Japan Geoscience Union Meeting 2013
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ISC, USArray と中国の地震観測網データを用いた全マントル 3 次元速度構造
Whole-mantle 3-D velocity structure obtained with ISC, USArray and China seismic network data

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グローバルトモグラフィーは全マントル 3 次元速度構造を求める手法として用いられており, 沈み込むスラブやマントルプルーム, 地球深部の構造を明らかにしてきた. ホットスポット火山の下にはホットプルームを反映するような低速度異常, 日本やアメリカの下には沈み込むスラブを反映する高速度異常が見られる (例えば Zhao, 2004, 2009; Zhao et al., 2013).

本研究では, グローバルトモグラフィーを用いて, より詳細な全マントル 3 次元速度構造の推定を行った. 本研究では水平方向に約 200 km 間隔, 深さ方向に 50-200 km 間隔にグリッドを配置した. 走時データは ISC, USArrya, 中国地震観測網のものを用いている. グローバルトモグラフィーでは ISC のデータがよく用いられるが, ISC の観測点には偏りがある. USArray や中国地震観測網のデータを用いることにより, トモグラフィーの解像度を上がることが期待される. さらに, 5 種類の P 波 (直達 P, pP, PP, PcP, Pdiff 波) の走時を用い, Zhao (2009) と山本・趙 (2010) で用いられている flexible grid 法により地球内部をモデル化した. 多数の後続波を用いることにより, 海域下の上部マントルの解像度を改善できる. インバージョンに用いる際の初期速度構造には 1 次元地球構造モデル iasp91 を用いた. インバージョンには約 13,000 個の地震により得られた約 200 万個の走時データを用いている.

インバージョンの結果より, 日本, アリューシャン列島, トンガ, 中央アメリカなどの沈み込み帯の下, ユーラシアや北アメリカ, オーストラリアなどの安定大陸には高速度異常が, 環太平洋火山帯, ホットスポット火山, 南太平洋の下には顕著な低速度異常がイメージングされた. 本研究ではこれまでのグローバルトモグラフィーの先行研究と調和的な結果を得られた. しかしながら, 密なグリッド配置と USArray, 中国地震観測網のデータを用いたことにより, 中国とアメリカ大陸下のマントル構造はこれまでのモデルよりもシャープなイメージを得ることができた.

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キーワード: トモグラフィー, スラブ, マントルプルーム
Keywords: tomography, slab, mantle plume

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SIT39-P02 会場:コンベンションホール 時間:5 月 24 日 16:15-17:30

斜方輝石－カンラン石間の水の分配に与える Al の効果：上部マントルダイナミクスへの考察
Effect of Al content on water partitioning between orthopyroxene and olivine: Implication for upper mantle dynamics

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Most minerals in the Earth's upper mantle contain small amounts of hydrogen (i.e. "water"), structurally bound as hydroxyl. Water has an important influence on the behavior of rock system. Water significantly affects physical property of minerals (e.g. ionic diffusion rates; (e.g., Goldsmith, 1987), electric conductivity; (e.g., Zhang et al., 2012), viscosity; (e.g., Karato and Jung, 2003)). Because small amount of water plays a key role in mantle rheology, precise knowledge on partitioning of water among mantle minerals is very important to understand the Earth's dynamics. For example, Mierdel et al. (2007) indicated that a high water solubility in aluminous orthopyroxene among mantle geotherm in the Earth's upper mantle would effectively contribute to a stiffening of the lithosphere. Water content of minerals is changed by chemical composition. For example, Al_2O_3 solubility of orthopyroxene (Opx) in the Earth's upper mantle decreases significantly with increasing pressure. In addition, Rauch and Keppler (2002) investigated effect of Al_2O_3 content on water solubility in orthopyroxene. The water solubility in orthopyroxene increases proportionally with increasing Al_2O_3 content. Thus water partitioning coefficient between orthopyroxene and olivine (Ol) may change significantly in the Earth's upper mantle. Therefore it is necessary to investigate the influence of Al_2O_3 in Opx on the partitioning coefficient of water between Opx and Ol under low OH concentration by high pressure temperature experiments.

In order to investigate the partitioning coefficient of water between Opx and Ol ($D_{(Opx/Ol)}$) under low OH concentration (4˜400 ppm), we performed high-temperature and high-pressure experiments using Kawai-type multi-anvil apparatus (SPI-1000) and piston-cylinder apparatus at the Magma Factory, Tokyo Institute of Technology, using starting materials of natural Ol (Ol; KLB-1) and synthetic orthopyroxene with various Al content (Opx; $(Mg,Fe)_{2-x}Al_{2x}Si_{2-x}O_6$ (x=0, 0.0125, 0.025, 0.05)). Powdered minerals were enclosed in Mo foil capsule to form monomineralic layers with more than 300 micron meters in thickness each and put it in a $Au_{75}Pd_{25}$ capsule at pressures of 1, 3, 4.5 and 6 GPa and temperature of 1300^{o}C. Oxygen fugacity was controlled by Mo-MoO_2 buffers. Water contents were obtained with a vacuum type Fourier transform infrared spectrometer (FT-IR6100, IRT5000). Water content of minerals was calculated based on Paterson's (1982) calibration. Run products were polished down to doubly polished slab. After polishing and prior to FT-IR analysis, samples were stored in a vacuum oven at ˜120^{o}C over night. Detection limit in the IR spectra at 3200-4000 cm^{-1} is typically less than 1 ppm due to very low back ground of vacuum type FT-IR.

Water partitioning coefficient between Ol and Al-free Opx are $D_{(Al-free\ Opx/Ol)}$ = 0.5˜1.8. On the other hand, that between Al-bearing Opx and Ol are $D_{(Al-bearing\ Opx/Ol)} > 7.0$. Thus $D_{(Opx/Ol)}$ increases dramatically by incorporating Al_2O_3 in Opx at given temperature. $D_{(Opx/Ol)}$ also increases with increasing pressure at given Al_2O_3 content in Opx. In other words, the slope of the curve exponential approximation increases with pressure. Under low water fugacity conditions, $D_{(Opx/Ol)}$ stays nearly constant or increases with increasing pressure within the spinel-peridotite stability field. In the garnet peridotite field, however, $D_{(Opx/Ol)}$ decreases dramatically with increasing pressure from about 3 GPa to 6 GPa. Especially, from 4.5 GPa to 6 GPa, this value becomes dramatically smaller (˜ 2 order) with increasing pressure. Then, $D_{(Opx/Ol)}$ becomes much smaller than unity in at pressures from 4.5 GPa to 6 GPa. A maximum value in $D_{(Opx/Ol)}$ at 3 GPa. This results indicate that viscosity of the upper mantle might become softer at deeper than 150 km.

キーワード: 水の分配, 斜方輝石, カンラン石, 上部マントル, Al 濃度
Keywords: water partitioning, orthopyroxene, olivine, upper mantle, Al content

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地震波トモグラフィーモデルの三次元可視化による沈み込むスラブ構造の解明
Geometry of subducted slab: three-dimensional visualization of seismic tomographic model

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It is well known that the style of slab subducion in the mantle has a wide variation. Subducted slabs form convective down-welling of the Earth's lithosphere, which play a role in thermal and material transport from the surface into the Earth's interior, therefore describing the style of slab subduction is important to understand mantle dynamics and thermal evolution in the Earth. Seismic tomographic models have been developed to provide clear images of subducted slabs. Most of these images have been presented based on two-dimensional visualization of the models. Subducted slabs are marked by the region of positive values of seismic velocity perturbation continuing from trenches, but their profile cannot be defined quantitatively by a certain value of seismic velocity perturbation, in part because of the intrinsic nature of subducting slab and in part because of uncertainties and errors involved in tomographic model. Two-dimensional view of tomographic model does not depict the slab by a certain value of anomaly but shows spatial variation of seismic velocity, through which one may extract image of the subducted slab. However, it is difficult to understand the three-dimensional geometry of the subducted slab from the two-dimensional view of tomographic model, even if successive slices of the model are provided. This is because the cross-sectional image of a slab depends on the direction and the position of the cross-section, and some subducted slabs continue to each other in very complicated geometry. Seismic tomographic model is originally a three-dimensional scalar field. Three-dimensional visualization of the tomographic model should be more appropriate to illustrate precisely the geometry of the subducted slabs. Most of the previous methods for three-dimensional visualization display the iso-surface of seismic velocity perturbation, which, however, does not give in general natural image of the subducted slab because the slab cannot be delineated by a fixed value of the seismic velocity perturbation as mentioned above. In this study, we propose a new method for visualizing three-dimensionally seismic tomographic model to express the geometry of the subducted slabs. This method is an extension of the two-dimensional contour image in a sense that it can show variation of the seismic velocity perturbations. The mantle domain is divided into small blocks, and by rendering these blocks the three-dimensional tomographic image is obtained. Surfaces of a block are colored with their transparency dependent on the velocity perturbation in the block. The subducted slab is imaged as an assembly of blocks with various degree transparency by this new method, which is a most faithful representation of the slab image contained in the original tomographic model because no interpolation, extrapolation or smoothing is involved in the method. Hence, this method provides a slab image consistent with that obtained from two-dimensional cross-sections. We visualize here some subducted slabs around the Circum Pacific by using the new method to demonstrate that the complicated structures of the slabs difficult to interpret by two-dimensional images are figured out based on the three-dimensional view. The simple visualization proposed here will be useful to describe the geometry of subducted slabs and to clarify the evolutional processes of them.

キーワード: 地震波トモグラフィーモデル, 沈み込むスラブ, 三次元可視化
Keywords: seismic tomographic model, subducted slab, three-dimensional visualization

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ＧＨｚ音速法とブリリュアン散乱法の併用によるマントル鉱物のその場弾性測定
GHz Ultrasonic and Brillouin scattering in a Diamond Anvils Cell

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Advances in GHz ultrasonic technology have made it possible to make elastic wave measurements in a diamond anvils cell (DAC). This new technique is a powerful method to explore fundamental problems in earth physics and material science because of the faculties of the DAC to withstand extreme conditions. Combining GHz ultrasonic,Brillouin scattering method, and DAC, we can investigate elastic properties of mantle minerals at the coressponding pressure and temperature condition at the deep mantle.

キーワード: GHz 音速法, ブリリュアン散乱, ダイヤモンドアンビル, マントル鉱物, 弾性
Keywords: GHz ultrasonic, Brillouin scattering, Diamond Anvils Cell, mantle mineral, elasticity

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酸素欠損カルシウム・アルミニウム・ケイ酸塩ペロブスカイトの結晶化学
Crystal chemistry of oxygen deficient calcium aluminum silicate perovskites

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昨年の会議で酸素欠損ペロブスカイト相である $Ca_2AlSiO_{5.5}$ 低圧相の結晶構造について報告した (SIT41-03)。今回は $CaSiO_3$-$Ca_2Al_2O_5$ 系の別の安定相である $Ca_2Al_{0.8}Si_{1.2}O_{5.6}$ 低圧相 (Blab et al, 2007) の結晶構造と、これらの酸素欠損ペロブスカイト相の結晶化学について報告する。

$Ca_2Al_{0.8}Si_{1.2}O_{5.6}$ 低圧相はマルチアンビル高圧装置を使って、11 GPa, 1500 ^{o}C で合成した。粉末 X 線回折パターンは SPring-8 の BL19B2 の大型デバイ・シェラーカメラで得た。Si と Al 周りの局所構造は ^{29}Si MAS NMR と ^{27}Al 3Q MAS NMR で調べた。結晶構造は実空間探索法 (FOX プログラム) で求めた。精密化はリートベルト法で行った (RIETAN-FP; Izumi & Momma, 2007)。解析方法の詳細は、Kanzaki and Xue (2012) とほぼ同じである。

粉末 X 線回折パターンは以前の報告と一致し、格子常数は (Blab et al., 2007) の報告
どおり、10 層の超構造のそれと一致した。空間群は C2/c であった、^{29}Si MAS NMR スペクトルには４配位と６配位 Si に相当するピークがそれぞれ１本あり、^{27}Al 3Q MAS NMR スペクトルには６配位 Al のピークが１つあった。結晶構造は NMR からの情報と $Ca_2AlSiO_{5.5}$ 低圧相の構造から解くことができた。

結晶構造はペロブスカイト様の八面体３層と SiO_4 の２層が交互に立方晶ペロブスカイト [111] 方向に２回積み重なり、10 層の超構造を作る。八面体３層は中心が SiO_6 層であり、上下が AlO_6 層からなる。この構造は低圧 $Ca_2AlSiO_{5.5}$ 相に SiO_6 層を挿入することで導くことができる。これらの相に共通する特徴は、SiO_4 ４面体からなる２層の存在であり、Si ４面体は１つの非架橋酸素を持つ。これはブラウンミラーライトおよびペロブスカイトのように Si(Al) ２個に繋がっている架橋酸素しかない構造とは異なる。

$Ca_2Al_{0.8}Si_{1.2}O_{5.6}$ と $Ca_2AlSiO_{5.5}$ 相がそれぞれ３層、２層の八面体から成ることを考えると、八面体１層のみからなる構造を想像することができる。実際にそのような構造は常圧で実在する ($BaCa_2MgSi_2O_8$) (Park et al., 2011)。ただし八面体は MgO_6 からなる。この構造は merwinite($Ca_3MgSi_2O_8$) から派生した構造であり、merwinite 自体を酸素欠損ペロブスカイトの一員と捉えることができる。本研究により、八面体層の数の異なる一連の構造が酸素欠損ペロブスカイトにおいて存在することが分かった。この酸素欠損の局所構造は Al や Fe^{3+} を固溶したカルシウムペロブスカイト相において生じる可能性がある。

この研究の一部は三朝国際インターンプログラム 2012(S.N.) で実施された。

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キーワード: ケイ酸塩ペロブスカイト, 酸素欠陥, 高圧相, 結晶構造, 核磁気共鳴, $Ca_2Al_{0.8}Si_{1.2}O_{5.6}$
Keywords: silicate perovskite, oxygen defect, high pressure phase, crystal structure, NMR, $Ca_2Al_{0.8}Si_{1.2}O_{5.6}$

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下部マントルにおけるカリウムを含む NAL 相の安定性
The effect of potassium on the stability of NAL phase in the lower mantle

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High-Pressure (*P*) and high-temperature (*T*) experiments were conducted at *P* = 33 to 144 GPa and *T* = 1,800 to 2,700 K in order to examine phase relations on the join $Na_{1.00}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$ - $K_{1.00}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$. Stable phases were identified in-situ at high *P-T* in a laser-heated diamond-anvil cell (DAC), based on synchrotron X-ray diffraction measurements. The results show that K-rich new aluminous (NAL) phase forms continuous solid solution on the join $Na_{1.00}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$ - $K_{1.00}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$ at 30 GPa. And, NAL is formed as a single phase up to the lowermost mantle conditions in both $Na_{0.50}K_{0.50}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$ and $K_{1.00}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$ compositions. On the other hand, single-phase NAL is found only to 100 GPa at 2,500 K, and NAL coexists with calcium-ferrite type (CF) phase at 120 GPa and 2,300 K in $Na_{0.75}K_{0.25}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$. Considering the NAL phase with $Na_{1.00}Mg_{2.00}Al_{4.80}Si_{1.15}O_{12}$ composition is stable only up to 45 GPa at 1,850 K, these results clearly indicate that the presence of potassium drastically expands the stability *P-T* field of NAL. In addition to hollandite, the NAL phase should be an important host of potassium in the deep lower mantle, formed in K-rich materials such as subducted continental crust.

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中央海嶺玄武岩（MORB）の下部マントル条件下における相関係と密度変化
Phase relations and density changes in mid-ocean ridge basalt (MORB) under the lower mantle condition

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The phase relations and density of a mid-ocean ridge basalt (MORB) composition were investigated at pressures 43 and 53 GPa and at a temperature of 2050 K using multianvil apparatus with sintered diamond anvils. The unit-cell volumes of the samples and the produced pressures were determined using in situ X-ray diffraction measurements at SPring-8, while chemical analyses of the quenched samples were made using transmission electron microscopy (TEM). The observed diffraction lines were assigned to those of five phases, namely MgSiO3-rich perovskite phase (MgPv), CaSiO3-rich perovskite phase (CaPv), stishovite phase (St), calcium ferrite-type phase (CF), and the new alminous rich (NAL) phase. The phase proportions were estimated from a least squares mass balance calculation using chemical compositions of the phases obtained by the TEM analyses. The density of MORB at each pressure and temperature was calculated using the measured volumes, phase proportions, and chemical compositions of the coexisting phases. The present phase relations and phase proportions in MORB are consistent with the results of recent study (Ricolleau et al., 2010) except for the presence of a small amount of the NAL phase even at the pressure of 53 GPa. The calculated MORB densities were then compared with the density profile of PREM. It is demonstrated that MORB is 2.0%˜2.8% denser than that of PREM at pressure of 43 GPa and 53 GPa, suggesting that basaltic oceanic crust may subduct to deeper region of the lower mantle.

キーワード: 高圧相関係, MORB, 下部マントル条件, X 線その場観察, マルチアンビル装置
Keywords: high pressure phase relation, MORB, lower mantle, in situ X-ray diffraction, multi-anvil apparatus

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地球深部物質の高温高圧実験に向けた CO_2 レーザー両側加熱装置の開発
Double CO_2 laser heating system for high P-T experiments of the deep Earth's materials in a diamond anvil cell

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A laser heated diamond anvil cell (LHDAC) has been widely used for understanding the behavior of materials under the high pressure and temperature conditions of the Earth's and planetary deep interiors. Near IR lasers such as YAG, YLF and fiber lasers, with a wavelength of about 1 micrometer, are generally used for LHDAC experiments. However, they are unsuitable for heating transparent materials including MgO, $MgSiO_3$, SiO_2 and $CaSiO_3$ without metal absorbers. The CO_2 laser with wavelength of about 10 micrometer enables to directly heat these materials. For laser heating system using near IR lasers, the double-sided laser heating technique has been improved to reduce the temperature gradients in the sample. Here, we developed a double-sided heating system using the CO_2 lasers for high P-T experiments of the mantle materials in a DAC.

The system consists of two CO_2 lasers, optical systems to focus the lasers and monitor the sample and a spectroradiometric system for temperature measurements. By using lenses designed for the CO_2 laser wavelength, the laser paths are separated from optical paths for collecting thermal radiation and visual observation because the collecting lenses made of SiO_2 glass high absorption of the wavelength. The both side lasers can be controlled separately. Two dimensional image of the sample are observed by CCD camera. Temperatures are measured by using the spectrometer. The heated position was synchronized with observed position by both CCD camera and spectrometer.

We will report the heating experiments of oxide by using developed double-sided CO_2 laser heating system.

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レーザー衝撃圧縮した FeSi の音速密度測定
Sound velocity and density measurements of FeSi alloy by laser-shock compression

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It is well known that Earth's core consists of mainly iron (Fe) alloyed with a few percent of light elements. Several light elements (hydrogen, carbon, oxygen, silicon, sulfur, etc.) have been considered as the candidate of the composition of Earth's core, but its composition is still unclear. In order to constrain the core composition, it is important to measure the sound velocity of iron alloys because it can be directly compared with the seismic wave. Silicon (Si) has been proposed as a major light element in the inner core [Mao et al., 2012]. So we measured the sound velocity of laser-shocked FeSi alloy in order to investigate the effect of Si for sound velocity of liquid Fe in the outer core.

The starting sample was prepared by synthesizing from mixture of Fe (99.98% purity) and Si (99.9% purity) slugs at arc furnace. The compositions of Fe and Si are 66.5 wt.% and 33.5 wt.%, respectively. We measured sound velocities and densities of FeSi at high pressure and high temperature conditions at the large laser facility in Institute of Laser Engineering, Osaka University. The sound velocities were measured by the x-ray radiography [Shigemori et al., 2012].

We obtained the sound velocity and density of FeSi at pressures around 700 GPa. It is seen that Si has the effect of increasing the sound velocity of liquid Fe. Comparing our experimental results and PREM model [Dziewonski and Anderson, 1981], Si may be contained up to 17 wt.% at 135 GPa, and up to 6.4 wt.% at 330 GPa in the outer core.

キーワード: レーザー, 音速, 外核, FeSi
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$MgSiO_3$ ポストペロブスカイト相の状態方程式
Equation of state of $MgSiO_3$ post-perovskite phase

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1995 年、太陽系外に木星質量程度の惑星が発見されて以来観測技術はめまぐるしく進歩し、近年では地球の数倍の質量をもつスーパーアースも多数発見されるようになってきた (例えば Queloz et al., 2009)。このような天体では、その内部圧力は地球をはるかに凌ぐものとなる。スーパーアースの様な天体の内部構造を議論するためには、数百万気圧領域（マルチメガバール領域）での物質科学、特に主要構成物である珪酸塩や酸化物の状態方程式が必要となる。岩石を主体とするマントルと金属鉄を主体とする核からなる地球型惑星の構造は、当然のことながらこれまで地球を中心に考えられてきた。地球マントルの主要構成鉱物である $MgSiO_3$ ペロブスカイトはマントル最下部の条件で $CaIrO_3$ 型のポストペロブスカイト相へと相転移することが発見 (Murakmi et al., 2004) されて以来、ポストペロブスカイト相に関する数多くの実験的・理論的研究がなされてきた。しかし上述のスーパーアースの様な天体を想定したマルチメガバール領域での実験は全くなされておらず、内部構造を議論するための基礎物性データが欠乏している。ここでは、地球型惑星マントルの主要構成物質である $MgSiO_3$ ポストペロブスカイト相について、スーパーアースの様な系外惑星への適用が可能なマルチメガバール領域の状態方程式の確立を目的とする。

出発試料には Mg_2SiO_4 フォルステライトを用い、金 5wt.%を粉末混合した後ディスク状に圧着し、さらにプラズマスパッタリングによって表面に均質な金コーティングを施した。この試料をダイヤ表面との間の断熱材である $MgSiO_3$ エンスタタイトガラスとともに対称型ダイヤモンドアンビルセル（以下 DAC）に封入し高圧力を発生した。また DAC 内の試料に Fiber レーザー (λ=1092nm) を照射し高温を発生した。ここでレーザーの吸収体は金である。SPring-8 BL10XU において高温高圧下の試料の X 線回折パターンを取得し、相同定を行った。このとき用いた X 線の波長は 0.41418 A, 0.41318 A であり、回折パターンの取得には IP を用いた。圧力は金の格子体積から決定した (Tsuchiya, 2003)。

約 120 GPa, 2500 K での加熱後に $CaIrO_3$ 型のポストペロブスカイト相の生成を確認した。この後、加圧と加熱を繰り返し、290 GPa までの圧力範囲と 300 K 及び 1500-2000 K までの温度条件での体積データの取得に成功した。289.9 GPa, 300 K での格子定数は a=2.341(3) A, b=7.570(11) A, c=5.823(3) A で、体積は 103.19(46) A^3 であった。この実測された体積は先行研究である Oganov and Ono (2004)、Tsuchiya et al. (2005)、Ono et al. (2006)、Guinot et al. (2007) からの予測値に対して、それぞれ-0.3 %、0.7 %、1.7 %、2.7 %の違いがあった。

キーワード: post-perovskite, Super Earth
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