Synthetic forsterite grain boundaries: Tilt [100] and 9.9° to 21.5°

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Forsterite is a main constituent of rocks in the Earth's mantle. The refractory nature of forsterite makes it suitable for ceramics used in thermal insulations. The properties of rocks and ceramics are largely determined by their grain boundaries. Structure and transport properties of grain boundaries in rocks are still poorly understood. In general grain boundary structure, grain boundary energy and grain boundary properties depend on orientation. Low angle grain boundaries show dislocations, have low grain boundary energy and their transport properties (e.g. grain boundary chemical and thermal diffusion, grain boundary migration and sliding) are slow. High angle grain boundaries do not reveal dislocations, have high grain boundary energy and their transport properties are fast. In oxides, the transition from low to high angle grain boundaries is not studied in detail, but the transition to a high angle grain boundary is commonly defined at an angular lattice misorientation of ~ 10°-15°.

We synthesized a series of symmetric tilt grain boundaries in forsterite bicrystals with tilt axis **a** and increasing tilt angle from 9°-21° by direct bonding (Heinemann *et al*. 2001, 2005). For each bicrystal two oriented and polished synthetic forsterite single crystal plates were joined at room temperature and annealed at 400°C in vacuum for one week. All bicrystals were cut in two parts and one part was annealed further at 1650°C for 48h. Specimens were prepared for investigations in the TEM with focused ion beam (FIB).

HRTEM investigations of the grain boundaries parallel to tilt axis **a** show symmetric tilt grain boundaries with arrays of regular spaced edge dislocations between undisturbed crystal regions for all annealing temperatures and all tilt angles. The grain boundary structure developed below 400°C and did not change till 1650°C. All grain boundaries with tilt angles from 9°-21° are low angle grain boundaries. The Burgers vector of the edge dislocations is **c**. The regular dislocation spacings decrease with increasing tilt angles and dislocation cores do not overlap up to a tilt angle of 21°.

The dislocation model of low angle grain boundaries can be applied and the observed dislocation spacings d are related to tilt angle θ and Burgers vector length b by Frank's formula:

$$d = b/(2sin(2/\theta)) \approx b/\theta \qquad \text{for small } \theta$$

with tilt angles increasing from 9° to 21° the dislocation spacing decreased.

Using Frank's equation and a rough estimation of the dislocation core radius of $r_0 \sim 0.4\text{nm} \sim 2/3b$ we propose that in forsterite the transition between low and high angle grain boundary occurs at a misorientation of ~ 42°.

References

Heinemann S. *et al*. (2001) *Phys Chem Minerals* **28** 685-692
Heinemann S. *et al*. (2005) *Phys Chem Minerals* **32** 229-240

Formation of oceanic zircons

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Zircon is an omnipresent accessory phase in gabbroic rocks collected along mid-ocean ridges. We obtained *in situ* U-Pb ages and REE compositions of well-documented (BSE, color-CL imaging) zircons from three locations along the Mid-Atlantic Ridge. In order to avoid contamination, we only used zircons found within petrographic thin sections.

The medium to coarse grained zircons of this study were found in highly evolved, oxide gabbro veins crosscutting mantle peridotites and are as abundant as 15 modal percent. They are generally subhedral to perfectly euhedral in shape, can exceed 1 mm and appear homogeneous in BSE images. Color-CL reveals a dominant sector zoning in dark and bright blueish-grey. Within the individual sectors, a fine oscillatory zoning can be generally resolved as well.

All near-ridge zircons have U concentrations less than 50 ppm and yield ages of approx. 1 Ma and younger. This contrasts strongly with Paleozoic-Proterozoic ages reported on similar samples from the same locations, which may have resulted from contamination during sample preparation. The steep REE patterns of all samples are very similar: low LREE and very high (up to 10,000x CI-chondrite) HREE with pronounced positive Ce and negative Eu anomalies. Their absolute REE abundances are bimodal. The CL-bright sectors have a factor 2 to 3 times lower REE concentrations than the associated darker sectors. Average CL-bright zones from all samples are chemically virtually indistinguishable. Significant core-rim zoning is absent. These features are consistent with a cumulate-type origin from nearly identical highly evolved melts. This requires relatively large melt volumes that would not change in HREE concentration during zircon formation.

Titanium concentrations are sector-independent and yield temperatures around 830°C. This suggests that there is no temperature gradient between the evolved melt and the peridotite wall rock. Along cracks, rare patchy yellow and very bright blue luminescence domains occur, generally characterized by low trace element abundances except for high U (up to 290 ppm) and significantly lower Ti-in-zircon temperatures. This suggests that low-T hydrothermal dissolution-recrystallization reactions are possible, which potentially affect whole-grain U-Pb (-He) systematics.