TEXAS TECH UNIVERSITY
Department of Mechanical Engineering

Ph.D. Defense Announcement

Studies of Materials under Non-hydrostatic Conditions for Potential Engineering Applications

by

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Abstract

Non-hydrostatic condition is a general phenomenon in which materials exist in the nature. Understanding the behaviors of materials under it will help gaining insights into the physics and chemistry behind these phenomena. In this dissertation, we attempt to explore the behaviors of materials under non-hydrostatic conditions to seek its potential engineering applications. Three topics are covered: the search of new scintillators via non-hydrostatic compression, the synthesis of novel phases from known materials under shear load, and the reaction of super-hard materials to shear stress. The diamond anvil cell and the rotational anvil cell accompanied with synchrotron X-ray diffraction, Raman spectroscopy, transmission electron microscope, and X-ray photoelectron spectroscopy were employed in the investigation.

$MnWO_4$ was studied by synchrotron X-ray diffraction to 50.1 GPa in a diamond anvil cell. Comparison experiments under the hydrostatic and non-hydrostatic conditions were performed. A structural phase transformation is observed, of which the high-pressure phase is determined to be the triclinic structure of $CuWO_4$. Under the non-hydrostatic condition, the phase transformation of $MnWO_4$ initiates at a far lower onset pressure and forms a purer high-pressure phase. The low-pressure and the high-pressure phases are discovered to coexist in a long pressure range under both the hydrostatic and non-hydrostatic conditions. The triclinic structure is thus believed to be energetically comparable to that of the low-pressure one and revealed at a far lower pressure. Furthermore, the discovery of the scheelite phase of $MnWO_4$ under compression suggests that the wolframite tungstates could be a new source of scintillating materials.

Diamond synthesis from graphite is achieved at below 1 GPa and room temperature using a rotational anvil cell. By applying large plastic shear, graphite transformed into cubic and hexagonal diamonds at extremely low pressures of 0.4 and 0.7 GPa, respectively. The formation of a new orthorhombic diamond phase was also

observed with pressure elevation to 3 GPa. It is discovered that shear, instead of pressure, plays the key role in this transformation. The discovery of this transformation reveals new mechanisms of shear-induced phase transformations at drastically reduced pressures and will lead to new materials synthesis strategies. Furthermore, the formation of diamonds under unconventionally low pressures also opens up new thoughts in geophysics that the micro-diamonds at geological sites could have formed in the cold crust due to shear-related historical activities instead of the conventional subduction-exhumation process.

Decomposition process of B_4C was observed to initiate at 1.0 GPa using a rotational anvil cell. The products are determined to be a boron-very-rich compound, $B_{50}C_2$, and a pure carbon substance, nano-crystalline graphite. It is discovered that B_4C undergoes two different transformation pathways, amorphization and decomposition, under large plastic shear at the same time. It suggests a new explanation, in addition to amorphization, to B_4C's mystery shear strength drop at 20 GPa. The decomposition and amorphization of B_4C at extremely low pressures also reveals that shear combined with modest pressure is a powerful tool in initiating phase transformations and chemical reactions than hydrostatic compression. Furthermore, the discovery of such shear-induced decomposition of boron carbides also enlightens (a) a new strategy of scanning for super-hard materials, (2) a potential replacement material with better shear strength for B_4C.