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Lattice preferred orientation of hcp-iron induced by shear deformation

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Many hypotheses have been proposed for origin of seismic anisotropy in the Earth's inner core. Plastic deformation of constituent material (most probably hexagonal-close-packed (hcp) iron) is one of the candidate processes to form the inner core anisotropy (e.g. Sumita and Bergman, 2009). Therefore knowledge of deformation induced lattice preferred orientation (LPO) of hcp-iron is important for understanding of nature of the inner core. Only limited numbers of experimental studies have been reported on deformation induced LPO of hcp-iron because this phase is unquenchable to ambient condition. In the previous studies, hcp-iron was deformed by uniaxial compression, and slip activities in deforming sample were indirectly estimated based on elastoplastic self-consistent modeling (e.g. Merkel et al., 2004). In this study, we have carried out shear deformation experiments on hcp-iron using D-DIA and determined its deformation induced LPO directly.

Pre-sintered fine-grained (d $<$ 10 um) aggregate of bcc-iron was used in the experiments. Shear deformation experiments of hcp-iron were carried out at P = 9-18 GPa and T = 723 K using a D-DIA apparatus, SPEED-Mk.II-D, installed at BL04B1, SPring-8 (Kawazoe et al., 2011). In the deformation experiments, pressure medium of 4.5 or 5.0 mm (Mg,Co)O cube and WC and cBN second stage anvils with 2.5 or 3.0 mm truncation were used. The sample iron was sandwitched between two 45^o-cut Al_2O_3 pistons in the cell assembly. Shear strain rates in the experiments were ~2 x 10^{-4} or ~0.6 x 10^{-4} s^{-1}, and total shear strain is ~2. Development of LPO in the deforming sample was observed in-situ based on two-dimensional X-ray diffraction using an imaging plate detector and monochromatized synchrotron X-ray with energy of 49-51 keV. LPO of sample was determined from the two-dimensional diffraction pattern using a software ReciPro (Seto, 2012).

In shear deformation of single phase hcp-iron, $<$0001$>$ and $<$112¯0$>$ axes gradually aligned to be sub-parallel to shear plane normal and shear direction, respectively, from initial random orientation. The $<$0001$>$ and $<$112¯0$>$ axes are back-rotated from shear direction by ~30^o. In the experiments where deformation started from fcc-iron, successive phase transformation from fcc phase to hcp phase occurred during shear deformation, and resultant LPO pattern of hcp-iron is similar to that in the single phase deformation. The strength of final LPO in hcp-iron from the experiments with successive phase transformation is stronger than that from the single phase deformation experiments. The above results suggest basal slip $<$112¯0$>${0001} is the dominant slip system under the studied deformation conditions. The stronger LPO observed in deformation with successive phase transition may be due to assistance of transformation shear induced by martensitic transformation from fcc to hcp phase.

It has been shown that Earth's inner core has an axisymmetric anisotropy with P-wave traveling ~3% faster along polar paths than along equatorial directions. Although elastic anisotropy of hcp-iron at the inner core conditions is still controversial, recent theoretical studies consistently shows that P-wave velocity of hcp-iron is fastest along $<$0001$>$ direction at least at low-temperatures (e.g. Sha and Cohen, 2010). In this study, we showed that the basal slip $<$112¯0$>${0001} is dominant in deformation of hcp-iron. Therefore it could be suggested that most part of the inner core deforms with shear plane sub-parallel to equatorial plane.