An example of high-7, high-symmetry crystallization: Spherical (Mg,Fe)-oxides formed by particle attachment in the shocked martian meteorite Northwest Africa 7755

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ABSTRACT

Crystallization is one of the most fundamental processes for both solid inorganic and organic materials in nature. The classical crystallization model mainly involves the monomer-by-monomer addition of simple chemical species. Recently, nanoparticle attachment has been realized as an important mechanism of crystallization in comparatively low-temperature aqueous natural and synthetic systems. However, no evidence of crystallization by particle attachment has been reported in petrologically important melts. In this study, we described spherical (Mg,Fe)-oxides with a protrusion surface in a shock-induced melt pocket from the martian meteorite Northwest Africa 7755. Transmission electron microscopic observations demonstrate that the (Mg,Fe)-oxides are structure-coherent intergrowth of ferropericlase and magnesioferrite. The magnesioferrite is mainly present adjacent to the interface between (Mg,Fe)-oxides spherules and surrounding silicate glass, but not in direct contact with the silicate glass. Thermodynamic and kinetic considerations suggest that development of the spherical (Mg,Fe)-oxides can be best interpreted with crystallization by particle attachment and subsequent Ostwald ripening. This indicates that crystallization by particle attachment can also take place in high-temperature melts and has potential implications for understanding the nucleation and growth of early-stage crystals in high-temperature melts, such as chondrules in the solar nebula, erupted volcanic melts, and probably even intrusive magmas.

Keywords: Crystallization by particle attachment, ferropericlase, magnesioferrite, shock-induced melt pocket, martian meteorite, Northwest Africa 7755

INTRODUCTION

Nucleation and growth of crystals are fundamental processes during the formation of natural and synthetic solid materials. Their mechanisms have been of long-term interest to scientists in the fields of physics, chemistry, material science, and Earth and planetary sciences. Understanding the nucleation and growth mechanisms of crystals are not only important to interpret the formation and evolution of organic and inorganic matters in nature, but also critical to control the physicochemical properties of synthetic materials.

Nucleation and growth models that involve the monomer-by-monomer addition of simple chemical species can account for the development of crystals in most natural and synthetic systems. However, in the past two decades, crystallization models involving particle attachment have been proposed to interpret abundant phenomena that were difficult to be interpreted with the monomer-by-monomer nucleation and growth models (e.g., Penn and Banfield 1998; Banfield et al. 2000). Recently, the evidence, indicators, consequences, pathways, and thermodynamic and kinetic considerations during crystallization by particle attachment have been reviewed (Ivanov et al. 2014; De Yoreo et al. 2015). The crystallization by particle attachment usually involves an intermediate phase, which could be nanocrystal, poorly crystalline nanoparticle, amorphous nanoparticle, droplet, complex, and oligomer (De Yoreo et al. 2015). However, most of the systems involving crystallization by particle attachment are comparatively low-temperature systems, covering synthetic solution systems with organic matters, biogenic systems, and hydrothermal systems (De Yoreo et al. 2015). Recently, a two-step crystallization, which might be related to crystallization by particle attachment, has been proposed for the formation of Al2O3 particles in supersaturated vapor (e.g., Ishizuka et al. 2016). Crystallization in high-temperature melts, typically petrologi-