Crystallization Kinetics of High-Pressure Phases from Amorphous Plagioclase

Time-resolved X-ray diffraction measurements have revealed that amorphization processes in plagioclase decrease with increasing temperature, and that the crystallization kinetics in the amorphous plagioclase is different from that in natural plagioclase. These findings have important implications for the plagioclase break-down observed in shocked meteorites.

The evolution of asteroids by collisions was a main process of planetary formation in the early solar system. The physical conditions of the collisional processes are recorded in shocked meteorites, resulting in amorphization and high-pressure transformations of plagioclase, a major constituent mineral. The amorphous plagioclase and high-pressure phases of plagioclase commonly observed in meteorites must be important clues for understanding the collision conditions. However, their study has been hampered by problems. The experimental conditions for plagioclase amorphous were affected by shock and diamond anvil cell (DAC) experiments have been limited to time scales much shorter and to lower temperatures compared to the conditions of natural shock events, resulting in unrealistic high experimental estimates of amorphization pressure [1]. It is well known that plagioclase decomposes into jadeite and silica phases (coesite or stishovite) at high pressures. However, in shocked meteorites, jadeite has been found without the crystalline silica phase even in grains with the chemical composition of plagioclase [2]. Equilibrium phase relations of plagioclase can not explain the presence of unusual assemblages of high-pressure phases in meteorites. In order to solve these problems, we have conducted in situ X-ray diffraction experiments on the plagioclase amorphization and crystallization kinetics of high-pressure phases from amorphous plagioclase using a Kawai-type high-pressure apparatus and synchrotron radiation.

Two kinds of plagioclase feldspars with different contents of NaAlSi3O8 albite (Ab), CaAl2Si2O8 anorthite (An), and Na8Si4O10 Orthoclase (Or) were used as the starting materials in the present study. One of the samples was natural labradorite (Ab45.0An51.8Or3.2) powder, the other was natural albite (Ab98.0An0.4Or1.6) powder. Pressure was generated using a double stage system in the high-pressure apparatus MAX-80 and MAX-111I installed at AR-NESC and BL-14C2, respectively. The pressure was calculated from the unit cell volume of gold, and temperature was monitored by recording W3%Re-W25%Re thermocouple X-ray diffraction patterns every 10 sec at high pressures and high temperatures using the white X-ray energy dispersive method.

We carried out a total of 9 experiments for pressures between 8 and 20 GPa and temperatures between 25 and 1500°C. Figure 1 shows an example of the changes in the X-ray diffraction pattern of plagioclase during cold compression and heating. Cold compression of the samples caused broadening of the X-ray diffraction peaks in plagioclase, however full amorphization was not observed at room temperature even at a pressure of 20 GPa. The X-ray peak broadening in plagioclase becomes more significant with increasing temperature after the cold compression. Finally, plagioclase amorphization occurred by heating at high pressure. We found that the amorphization pressure decreases with increasing temperature. For example, we observed that labradorite becomes amorphous at 16.4 GPa and 470°C. This is a much lower pressure than was reported in previous shock experiments (30-32 GPa) [1]. Negative slopes of the amorphization boundaries are inferred from our experimental results. This may indicate the metastable extension of the melting curve of plagioclase, as suggested in other materials such as water ice and silica phase [3]. The amorphous plagioclase survives kinetically without crystallization even at relatively high temperatures of around 1373 K.

Changes in the X-ray diffraction patterns during crystallization of high-pressure phases from amorphous plagioclase (labradorite). g = graphite capsule; au = gold pressure marker; st = stishovite; jd = jadeite; gt = garnet.

REFERENCES

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MN-NESC and 14C2