High silicon self-diffusion coefficient in dry forsterite

H-Z. Fei[1*], C. Hegoda[2], D. Yamazaki[2], M. Wiedenbeck[3], H. Yurimoto[4], S. Shcheka[1], and T. Katsura[1]

[1]BGI, Uni. Bayreuth, [2]ISEI, Okayama U., [3]GFZ Potsdam, [4]Dept. Nat. His. Sci., Hokkaido U. (hongzhan.fei@uni-bayreuth.de)

Introduction

Diffusion coefficients of silicon (D_{Si}) in mantle minerals provide the basic understanding of rheology. Jaoul et al. (1981) and Dohmen et al. (2002) measured D_{Si} at ambient *P* in forsterite (*Fo)* and in natural olivine (*Ol)*, respectively, providing results of ~2-3 orders of magnitude lower than that estimated from dislocation climb rates (Kohlstedt, 2006). In this study, we measured D_{Si} in dry *Fo* at 1600 and 1800 K, 0-13 GPa, and obtained a much higher $D_{si.}$, which well explains the high dislocation climb rates.

Conclusions

- Negative *P* dependence of D_{Si} with ΔV=1.7±2.3 cm³/mol.
- D_{Si} in dry *Fo* at ambient *P* is much higher than previous studies and consistent with dislocation climb rates.
- Effect of iron, water, and structural difference of $(Mg,Fe)_2SiO_4$ on D_{Si} is small.
- D_{Si} slightly increases with depth in the upper mantle.
- η slightly decreases or nearly constant with depth.

Experimental procedure

- **Sample**
  - *Fo* single crystal
- **Deposition**
  - $Mg_2{}^{29}SiO_4$ thin film (300-500 nm)
  - ZrO_2 thin film (~100 nm)
- **Annealing**
  - Multi-anvil & ambient *P* furnace
  - 1600 & 1800 K
  - 0 – 13 GPa
  - 0 – 41 hours
  - "Dry" condition (C_{H2O} < 1 ppm)
- **Polishing**
  - Reduce surface roughness
- **SIMS**
  - Cameca 6f with Cs^+ primary beam
  - Depth profiling mode

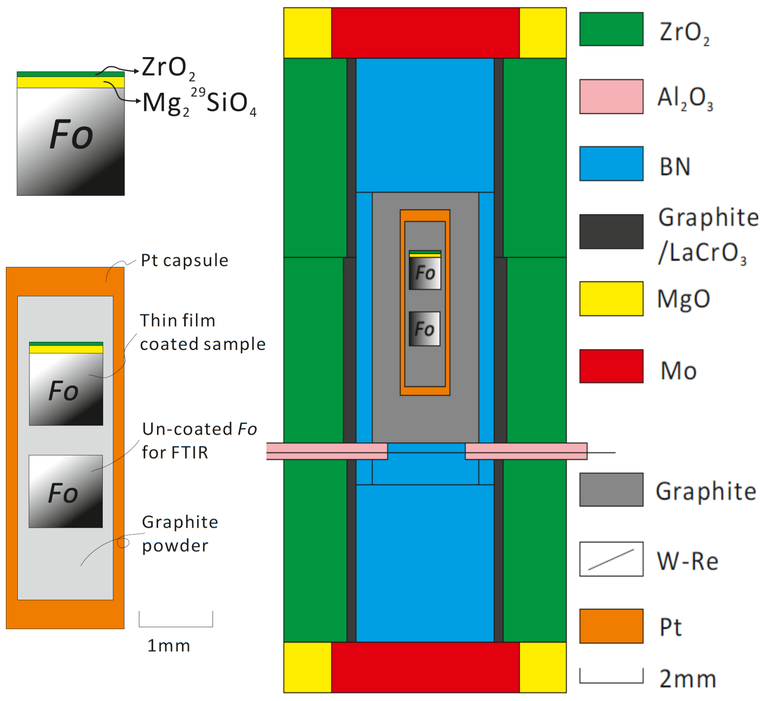

Fig. 1. coated samples and multi-anvil assembly

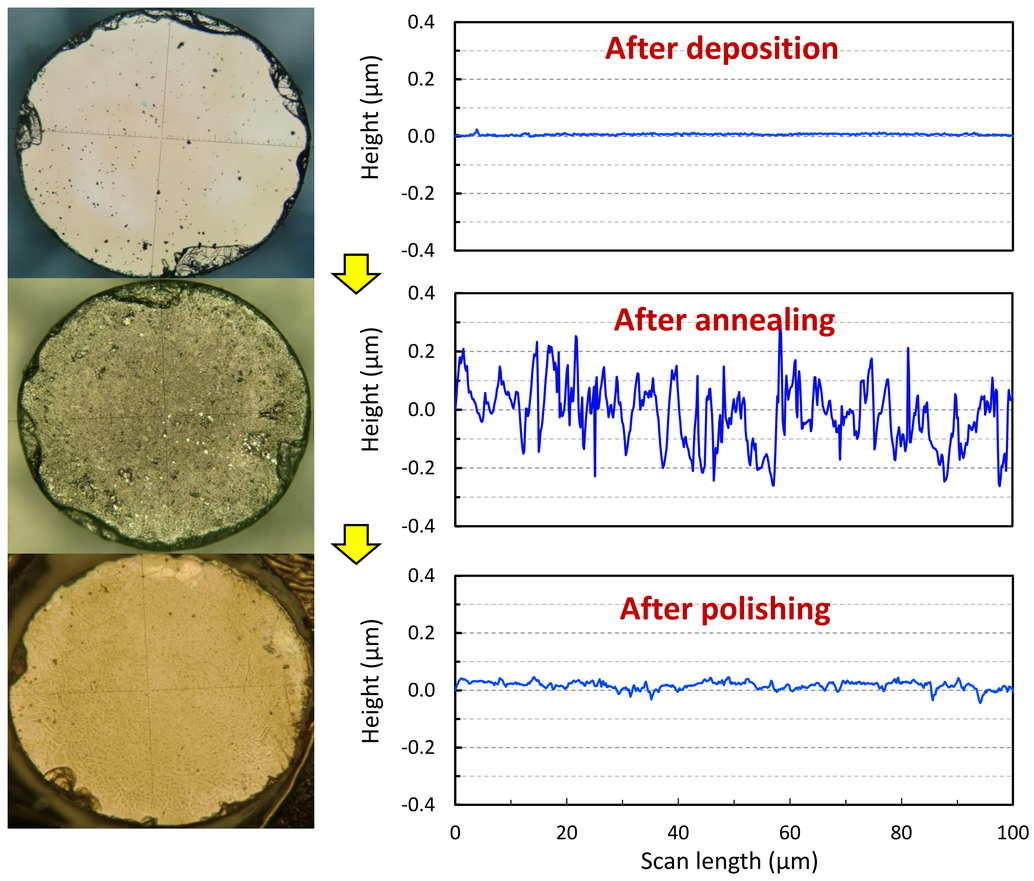

Fig. 2. surface roughness after each step

Results

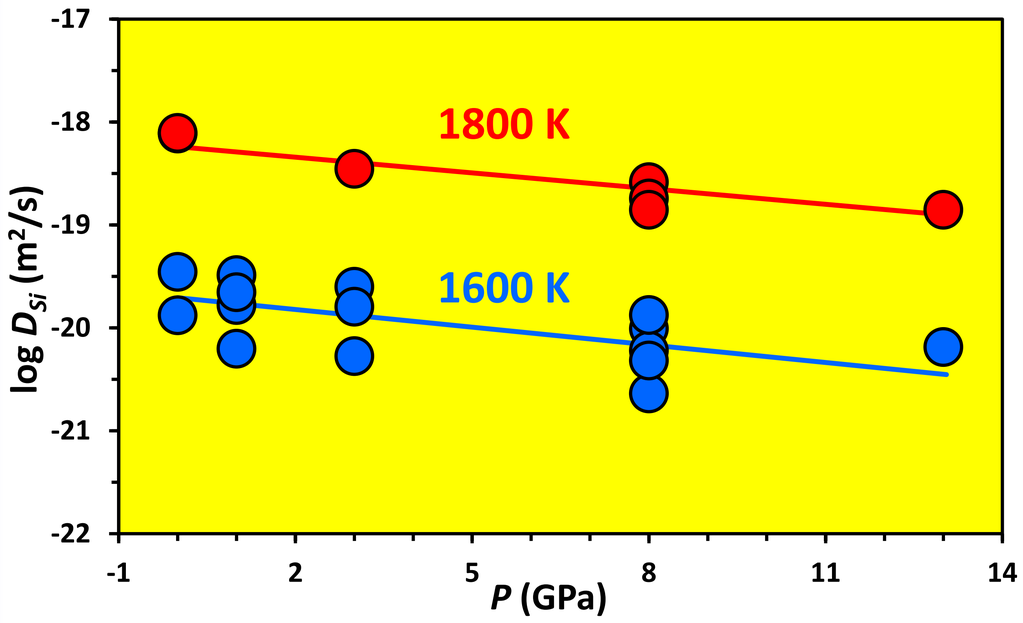

Fig. 4. logD_{Si} with pressure

- Negative pressure dependence of D_{Si} in forsterite.
- ΔV = 1.7±2.3 cm³/mol, ΔE = 407±50 kJ/mol.

Surface problem:

-- Surface roughness largely increased after diffusion annealing (Fig.2).

-- Solved by:

- Careful polishing (in colloidal silica solution)
- Roughness calibration with linear relationship between nominal diffusion length and roughness (Fig. 3).

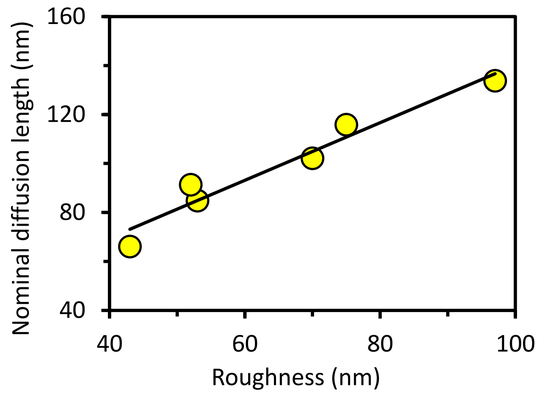

Fig. 3. nominal diffusion length in 0-time runs

Discussion

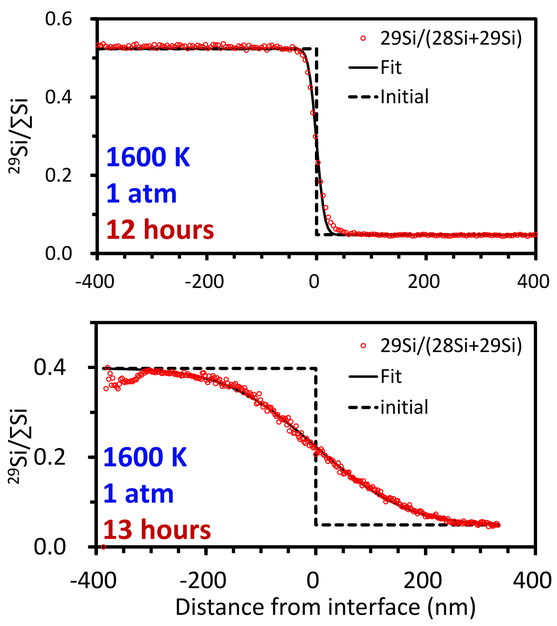

Fig. 5. Large difference of diffusion profiles none/with ZrO_2

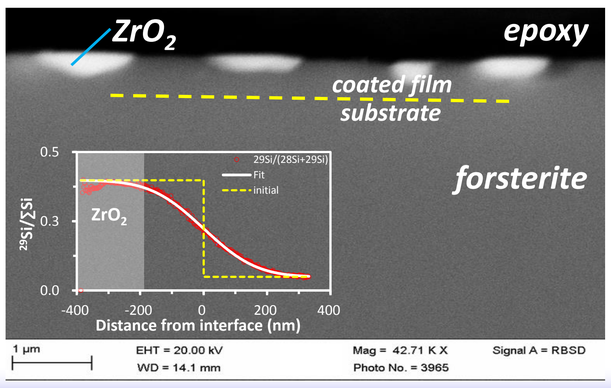

Fig. 6. SEM image of cross section

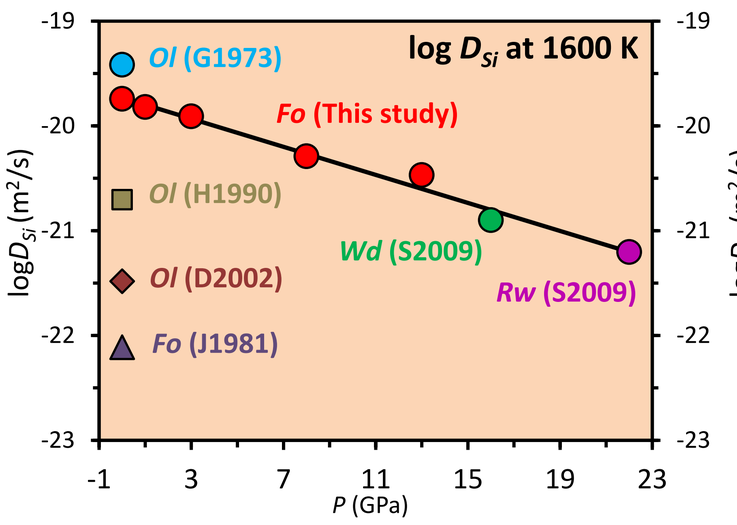

Fig. 7. D_{Si} in *Fo, Ol, Wd* & *Rw*

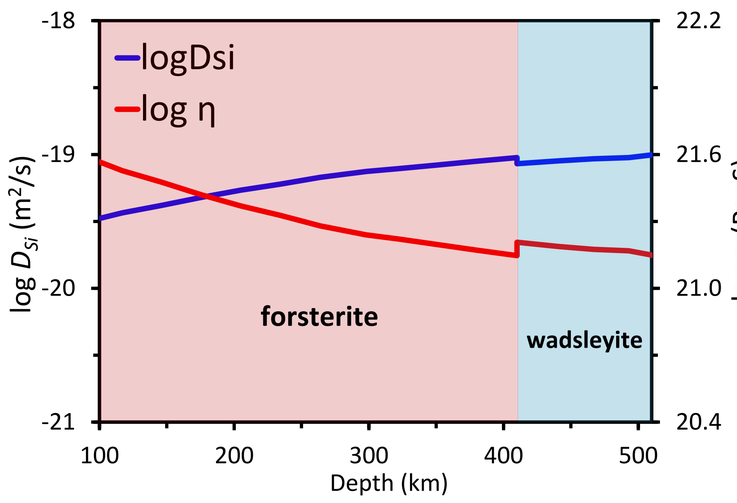

Fig. 8. D_{Si} & η in the upper mantle

- D_{Si} in this study is much higher than previous studies at ambient *P*.
- Consistent with dislocation climb rate (G1973).
- Linear relationship of D_{Si} in dry *Fo*, iron and water bearing *Wd* and *Rw*.
- Effect of iron, water, and structural difference of $(Mg,Fe)_2SiO_4$ on D_{Si} is small.
- D_{Si} slightly increases with depth in the upper mantle.
- η slightly decreases or nearly constant (assuming inversely proportional to D_{Si}).

- Diffusion profile is much longer with ZrO_2 than without ZrO_2.
- Without ZrO_2, large deformation of thin film caused bad contact with substrate.
- Presence of ZrO_2 does not affect D_{Si} directly (Fig. 6).
- Perhaps large deformation of thin films occurred in previous studies at ambient *P*.