

Table 3.8 (con't.)

Authors	Reference	Observations
Deribas et al. [66D2]	[66D2]	coesite (trace), amorphous quartz recovered
Dremin and Breusov	[68D4]	review of laboratory observations
Deribas et al.	[68D2]	coesite, stishovite (trace) discovered
Stöffler	[72S4]	review of geophysical observations
German	[73G2]	amorphous, orthorhombic quartz recovered
Ananin et al.	[74A2]	amorphous quartz recovered

who found hard graphite, presumably the reversion products of diamond microseeds, in graphite loaded with short duration pulses.

Although the ratio of hexagonal diamond to cubic diamond appears to be a function of pressure, temperature and quench rate from the surrounding matrix, details have not been published. Deribas and Staver [77D3] have reported progress in control of temperature and pressure with the use of copper and iron matrix materials and have begun exploration of a stability diagram for shock synthesis of diamond. Deribas and Staver [74D2] also performed studies to better understand the tubular loading systems widely used for recovery in the Soviet Union. Trefilov et al. [78T2] have reported shock synthesis of more perfect diamonds by preheating graphite such that the final shock temperature is  $> 4300$  K.

Shock-synthesized diamonds have different abrasive properties from those of their natural or synthetic static-high-pressure counterparts. Because they are particularly effective for lapping and polishing of hard materials, they have been produced commercially by Allied Chemical Company and DuPont and in the Soviet Union.

Dense forms of quartz are of less technological interest than diamond and zBN but widespread geophysical interest and other technical uses for crystalline quartz and vitreous silica have led to significant effort in shock-wave synthesis of dense forms. Coesite, with a density of  $3.01 \text{ Mg/m}^3$  and hexagonal symmetry, was first synthesized by Coes [53C1] at a static pressure of 3.5 GPa in 1953. Subsequently, Stishov and Popova [61S2] synthesized a rutile-structure quartz with a density of  $4.35 \text{ Mg/m}^3$  at static pressures greater than 16 GPa, which is called stishovite in the United States and stipovorite in the Soviet Union. Although yields are not large, both coesite and stishovite have been synthesized in crystalline quartz by shock compression. Permanent densification has been observed in shock-loaded vitreous silica [62W1], but dense crystalline phases have not been recovered from shock-loaded solid samples. Deribas et al. [68D2] have successfully recovered dense crystalline quartz from powdered vitreous silica samples and Ananin et al. [74A1] have reported recovery of an unspecified partially crystallized form of quartz from vitreous silica. Work on synthesis of dense and amorphous quartz from  $\alpha$ -quartz is summarized in table 3.8.

Large yields of amorphous quartz are achieved from crystalline quartz shock loaded between 25 and 50 GPa [62W1]. This threshold pressure is apparently dependent upon the recovery fixture [74A1]. Whereas yields of stishovite of a few per cent are found in quartz rocks subjected to meteoritic impact [72S4], stishovite is only obtained in trace amounts in laboratory experiments. The longer pressure pulse durations associated with meteoritic impacts are apparently effective in growth of both stishovite and coesite. It is also of interest that meteor crater samples show larger yields of coesite than stishovite whereas the opposite is true for laboratory experiments.

Coesite and stishovite in meteor crater samples are selectively associated with regions of di-plectic glass (layered glass with alternate layers of isotropic and anisotropic glass). Recalling the previous discussion of heterogeneous yielding in section 3.4, it is likely that local hot regions caused by heterogeneous yielding provided the conditions necessary for nucleation of these dense phases.

Deribas et al. [66D2, 68D2] have been the only group successful in recovering coesite in the laboratory. It is notable that they utilized powder samples of low density to achieve significantly higher shock temperatures than would be obtained with samples of normal density.

Bridgman and Simon [53B1] first observed that vitreous silica undergoes a permanent increase in density under static high pressure. In a detailed investigation, Wackerle [62W1] found permanent densification in samples recovered after shock loading to 25 GPa. The results of these and other observations are summarized in table 3.8. The data from various investigators are somewhat scattered but data from a given investigator show consistent behavior. Such differences are probably due to different stress and temperature histories achieved in different recovery fixtures and the use of different starting materials. In spite of the scatter, general features are clear: (1) permanent densification to densities between 2.4 and 2.5 Mg/m<sup>3</sup> is observed; (2) at sufficiently high pressure (or temperature) densification is not observed or is greatly reduced; and (3) there is a stress threshold between 4 and 8 GPa for the onset of densification. Ananin et al. [74A1] have annealed the recovered dense samples and formed crystobolite.

There has been considerable interest in the possibility of recovering metallic hydrogen from high-pressure experiments. Because of the large increase in temperature in shock-compression experiments, metallic hydrogen would not be expected to be observed (see Ross and Shiskivich [77R2]). Isentropic compression experiments with pulsed magnetic implosion minimize the increase in temperature but have also not proven successful in producing metallic hydrogen. A short summary of the work is given by Duvall and Graham [77D6].

There are considerable data on unique chemical reactions and introduction of unique defects in samples achieved under shock compression. Most of this work is carried out in the Soviet Union and has been reviewed by Adadurov et al. [73A1]. The reader can find other summaries by Dremin and Breusov [68D4] and Duvall and Graham [77D6].

Material synthesis with shock loading appears to be an endeavor of considerable promise and past work has shown notable results. In all cases examined in detail the role of shock-induced defects in nucleating dense phases has been shown to be crucial. The use of quenching materials appears to be of critical importance. The determination of phase stability data for interesting materials is of immediate importance and shock-compression experiments appear to be ideally suited for determination of higher-pressure phase diagrams. Phase diagrams [74W2] based on a supposed metallic carbon transition under shock loading [61A1] should certainly be revised now that those measurements are thought to be in error (see, e.g., [77D6]).

## 4. Electrical and magnetic properties

### 4.1. General considerations

When physical properties are studied under shock loading, basic difficulties are encountered in both experimental design and physical interpretation that are not experienced in either the