Carbon migration in olivines under natural irradiation: experimental and numerical modelling

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Better understanding of elements' migration in natural crystals under irradiation at low and high temperature is important for modelling the composition of asteroids and planets. Carbon migration in olivines under irradiation of deuterons and α-particles is considered at present work.

Technique and results

We used polyenergetic ion implantation and SIMS (Shilobreeva et al., 2000) to study thermal diffusion of carbon in olivines. The carbon depth profiles were measured by SIMS as implanted and after annealing (1100 and 300 K in air). We found diffusivities: $D_{th}=2.1*10^{-15}$ cm^2s^{-1} (1100 K); $D_{th}<6*10^{-20}$ cm^2s^{-1} (300 K). The lower limit of the activation energy (for 300-1100 K) was calculated (0.37 eV). The radiation-enhanced diffusivity ($D_{rad}=1.6*10^{-12}$ cm^2s^{-1} at 300 K) that we found by nuclear reaction $^{12}C(d, p)^{13}C$ (Kuzmin et al., 1998) exceeds the thermal on ~7 orders of magnitude. Here are for the first time considered the interaction of _–particles from natural U and Th with olivine crystals as applied to carbon diffusion. Simulation of the distribution of _–particles generated vacancies using the TRIM-98 code has shown that their concentration is comparable to the concentration of migrating carbon in the crystal. The maximum carbon content (6 ppm) in olivines of meteorites, caused by generated vacancies of natural _–radionuclides, was first established.

Conclusions

The thermal and radiation-enhanced diffusivities of carbon in olivines are found. The hypothesis of radiation-enhanced diffusion of carbon in olivine crystals of meteorites at low temperatures is put forward. The vacancy mechanism of radiation-enhanced diffusion of carbon was assumed.

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References

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P-V-T equation of state of $MgSiO_3$ perovskite and the chemical composition of the lower mantle

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Recent discoveries in seismology provide new insights on the structure and dynamics of the Earth's deep interior, yet our knowledge of the bulk chemical composition of the lower mantle is not well established. Laboratory P-V-T measurements have played an important role in constraining lower-mantle composition from seismic density and velocity profiles. However, the thermal equation of state of $(Mg,Fe)SiO_3$ perovskite, a dominant lower mantle constituent (>70%), is still controversial: while earlier measurements (Knittle et al., 1986; Mao et al., 1991) suggest higher thermal expansivity values, more recent measurements (Wang et al., 1994; Funamori et al., 1996) indicate lower thermal expansivity at zero pressure. Among these, only few data were measured at lower-mantle P-T conditions (Funamori et al., 1996; Saxena et al., 1999; Fiquet et al, 1996,2000). Especially the measurement by Funamori et al. (1996) yields the strongest constraint on the Grüneisen parameter of $(Mg,Fe)SiO_3$ perovskite at lower-mantle conditions.

A 2.5-GPa underestimation of pressure at 600-800 km depth conditions was recently found (Shim et al., 2001) in Anderson et al. (1989)'s gold EOS, which has been a widely used pressure scale in multi-anvil studies including the measurement by Funamori et al. (1996). We corrected pressures in Funamori's data using the gold scale by Jamieson et al. (1982), which yields a pressure scale consistent with the platinum scale. Inversions with the Birch-Murnaghan-Debye equation show that this pressure correction for the Mg-silicate perovskite data yields a thermal expansivity between the high and low values. If resistance- or laser-heated diamond-cell data (Saxena et al., 1999; Fiquet et al., 1998,2000) are included, our pressure correction reconciles the previous discrepancy in the thermal equation of state of $(Mg,Fe)SiO_3$ perovskite; the high thermal expansivity reported by Knittle et al. (1986) and Mao et al. (1991) is reproduced.

Calculations using these inversions show that the density of a pyrolite-composition high-pressure mineral assemblage is lower than the lower-mantle PREM density by 1 %. In order to compensate for this discrepancy, either 30 % Si enrichment or 3 % Fe enrichment in lower mantle composition, or 300 K decrease in mantle geotherm is necessary. As a 300 K decrease in mantle geotherm results in very cold lower-mantle temperatures (1600 K at 660-km depth and 2100 K at the core-mantle boundary), it is more likely that the chemical composition of the bulk of the mantle is not pyrolitic. The lower mantle may be chemically distinct from the upper mantle.