High silicon self-diffusion coefficient in dry forsterite

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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.

Experimental procedure
- **Sample**: Fo single crystal
- **Deposition**: Mg,$^{30}$SiO$_3$ 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 (CO$_2$ < 1 ppm)
- **Polishing**: Reduce surface roughness
- **SIMS**: Cameca 6f with Cs$^+$ primary beam
- **Depth profiling mode**

Results
- **Negative pressure dependence of $D_{Si}$ in forsterite.**
- $\Delta V = 1.7 \pm 2.3$ cm$^3$/mol, $\Delta E = 407 \pm 50$ kJ/mol.

Discussion
- **Fig. 5. Large difference of diffusion profiles none/with ZrO$_2$**
- **Fig. 6. SEM image of cross section**

Conclusions
- **Negative $P$ dependence of $D_{Si}$, with $\Delta V = 1.7 \pm 2.3$ cm$^3$/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)$_2$SiO$_4$ on $D_{Si}$ is small.**
- **$D_{Si}$ slightly increases with depth in the upper mantle.**
- **$\eta$ slightly decreases or nearly constant with depth.**

Surface problem:
- **Fig. 2. Surface roughness after each step**
- **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).

Figures:
- **Fig. 1. coated samples and multi-anvil assembly**
- **Fig. 4. $\log D_{Si}$ with pressure**
- **Fig. 5. Large difference of diffusion profiles none/with ZrO$_2$**
- **Fig. 6. SEM image of cross section**
- **Fig. 3. nominal diffusion length in 0-time runs**
- **Fig. 7. $D_{Si}$ in Fo, Ol, Wd & Rw**
- **Fig. 8. $D_{Si}$ & $\eta$ in the upper mantle**

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