Shear-driven formation of diamond during cold compression of graphite and glassy carbon

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Abstract

Carbon's exceptional versatility in forming diverse phases makes it important across modern applications, ranging from energy storage to industrial cutting tools. Significant scientific interest remains in exploring the mechanisms governing carbon phase formation, particularly diamond which has outstanding properties. Previous work has demonstrated that cold-compressed graphite can transform into metastable, high-density exotic structures under elevated pressure including M-carbon, W-carbon, and Z-carbon [1-3]. However, none of these phases have proven recoverable at ambient conditions. Understanding the pathways leading to diamond formation carries considerable importance, as diamonds serve as mineralogical markers of impact events and high-pressure metamorphism in meteorites and planetary crusts. Beyond pressure and temperature, shear stress has emerged as an additional critical variable governing whether diamond or other dense, diamond-like phases will nucleate [4-5].

This study examines the formation of high-density carbon phases from highly oriented pyrolytic graphite (HOPG) and glassy carbon precursors subjected to room-temperature compression under non-hydrostatic, high-shear conditions. Samples were processed in both conventional and rotational diamond anvil cells (DACs) to vary the compression environment. Recovered samples were sectioned into lamellae by focused ion beam (FIB) milling and subsequently characterized by transmission electron microscopy (TEM). Using electron energy loss spectroscopy (EELS) spectrum imaging, we demonstrate that high-density diamond phases are recoverable from both precursor materials without sample heating and at lower pressures than generally required. Microstructural analysis revealed clear signatures of shear-driven deformation, including shear bands and associated defects, while diffraction analysis identified a range of phases beyond conventional diamond: amorphous diamond, nanocrystalline lonsdaleite, and mixed cubic/hexagonal diamond stackings. The diversity of recovered phases is attributed to the heterogeneous stress conditions present within the sample chamber. Collectively, these findings establish that elevated temperatures are not a prerequisite for diamond-like phase formation, implying that diamond can arise across a broader range of geological and synthetic environments than previously recognized.

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