Smoothing of polycrystalline diamond via gas cluster ion beam technique

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Polycrystalline diamond (PCD) is a material of significant interest due to its exceptional hardness, thermal conductivity, and chemical stability, making it ideal for various industrial applications such as cutting tools, heat sinks, and optical components. However, the inherent surface roughness of PCD, resulting from its polycrystalline nature, poses challenges in achieving the desired surface finish for high-precision applications. Traditional mechanical polishing methods often induce surface damage and are limited in their ability to achieve ultra-smooth surfaces. This abstract presents the gas cluster ion beam (GCIB) technique as an innovative approach to effectively smooth the surface of PCD, addressing the limitations of conventional methods. The GCIB technique involves the use of ionised clusters of gas atoms, which are accelerated towards the target surface. Each cluster consists of tens to thousands of atoms, and upon impact, the energy is distributed among the atoms, resulting in a gentle yet effective sputtering process. This unique characteristic of GCIB allows for removing surface asperities without causing significant subsurface damage, making it particularly suitable for delicate materials like PCD. In this study, PCD samples were subjected to GCIB treatment under various conditions to optimise the smoothing process. The initial surface roughness of the PCD samples was characterised using Atomic Force Microscopy (AFM), White Light Interferometer (WLI) and Scanning Electron Microscopy (SEM). The GCIB parameters, including ion energy, cluster size, irradiation dose and angle, were systematically varied to investigate their effects on surface smoothing. Post-treatment surface analyses were conducted to evaluate the improvements in surface roughness and to identify any potential changes in the material properties. The results demonstrated a significant reduction in surface roughness of the PCD samples after GCIB treatment. The optimised conditions led to a reduction in surface roughness from an initial average roughness (Ra) of several hundred nanometres to nanometre, even sub-nanometre levels. The WLI and AFM images revealed a marked decrease in surface roughness, and the SEM analyses confirmed the absence of surface damage or microcracks, which are commonly associated with mechanical polishing techniques. Furthermore, the study explored the underlying mechanisms of the GCIB smoothing process. The interaction between the gas clusters and the PCD surface was analysed using molecular dynamics simulations, providing insights into the energy dissipation and material removal processes at the atomic level. The simulations supported the experimental findings, illustrating the effectiveness of GCIB in achieving ultra-smooth surfaces through a combination of physical sputtering and surface atom rearrangement. In conclusion, the GCIB technique offers a promising solution for the surface smoothing of PCD, overcoming the limitations of traditional polishing methods. The ability to achieve sub-nanometre surface roughness without inducing subsurface damage opens new possibilities for the use of PCD in high-precision applications. Future work will focus on further optimising the GCIB parameters and exploring its applicability to other polycrystalline materials. The findings of this study contribute to the advancement of precision manufacturing technologies and underscore the potential of GCIB as a versatile tool for surface engineering.