



Research on the Polishing Technology of Diamond Semiconductor Substrate Material

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Abstract. This paper primarily examines three distinct diamond polishing techniques: mechanical polishing, thermal chemical polishing, and laser polishing. As the demand for high-performance diamond semiconductors grows in advanced electronics and optics, efficient and precise polishing methods have become critical to achieving optimal material performance. A comprehensive comparison of these techniques is essential to address the trade-offs between processing efficiency, surface quality, and cost, thereby advancing diamond-based applications in extreme environments. The study analyzes the advantages and disadvantages of these techniques and provides guidance on selecting the most suitable method. Diamond is a crucial semiconductor material; however, its high hardness makes it challenging to process and polish. Different polishing techniques are required for diamonds of different shapes. Mechanical polishing is simple and efficient but can damage the sub-surface of the diamond at high speeds. Laser polishing has achieved significant success in precise polishing, but the difficulty in controlling laser energy can lead to damage or loss. Thermal chemical polishing can produce low-damage surfaces with high removal efficiency, but its complex equipment and environmental limitations restrict its application.

Keywords: Semiconductor substrate materials, Diamond, Diamond polishing technology.

1 Introduction

In recent years, with the rapid advancement of technology, people's attention and use of the Internet and artificial intelligence have increased significantly. Consequently, the development of various electronic products has accelerated, and the internal components required for these devices have become increasingly precise and detailed. This has led to higher demands on material polishing and manufacturing processes to enhance the overall stability of the system. Diamond is an exceptionally superior semiconductor substrate material; however, due to its high hardness, roughness, and relatively thick profile, processing and polishing it are particularly challenging. Currently,

there are numerous processing technologies available. Given the high precision requirements of semiconductors for diamond, the research focus has been on the processing technology, polishing techniques, and equipment for diamond.

In laser polishing, Rothschild reported on the LP technique for diamond [1]. Okuchi analyzed the surface properties of diamond after laser processing using three types of pulsed lasers: nanosecond near-infrared, nanosecond near-ultraviolet, and femtosecond near-infrared lasers. However, each method has its own advantages and disadvantages [2]. In 1920, Tolkowshy proposed that the removal of diamond material is (Thermochemical polishing, TCP)、Chemical mechanical polishing (CMP) exhibits brittle fracture at the microscale[3]. In his experiments, Grodzinski discovered that when diamond is placed on metal plates such as iron and nickel at temperatures ranging from 600°C to 1800°C, the contact surface of the diamond dissolves into the metal, resulting in a smooth surface. This led him to propose a method of using hot metal plates to assist in the polishing of diamonds [4]. In recent years, significant progress has been made in diamond polishing technology, with a focus on improving polishing efficiency, reducing surface roughness, minimizing surface damage, and achieving ultra-precision processing of large-sized diamonds. Key areas of research include precision CMP, catalyst enhancement, laser processing and composite technologies, and robotics and automation. Additionally, new polishing materials, such as nano-diamond grinding liquids, have been developed. Therefore, this study aims to systematically review the advantages and limitations of various existing polishing techniques and to establish a scientific and reasonable method for selecting polishing technologies.

2 Research status of diamond polishing technology

The commonly used are mechanical polishing, laser polishing and thermal chemical polishing. In essence, these three technologies are designed to make the diamond surface much finer and the diamond material more refined.

2.1 Mechanical polishing

In 1920, Tolkowshy proposed that the removal of diamond materials involves brittle fracture at the microscale [5]. Mechanical polishing is a technique that uses the friction between diamond and a high-speed grinding wheel to polish the diamond surface. When the diamond contacts the high-speed grinding wheel, it generates significant heat, leading to extremely high temperatures. These high temperatures cause the diamond to transform into softer carbon, which is then removed by cutting the graphite. Research indicates that in terms of hardness, the transformation of amorphous sp³ to sp² is relatively difficult and has a lower removal rate. Conversely, in terms of softness, the transformation of amorphous sp³ to sp² is easier, resulting in a higher removal rate.

2.2 Advantages and disadvantages of mechanical polishing

MP equipment, due to its simple principle, consists of a high-speed motor and a polishing disc. By improving the polishing disc or the motor, the polishing quality can be enhanced. It is essential to maintain high speed while enhancing stability on the electrode. Xun's research found that adding iron to the corundum grinding wheel can effectively increase the removal rate of polishing when the rotational speed is increased to 500 r/min [6]. Another method involves using a polishing disc with micron-level diamond abrasive grains to polish single-crystal diamonds, resulting in a smooth diamond surface. Currently, MP technology is a relatively mature surface processing technique, characterized by its simplicity, high efficiency, and large-scale production capabilities. It can achieve a relatively smooth surface and is suitable for rough, medium, and fine polishing. Therefore, it is the mainstream method for diamond polishing. However, for large-sized diamond polishing, MP still faces some issues: the high temperature generated by high-speed friction may damage the polishing disc, affecting the polishing quality; additionally, under high-speed conditions, MP can cause sub-surface damage to the diamond, and due to the flatness and pressure of the polishing disc, the diamond surface is prone to scratches or cracks, and the edges are susceptible to cracking. Therefore, for high-end equipment, more advanced polishing methods are required for processing.

2.3 Laser polishing

In 1986, Rothschild reported on the LP technique for diamond [7]. Laser polishing involves irradiating the surface of a diamond with a laser to generate high temperatures, which cause physical changes in the diamond and achieve the desired polishing effect. Essentially, this process involves converting the diamond into graphite through high temperatures, which is then removed by burning off the graphite layer after irradiation. The surface morphology and Raman spectroscopy were used to analyze and study laser polishing, revealing that as the number of laser scans increased, the depth of the graphitization layer decreased, and after 40 scans, the graphitization layer was completely eliminated.

2.4 Advantages and disadvantages of LP

LP technology can provide high energy, effectively removing irregular small crystal particles from the diamond surface to achieve a rough polishing and a relatively smooth surface. Ozkan used Nd-YAG laser to first remove large crystal particles from the surface, followed by Argon Fluoride Excimer Laser ($\lambda = 193\text{nm}$) to remove smaller crystal particles, achieving a surface roughness of $\leq 1 \mu\text{m}$. Additionally, LP technology can polish specific areas through programming, addressing the limitation of other polishing techniques that can only polish fixed areas. This makes LP technology highly applicable in targeted polishing, and it is also widely used in the production of titanium alloys [8], making the titanium alloy surface smoother. It is also highly effective on quartz glass. However, the core of LP technology lies in the energy transfer from the laser

beam photons to the diamond surface, which is influenced by factors such as the wavelength and energy density of the laser, making precise control difficult. This often results in damage to the sub-surface of the diamond, and in severe cases, may even cause the diamond surface to be penetrated. To address this, Kononenko proposed pre-depositing different absorption coatings (titanium, graphite) on the diamond surface to attempt to eliminate laser-induced sub-surface damage. It was found that when the diamond surface is ablated by 10 m laser pulses, both coatings can reduce the surface ablation value, preventing laser penetration into the diamond, but it is difficult to achieve a smooth and flat surface. LP technology has the advantages of high efficiency, not limited by complex surfaces and can achieve fixed-point polishing. However, due to the difficulty in controlling laser energy, it may cause some damage to the surface [9].

2.5 Thermochemical polishing

In his experiments, Grodzinski discovered that when diamonds are placed on metal surfaces with temperatures ranging from 600°C to 1800°C, the high temperature causes the diamond to melt, making the contact surface smooth. This led him to propose a method of using hot metal plates to assist in polishing diamonds [10]. At high temperatures, diamonds undergo chemical reactions with the metal, and the heat released softens the diamond into carbon, which then dissolves into the metal plate. Thus, temperature is the primary mechanism for the removal process.

2.6 TCP Advantages

The mechanism of TCP involves the chemical reaction between diamond and metal plates. At high temperatures, the diamond undergoes a transformation period during which it reacts chemically with the metal. Sun found that treating diamond films with solid and molten rare earth Ce at temperatures above 800°C can achieve a diamond removal rate of several hundred micrometers, resulting in a smooth surface within minutes. This method is highly efficient and can produce a highly smooth surface in a short time, making it a practical polishing technique [11]. TCP achieves material removal by causing chemical reactions between metal and diamond at high temperatures, offering the advantage of producing a low-damage flat surface. Additionally, its high removal efficiency allows for the creation of a smooth surface within minutes. Zhang used molten iron to polish CVD polycrystalline diamond, achieving a smooth surface on the diamond. The molten iron undergoes a thermochemical reaction with the CVD polycrystalline diamond at high temperatures, corroding the diamond's surface and achieving the polishing effect [12].

3 Summary of the advantages and disadvantages of current technologies

Table 1 is summary of the advantages and disadvantages of current technologies. Mechanical polishing, laser polishing, and thermal chemical polishing each have their own advantages and disadvantages, and are all widely used methods. Therefore, when a diamond needs to be polished and cut, researchers must select the appropriate polishing technique based on the diamond's shape. Not all existing polishing techniques are suitable for industrial production; some can only be used in laboratories. During experiments, multiple polishing techniques can be combined to meet specific polishing requirements of diamonds. With the advancement of artificial intelligence and automation, it might be possible to integrate AI and automation into polishing technology to monitor the polishing process in real time. Researchers can also explore more efficient, environmentally friendly, and versatile methods to develop diamond polishing technology.

Table 1. Summary of the advantages and disadvantages of current technologies.

	Advantage	Disadvantage
Mechanical polishing	Simple equipment, high efficiency, suitable for mass production	At high speeds, the sub-surface of diamond will be damaged and scratches and cracks are easy to occur
Laser polishing	A relatively complete polished surface can be obtained, and it has great application in fixed-point polishing.	The energy of the laser beam is difficult to control and may penetrate or cause some damage.
Thermochemical polishing	The plane that can be damaged by the acquisition is available, and the removal efficiency is high.	The operation and equipment are complex, the scope is limited due to environmental influence, and it is difficult to obtain large, smooth surface

4 Conclusion

This article provides a detailed study and analysis of three polishing techniques: mechanical, laser, and thermal chemical. It summarizes the advantages and disadvantages of each technique and how to select the appropriate one based on the material's shape and size. The article aims to introduce these three common polishing techniques to assist researchers in choosing the most suitable method and understanding their pros and cons. It also advises researchers to select the appropriate diamond polishing technique based on the diamond's shape and the specific needs of production or experimentation. The article highlights the suitability of mechanical, laser, and thermal chemical polishing for different production scenarios, helping researchers make informed decisions. Furthermore, it suggests integrating automation and artificial intelligence into polishing

technology to develop more efficient and environmentally friendly methods. Additionally, it proposes upgrading existing polishing technologies to enhance efficiency and reduce waste. It also explores the possibility of using multiple diamond polishing techniques simultaneously on a single diamond to achieve superior polishing results.

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