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On the Polishing Techniques of Diamond and Diamond Composites

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Abstract. This article reviews the state-of-the-art techniques for polishing diamond and polycrystalline diamond composites. A focus is on their material removal mechanisms and features. It concludes that while each of them has its advantages and drawbacks, the technique by dynamic friction has a promising potential for polishing production.

Introduction

Diamond has been the king of jewels, and is also a desirable material for many industrial applications because of its unique combination of optical, thermal, mechanical, chemical and electrical properties. For example, diamond has the highest hardness and thermal conductivity of any known material and possesses a high electrical resistivity, a large optical band gap and a high transmission from ultraviolet to infrared regions. It also has a high chemical inertness to most corrosive environments, a low adhesion and friction, and an extremely low thermal expansion coefficient [1-4]. The full industrial exploitation of such unique combination of properties has been limited by the scarcity and expense of natural diamond, but a large quantity of polycrystalline diamond (PCD) composites have been available for various applications since the 1960s. From the 1980s the technology of "chemical vaporized deposition (CVD)" has been rapidly developed to produce diamond films. These have fuelled the hopes of high-tech devices to be manufactured from diamond, ranging from optical windows to heat spreaders. However, these diamond products are mostly rough and usually cannot be directly used in many cases. Polishing is therefore necessary.

Because of the extreme hardness and chemical inertness of diamond, the polishing of diamond and its composites has been very difficult, based on the diamond-cutting-diamond approach. The polishing rate of such processes is extremely low, being of the order of 10 nm/h [5,6]. Since the late 1980s, various physical and chemical means have been proposed [5]. However, to the authors' knowledge, no comprehensive discussions on the polishing techniques of diamond have been available in the literature since 2000.

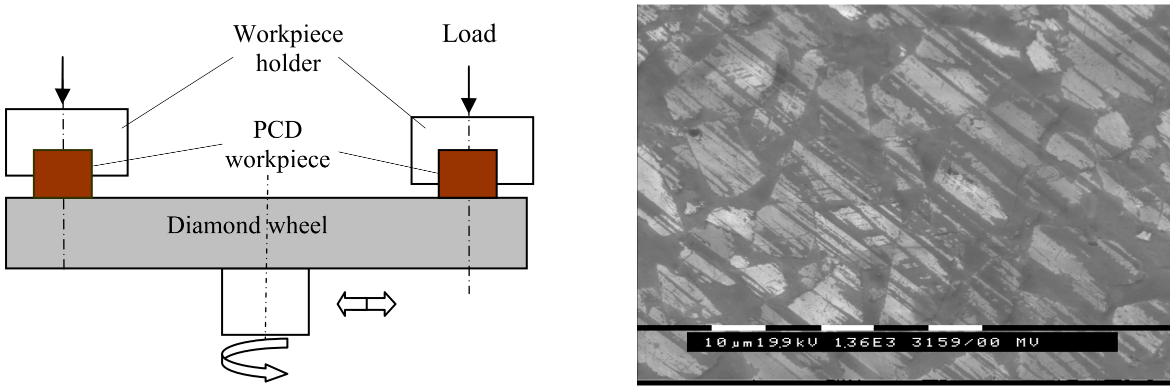
This article will discuss various polishing techniques available for diamond and its composites and provide an understanding of their material removal mechanisms and features.

The Polishing Techniques

The techniques for polishing diamond can be broadly classified as contact and non-contact. Those using mechanical, chemical and thermal methods or a synergistic combination of them include mechanical polishing, chemo-mechanical polishing, thermo-chemical polishing, high energy beam (laser/plasma/ion beam) polishing, electrical discharge machining (EDM) and dynamic friction polishing (DFP).

Mechanical Polishing. This is a traditional method and usually uses a cast iron wheel (called scaife) of selected porosity, charged with diamond powder [1,7,9]. The surface to be polished is placed against the scaifes of about 300 mm in diameter rotating at 2,500 rpm. It is recommended to apply a contact pressure of 2.5-6.5 MPa for diamond grinding and 1-2.5 MPa for polishing [8]. To avoid recharging the scaife with diamond grits, diamond-bonded wheels have been used, which is expensive but avoids the process interruption and reliance on skilled labours in loading abrasives.

The polishing rate increases with the load applied and the speed of the scaife [8,10]. It also depends strongly on the crystal orientation and direction of abrasion [8]. The ratio of the maximum removal rates along (110), (100) and (111) planes are 1:0.6:0.1, showing that it is the easiest to polish in the (110) plane. A higher removal rate is generally obtained under higher speeds and greater loads. Figure 1 shows a schematic illustration of the mechanical polishing of PCD in industry using a diamond bonded wheel, and an example of a polished PCD surface.



(a) Schematic diagram of the apparatus (b) Polished surface morphology

Fig.1 Mechanical polishing of PCD [11]

The material removal during mechanical polishing of diamond has been considered as a mechanical process of micro-cleavage [1,12]. The abrasion resistance of the diamond depends on the position of the cleavage planes relative to the surface subjected to polishing. Since 1981, some investigations have been conducted to understand the material removal mechanism [1,9,10,13-21]. With the aid of high resolution microscopes, it was found that in addition to the mechanical removal there are other mechanisms including 1) *thermal wear* caused by burning or carbonization due to the temperature rise at some spots where the high temperature leads to changes of the mechanical properties of diamond and promotes its wear; and 2) *chemical wear* induced by irreversible phase transformation of the diamond at the polishing surface to sp^2 bonded carbon such that the weakly bonded material is removed or fractured more easily [10,19,22], of which the former can generate a good surface finish with acceptable polishing rates, but the latter tends to damage both the diamond and the polishing wheel.

To increase the polishing rate, some techniques have been proposed. Tang *et al* [23] used a thick diamond film to polish thick CVD diamond films and achieved a material removal rate of up to 10 µm/h and a surface roughness of Ra = 1.35 µm. Kim [24] patented a technique by coating amorphous silicon oxide (SiO_x, $x = 1.97$) on a scaife. In this case, when a diamond specimen is rubbed against the scaife, the SiO_x reacts with the diamond carbon to form CO and CO_2 thereby chemically removing carbon from the surface in addition to mechanical removal. It was claimed that this technique could produce ultra-smooth single-crystal diamond surfaces with a roughness of 10 Å rms at a polishing rate of 20-40 µm/h. Tsai *et al.* [25] developed a catalytic grinding wheel to reduce polishing time, using cast iron as the binder in the primary diamond wheel to act as the catalyst. The combined catalytic reaction and grinding performed effectively. In this process, however, a heating device is needed to increase the reaction activity. These methods, though claimed as mechanical, have actually chemical effects in the processes.

Chemo-mechanical Polishing. This type of techniques uses mechanical polishing in conjunction with chemicals to enhance the removal rate and to obtain a better surface finish. Mostly, they exploit the high temperature oxidation property of diamond [7,26]. Figure 2 shows a schematic diagram of a chemo-mechanical polishing apparatus [27], where diamond under an externally applied load comes into contact with a polishing plate in the presence of oxidizing chemicals at a temperature slightly above the melting point of the oxidizing agent. The polishing disk is commonly made of cast iron [27,28] or a ceramic such as polycrystalline alumina Al_2O_3 [26,29-31]. Oxidizing agents such as $NaNO_3$, KNO_3 and KOH of melting temperatures 308, 324 and 360 °C respectively have been commonly used. Mixtures of several oxidizing agents have also been tried to decrease the operating temperature but increase the material removal rate (*e.g.*, $KMnO_4$ + H_2SO_4 for polishing at 70 °C [32] and $LiNO_3$ + KNO_3 for polish at 350 °C [27]). Diamond abrasives can be used to improve the removal efficiency.

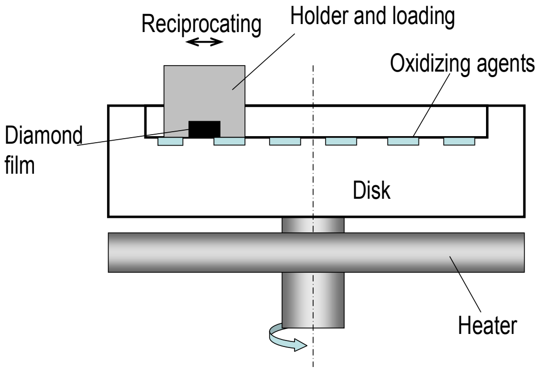


Fig.2 Schematic structure of a chemo-mechanical polishing apparatus [27]

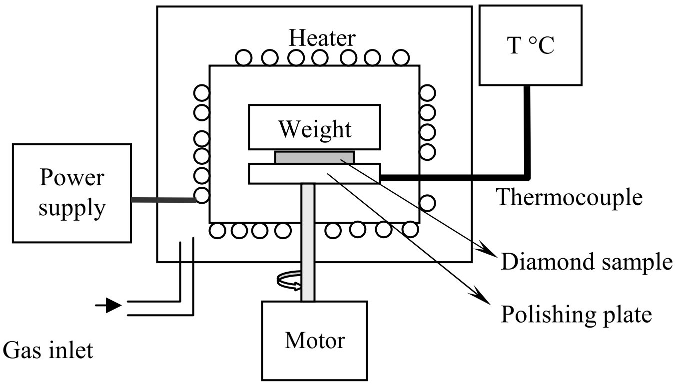


Fig.3 Schematic diagram of a thermo-chemical polishing apparatus [33]

In chemo-mechanical polishing, the compound effect of mechanical abrading and oxidant etching plays a main role in the material removal process. It was considered [26] that during polishing the protruding portions of a diamond specimen contact mechanically with diamond powder or polishing plate, which generates micro-cracks on the brittle diamond crystal surface. The oxidizing chemicals then enter the micro-cracks, under pressure and elevated temperatures, react with the diamond carbon and form CO or CO_2. Wang *et al.* [27] detected graphite and amorphous carbon on the surface of polished diamond films, and concluded that the oxidization and graphitisation combined with mechanical cracking account for the high material removal rate in chemo-mechanical polishing of diamond.

The typical polishing speed and pressure used in chemo-mechanical polishing are about 40 m/s and 1.4 MPa, respectively, and the achieved polishing rate is of the order of 0.5 μm/h (on 3×3 mm^2 specimen) [28]. It was found that compared with a mechanical polishing technique, a chemo-mechanical polishing method gives a much better surface integrity [34] and a much smoother surface (~ Ra =20 nm) [32] in a shorter duration.

Thermo-Chemical Polishing. This is a process using a hot metal plate, based on the thermo-chemical reaction between a diamond surface and a hot metal plate at an elevated temperature (730 – 950 °C), as shown schematically in Fig.3 [33]. The diamond surface is pressed by a pressure of around 15 kPa onto a rotating metal plate with a typical speed of 2.8 mm/s, where the pressure and speed needed are lower than that in a conventional mechanical polishing. The metal plate can be of various materials such as iron, nickel, manganese and molybdenum [35-39], but iron has been found to be the most effective.

Polishing rate increases exponentially with the temperature rise and also increases with a higher pressure due to the pressure-enhanced diamond-plate contact [33]. However, it was found that a greater speed of the polishing plate eventually reduces the material removal rate. The mechanism of such an effect is not totally clear, although some researchers suggested that it could be attributed to the unsteady contact of the two surfaces when the plate rotated faster [33]. It was reported that a fine polishing could be attained at a low temperature (750 °C) when a good contact between the diamond film and polishing plate took place without adhesive forces. A very fine surface of Ra = 1.5 nm could be obtained by this technique [40]. In addition, the effect of diamond orientation becomes negligible [41].

The polishing mechanisms involve the interaction of diamond with transition metals at an elevated temperature, and conversion of diamond into non-diamond carbon followed by the carbon diffusion into the metal [42-46]. Zaitsev *et al* [45] developed a diffusion model for thermo-chemical polishing. Assuming that the graphitization rate is much higher than the diffusion rate, they derived the following formula for calculating the removal rate of diamond R by thermo-chemical polishing:

$$R(T,t) = \frac{A_p}{A_s}\int_0^d C(x,T,t)dx - C_0 d \tag{1}$$

where T is temperature, t is time, C_o is the initial carbon concentration in the polishing plate, d is the polishing plate thickness, A_p is the area of the polishing plate swept by the sample, A_s is the area of the polished sample's surface, and

$$C(x,T,t) = C_s(T) + [C_0 - C_s(T)]erf[\frac{x}{2\sqrt{tD(T)}}] \tag{2}$$

is the concentration of the carbon at a depth x in the polishing plate, where

$$D(T)\ [cm^2 s^{-1}] = D_0(T)\ exp\ [-\frac{Q(T)}{RT}] \tag{3}$$

is the diffusion coefficient, $R = 8.3145\ J\,K^{-1}\ mol^{-1}$ is the gas constant, C_s is the carbon concentration at the surface of the polishing plate which can be expressed as

$$C_s = \alpha(P)\ C_l, \tag{4}$$

where coefficient $\alpha(P)$, depending on the pressure of the sample against the polishing plate, represents the quality of the diamond–metal contact with $\alpha = 1$ for an ideal contact. The change of the frequency factor $D_0(T)$ and activation energy $Q(T)$ with temperature can be approximated by:

$$D_0(T)\ [cm^2 S^{-1}] = 7\ x\ 10^{-8}\ exp(1.2\ x\ 10^{-2} T) \tag{5}$$

$$Q(T)\ [kJmol^{-1}] = 2.5\ x\ 10^2\ exp\ (1.5\ x\ 10^{-3} T). \tag{6}$$

The removal rate by thermo-chemical treatment has been quantitatively described by the diffusion mechanism, provided that the carbon content on the surface of the metal attains its solubility limit. To provide this condition, the metal must decompose the diamond into non-diamond carbon fast enough and work as a good absorber of this carbon.

Another thermo-chemical method, *diamond etching*, uses the principle of diffusion reactions [47], as shown in Fig.4 [48,49]. Metal (*e.g.*, iron) foils are placed in contact with the diamond films under load at an elevated temperature (around 900 °C for iron) in an argon atmosphere. The thinning process also creates relatively smooth surfaces by eliminating much of the roughness from the top faceted surface of the diamond film. A very sharp Raman peak at 1332 cm^{-1} indicates the high quality of the diamond produced by this technique [47]. The method has been extended further by replacing iron with manganese or molten rare earth metals/alloys (such as Ce or La) where the same diffusion reaction principle applies but at a lower contact pressure [49-54]. A reduction in the process temperature from 900°C to 600°C with an etching kinetics more than 60 µm/min [53] has been achieved by using rare-earth/transition-metal alloys, such as 89% Ce 11% Ni (by weight) with a eutectic point of 477°C [49].

A variation of the technique has been proposed, which places the diamond against the surface of a metal plate and heating them to a temperature greater than the melting point of metal carbide but less than the melting point of the metal itself [55]. The carbon atoms in the diamond diffuse or dissolve through solid state diffusion into the metal. It was claimed that the method is suitable for polishing surfaces of three dimensional structures.

High Energy Beam Polishing. This is a kind of non-contact polishing techniques using high energy beams such as plasma/ion/laser beams. They generally do not require the application of polishing forces or heating the bulk sample. Because of this, these techniques have the advantages in polishing non-planar surfaces and small areas. Nevertheless, the cost is high because they require expensive equipment and a controlled environment, *e.g*., in a vacuum.

Ion/plasma beam polishing uses the principle of bombardment of the diamond surface with reactive/non-reactive ion beams [6,57]. Surface asperities are removed by sputtering and etching by the oxygen ions produced by plasma/ion beam. In the non-reactive ion irradiation process there is atomic removal of surface atoms as a result of momentum transfer between incident ionic species and the surface atoms [58-61]. In reactive ion etching (RIE), the interaction between incident ions and surface atoms leads to a reactive atomic removal of the surface and hence generated a smooth surface [62-64]. Using this kind of techniques, the polishing rates depend on the incidence angle of ion irradiation with respect to the diamond surface and the type and energy of irradiating ions. RIE is faster than non-reactive ion beam sputtering because oxygen oxidizes the carbon [7,65], but may cause surface contamination due to plasma heating. The material removal rate is about 9.5 μm/h ending up with a very smooth surface of $Ra \leq 0.4$ nm [66].

Laser polishing is based on the transient thermal oxidation and/or evaporative ablation of the rough diamond surface. Asperities on a diamond surface are removed by localized heating via high-temperature graphitization and oxidation [67]. Nd-YAG Q-switched pulsed [68-71] and excimer lasers [56,72-75] have been widely used. Polishing rate and quality relies on many factors such as grain size, microstructure, laser spot size with respect to grain size, and laser power and incidence angle of a laser beam. For example, a large incidence angle results in a lower material removal rate, and an incidence angles of 30-60° produces a smoother surface. A polishing rate of about 100 nm/min can be obtained using a high peak power YAG laser in an oxygen ambient [5,7].

Electrical Discharge Machining (EDM). The EDM process has been used in cutting electrically conductive materials and then PCDs [1,76]. Guo *et al.*[77,78] and Lu *et al.* [79] introduced this process to polish CVD diamond films. A thin layer of electrically conductive material is needed before polishing for a dielectrically conductive CVD film. During machining, graphitization of the diamond enables the EDM process to continue. Experiments have shown that an EDM takes about four minutes to reach a surface roughness of Ra = 1.5 μm on a 25 mm × 25 mm sample with an initial roughness of Ra = 13.3 [77].

The material removal process associated with EDM is complex, accomplished possibly by four mechanisms: explosion caused by the spark, graphitization of diamond, evaporation and oxidation of carbon, and chemical reaction to form carbides.

Dynamic Friction Polishing (DFP). This method was developed by Suzuki *et al.*[80] for polishing single crystals [80,81] and PCD composites [82-87]. The schematic equipment of DFP is similar to mechanical polishing, as shown in Fig.1, except the polishing plate is made of metal disk instead of diamond wheel. This method does not use abrasives but press a diamond at a given pressure onto a metal disk rotating at a high speed in the atmosphere. It is a combination of the mechanical removal via rubbing at the contact sliding interface with the thermo-chemical reaction created by frictional heating.

It was reported [85,86] that when DFP on a PCD composite is carried out at the speed of 25 m/s and pressure of 3.1 MPa, a high material removal rate, 15 μm/min, could be achieved. The surface roughness could be reduced from 1.7 to 0.15 μm Ra in three minutes. After that, when the specimens were polished by a mechanical abrasive process for a further short duration (~15 minutes), the surface roughness could reach Ra = 50 nm. This is a tenfold reduction compared with the mechanical abrasive polishing process currently used in industry.

The material removal mechanism of dynamic friction polishing can be described as: conversion of diamond into non-diamond carbon takes place due to the frictional heating and the interaction of diamond with the catalyst metal disk; then a part of the transformed material is removed mechanical by the continuing rubbing of the disk; another part of the non-diamond carbon oxidizes and escapes as CO or CO_2 gas and the rest diffuses into the metal disk [83-85].

The metal disk used in DFP can vary provided that it consists of catalytic elements. For example, some [83-85] used nickel and stainless steel but some others [88] used an intermetallic compound consisting of one or more elements selected from the group of Al, Cr, Mn, Fe, Co, Ni, Cu and Pt and one or more from the group of Ti, V, Zr, Mo, Ta and W. DFP has been conducted at both room temperature and heated environment such as 100 to 800 °C. Another advantage of DFP is that it can be carried out on a normal grinding machine.

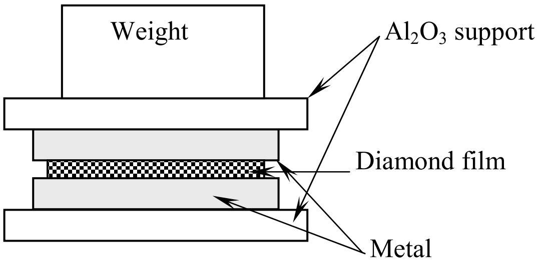


Fig.4 Schematic illustration of the diamond-etching method [49]

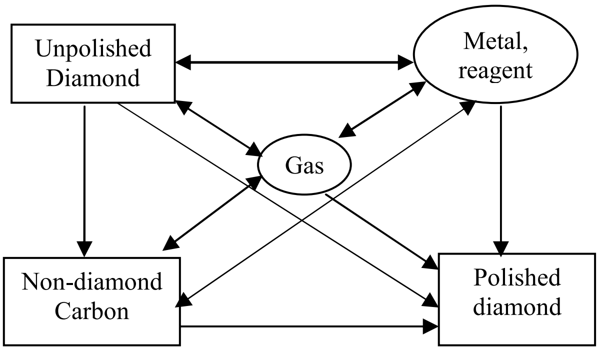


Fig.5 Schematic of polishing pathways related to diamond polishing

Discussion

The above introduction to various techniques for polishing diamond and its composites has shown that the material removal mechanisms are mainly as follows: a) micro-cleavage; b) conversion of diamond to graphite which is in turn removed by micro-cleavage, atomic diffusion or chemical reaction; c) diffusion of carbon into soluble metals; d) chemical reaction; and e) evaporation/ablation and sputtering. In all these, temperature plays an important role and it is clear that many processes, such as chemical reactions, occur only at high temperatures. These are further discussed in the following sections.

Micro-Cleavage. If two moving surfaces are brought into contact with each other, friction arises between the two surfaces. When the friction force is large enough to break the atomic binding of the material, atoms on the surface layer are chipped away from the surface. Micro-cleavages occur easily at the protruding portions of a surface and create a smooth surface. If abrasive powder is used, polishing rate and polished surface roughness are related to the size of the powder. Because diamond is the hardest known material, diamond powder is used for polishing a diamond surface via the micro-cleavage mechanism.

Transformation of Diamond to Non-Diamond Carbon. There are several types of carbon lattice structures including graphite, amorphous carbon, diamond and fullerene [3]. Thermodynamically, diamond is a metastable phase of carbon, and could convert to graphite at room temperature and atmospheric pressure. However, the reaction rate is so slow that the change is normally undetectable. Increased temperature will accelerate its conversion to graphite [82]. Generally diamond transforms to graphite at appreciable rates only at high temperatures (>2000K). However, graphitization can occur at relatively low temperatures (~970 K) when diamond is in contact with transition metals with intermediate reactivity (e.g., Fe, Ni, Co and Cr), because these metals can catalyse the conversion of diamond to graphite at low pressure and at temperatures above 700 °C. Under these conditions, protruding crystals on a diamond surface in contact with a catalytic material will transform into graphite or other non-diamond carbon which is in turn removed more easily. This mechanism plays a major role in thermo-chemical polishing, DFP, and is involved in more or less all the diamond polishing techniques.

Diffusion of Carbon into Soluble Metals. Carbon atoms could diffuse into carbon soluble metals such as Fe, Ni, Mo and rare earth alloys. These metals are ready to react with any source of free carbon and absorb them. Such reaction is easily triggered under the temperature and pressure conditions in a diamond polishing. When a diamond surface is in contact with metal at an elevated temperature, carbon atoms in the diamond surface diffuse into the metal until it is saturated. The diffusion path for atoms from protruding parts of the specimen is shorter and thus these areas are attacked at a greater rate. As the carbon diffusion coefficient and carbon solubility of the mating material increase, polishing rate increases. This mechanism dominates thermo-chemical polishing and thermo-etching.

Chemical Reaction. Chemical reaction may be accomplished with gas, liquid or solid metal/metal oxides. There would be gas-surface reactions when diamond is exposed to a reactive atmosphere, such as oxygen or hydrogen at elevated temperatures. These reactions mainly happen in laser, RIE, thermo-chemical polishing and DFP. Diamond will also react with oxidizing reagents such as KOH or KNO_3 under pressure and at elevated temperatures slightly above the melting point of the reagents [26]. The heat and pressure decompose the reagent liquid to oxygen and other constituents, and then the oxygen reacts with the diamond to form CO or CO_2. This reaction occurs in chemo-mechanical polishing. Under pressure and at elevated temperatures, diamond also reacts with some metals, such as Ti, Fe, V, Mn and Cr, to form carbide. Furthermore, in a thermo-chemical process, metals such as iron can be oxidized and then have a reductive reaction with carbon or hydrogen. In these reactions, metal oxides such as Fe_2O_3 will reduce the level of carbon in metal disk and convert it into free iron and form CO or CO_2. Non-diamond carbon then diffuses into the free iron formed from the above reactions along with the evaporation of CO or CO_2.

Evaporation and Sputtering. If sufficient heat is applied to a material surface, the surface will melt and/or evaporate, thus the protruding crystals on the surface of a diamond can be evaporated to produce a smooth surface. Different heating sources, such as electric arcs and high energy beams can be used. This mechanism is dominant in laser and EDM polishing techniques.

When high-energy ions or atoms collide with a diamond surface, the diamond structure is broken and carbon atoms are removed from the surface; this physical process called sputtering [7]. This material removal mechanism takes place in ion beam polishing.

Polishing Pathway and Comparison. The above removal mechanisms involve different diamond polishing techniques. Each technique consists of one or more different mechanisms. Figure 5 shows a schematic of polishing pathways related to diamond polishing.

Table 1 summarises some key processing issues of the polishing techniques discussed above. Mechanical, chemo-mechanical, thermo-chemical and dynamic friction techniques are contact polishing methods which are normally used for planar surfaces. Those using high energy beams and EDM are non-contact techniques that can be readily used for non-planar surfaces.

Mechanical polishing is a relatively straightforward process and there is no requirement for substrate heating. It has been widely used in industry. This method produces a polished surface with roughness of the order of 0.02 μm Ra, and the polishing does not drastically change the chemical quality of the diamond surface. But the process has extremely low polishing rate (a few tens nm/h) and is very costly, consuming diamond abrasive or diamond wheel.

Compared with mechanical polishing, a chemo-mechanical method can provide a higher material removal rate, a better surface finish and less damage. However, the reaction products tend to accumulate on the polishing disk, which needs to be removed to maintain a continuous polishing process. Heating the polishing disk and adding oxidizing agents increase the complication of polishing process.

The thermo-chemical technique offers a fine surface finish in conjunction with a higher polishing rate, of the order of a few μm/h, compared with mechanical polishing. However, an efficient polishing can only be achieved by heating the polishing disk to a temperature over 750 °C and needs to be conducted in an evacuated atmosphere or in a reductive atmosphere so as to prevent the metal from oxidation. In addition, surface non-uniformity can occur due to contamination etc.

The thermo-etching technique is applicable simultaneously to a large number of diamond films, and has good perspectives for the shaping of diamond into a non-flat geometry. However, this method does not provide a fine finish of the treated surface, resulting in a roughness of the order of a few micrometers Ra.

The advantages of high energy beam polishing techniques are as follows. They have high material removal rates and are non-contact processes such that they can deal with complex surfaces and achieve a surface roughness of the order of a few nm (Ra). However, they have obvious disadvantages as well, such as complex setups, high cost, non-uniformity, inefficiency in polishing large areas and contamination from the graphitic layers, critical requirements on sample orientation with respect to beam incidence, etc.

EDM polishing provides a high material removal rate at the cost of a rough finish, up to a few microns (Ra), which does not meet many industry requirements. As such, EDM is suitable mostly for rough polishing.

DFP seems to have a promising potential compared with the others. The advantages include 1) abrasive-free, 2) high polishing rate, 3) no need of special equipment for heating or environmental control, and 4) applicable to single crystalline diamond, PCD and their composites. The disadvantage of the process is mainly due to the requirement of a high polishing load which, if not properly selected, will crack workpieces.

Table 1 Summary of various polishing techniques

	Mechanical polishing	Thermo-chemical	Chemo-mechanical	Ion beam	Laser	EDM	DFP
Bulk processing temperature	Room	750-950 °C	>350 °C	Room or 700 °C for RIB	Room	Room	Room, Friction heat
Nature of processing	Contact	Reactive contact	Reactive contact	Non-contact	Non-contact		Reactive contact
Polishing mechanism	Micro-chipping	Graphitization, diffusion,	Micro-chipping, Oxidation	Sputtering	Evaporation	Evaporation	Graphitization, micro-chipping, oxidation, diffusion
Main applications	Planar surfaces	Planar surfaces	Planar surfaces	Non-planar surfaces possible	Non-planar surfaces possible	Non-planar surfaces possible	Planar surfaces
Size limitations	No limit	Plate size	Plate size	Beam size	No limit	No limit	Disk size
Special requirements	None	Need environmental control	None	Need high vacuum	Need scanning of the sample	None	None
Set-up	Rigid and geometry sensitive	Rigid and geometry sensitive	Simple	Complex	Simple	Geometry sensitive	Rigid and geometry sensitive
Equipment cost	Low	Medium	Low	High	High	Medium	Low
Large area processing cost	Low	Low	Low	High	Medium	Low	Low
Reported roughness (Ra)	20 nm	5 nm	20 nm	1-50 nm	5-70 nm	1330 nm	100 nm
Polishing rate	Tens of nm/hr	Few µm/hr	Few µm/hr	Tens of µm/hr	Hundreds of µm/hr	Few µm/min	15 µm/min
Surface contamination	Little	Yes	Yes	Yes	Yes	Yes	Yes
Potential for commercialization	High	Poor	Medium	Medium	High	High	High

Concluding Remarks

This paper has reviewed the major techniques and their associated material removal mechanisms for polishing of diamond and PCD composites. The comparison shows that each technique has its advantages and disadvantages. The following are probably some key factors to consider in selecting a proper technique for application: (a) shape of the diamond workpiece to polish, (b) surface finish requirement, (c) quality of surface integrity, (b) polishing efficiency, and (e) equipment cost. Dynamic friction polishing seems to have a promising application potential due to its merits of abrasive-free operation, high material removal rate and flexible polishing environment. However, further research is necessary to find out optimized DFP conditions.

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