氏　名	谢　龙剑		
授与した学位	博　士		
専攻分野の名称	理　学		
学位授与番号	博甲第　　　５８３２　　　号		
学位授与の日付	平成３０年　９月２７日		
学位授与の要件	自然科学研究科　　　地球惑星物質科学専攻 （学位規則第４条第１項該当）		
学位論文の題目	Development of boron-doped diamond heater in the Kawai-type multi-anvil apparatus and its application to determine silicate melt viscosity at conditions of deep magma ocean （ボロンドープダイヤモンドヒータの開発とマグマオーシャン深部条件でのケイ酸塩メルトの粘性率測定への応用）		
論文審査委員	准教授　　米田　　明	教授　　神崎　正美	准教授　山崎　大輔
	准教授　　芳野　　極	准教授　山下　　茂	教授　John Hernlund （東京工業大学）

学位論文内容の要旨

In this PhD thesis, I summarize my achievements in the recent three years after the interim evaluation September 2015. It consists of three parts: (1) boron-doped diamond (BDD) heater developed in the multi-anvil apparatus, (2) viscosity measurement of silicate melts up to ~30 GPa using *in-situ* falling sphere method, and (3) implications for the evolution of the magma ocean based on the silicate melt viscosity newly measured in the present study.

Breakthroughs both in experimental techniques and in geoscientific modelling for the early Earth are achieved in this study. Highlights of my study are (1) generation of ~4000 K temperature (world highest) in the Kawai multi-anvil apparatus by using BDD heater, (2) world first measurements of silicate melt viscosity under the lower mantle condition by applying BDD heater in the *in-situ* falling sphere viscometry; the viscosity data experimentally reproducing all the four pressure induced densification mechanisms predicted in molecular dynamic simulation, (3) the estimated viscosity of magma ocean suggests a fractional solidification of magma ocean.

Combined with our fractional solidification model and geochemical data of primary upper mantle, we estimated the depth of fractionated magma ocean is ~880 km and the thickness of cumulate layer in lower mantle is ~220 km. After fully solidification, the cumulate layer is bridgmanite-enriched, neutral (or slightly denser ~2 ‰) and stronger (viscosity contrast ~30), compared with pyrolite mantle. Because of its high viscosity, the solidified accumulate layer may be transferred to the depth of ~1000 km by later mantle convection and still persists there at present day. It may contribute to the viscosity peak at 800-1400 km of present solid Earth.

論文審査結果の要旨

Ph. D defense for Mr. Longjian Xie was held on August 23, 2018.

In his PhD thesis, he summarized his achievements during the recent five years. It consists three aspects: boron-doped diamond (BDD) heater development in multi-anvil apparatus, viscosity measurement of silicate melts up to ~30 GPa using *in-situ* falling sphere method and discussion on the evolution of the magma ocean (MO) based on the silicate melt viscosity newly measured in his study. Breakthroughs both in experimental techniques and in geoscientific modelling for the early Earth are achieved in this study. Highlights of his study are (1) generation of ~4000 K temperature (world highest) in the Kawai multi-anvil apparatus by using BDD heater, (2) world first measurements of silicate melt viscosity under the lower mantle condition by applying BDD heater in the *in-situ* falling sphere viscometry, (3) the viscosity data first time reproduces, experimentally, all the four pressure induced densification mechanisms proposed by molecular dynamic simulation, (4) the viscosity data also suggests a fractional solidification of magma ocean, and (5) the fractional solidification model suggests that the primary upper mantle may be the residual of a ~900 km MO after a combination fractionation of bridgmanite and $CaSiO_3$ perovskite (mass ratio: 94:6), which formed a cumulate layer (~660-900 km depth) at the bottom of MO. After fully solidification, the accumulate layer is bridgmanite-enriched, neutral (or slightly denser ~2 ‰) and stronger (viscosity contrast ~30), compared with pyrolite mantle. Because of its high viscosity, the solidified accumulate layer may be transferred to the depth of ~1000 km by later mantle convection and still persists there at present day. It may contribute to the viscosity peak at 800-1400 km of present solid Earth.

We considered that this thesis contains the important results on the Earth science. Therefore, we concluded that this thesis is proper to be accepted as a dissertation of Doctor of Philosophy in Science of Okayama University.