0.85, 6% Co) tungsten carbide (WC) with grain size of 0.5-0.8µm are selected as specimens. Prior to diamond film deposition, the surface of the ball end mill was treated with Murakami's solution (KOH: K3(Fe (CN)6: H2O= 1:1:10) and Caro's acid (H2O2 + H2SO4. As shown in Table 1, this study investigates deposition of diamond film on the tungsten carbide milling tools, with magnets and without magnets, with an indication of magnetic field direction. Details of the coating parameters selected for fabricating diamond films are listed in Table 2. Surface morphology of the diamond film was investigated by scanning electron microscope (SEM: Tescan VEGA 3) to observe coating thickness and grain size of the films.

Table 1 Parameters of different samples

Samples	Magnetic field strength	Direction
M1	100mT	South
N1	-	-

Table 2 Deposition parameters for diamond film

Parameters	
Power (W)	13000
Methane content (sccm)	30
Tool temperature (°C)	860
Pressure (Pa)	2500
Duration (h)	4
Hyrogen content (sccm)	3000
Methane content (sccm)	30

3. Results and discussion

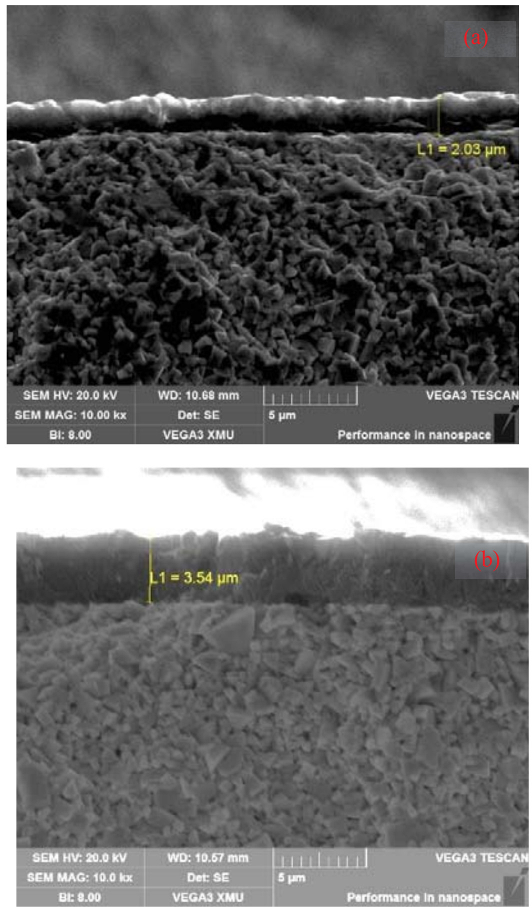
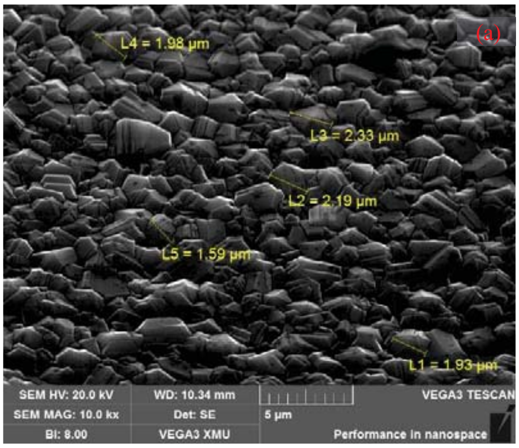


Fig. 3 Diamond film coating thickness captured by SEM (a) N1 and (b) M1

Figure 3 shows cross-sectional profiles of diamond films growth of N1 sample (without magnetic flux density) and M1 sample (with magnetic flux density), respectively. Under an absence of magnetic field, coating film thickness of N1 tool is measured to be 2.03µm. As for the M1 tool produced under the magnetic flux density of 100mT, the coated diamond film thickness on the milling tool is measured to be 3.54µm, which is thicker than that of the N1 tool. The result demonstrates that growth rate of film on the M1 tool is higher than that on the N1 tool since both specimens share an equal deposition time of 4 hours. This demonstrates that increasing the magnetic flux density by 100mT results in a faster growth rate in diamond coating.



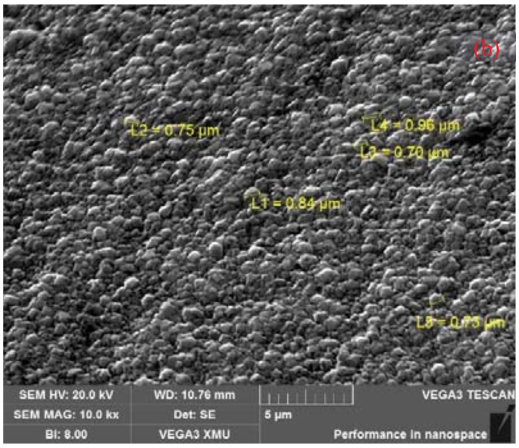


Fig. 4 Diamond film grain size captured by SEM (a) N1 and (b) M1

Figure 4 shows the micro-topographies of diamond films of N1 tools as well as M1 respectively. With the absence of the magnetic field, the average grain size of N1 tools is around 0.80µm. In contrast, the average grain size of M1 tools is smaller compare N1, which is around 2.00µm. As a result of the accumulation of cations on the substrate and the enhancement of ion collisions that take place under the influence of a magnetic field, which causes ion bombardment on the film surface [13], this result suggests that the presence of a magnetic field decreases the diamond grain size of the coating that is produced by the magnetic field system.

4. Conclusion

In conclusion, the experiment involved depositing diamond film onto two specimens under two distinct conditions, one by conventional HFCVD and the other by HFCVD with a novel 100mT magnetic field system and magnetic field strength assisted. Results from SEM indicate that the magnetic field system present during deposition affects the properties of diamonds. As determined by SEM, the thickness of the film increased by 50%. The grain size was reduced by 88% when a magnetic field was applied. With the assistance of a magnetic field provided to the HFCVD machine, the grain size and growth rate of diamond film coated on the tungsten carbide milling tools are enabled to regulate possibly.

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REFERENCES

[1] H. Wang, X. Song, X. Wang, F. Sun, Fabrication, tribological properties and cutting performances of high-quality multilayer graded MCD/NCD/UNCD coated PCB end mills, Diam. Relat. Mater. 118 (2021) 108505. https://doi.org/10.1016/j.diamond.2021.108505.

[2] X. Shen, C. Wang, F. Sun, The effects of deposition parameters on the grain morphology and wear mechanism of monolayer diamond grinding tools fabricated by hot filament CVD method, Diam. Relat. Mater. 89 (2018) 312–321. https://doi.org/10.1016/j.diamond.2018.09.021.

[3] X. Lei, B. Shen, L. Cheng, F. Sun, M. Chen, Influence of pretreatment and deposition parameters on the properties and cutting performance of NCD coated PCB micro drills, Int. J. Refract. Met. Hard Mater. 43 (2014) 30–41. https://doi.org/10.1016/j.ijrmhm.2013.10.016.

[4] P.W. May, N.M. Everitt, C.G. Trevor, M.N.R. Ashfold, K.N. Rosser, Diamond deposition in a hot-filament reactor using different hydrocarbon precursor gases, Appl. Surf. Sci. 68 (1993) 299–305. https://doi.org/10.1016/0169-4332(93)90249-B.

[5] T.D. Moustakas, The role of the tungsten filament in the growth of polycrystalline diamond films by filament-assisted CVD of hydrocarbons, Solid State Ionics. 32–33 (1989) 861–868. https://doi.org/10.1016/0167-2738(89)90368-8.

[6] Y. Takamori, M. Nagai, T. Tabakoya, Y. Nakamura, S. Yamasaki, C.E. Nebel, X. Zhang, T. Matsumoto, T. Inokuma, N. Tokuda, Insight into temperature impact of Ta filaments on high-growth-rate diamond (100) films by hot-filament chemical vapor deposition, Diam. Relat. Mater. 118 (2021) 108515. https://doi.org/10.1016/j.diamond.2021.108515.

[7] H. Long, S. Li, H. Luo, Y. Wang, Q.P. Wei, Z.M. Yu, The effect of periodic magnetic field on the fabrication and field

emission properties of nanocrystalline diamond films, Appl. Surf. Sci. 353 (2015) 548–552. https://doi.org/10.1016/j.apsusc.2015.06.151.

[8] Y. Wang, J. Li, H. Long, H. Luo, B. Zhou, Y. Xie, S. Li, Q. Wei, Z. Yu, A periodic magnetic field assisted chemical vapor deposition technique to fabricate diamond film with preferred orientation, Surf. Coatings Technol. 292 (2016) 49–53. https://doi.org/10.1016/j.surfcoat.2016.03.026.

[9] R.B. Little, X. Wang, R. Goddard, Nano-diamond synthesis in strong magnetic field, J. Clust. Sci. 16 (2005) 53–63. https://doi.org/10.1007/s10876-005-2715-9.

[10] C. Luo, Q. Fu, C. Pan, Strong magnetic field-assisted growth of carbon nanofibers and its microstructural transformation mechanism, Sci. Rep. 5 (2015) 1–6. https://doi.org/10.1038/srep09062.

[11] Y. Wang, Q. Wei, Z. Yu, H. Long, Z. Deng, Y. Xie, J. Li, C. Te Lin, L. Ma, K. Zhou, Field emission properties of the caterpillar-like structural carbon film grown by magnetic and electric fields coupling HFCVD, Appl. Surf. Sci. 423 (2017) 788–792. https://doi.org/10.1016/j.apsusc.2017.06.240.

[12] R.B. Little, R. Goddard, Magnetization for lower temperature, selective diamond and carbon nanotube formation: A milestone in carbon physicochemical condensation, J. Appl. Phys. 95 (2004) 2702–2712. https://doi.org/10.1063/1.1643784.

[13] Y. Wang, J. Li, N. Hu, Y. Jiang, Q. Wei, Z. Yu, H. Long, H. Zhu, Y. Xie, L. Ma, C. Te Lin, W. Su, Effect of magnetic and electric coupling fields on micro- and nano- structure of carbon films in the CVD diamond process and their electron field emission property, Mater. Res. Express. 5 (2018). https://doi.org/10.1088/2053-1591/aab11b.