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Crystallography and magnetic domain states of dusty olivine observed by electron holography: implications for recording of magnetic fields in the proto-planetary disc

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Dusty olivines are chondrules found in some L and LL chondrites which contain iron-nickel nanoparticles that are believed to have exsolved from the host olivine in a brief heating event shortly after chondrule formation. Geochemical analyses indicate that the iron particles have not equilibrated with the surrounding material, suggesting that they have the potential to record the magnetic field of the early solar system and hence evaluate proposed mechanisms for the heating event and the chondrules' proximity to the strongly magnetic young sun. However, the ability of these particles to preserve primary magnetic signals over timescales on the order of the age of the solar system is dependent on their crystallography and the domain states of the magnetic carriers.

We employ the transmission electron microscopy technique of electron holography to directly observe the magnetic domain states in the iron-nickel particles in synthetic dusty olivine and examine if they have the characteristics required for stable magnetic recording. Particles exhibiting pseudo-single domain (PSD) vortex states are common, but uniformly magnetised single domain (SD) behaviour is observed in elongated particles with a wide range of sizes. These observations of domain state allow the determination of the PSD-SD boundary in iron as a function of particle size and elongation and the location of the boundary as observed in experiments is broadly consistent with theoretical predictions. The holography technique also provides quantitative measurements of the magnetic moment which can be used to accurately calculate the volume of nanoparticles and infer the particle shape in three dimensions from a single measurement. Combining the volume information with constraints on coercivity, the thermal relaxation characteristics of the particles can be calculated and we demonstrate that the high-coercivity component of remanence would remain stable for 4.6 Ga, even at temperatures approaching the Curie temperature of pure iron. The high coercivity of the particles, together with the chemical protection offered by the surrounding olivine, is likely to make them resistant to shock remagnetization, isothermal remagnetization and terrestrial weathering, making dusty olivine a credible recorder of pre-accretionary magnetic fields.